Liquidity measures
throughout the lifetime of the US Treasury bond

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THIS DRAFT: December 2015

Abstract

We examine the price impact of different components of liquidity throughout the lifetime of the US Treasury bond. Using the GovPx dataset, we provide a comprehensive empirical analysis of the impact of the liquidity proxies on the yield spreads of the two-year notes. The findings show that the liquidity premium has a deterministic main age-based component. The ability of microstructure-based liquidity measures to reflect this life cycle and their impact on prices are negligible. There is a stochastic component of the liquidity premiums that depends on the unexpected value of the liquidity proxies and the current market-level and bond-level conditions.

Keywords: liquidity, fixed income, pricing, life cycle, government bonds.

This work was supported by the Spanish Ministerio de Ciencia y Tecnología (ECO2014-59664-P), and Junta de Comunidades de Castilla-La Mancha (PEII-2014-019-P). Any errors are solely the responsibility of the authors.

1 Introduction

Liquidity is a key factor in the pricing of fixed income securities. A number of papers emphasize its role. Since the seminal work by Amihud and Mendelson (1991), there have been many studies showing that security's liquidity is priced in Treasury markets. The observed differences in prices imply that market participants price liquidity. Investors are willing to pay a higher price for liquid assets. Otherwise, the more highly liquid securities are traded with a liquidity premium that implies a higher price and therefore a lower yield-to-maturity.

The traditional liquidity analysis examines differences in liquidity between assets, i.e., they are due to different bond characteristics and the bond's fundamentals, such as bond age (or time from issuance), term to maturity, amount outstanding, and coupon rate. Earlier studies also use other proxies for liquidity or illiquidity, such as the quoted bid-ask spread, the percent of trading days, the trading volume, the turnover, or the number of 'runs'.[1] The recent availability of intraday transaction prices in the secondary US corporate bond markets, i.e., the TRACE dataset, has encouraged the development of a new branch of literature. This literature often translates traditional microstructure-based measures of stock markets to the new potentially analyzable dataset. Recent papers based on these proxies show important pricing implications associated with corporate bond illiquidity.

We examine a set of these microstructure-based illiquidity proxies from a critical perspective. To compute these new measures in a precise manner, high-frequency datasets or, at the least, intraday datasets are required. However, most papers use an adaptation of these proxies computed from daily data. This data frequency may imply that the measure is inaccurately computed or even that it may become meaningless. Additionally, Treasury bond markets and especially corporate bond markets are by far less liquid than stock exchange markets.[2] The lack of trading during days is frequent in these markets. Moreover, bonds have a finite maturity, whereas stocks, the assets for which these measures were proposed, have an infinite maturity. The age and time to maturity are relevant determinants of the current and potential liquidity of a bond. Amihud and Mendelson (1991) show 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 of time gradually acquire an increasing fraction of the issue. Similarly, Sarig and Warga (1989) show that the on-the-run or just-issued security is by far the most highly liquid bond and is traded with a liquidity premium on prices. All these concerns may affect the interpretation of the results obtained from these proxies.

We emphasize that market participants take into account that a bond has a finite life and its liquidity passes through different stages that are well-known by the market.

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

[2] For example, Edwards, Harris and Piwowar (2007) show that, of the 70,000+ corporate bonds outstanding in 2004, less than 17,000 experienced more than 9 trades that year.

For example, suppose that the trading activity of two government bonds, for which all characteristics are equal except age, is equally intense during a certain day. The microstructure-based measures will show similar values for all these liquidity proxies. However, the liquidity premium involved in their prices most likely should be different. The reason is that market participants most likely consider the expected current liquidity involved in the price, depending on the potential future liquidity of each bond. The buyer of the oldest bond wishes to pay a lower price than he would pay for the youngest bond because its expected current and future liquidity are lower. Investors price the costs of the illiquidity that they would incur whether unwind positions before maturity. In this sense, Goldreich, Hanke and Nath (2005) observe the relevance of future liquidity as the main component of the liquidity premium observed between on-the-run and off-the-run US Treasury 2-year notes.[3] In addition, the expected future liquidity is generally different from the current liquidity and changes predictably over time. The current price of Treasuries reflects the expectation of the costs and benefits of future liquidity.

Recent papers highlight the difference between market-level illiquidity and bond-level illiquidity. Li, Wang, Wu and He (2009) stress the significant role played by market-wide liquidity in the pricing of Treasury securities. They compute the systematic illiquidity risk and show that its effect goes beyond the effect of the level of liquidity proxied for microstructure-based liquidity measures. They observe that the microstructure-based liquidity measures may be very noisy proxies for liquidity risk. Fontaine and García (2012) show the relevant importance of funding liquidity or funding conditions in the repo market as an aggregate risk premium in the Treasury market. However, Bao, Pan and Wang (2011) observe that the level of illiquidity in the market leads to transitory components in the bond prices.

The main objective of this paper is to examine the price impact of the different components of liquidity throughout the lifetime of the US 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? 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.

Our analysis of liquidity measures throughout the lifetime of the notes corroborates the liquidity proxies' dependence on the aging of the bond. 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) 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

[3] Díaz, Merrick and Navarro (2006) propose a liquidity 'life cycle' function and corroborate the price impact of the expected future liquidity in the liquidity premium observed in the Spanish government bond market.

proposed by Jankowitsch, Nashikkar and Subrahmanyam (2011).[4] A preliminary descriptive analysis of the behavior of the microstructure-based illiquidity proxies throughout the lifetime of the note casts some doubt about what they are actually measuring. According to these proxies, the findings show that the on-the-run and first off-the-run notes are the most highly illiquid assets on the market and that liquidity progressively improves as maturity approaches. Additionally, they are not able to identify 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. 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 results for the microstructure-based liquidity proxies are inconsistent with expectations. Even controlling for current market-level and bond-level conditions, the random behavior of these illiquidity proxies is predominant. Thus, we observe 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 two-year Treasury note and its theoretical yield, as given by an explicit term structure model.[5] This methodology of comparing the yield-to-maturity of the original bond with that of a theoretical bond with identical cash flows has been applied by Díaz and Skinner (2001), Fleming (2003) and Díaz, Merrick and Navarro (2006), among others.[6] The theoretical yield-to-maturity is obtained from discounting the original cash flows of the bond 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.[7] The fitted term

[4] Many studies have focused on identifying the most appropriate proxy for liquidity in Treasury markets (e.g., Fleming, 2003) or corporate bond markets (e.g., Helwege, Huang and Wang, 2013).

[5] We restrict the analysis to two-year Treasury notes. Successive reissuance processes that depend on financial needs affect the liquidity life cycle of longer original maturity notes and bonds.

[6] The literature also includes different proposals. One method consists of comparing the yields or prices of pairs of assets with similar maturity. Early papers such as those by Amihud and Mendelson (1991) and Kamara (1994) use the yield spread between a bill and a note with a similar term to maturity. Similarly, Fontaine and García (2012) analyze pairs of securities composed of the youngest bond in a certain maturity bin and other securities in the same maturity bin. Other papers, such as those by Daves and Ehrhardt (1993) and Bühler and Vonhoff (2011), compare matched portfolios of STRIPS with coupon-bearing Treasury bonds. Another method is used by Krishnamurthy (2002) and Goldreich, Hanke and Nath (2005). They match the newer on-the-run bond upon issuance with the newer first-off-the-run bond and follow the pair during the month when both bonds remain in this auction status.

[7] There are popular yield curve datasets available. They can be downloaded from the Federal Reserve H.15 series and the US Department of the Treasury websites. However, we prefer to fit the yield curve from

structures reflect the average liquidity level in the market. Thus, our yield spread can be understood as a 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 lifetime of the 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 bond's age increases, liquidity premiums begin to be positive, and its volatility increases. The mean yield spread ranges from -4.3 bp for the on-the-run, -2.3 bp for the first off-the-run, and 5.9 bp for the remaining notes. On average, we observe liquidity premiums among 2-year notes of approximately 10 bp 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 bp in fall 1998 after the 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 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 negligible 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 explains 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. 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 stochastic component of the liquidity premium.

To ensure that the results are robust to alternative sub-samples and alternative specifications of the liquidity proxies, we report the results using two sub-samples (the second period begins in August 1998 with the Russian financial crisis) and including Turnover as a proxy for trading activity and Amivest and Roll microstructure-based illiquidity proxies. 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 notes. Market players consider a liquidity term structure in the decision-making process. Second, the ability of popular microstructure-based liquidity measures to reflect this cycle and their impact on prices are negligible. Third, there is a stochastic component of the liquidity premiums that

exactly the same prices that we use in the liquidity premium analysis. Therefore, we avoid potential biases of using the yield curves obtained from different prices and yields-to-maturity as input.

depends on the unexpected value of the liquidity proxies and the current market-level and bond-level conditions.

Own analysis has certain similarities with that provided by Goldreich, Hanke and Nath (2005). They explain the price difference between the first off-the-run and the on-the-run two-year notes based on the current and expected future value of several trading activity measures. Although we also base the analysis on the two-year note segment, we consider a predictable component of the liquidity premium and incorporate several microstructure-based liquidity measures to control for market-wide and bond-level liquidity throughout the full lifetime of the bond. Additionally, we estimate less noisy yield spreads between the yield-to-maturity and the yield of an identical asset with the average market liquidity.

Our paper is organized as follows. Section 2 addresses liquidity in debt markets, the different measures used to quantify liquidity and their evolution throughout the lifetime of the bonds according to the literature. Section 3 describes the specific characteristics of the US 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. Section 5 defines the methodology for estimating yield spreads and shows the analysis of the ability of the liquidity proxies to explain the yield spreads. In addition, it includes the robustness checks. Finally, section 6 concludes.

2 Liquidity in debt markets

The measurement and monitoring of liquidity are relevant for making investment decisions in fixed income markets, in particular in government bond markets. Liquidity is a key aspect in determining the price and the return offered by fixed income assets. A basic definition is that which defines liquidity as the ability of an asset to be turned into money. We state that an asset is liquid if it can be traded on the market in a short period of time without causing significant losses in value. Fleming (2003) includes a definition of liquidity from O'Hara (1995) and Engle and Lange (1997): “a liquid market is defined as one in which transactions can be done without cost”.

High liquidity would indicate that an asset can be negotiated quickly and without significant loss of value. In this case, investors would expect higher asset prices and a lower yield-to-maturity. By contrast, low liquidity means that the cost of trading an asset will be high; thus, investors would expect lower prices and, by contrast, a higher profit. In other words, a market with low transaction costs is known as a liquid market, whereas a market in which there are high transaction costs is called an illiquid market. Measuring these costs is not simple because they depend on numerous factors, such as the size of the negotiation, time, place of negotiation, and partners.

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, age, term to maturity, issue auction status, economic activity cycle, interest rate volatility, and investor risk aversion. Fisher (1959) postulates that the larger the size of the issue is, the easier the bond trading. Sarig and Warga (1989) and Warga (1992) conclude that off-the-run bond portfolios and on-the-run bond portfolios obtain significantly different returns. Amihud and Mendelson (1991) observe that illiquid bonds are more common among bonds with a shorter residual time to maturity. By the time that notes approach maturity, they have already been locked away in investors' portfolios. A large part of each issue is not readily available for trading.

In the previous literature, there are a number of measures that have been traditionally used as bond liquidity proxies. These include proxies such as the trading volume, trading frequency, bid-ask spread, quote size, trade size, price impact coefficient, and on-the-run/off-the-run yield spread. In the case of the US Treasury market, Fleming (2003) examines some measures used in the literature and postulates that the bid-ask spread is a useful tool for assessing and tracking Treasury market liquidity. For instance, Houweling, Mentink and Vorst (2005), Longstaff, Mithal and Neis (2005) and Chen, Lesmond and Wei (2007) conclude that liquidity proxies are significant explanatory variables for credit spreads.

Goldreich, Hanke and Nath (2005) use the average spread quoted bid-ask, the average effective spread bid-ask, the average size quoted, the number of quotes per day, the number of trades per day, or the daily volume, among others. They find evidence that the quoted spread and the measures of market trading activity add the greatest explanatory power and that the other measures, which are depth measures, add little explanatory power to explain the yield difference between off-the-run and on-the-run notes. Johnson (2008) uses the bid-ask spread and price impact illiquidity measure in government bonds. Ejsing and Sihvonen (2009) use the trading volume, quoted depth, quoted bid-ask spread, and the liquidity ratio proposed by Bollen and Whaley (1998). The turnover ratio, used by Dick-Nielsen, Feldhütter and Lando (2012), among others, is a market impact measure that relates a bond trading volume over its amount outstanding. Another measure used by Goyenko, Subrahmanyam and Ukhov (2011) is the quoted bid-ask spread, which relates the price range to the average effective spread. Díaz, Merrick and Navarro (2006) use the individual market share of each type of issue and the auction status of the issue in the Spanish debt market.

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, such as the trading volume, turnover size, number of trades, and effective bid–ask spread, are not directly observable. Recently, the availability of high-frequency data, especially in the case of the TRACE dataset from the US corporate bond market, has made it possible to incorporate and adapt from stock exchange markets new liquidity measures in the analysis of fixed income liquidity.

The new set of liquidity measures inspired by the traditional microstructure literature on stock markets is applied to corporate bond market data. Most of these proxies focus their attention to the illiquidity measure by Amihud (2002), which may be applicable to fixed income assets. Originally, this measure, which is based on Kyle (1985)'s lambda, was proposed for the equity market. The Amihud (2002) measure is defined as the price impact of a trade per unit traded. It is calculated as the average of the daily ratio of the absolute return to volume. It has been applied to corporate bond markets, among others, by Jankowitsch, Nashikkar and Subrahmanyam (2011) and Friewald, Jankowitsch and Subrahmanyam (2012).

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. Bao, Pan and Wang (2011) propose a measure of illiquidity for corporate bonds. 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 (γ) as a measure of illiquidity. This measure, γ, is a variant of the measure by Roll (1984), but these authors consider that γ captures the broader impact of illiquidity on prices, above and beyond the effect of the bid-ask spread. Alternatively, Cooper, Groth and Avera (1985) and Amihud, Mendelson and Lauterback (1997), among others, use the Amivest measure as a liquidity ratio insofar as it seems to be a good indicator of market depth, i.e., a larger liquidity implies a lower price impact. It is computed as the average between the volume traded and the absolute return.

Jankowitsch, Nashikkar and Subrahmanyam (2011) propose the Price Dispersion measure as an estimation of the absolute deviation between traded prices and market-wide valuation, controlling for the effect of the trading volume on each trade. Given that it is computed as a root square of this dispersion, it can be interpreted as the volatility of this variation. It is an illiquidity measure; a higher value would indicate higher deviations, suggesting higher transaction costs for dealers and investors. Alternatively, Dick-Nielsen, Feldhütter and Lando (2012) 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,[8] and the standard deviations of both previous variables.

Our initial intuition is that both a number of idiosyncratic aspects of bond markets and certain critical characteristics of these markets may hinder a blind and direct adaptation of measures from stock markets to fixed income markets. On one hand,

[8] Feldhütter (2012) argues that Imputed Roundtrip Trades occur when two or three trades in a given bond with the same trade size occur on the same day after a longer period with no trades. This phenomenon may imply that a dealer matches a buyer and a seller and collects the bid-ask spread as a fee. When the dealer has found a match, a trade between the seller and the dealer and a trade between the buyer and the dealer are performed.

Treasury bond markets and especially corporate bond markets are certainly less liquid than stock exchange markets. In their original expressions, some proxies cannot be accurately computed from bonds that are not traded daily. Other proxies may become meaningless in this context. On the other hand, most of the popular liquidity measures take a static picture of liquidity at a particular point in time. Doing so may be sufficient to determine a possible liquidity premium in stocks because stocks have an infinite maturity. Thus, current liquidity can be a good proxy for the future liquidity of a stock. However, bonds have a finite maturity. Amihud and Mendelson (1991) show that the aging of the bond reduces and even the bond's liquidity. Similarly, Sarig and Warga (1989) conclude that bond liquidity inversely depends on age. The on-the-run bond of a certain maturity, i.e., the just-issued bond or the bond issued at the most recent auction, is by far the most highly liquid and the most commonly traded bond.

Recent studies highlight the role of market-wide liquidity on the pricing of corporate bonds. In addition to bond level aspects, monetary and macroeconomic shocks and other phenomena, such as flight-to-quality, flight-to-liquidity or certain episodes of market turmoil, have a relevant impact on the liquidity premium. Two different but highly correlated phenomena that affect liquidity premia bear on government bond prices. In times of financial turmoil, there is the phenomenon known as the 'flight to quality'.[9] Investors become more risk-averse, and some market participants abruptly decrease their portfolio exposure to securities that bear credit risk. They prefer safer securities, i.e., the default risk-free issues.[10] Fleming and Remolona (1999) report the 'flight to liquidity' phenomenon, in which bondholders prefer more highly liquid securities rather than less liquid securities. This implies that bondholders unwind positions on corporate bond markets and place their interest in government fixed income securities. In this sense, Fleming (2003) identifies significant spikes in Treasury market liquidity, mainly in October 1998 and also in October 1997 and February 2000. Beber, Brandt and Kavajecz (2009) and Acharya, Amihud and Bharath (2013) report the existence of the time-varying liquidity risk of corporate bond returns, conditional on episodes of market stress and flight to liquidity. In times of adverse economic and financial conditions, a greater demand for liquidity increases liquid Treasury security prices by more than usual.

In the case of government bonds, the liquidity premium should also reflect the joint impact of two components, a bond-level liquidity and a market-level liquidity. On one hand, punctual fluctuations in bond-level liquidity proxied by both microstructure-based liquidity measures and the bond's fundamentals may affect a liquidity premium on prices. On the other hand, an increased perception of market risk may increase the spread between on-the-run and off-the-run government bonds. Longstaff (2004) quantifies a liquidity premium in Treasury bonds that can represent as much as ten percent of the value of the bond. As possible determinants, Longstaff notes the market sentiment, the

[9] See, for example, Bernanke and Gertler (1995), Longstaff (2004), Vayanos (2004), Beber, Brandt and Kavajecz (2009) and Dick-Nielsen, Feldhütter and Lando (2012).

[10] Recently, there have been several episodes of negative interest rates resulting from Treasury bill auctions in United States, Switzerland and Germany. In concrete terms, investors asked to pay more than the nominal amount for the promise of receiving the nominal amount at the maturity date.

supply of Treasury securities available to investors, and flows into equity and money market mutual funds. Li, Wang, Wu and He (2009) stress the significant role played by market-wide liquidity in the pricing of Treasury securities. They compute the systematic illiquidity risk and show that its effect goes beyond the effect of the level of liquidity proxied by microstructure-based liquidity measures. Fontaine and Garcia (2012) show the relevant importance of funding liquidity or funding conditions in the repo market as an aggregate risk premium in the Treasury market.

2.2 Liquidity throughout the lifetime of the 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 of time 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 'just-issued' security is the 'on-the-run' among those that have the same original term to maturity. The 'on-the-run' issues focus the interest of investors, concentrating most of the trading volume in this secondary market. After a new issue is auctioned, the new 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 bond from the most recent Treasury auction or 'just-issued' security of a given maturity is the most actively traded among the issues of the same original maturity and thus is the most liquid. 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), the literature observes that on-the-run bonds are the more highly liquid securities.[11] The higher the liquidity is, the more expensive the bond. A high price implies a low yield-to-maturity.

Therefore, the on-the-run 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 explain this phenomenon. The trading activity in the market is concentrated in this issue. All institutional investors wish to include this 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

[11] See, for example, Graveline and McBrady (2011), Brandt, Kavaiecz and Underwood (2007), Mizrach and Neely (2008), and Pasquariello and Vega (2009).

market.[12] These investors choose to hold these liquid securities because they can sell them more quickly and without high losses. Duffie (1996), Graveline and McBrady (2011) and Barnejee and Graveline (2013) show that on-the-run Treasuries are appealing securities for market intermediaries who wish to create short positions. These short-sellers can easily borrow and sell on-the-run securities in the repo market when initiating a short position, and they can easily repurchase them when closing out a short position. 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.[13] Although off-the-run bonds are cheaper than on-the-run bonds, investors think that they are difficult to find and scarce in markets (see Vayanos and Weill, 2008).

The implication is that the current age of a bond 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 bond's age in a regular and predictable manner over the time. If the bond auction status passes through a 'life cycle', then we can state that the bond's liquidity also passes through a similar 'life cycle'.

In this sense, Goldreich, Hanke and Nath (2005) 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. This paper has several limitations in the study design and implementation.[14] Additionally, Graveline and McBrady (2011) call these results into question. The latter authors observe that the on-the-run price may suddenly drop when the asset losses this auction status immediately after a new bond is auctioned. This fact is contrary to the proposal of Goldreich, Hanke, and Nath, in which a new auction may not have a significant impact on the price of the old on-the-run because both the current and the expected future liquidity are reflected in the current market price.

Díaz, Merrick and Navarro (2006) propose an alternative analysis. The two-stage 'on/off-the-run cycle' division used for US 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 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

[12] Krishnamurthy (2002) observes that variations in the bond/old bond spread are driven by the Treasury supply of bonds and aggregate factors that affect investors' preference for liquid assets.

[13] Barnejee and Graveline (2013) find that an average liquidity premium on 10-year on-the-run notes relative to less liquid off-the-run notes is 94 basis points.

[14] First, it only examines the one-month on-the-run period. Second, it only includes trading activity proxies based on quoted prices and volumes. Third, the proposed proxy for the liquidity premium can be very noisy. They compute the yield differences between the quoted yield of the first-off-the-run security and the quoted yield of the on-the-run security. Thus, these premiums are estimated from quoted prices instead of traded prices, and they depend on the shape of the yield curve and the coupon size because they are comparing notes of different coupon rates and maturities. Fourth, the panel data model regresses the yield differential in average expected future trading costs proxied by the realized future trading costs. These transaction costs are computed as the average difference between several trading activity proxies for the first-off-the-run and the on-the-run notes during the first month after issuance.

is much more important than the current liquidity for explaining relative Spanish Treasury bond values.

3 Data and Sample Period

Both by trading volume and by number of investors and trades, the US debt market is the largest debt market in the world. These securities play an important, even unique, role in international financial markets because of their safety, liquidity and low transaction costs. The amount outstanding of US government debt in January 1996 was more than $4.9 trillion, and $3.3 trillion was traded on financial markets. The amount outstanding had risen to more than $18 trillion by August 2015.[15] The US Department of the Treasury sells securities through auctions on a regular schedule to finance the national debt. Government bonds offer the security and safety of the US federal government.

[INSERT FIGURE 1 ABOUT HERE]

Treasury bills, notes, bonds and TIPS are regularly issued. Although T-bills are issued at discount, the remaining securities pay a semiannual coupon. Treasury notes have intermediate maturities, i.e., 2-, 3-, 5-, 7- and 10-year maturities, and Treasury bonds have the longest maturities, 20 years and 30 years. Most US debt securities consist of a medium-term and long-term maturity, comprising approximately 50% of the total debt issued, as shown in Figure 1. In terms of trading activity, US Treasury debt is one of the largest sectors of the bond market. The secondary market is liquid, with large trading volumes and narrow bid-ask spreads.[16]

The dataset used in the analysis of US Treasury liquidity has been obtained from the GovPx (Government –securities– Pricing Information System) database. This database collects 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 US 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, when the GovPx daily trading volume average was $77.1 billion, to 2001, when it was barely higher than $1.7 trillion.[17] Figure

[15] Source: the Treasury Direct website, available at http://www.treasurydirect.gov/tdhome.htm.
[16] For a further description, see Fleming and Sarkar (1998).
[17] The average daily volume in 1997 was $79.7 billion, more than the 1998 average of $71.5 billion. In 1999, it was $52.5 billion, and during the first half of 2000, the GovPx average daily volume was $39.6

2 shows the time evolution of the trading activity reported by GovPx in the US Treasury bonds and notes segment. The emergence of the new electronic trading platform at the beginning of our century had a clear impact on the trading activity in the interdealer broker market and the quality of the information reported by GovPx. The GovPx dataset does not provide a reliable indicator of transactions after March 2001. Indeed, GovPx has no longer reported volume information since May 2001. This fact is also noted in other papers, such as that by Li, Wang, Wu and He (2009).

[INSERT FIGURE 2 ABOUT HERE]

Our sample period is affected by these constraints. The dataset includes every trade between January 1996 and November 2000.[18] To complement the dataset, we use information on the amount outstanding and auction details obtained from the official website of the US Department of the Treasury. For the study period, there are 1,302 trading days and 251,680 observations. We consider all the traded US 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 and their average trading volume. Several patterns can be observed. The most actively traded issues by far are both 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. Two-year and 5-year notes have a regular number of simultaneous outstanding issues during the period of analysis because they are uninterruptedly issued during the period.

[INSERT TABLE 1 ABOUT HERE]

We focus our liquidity analysis on the 2-year Treasury note segment. Three main reasons justify this choice. First, this segment is the most actively traded segment on the market.[19] Second, the analysis of 2-year notes avoids the effects of the reissuance program. For instance, this is the case of some 5-year notes. Three years after its original issuance, a new tranche of the seasoned 5-year note can be issued as a 2-year note. Similar to any other new auctioned asset, the trading activity rises dramatically. Even the GovPx changes the manner in which the entire issue is denominated. The original CUSIP is now

billion, 25% less than the daily average for 1999. In this sense, Mizrach and Neely (2006) analyze the transition from GovPx to electronic trading in the secondary Treasury market.

[18] The reported GovPx information from December 2000 is limited, causing distortion in the measures used. However, other authors such as Li, Wang, Wu and He (2009) use the GovPx dataset until December 2002.

[19] Most of the studies on US Treasury securities are focused on bonds with 2-, 5- and 10-year maturities, given that these are issues that have never been interrupted, having regular broadcast dates, and a greater number of observations and information are available. Goldreich, Hanke and Nath (2005) use data from 2-year bonds; Pasquariello and Vega (2009) use data from 2-, 5- and 10-year bonds, similar to Fleming (2003); and Strebulaev (2002) uses data from 2-, 3-, 5- and 10-year bonds, which have more regular releases.

reported as a '2-year note'.[20] We consider the issue to be a 5-year note during the period from the original issuance until the new tranche is issued. At which point, we consider the issue to be a different '2-year note'.[21]

Third, the on/off-the-run period of 2-year notes is the clearest among all the original terms to maturity, as shown in Figure 3. 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 100 weeks 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 maturity. Meanwhile, 2- and 5-year notes are issued monthly, whereas 3- and 10-year notes and 30-year bonds are issued four times per year. The quarterly issuance program maintains the on-the-run status during a longer period of time. Figure 3 also shows that 2- and 5-year on-the-run notes reach the highest levels of market share by far.

[INSERT FIGURE 3 ABOUT HERE]

4 Liquidity analysis

We assume that bond liquidity has two components. The main component is deterministic and depends on the bond aging process. Market players consider the bond age or alternatively the bond 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. A liquidity premium on prices can also be affected by market-wide liquidity as a consequence of monetary and macroeconomic shocks and other phenomena, such as flight-to-quality, flight-to-liquidity or certain episodes of market turmoil, in addition to punctual fluctuations in bond-level liquidity proxied by both microstructure-based liquidity measures and the bond's fundamentals.

In this section, we consider market share as a trading activity measure and liquidity proxy, in addition to three microstructure-based illiquidity proxies. We adjust them as 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.

[20] A sole identification number known as CUSIP (Committee on Procedures Uniform Securities Identification) identifies each US Treasury issue. In some cases, a new tranche of an outstanding issue is auctioned. The outstanding tranche and the new tranche are completely fungible. They share all characteristics, i.e., CUSIP, coupon rate, and maturity date.

[21] Three-, 5-, 7-, and 10-year Treasury notes and 20- and 30-year Treasury bonds have only been taken into account to allow us to estimate the individual market share for each issue.

4.1 Liquidity proxies

We consider four liquidity measures to proxy two different liquidity facets: the market impact and the price impact.[22] In the sections above, a number of liquidity proxies widely used by 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 Díaz, Merrick and Navarro (2006), we use market share as a proxy for trading activity because this measure is hardly influenced by instances of market-wide turmoil. They 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 Bao, Pan and Wang (2011), 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 bond level.

We calculate the measures for weekly age brackets based on daily data. The age of bond *i* on day *t* is computed as the difference between the 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 reduce spurious oscillations. Previous studies also average daily data. For the stock exchange market, Amihud (2002) estimates an annual illiquidity measure from daily data, and Cooper, Groth and Avera (1985) estimate the Amivest ratio on a monthly basis from daily data. For the corporate bond market, Bao, Pan and Wang (2011) use either trade-by-trade prices or end-of-day prices to calculate their Roll adaptation measure, whereas Dick-Nielsen, Feldhütter and Lando (2012) compute illiquidity weekly Roll and Bao measures by taking the median value of the daily measures within each weekly age range.

Market share ($MS_{i,k}$) is the ratio of the individual trading volume of a *k*-weeks-old bond, i.e., a bond during the week the bond has the age of *k*, to the total trading 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 *Amihud* ($AM_{i,k}$), for a *k*-week old bond *i* as follows:

[22] We consider alternative proxies in the robustness check section to corroborate the results. In concrete, we compute the turnover, the Roll (1984)'s measure, and the Amivest liquidity ratio (Amihud, Mendelson and Lauterback, 1997).

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

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

Bao, Pan and Wang (2011) propose an aggregate illiquidity measure, γ, which is a variant of the Roll (1984) measure. We compute $Bao_{i,k}$ for bond *i* in the last trading day *t* of the *k*-week of age as the negative covariance between the price change from a time and the price change from the following period. We use a three-week rolling window. This proxy is a measure of the impact of illiquidity on prices.

$$\gamma_{i,k} = -Cov(\Delta p_t, \Delta p_{t+1}) \quad (2)$$

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. 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 US corporate bond market, these authors 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 two-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 in Section 5.1. We compute the Price Dispersion ($PD_{i,k}$) for bond *i* in week *k* as follows:

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

where, for each bond *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 bond *i* on each day *t* during the week *k*.

Market Share is a proxy for liquidity, but the other three measures are illiquidity proxies. As the trading volume or the turnover (trading volume over amount outstanding), a higher market share implies more trading activity and improved trading conditions, i.e., the bond can be traded more easily and quickly and transaction costs are lower. In the case of the *Bao* measure, an illiquid bond 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 *Amihud* measure, higher values represent a larger price impact and transaction costs. Therefore, bonds with high Amihud values are less liquid bonds. Finally, a low level of the *Price Dispersion* measure indicates liquidity, i.e., the bond can be traded close to its fair value.

4.2 Estimating a liquidity 'life cycle'

Following Díaz, Merrick and Navarro (2006), we analyze the relationship between trading activity, proxied by *Market Share* (*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, i.e., *Amihud* (*AM*), *Bao* and *Price Dispersion* (*PD*).

In a first approximation of the problem, Figure 4 provides some insight into the *MS* behavior for a 2-year note. This figure plots the term structure of the average daily *MS* over the lifetime of the notes. It reflects the auction status and clearly corroborates the on-the-run phenomenon. An average MS of approximately 27 percent for the just-issued 2-year note (on-the-run) means that it is not only the most actively traded security for this maturity but also the most actively traded security on the entire US Treasury market. This issue concentrates the market trading, and it should be the most highly liquid security on the market. An issue remains as on-the-run for approximately 4 weeks. This period of time is the period between successive competitive auctions of new 2-year notes. The trading activity of the remaining outstanding 2-year notes (off-the-run) remains relatively low until maturity. The first-off-the-run trades with a four percent *MS* and second- and further-off-the-run only with a 0.5 percent *MS*.

In the scaled-up Panel B of Figure 4, we observe peaks in the *MS* when the time to maturity of the 2-year note is approximately 12, 6 and 3 months. This increase in trading activity may be because these securities can be used as a substitute for just-issued 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. In this period, these assets compete with the one-year Treasury bill.

[INSERT FIGURE 4 ABOUT HERE]

This trading activity 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 basis points (bp) for 2-year notes with ages of up to 3 weeks. This constant bid-ask spread jumps to 6.250 bp for 2-year notes 4 weeks old or older.

Figure 5 plots the time evolution of the weekly average and two standard deviation bands for the four liquidity proxies, depending on the aging of the note. Table 2 summarizes the main descriptive statistics for the full lifetime of the 2-year notes and separately identifies the on-the-run, first off-the-run, second and further off-the-run auction status. The term structure of the *MS* seems to fit the expected behavior of the liquidity and the liquidity premium according to the literature. However, the three price impact illiquidity proxies show irregular patterns that are difficult to explain. According to the results for the *Bao* and *PD* measures, the younger the note is, the higher the search and transaction costs. Thus, the on-the-run and first off-the-run notes should be, on average, the most highly illiquid assets on the market. In the case of the *AM* measure, it performs as expected during the on-the-run period. Additionally, the average *AM* value is much lower than the values observed in previous studies on the US corporate bond market (e.g., Dick-Nielsen, Feldhütter and Lando, 2012) which implies that a trade of similar volume in this segment of the government debt market moves the price less than it would do in the corporate bond market. As expected, this market is more highly liquid than the corporate bond market.

[INSERT FIGURE 5 AND TABLE 2 ABOUT HERE]

The two standard deviation bands show that the first year after issuance is the more volatile period for our liquidity proxies. The wide bands indicate that the mean is estimated with low precision. In the case of *MS* 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.

According to the evolution of the three microstructure-based measures, liquidity progressively improves as maturity approaches. Paradoxically, these assets 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. The impact of transaction costs on yields can be huge.[23] The puzzling results observed in Figure 5 are corroborated in Table 2.

One explanatory reason for the great volatility observed in Figure 5 and Table 2 may be market episodes that affect the liquidity of these assets. Otherwise, it is difficult to interpret some results according to intuition and the literature. Some doubts concerning what these measures actually measure appear. For instance, the average 'illiquidity' corresponding to a 38-week-old note measured by *Bao* is 0.0036 and shows a tenfold increase one week later (0.0359). These 2-year notes are very homogeneous assets; they

[23] A possible reason for this apparent increase in liquidity may be that these assets are used in transactions that attempt to replace repo operations. A repurchase agreement involves two opposite transactions, the sale of a security and a subsequent purchase of the same asset. Shorting (or buying) a short-term asset and waiting until maturity to buy it back (or to get your money back) are equivalent to a repo but involve lower transaction costs.

are issued by the same issuer, are affected by similar risks and have similar amounts outstanding, coupon rates and maturities.

Figure 6 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 very erratic, especially in the case of *Bao* and *PD*. 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 the three considered illiquidity proxies follow some trends along the lifetime of the notes but that it is difficult to find an economic explanation underlying them. The high volatility and irregular pattern suggest that they are part of a stochastic component of the liquidity, in which the age is not the main determinant. Thus, we hypothesize that liquidity has a main deterministic age-based component. The liquidity of a bond follows different stages that are well-known by the market. Thus, we can model a current expected liquidity function of the bond age with implications for prices. Our previous findings suggest that this determinist age-based component is driven by one of the liquidity facets, i.e., trading activity. Additionally, market-wide liquidity, and punctual fluctuations in bond-level liquidity proxied by both microstructure-based liquidity measures and the bond's fundamentals can also affect a liquidity premium on prices.

Following Díaz, Merrick and Navarro (2006), we model each of the four liquidity proxies as smooth, non-linear functions of the age of a 2-year note. 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 1 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 bond 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 the note is k-weeks-old. Using expression (4), the expected *MS* can be expressed as follows:

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

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

Figure 7 plots the actual and estimated values for the four considered 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.[24] We consider that 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 relationship between the observed value of the liquidity proxies and the expected liquidity according 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. As the bond's characteristics, we use *Age* expressed in weeks, the *Coupon* rate because this variable has tax implications, the log of the *Amount* outstanding, and the *Bid-Ask* spread.

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.[25]

[24] Both Goldreich, Hanke and Nath (2005) and Díaz, Merrick and Navarro (2006) 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.

[25] 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.

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*-squared (adj. 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, 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 estimated coefficient for the expected *Bao* is not statistically significant. The proxy for the flights to liquidity/quality (*AAA-10yrTr*) has significant effects in all cases by increasing the market liquidity, as measured by the *MS*, *Bao* and *PD* proxies, but with the opposite effect based on the *AM* proxy.

Based on these results, we observe that market players can very 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 random behavior of these illiquidity proxies is predominant. Thus, we observe 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 government bonds. We examine the price impact of the different components of liquidity throughout the lifetime of the US Treasury bonds. Our starting point is the consensus in the literature with respect to the liquidity pricing impact on fixed income securities.[26] In this sense, we also examine the explanatory power of the considered liquidity proxies to check their availability as measures of liquidity.

5.1 Estimating liquidity premiums

The classical literature computes the liquidity premium as the yield-to-maturity differential between Treasury notes and bills with the same remaining maturity. Amihud and Mendelson (1991) observe a higher bid-ask spread and brokerage fees for notes compared to bills and lower standard sizes of transactions. This lower liquidity of notes

[26] However, some paper is more skeptical. For instance, Elton and Green (1998) observe a restricted liquidity effect in prices of Treasury securities.

implies a higher yield-to-maturity than similar bills. Kamara (1994) concludes that the note-bill yield differential is systematically related to the differences in the liquidity (immediacy) risk. Fontaine and García (2012) propose an alternative to this method that consists of comparing pairs of securities composed of the youngest bond in a given maturity's bin and other securities in the same maturity's bin. Other papers use securities with different maturities, e.g., Krishnamurthy (2002) and Goldreich, Hanke and Nath (2005). 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. 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 different securities. For instance, these authors compare assets with different features, such as notes, bonds, bills, or STRIPS. Additionally, these securities bear different coupon rates and introduce a tax bias.

We use the method applied by Díaz and Skinner (2001), Fleming (2003), and Díaz, Merrick and Navarro (2006). 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 two-year Treasury note and its theoretical yield, as given by an explicit term structure model. The theoretical yield-to-maturity is obtained by discounting the original cash flows of the bond by the corresponding spot rates. These daily estimates of the zero-coupon interest rate term structure are obtained by the methodology by Svensson (1994) and from our daily GovPx dataset of all the traded Treasury bills and straight notes and bonds.[27] In this manner, we avoid possible biases that the use of other yield curves could may implied, given that they are estimated based on different prices of other different sets of securities. Our fitted term structure for each date reflects the average liquidity level in the market because, as input, we use the prices, reported by GovPX, at which all the Treasury securities (bills, notes and bonds) are traded during the day.

We fit the term structure of interest rates for each date. As the fitting method, we estimate the well-known and widely used parametric and parsimonious procedure by Svensson (1994).[28] 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:

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

[27] There are well-known yield curve datasets available. They can be downloaded from the Federal Reserve Board H.15 series and the US Department of the Treasury websites, or they can be bought from global financial data providers. They use different estimation methods and different security sets. For instance, H.15 considers off-the-run bonds; the Department of the Treasury uses on-the-run bills and bonds; and Bloomberg computes all the outstanding (even callable) bonds. We prefer to fit the yield curve based on the exact same prices that we use in the liquidity premium analysis.

[28] According to the Bank of International Settlements (2005), nine out of thirteen 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.

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

The estimated yield curve for each date is calculated from the trading prices of all the straight Treasury securities reported by the GovPx dataset. We minimize the sum of the squared errors on prices using a non-linear optimization program.

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 discounting each of the remaining cash flows of the original bond *i* 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*) 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 'liquidity premium' with respect to an identical asset with the average market liquidity.

Figure 8 plots the *YS* throughout the lifetime of the 2-year note. We can observe that the higher the age is, the higher 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, implying a higher price and therefore a lower yield-to-maturity. As the bond's age increases, liquidity premiums begin to be 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.[29] The literature 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.

[INSERT FIGURE 8 ABOUT HERE]

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 and -3.5 bp, respectively. Investors are paying for these securities a price higher than they would pay for an identical asset

[29] For instance, Dick-Nielsen, Feldhütter and Lando (2012) use one month to maturity as the threshold; Fontaine and Garcia (2012) fix the lower limit at two months to maturity; and both Gürkaynak, Sack and Wright (2007) and the UK Debt Management Office (DMO) exclude securities with less than three months to maturity for estimating US and UK yield curves, respectively.

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 bp. After the note loses this status, i.e., the note becomes second or further off-the-run, the *YS* values are mainly positive, with an average of 5.9 bp.

Based on these results, we observe that the liquidity premium between on-the-run and off-the-run notes is, on average, approximately 10.1 bp in terms of yield-to-maturity. This amount is computed as the sum of the *YS* with respect to the theoretical market-averaged yield-to-maturity for both assets. In terms of prices, this average value is 11 bp. Dick-Nielsen, Feldhütter and Lando (2012) 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 bp (or -15.0 bp) for the on-the-run notes.

The temporal evolution of these premiums may depend on market-wide factors as a consequence of monetary decisions, funding conditions on the repo market and macroeconomic shocks and other phenomena, such as flight-to-quality, flight-to-liquidity, certain episodes of market turmoil, and the impact of these events on market sentiment and risk aversion. Figure 9 plots 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 bp in August to -22.6 bp 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 highest levels of volatility in the market in the first week of October. The reported statistics in Table 5 detail the turmoil of 1998.

[INSERT FIGURE 9 AND TABLE 5 ABOUT HERE]

5.2 Liquidity proxies and the liquidity premium

Differences in liquidity/illiquidity should explain 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. 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. Market participants may consider this expected current liquidity level and its potential future values before making trading decisions. This level may be a key input in investors' decision-making process.

Table 6 reports the results from the regression of the *YS* on the actual value of each liquidity proxy. We also run regressions for the same models, where the note's *Age* is included as an additional explanatory factor. We observe that *Bao* is the only proxy whose estimated coefficient is not statistically significant. The adj. R^2 values are relatively low for the illiquidity proxies (less than 2.3%) and slightly higher in the case of the *MS* (7.4%). As noted in the sections above, the signs of the two significant illiquidity proxies are counterintuitive. A higher level of illiquidity measured by *AM* and *PD*, i.e., a higher price impact and transaction cost, implies a lower *YS* and liquidity premium. This result, which is difficult to explain, remains when we consider a joint model with the four liquidity proxies as explanatory variables (the last two columns in Table 6).

[INSERT TABLE 6 ABOUT HERE]

The results for the models that include the note's *Age* show that this is a relevant factor in explaining the *YS*. The adjusted R^2 substantially improves. The age of the note is able to explain a large portion of the variation in the *YS*. The older the note is, 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 negligible impact on the liquidity premium. Only our proxy for trading activity has a relevant explanatory power.

In Section 4.2, we propose expressions to predict the expected level of the four considered liquidity/illiquidity proxies based on the aging of the note. The estimated term structure of the MS provides good predictions of the current trading activity. We suggest that this deterministic liquidity component reflects the expectation of the current and the potential future liquidity. However, the expected component of the three illiquidity proxies obtains poor results.

We now test the role of the expected liquidity 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.

[INSERT TABLE 7 ABOUT HERE]

As expected, the predicted MS explains a relevant percentage of the *YS*. The coefficients of the expected AM, Bao and PD have the wrong sign, as in the previous analysis and are statistically significant. 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 coefficients of the unexpected liquidity/illiquidity. The abnormal MS, Bao and PD coefficients remain significant and with similar values after including age. A trading activity (proxied by MS) larger than expected reduces the *YS*. A price impact (proxied by Bao) higher than expected increases the *YS*. Unfortunately, the result for the abnormal PD is inconsistent, i.e., transaction costs wider than expected diminish the *YS*. The last model includes age and all of the expected and abnormal values of the liquidity/illiquidity proxies. 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.

These findings are robust to the inclusion of bond characteristics and control variables, as shown in Table 8. We incorporate the same variables noted in Section 4.2 in the models that consider current liquidity (see Table 6) and those that consider expected liquidity (see Table 7). These additional explanatory factors increase the adj. R^2 approximately 6%. The results show the impact of factors such as the size of the issue, shape of the yield curve, market sentiment and risk aversion. These results show the role of the stochastic component of the liquidity premium. 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.

5.3 Robustness checks

As robustness checks, we estimate the models for two different sub-samples. Moreover, we replace the four liquidity proxies with three alternative proxies. We consider an initial sub-sample that ends in July 1998. Figure 9 shows the beginning of the market turmoil initiated by the Russian financial crisis and the LTCM default from August 1998. This period is included in our second sub-sample.

As an alternative to *MS* as a proxy for trading activity, we consider the turnover (*TO*) ratio, 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. In empirical research on stock exchange markets, this measure 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*, the weekly average of the daily ratio of trading volume to absolute return for each bond *i*, as follows:

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

where $D_{i,k}$ is the number of days for which bond *i* is traded in week *k*; $TV_{i,t,k}$ is the par trading volume in million dollars for bond *i* on day *t* of week *k*; and $|r_{i,t,k}|$ is the absolute return of bond *i* on day *t* of week *k*.

We also replace the *Bao* measure with the Roll (1984) proposal. Indeed, Bao, Pan and Wang (2011) simply use a modified version of the original Roll measure. Roll (1984) 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*:

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

where Δp_t is the change in prices or the absolute return from *t*-1 to *t*. Following Dick-Nielsen, Feldhütter and Lando (2012), we use a rolling window of 21 trading days to compute this measure.

Table 9 shows the results of the robustness checks. The left-hand side of the table contains the results for the current and expected liquidity proxies previously used by the two proposed 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 estimated coefficient is 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.

6 Conclusions

This paper examines the price impact of the different components of liquidity throughout the lifetime of a US Treasury bond. We study the explanatory factors and the predictable behavior of the liquidity premium involved in the prices of two-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 results for the microstructure-based liquidity proxies are inconsistent with expectations.

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 bp for the on-the-run, -2.3 bp for the first off-the-run, and 5.9 bp for the remaining notes. This amount clearly depends on market-wide factors. The regression analysis indicates that a large portion of the liquidity premium follows a predictive behavior along the lifetime of the Treasury note. The current level of three common microstructure-based measures of illiquidity has a negligible impact on the liquidity premium. 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 explains a relevant percentage of the yield spread. The abnormal or unexpected value of three of the liquidity proxies has a statistically significant impact. 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 stochastic 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.

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Figure 1. Evolution of the total amount outstanding of US Public Debt. This figure shows the evolution of the total amount outstanding of US public debt in trillion dollars from 1996 to 2015. End-of-month data, computed on September 30 of each year, are shown. Values for 2015 are the amount outstanding on August 31, 2015. Panel A shows the total amount outstanding, including marketable, non-marketable and noninterest-bearing debt. Panel B shows the marketable total amount outstanding by Treasury securities. The designation 'Other' includes marketable debt, such as Treasury inflation-protected securities, floating rate notes and Federal Financing Bank debt. Source: www.treasurydirect.gov.

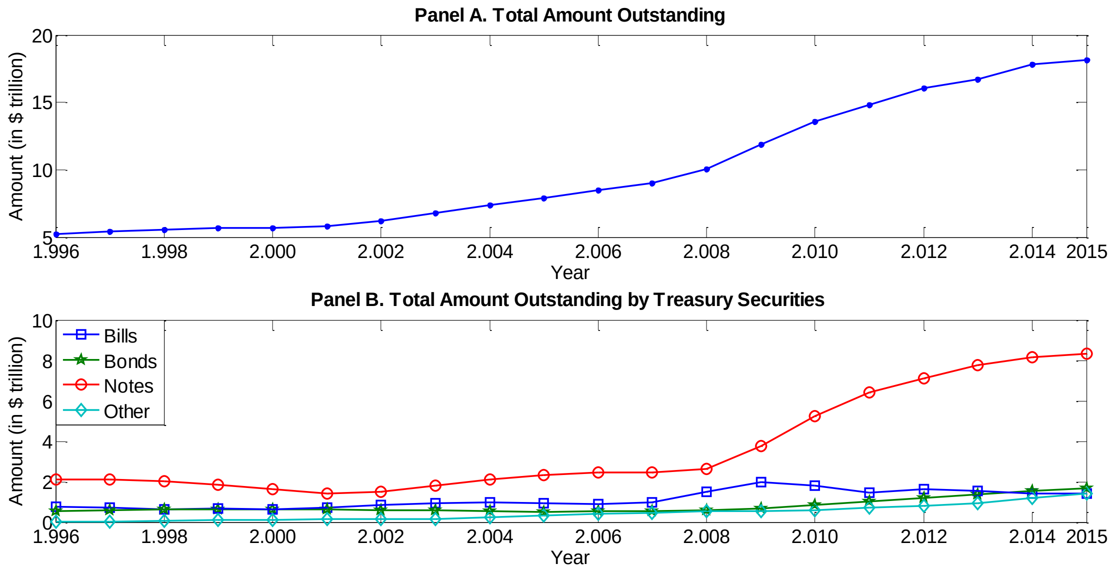


Figure 2. Trading activity reported by GovPx for the full market and the 2-year note segment. This figure shows the evolution of the monthly trading volume and the number of trades for all of the traded US Treasury notes and bonds reported by the GovPx dataset in trillion dollars from 1996 to 2001. The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

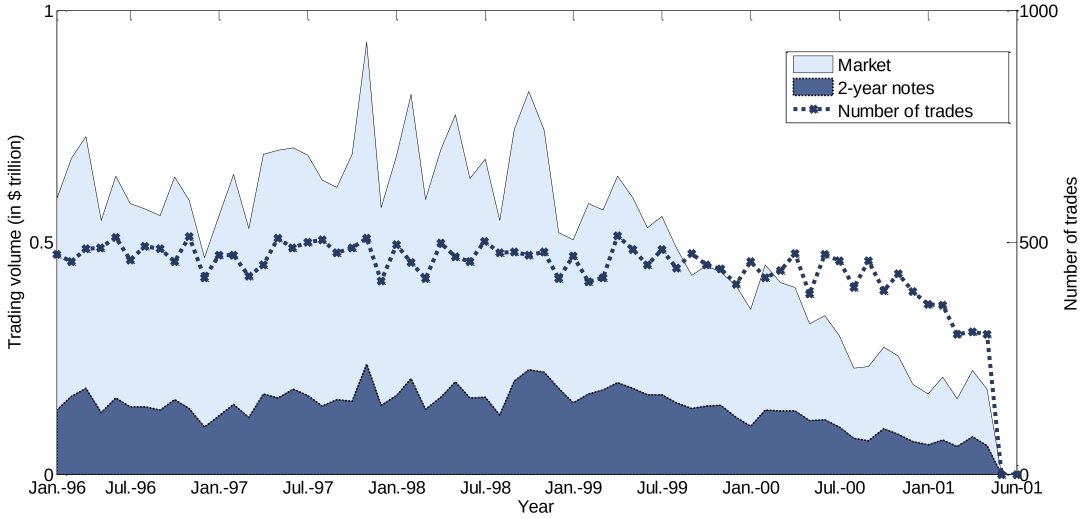


Figure 3. Average Market Share (2-, 3-, 5- and 10-year notes and 30-year bonds). This figure shows the average daily Market Share per weekly age range based on current transactions for 2-, 3-, 5- and 10-year Treasury notes and 30-year Treasury bonds. This measure is only computed for days with a positive trading volume. 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. Then, we assign a weekly age range to each bond with a daily age.

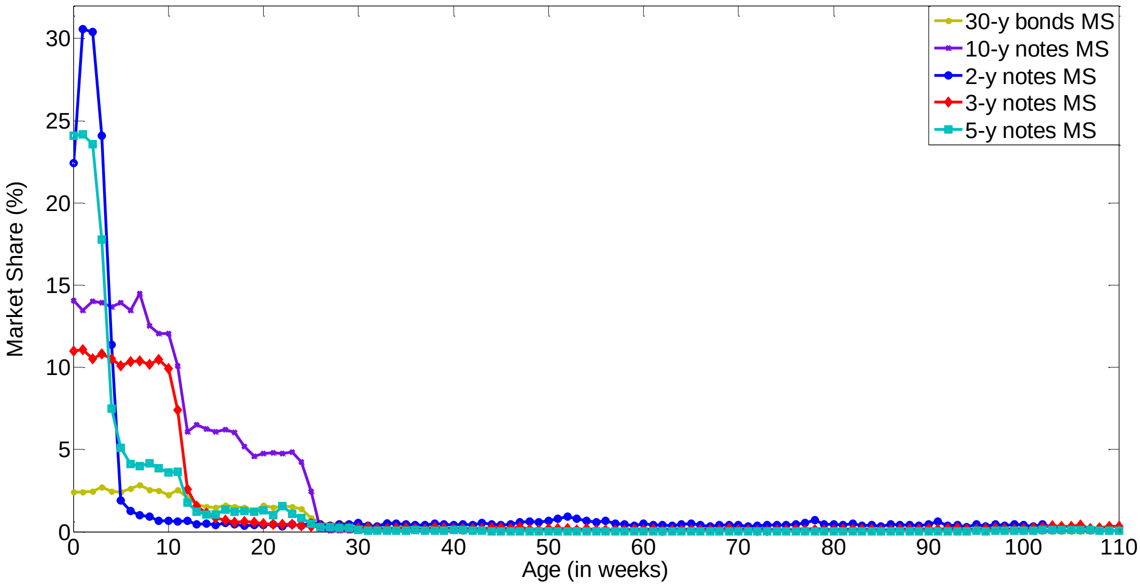
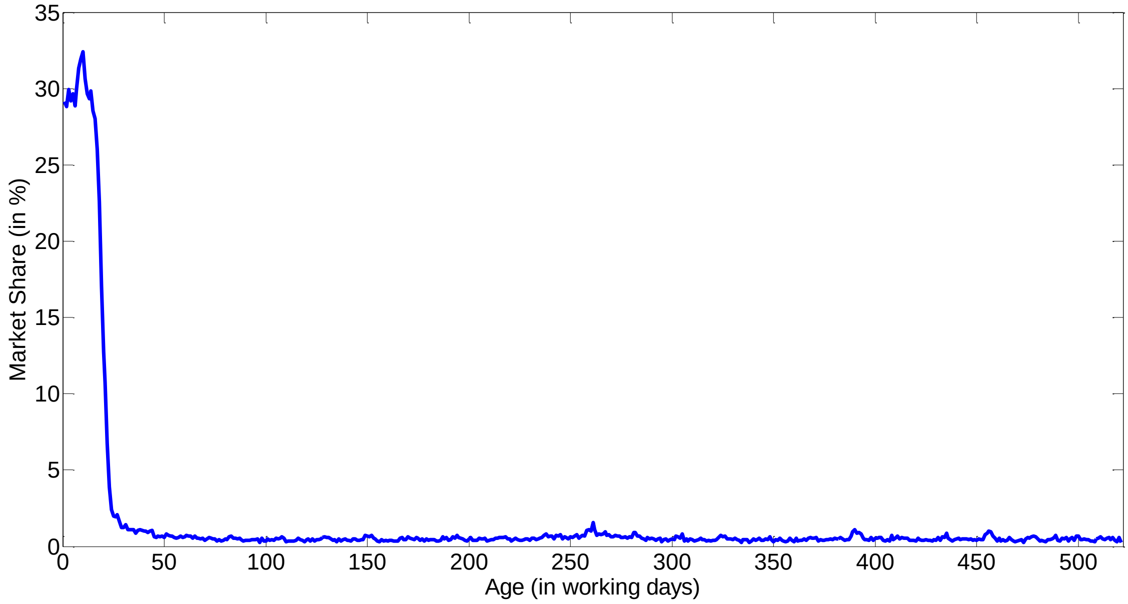


Figure 4. Average Market Share along the lifetime of the 2-year notes. This figure shows the average Market Share per note age, expressed in working days, based on current transactions for 2-year Treasury notes. Panel A shows the values for the average Market Share on all days, whereas Panel B is a scaled-up version up to 2% Market Share. The dataset includes 83 two-year Treasury notes with 27,261 daily transactions 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 working days between the issuance date and the trading day, controlling for holidays.

Panel A. Complete panel



Panel B. Expanded panel (scale from 0 to 2%)

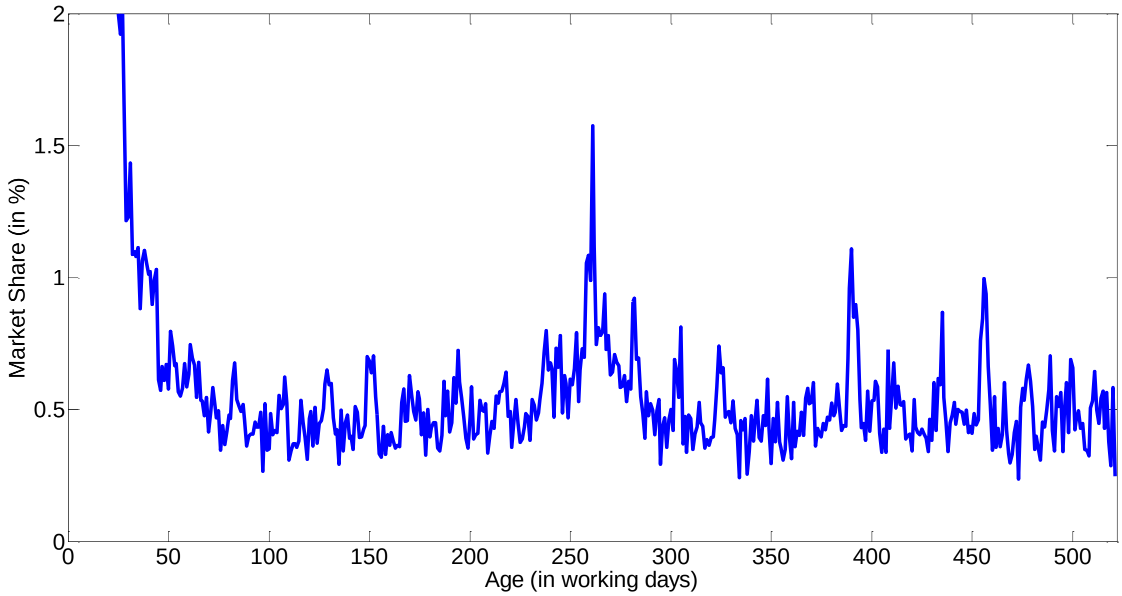


Figure 5. Average and two standard deviation bands for Market Share, Amihud, Bao, and Price Dispersion measures depending on aging. This figure displays the term structure of the four liquidity proxies: Market Share (panel A), Amihud (panel B), Bao (panel C), and Price Dispersion (panel D). The dataset includes 83 two-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 working days between the issuance date and the trading day, controlling for holidays, over 5 (five working days on a week). No exact values are rounded up in order to assign a weekly age range to each bond.

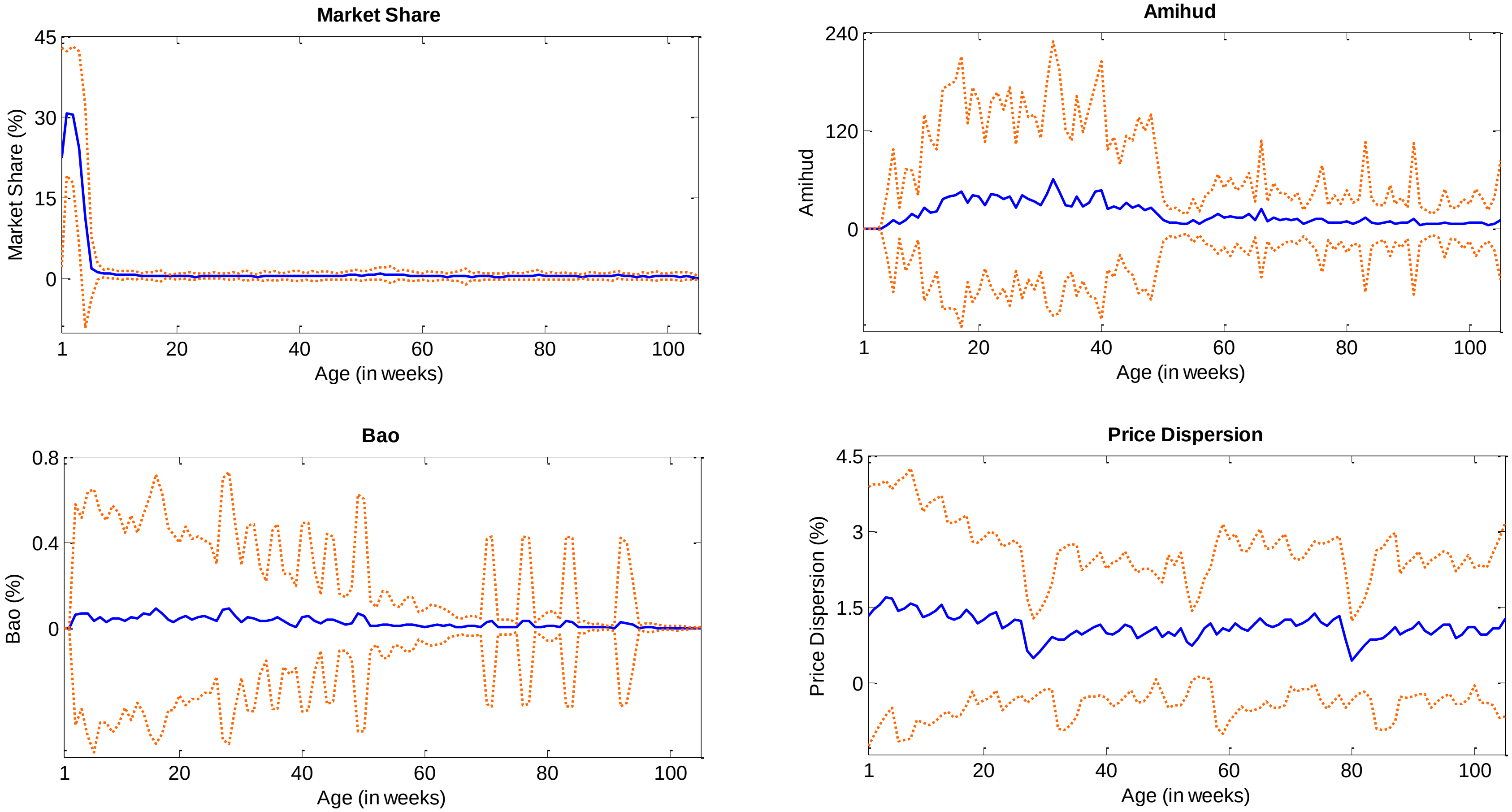


Figure 6. Monthly evolution of observed Market Share, Amihud, Bao, and Price Dispersion measures. This figure displays the average monthly evolution of the Market Share, Amihud, Bao and Price Dispersion measures by note status. On-the-run notes are the most recently issued notes, aged from 1 to 4 weeks; 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 two-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.

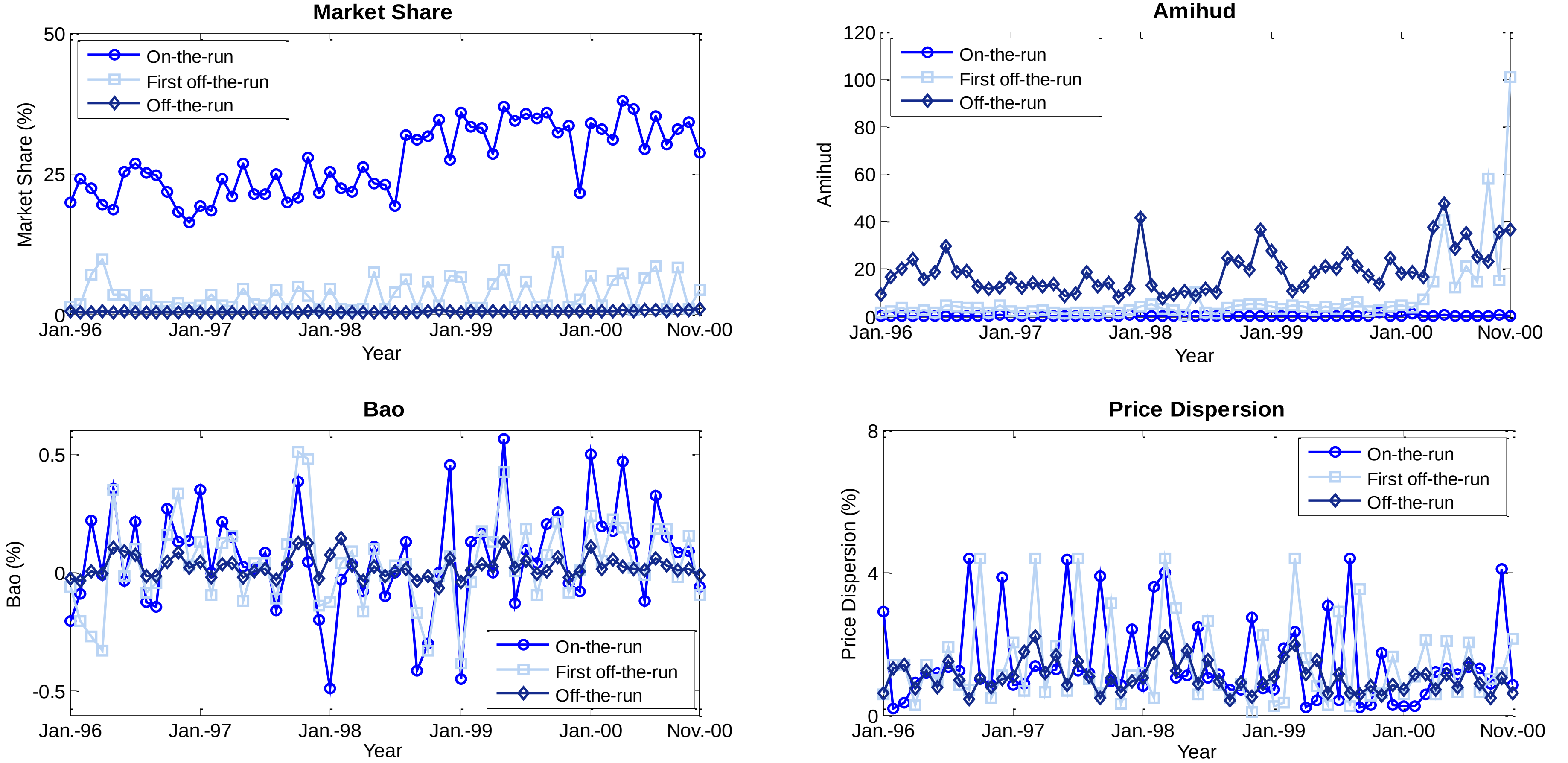


Figure 7. Average current and expected Market Share, Amihud, Bao, and Price Dispersion measures. This figure displays the average current and fitted weekly Market Share, Amihud, Bao and Price Dispersion measures. The fitted functions based on age are estimated according to expressions (4), (5), (6) and (7), which are described in section 4.2. The dataset includes 83 two-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 on a trading week as the difference in working days between the issuance date and the trading day, controlling for holidays, over 5 (five working days on a week). No exact values are rounded up in order to assign a weekly age range to each bond.

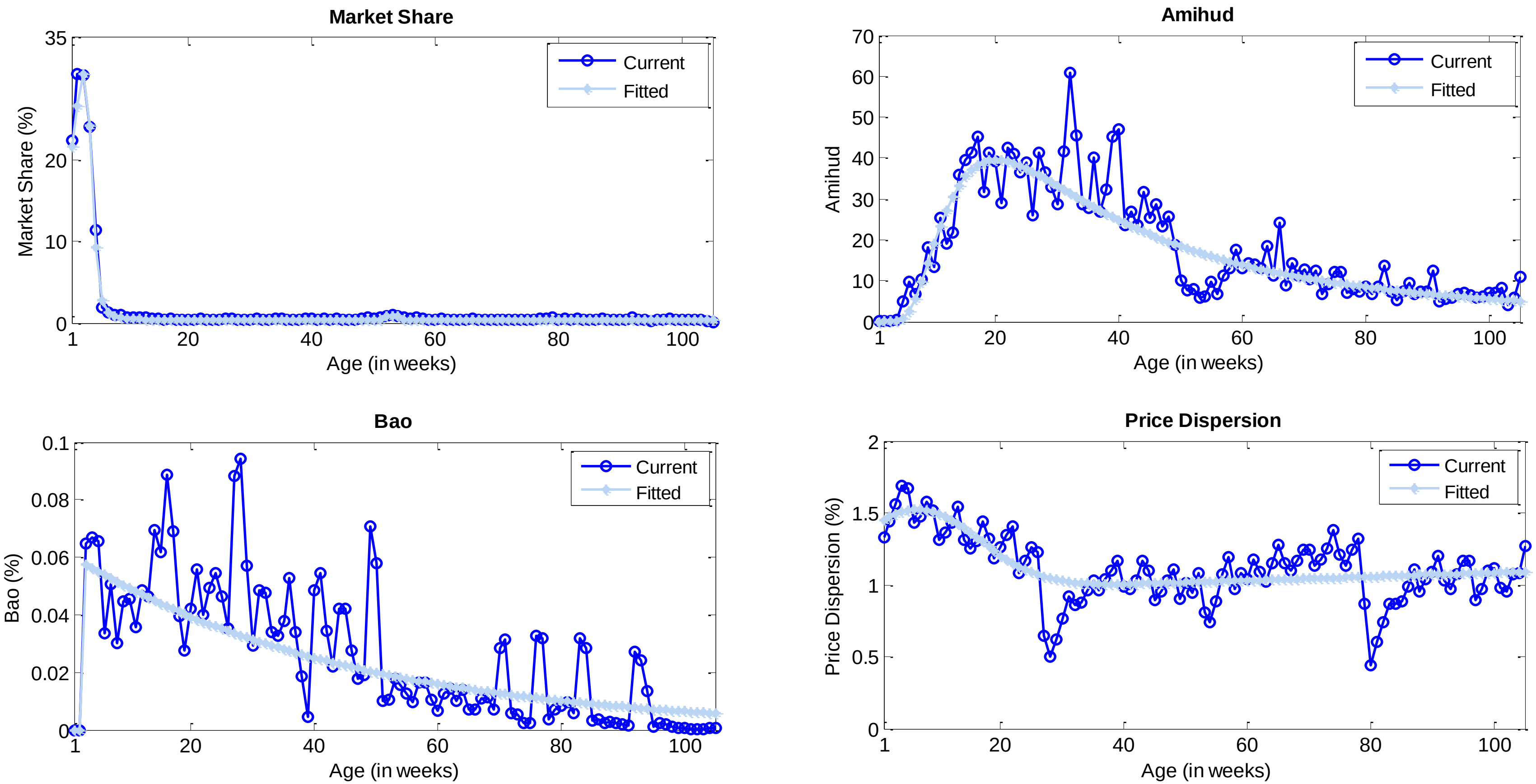


Figure 8. Yield spread throughout the lifetime. This figure plots the weekly mean yield spread (*YS*) across weekly age tranches. *YS* can be interpreted as a liquidity premium with respect to an identical asset with the average market liquidity. We estimate the *YS* for every single note and date as 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. The blue line depicts the weekly average *YS*, and the orange dotted lines depict +/- 2 standard deviation bands. The dataset includes 83 two-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 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 week as the difference in working days between the issuance date and the trading day, controlling for holidays, over 5 (five working days in a week). No exact values are rounded up to assign a weekly age range to each bond.

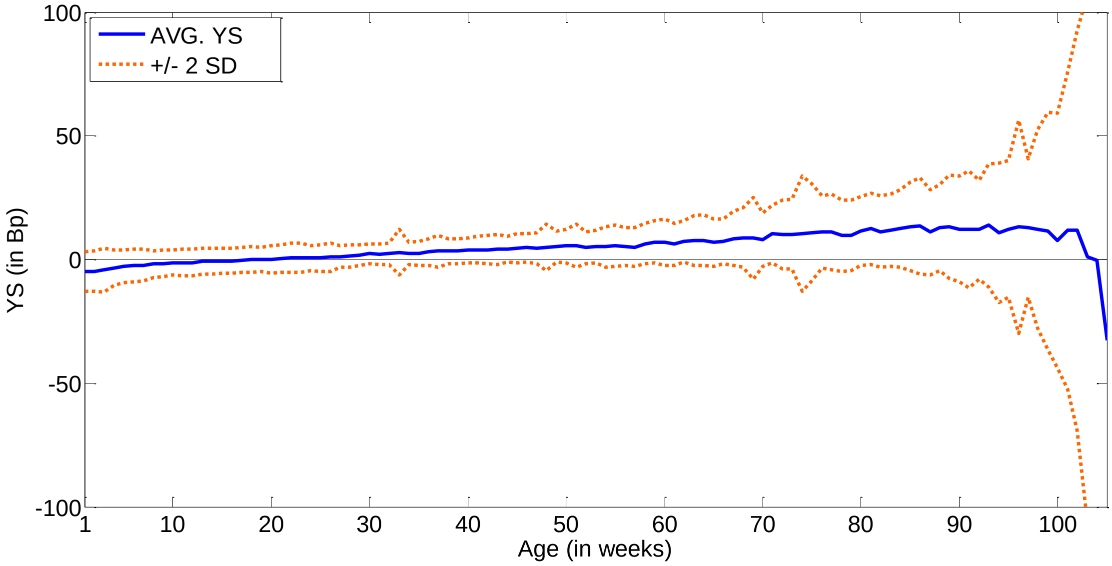


Figure 9. Monthly evolution of observed yield spreads. This figure displays the average monthly evolution of *YS* in basis points by note status. On-the-run notes are the most recently issued notes, aged from 1 to 4 weeks; first off-the-run notes represent the most recent off-the-run notes, aged from 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 two-year Treasury notes with 6,175 weekly values in 257 trading weeks 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.

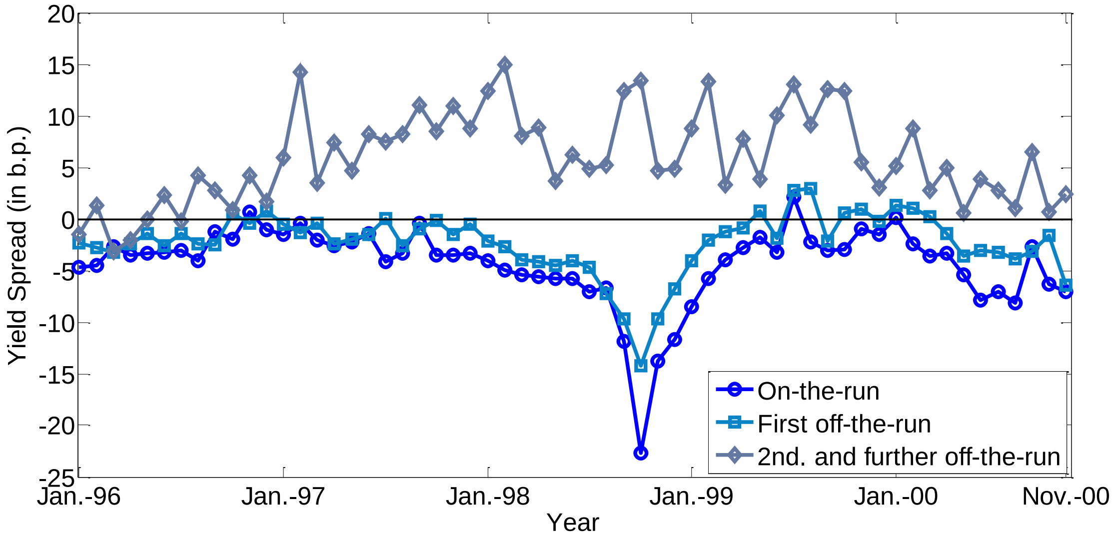


Table 1. Sample composition. This table provides information on the composition of the entire sample from the GovPx dataset by term to maturity. *Outstanding issues* is the number of simultaneous outstanding issues along the entire sample. *#Observations* is the total number of observations in the initial sample. *% Zeros* is the percentage of observations with zero trading volume. *Issues* is the number of different issues by original term to maturity. *Agg. 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
Outstanding issues	24	12 or less	24	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
Agg. 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. 5th, 25th, 50th, 75th, and 95th quantiles, mean, standard deviation, minimum, maximum and median for liquidity and illiquidity proxy measures. *MS, AH, Bao* and *PD* are the Market Share, Amihud, Bao and Price Dispersion measures, respectively. The results for Bao are multiplied by 100. The liquidity and illiquidity proxies are described in detail in Section 4 and are calculated weekly. *Panel A* shows the statistics for the entire sample, the lifetime is for the age range from 1 to 105 weeks. *Panel B* shows the statistics for the *on-the-run* note status, i.e., newer notes with age range from 1 to 4 weeks. *Panel C* shows the statistics for the first *off-the-run* notes, which are the newer notes once a new issuance occurs, with the age range from 5 to 8 weeks. *Panel D* shows the statistics for the oldest *off-the-run* notes, with the age range from 9 to 105 weeks. The dataset includes 83 two-year Treasury notes with almost 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, AH 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)	2nd & further off-the-run (weeks 9-105)
Panel A. Market Share				
$Q_{0.05}$	0.001	0.107	0.006	0.001
$Q_{0.25}$	0.002	0.231	0.010	0.002
$Q_{0.50}$	0.004	0.270	0.013	0.004
$Q_{0.75}$	0.007	0.347	0.021	0.006
$Q_{0.95}$	0.024	0.379	0.231	0.012
Average	0.016	0.269	0.038	0.005
Std dev	0.056	0.088	0.068	0.004
#Obs	6,175	238	237	5,700
Panel B. Amihud				
$Q_{0.05}$	0.252	0.009	0.552	0.643
$Q_{0.25}$	2.312	0.078	1.629	2.745
$Q_{0.50}$	6.066	0.112	2.721	6.741
$Q_{0.75}$	16.079	0.189	5.141	17.311
$Q_{0.95}$	74.611	0.584	23.282	78.989
Average	18.209	0.235	7.989	19.384
Std dev	39.468	0.567	28.947	40.418
#Obs	6,175	238	237	5,700
Panel C. Bao				
$Q_{0.05}$	-0.117	-0.400	-0.379	-0.100
$Q_{0.25}$	-0.005	-0.050	-0.088	-0.004
$Q_{0.50}$	0.002	0.075	0.040	0.002
$Q_{0.75}$	0.000	0.182	0.166	0.029
$Q_{0.95}$	0.215	0.483	0.489	0.188
Average	0.027	0.066	0.045	0.025
Std dev	0.157	0.240	0.267	0.148
#Obs	6,056	119	237	5,700
Panel D. Price Dispersion				
$Q_{0.05}$	0.001	0.002	0.001	0.001
$Q_{0.25}$	0.005	0.008	0.006	0.005
$Q_{0.50}$	0.009	0.010	0.011	0.009
$Q_{0.75}$	0.015	0.018	0.021	0.015
$Q_{0.95}$	0.027	0.042	0.044	0.025
Average	0.011	0.015	0.015	0.011
Std dev	0.008	0.012	0.012	0.008
#Obs	6,175	238	237	5,700

Table 3. Liquidity measures. This table reports the results from the regressions on each considered liquidity proxy. *MS* is a liquidity proxy, and *AM*, *Bao* and *PD* are illiquidity proxies. *Expected 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. *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 83 two-year Treasury notes with almost 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, AH 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. The t-statistics are based on the Newey-West estimate of the covariance matrix and are presented in parentheses: * significant at 10%; + significant at 5%; # significant at 1%.

	Market Share		*Amihud*		*Bao*		*Price Dispersion*	
Intercept	0.000	-0.057	0.229	-134.33	-0.005	-3.399	-0.557	27.483
	(2.56)+	(-3.90)#	(0.28)	(-6.06)#	(-0.11)	(-3.30)#	(-0.24)	(3.13)#
E[Liq]	1.044	1.042	1.047	1.054	1.211	0.263	1.037	1.013
	(36.63)#	(38.34)#	(14.66)#	(16.81)#	(4.43)#	(0.32)	(4.72)#	(4.47)#
Age		-0.000		-0.015		-0.005		-0.002
		(-1.55)		(-1.01)		(-1.49)		(-0.25)
Coupon		0.001		6.408		0.173		0.848
		(1.41)		(5.41)#		(3.70)#		(2.27)+
Amount		0.006		-4.819		0.663		-1.615
		(1.77)*		(-0.95)		(2.61)#		(-0.93)
Bid-ask		-0.000		1.342		-0.012		-0.101
		(-2.28)+		(14.16)#		(-1.86)*		(-0.35)
Level		0.204		1,069.28		2.496		-269.77
		(1.82)*		(5.04)#		(0.36)		(-4.31)#
Slope		0.266		1,086.86		-0.543		-734.009
		(0.93)		(2.13)+		(-0.03)		(-4.48)#
Curvature		0.557		-4,308.79		243.33		1,200.07
		(0.53)		(-2.30)+		(3.48)#		(2.39)+
SP500		0.000		0.000		0.001		0.001
		(1.85)*		(0.04)		(2.68)#		(0.41)
VIX		0.000		0.393		0.021		-0.149
		(1.80)*		(3.19)#		(2.21)+		(-4.10)#
BBB-AAA		0.006		26.748		-0.270		1.933
		(1.70)*		(3.39)#		(-0.88)		(0.94)
AAA-10yTr		0.007		18.917		-0.577		-7.890
		(2.65)#		(4.45)#		(-2.43)+		(-6.19)#
Market Vol		0.000		-0.819		-0.128		0.356
		(0.02)		(-0.48)		(-1.90)*		(0.92)
Adjusted R^2	0.878	0.881	0.095	0.132	0.012	0.035	0.039	0.085
#Obs	6,175	6,175	6,175	6,175	6,056	6,056	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 basis points, 5th, 25th, 50th, 75th, and 95th quantiles, mean, standard deviation, minimum, maximum and median. *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 single 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. We winsorize the 0.5% highest values and the 0.5% lowest values of the daily *YS*, 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. *On-the-run* (weeks 1 to 4), 1st *Off-the-run* (weeks 5 to 8) and *2nd and further Off-the-run* (weeks 9 to 105) represent different sub-samples, depending on the auction status. The last column excludes notes with a maturity of less than two months (the last 10 weeks before maturity). The dataset includes 83 two-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.

	Full sample	On-the-run	1st Off-the-run	2nd and further Off-the-run	
		Weeks 1 to 4	Weeks 5 to 8	Weeks 9 to 105	Weeks 9 to 95
$Q_{0.05}$	-5.80	-11.27	-7.60	-4.19	-2.64
$Q_{0.25}$	-0.04	-5.71	-3.52	0.74	0.92
$Q_{0.50}$	3.58	-3.58	-1.95	4.26	4.14
$Q_{0.75}$	9.11	-2.01	-0.44	9.76	8.96
$Q_{0.95}$	24.40	-0.02	1.65	25.06	20.11
Avg	5.23	-4.33	-2.32	5.94	5.77
Std	14.28	4.05	3.13	14.59	7.34
Min	-75.22	-29.32	-16.85	-75.22	-18.25
Max	127.43	3.36	5.28	127.43	86.43
#Obs	6,175	238	237	5,700	5,142

Table 5. Descriptive statistics for 2-year note yield spreads according to the auction status. This table shows the summary statistics for the 2-year *YS* in basis points, 5th, 25th, 50th, 75th, and 95th quantiles, mean, standard deviation, minimum, maximum and median. We estimate the *YS* for every single 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. We winsorize the 0.5% highest values and the 0.5% lowest values of the daily *YS*, 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. *On*, *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. The dataset includes 83 two-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.

	1996			1997			1998			1999			2000		
	On	1stOff	2nd+Off	On	1stOff	2nd+Off	On	1st Off	2nd+Off	On	1stOff	2nd+Off	On	1stOff	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 *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. *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 single 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. We winsorize the 0.5% highest values and the 0.5% lowest values of the daily YS, 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. We exclude notes with an age higher than 95 weeks. The dataset includes 83 two-year Treasury notes during 257 trading weeks. The period covers January 1996 to November 2000 and is based on data from GovPx.
The t-statistics are based on the Newey-West estimate of the covariance matrix and are presented in parentheses: * indicates significance at the 10% level; + significance at the 5% level; # significance at the 1% level.

Intercept	0.056	-0.034	0.053	-0.037	0.052	-0.037	0.065	-0.029	0.075	-0.027
	(20.34)#	(-10.29)#	(17.83)#	(-12.22)#	(18.73)#	(-11.97)#	(16.40)#	(-7.36)#	(18.29)#	(-6.20)#
MS	-0.354	-0.052							-0.359	-0.040
	(-16.25)#	(-2.50)+							(-14.25)#	(-1.92)*
AM			-0.000	0.000					-0.000	-0.000
			(-6.69)#	(0.10)					(-9.37)#	(-1.67)*
Bao					-0.000	0.003			0.001	0.003
					(-0.33)	(5.17)#			(1.04)	(5.34)#
PD							-0.001	-0.001	-0.001	-0.001
							(-5.94)#	(-3.49)#	(-5.71)#	(-3.74)#
Age		0.002		0.002		0.002		0.002		0.002
		(19.68)#		(21.45)#		(20.81)#		(20.91)#		(19.32)#
Adj. R^2	0.074	0.436	0.010	0.434	-0.000	0.420	0.023	0.439	0.080	0.425
#Obs	5,617	5,617	5,617	5,617	5,498	5,498	5,617	5,617	5,498	5,498

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Table 7. Yield spread and expected liquidity. This table reports the results from panel regressions of the *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. *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 single 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. We winsorize the 0.5% highest values and the 0.5% lowest values of the daily YS, 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. We exclude notes with an age higher than 95 weeks. The dataset includes 83 two-year Treasury notes during 257 trading weeks. The period covers January 1996 to November 2000 and is based on data from GovPx.
The t-statistics are based on the Newey-West estimate of the covariance matrix and are presented in parentheses: * indicates significance at the 10% level; + significance at the 5% level; # significance at the 1% level.

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]			-0.002	0.000					0.000	0.000
			(-9.79)#	(1.44)					(1.55)	(0.46)
AbnAM			0.000	0.000					0.000	0.000
			(-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 *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. *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 winsorize the 0.5% highest values and the 0.5% lowest values of the daily YS, 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. We exclude notes with an age higher than 95 weeks. The dataset includes 83 two-year Treasury notes during 257 trading weeks. The period covers January 1996 to November 2000 and is based on data from GovPx.
The t-statistics are based on the Newey-West estimate of the covariance matrix and are presented in parentheses: * indicates significance at the 10% level; $^{+}$ significance at the 5% level; $^{\#}$ significance at the 1% level.

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			0.000						0.000	
			(1.53)						(0.26)	
E[AM]				0.000						0.000
				(1.12)						(0.66)
AbnAM				0.000						0.000
				(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 *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 Section 4 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 winsorize the 0.5% highest values and the 0.5% lowest values of daily YS. We exclude notes with an age higher than 95 weeks. The period covers January 1996 to November 2000 and is based on data from GovPx. The t-statistics are based on the Newey-West estimate of the covariance matrix and are presented in parentheses: * indicates significance at the 10% level; $^{+}$ significance at the 5% level; $^{\#}$ significance at the 1% level.

	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	0.065	-0.188	0.083	0.131
	(0.14)	(-0.80)	(-3.42)$^{\#}$	(-2.90)$^{\#}$		(0.32)	(-0.86)	(0.58)	(0.84)
MS	0.016		0.246		TO	-0.030		-0.058	
	(0.57)		(1.93)*			(-2.85)$^{\#}$		(-1.60)	
E[MS]		-0.051		0.255	E[TO]		-0.044		-0.043
		(-1.31)		(1.61)			(-1.09)		(-0.63)
AbnMS		-0.139		0.280	AbnTO		-63.21		-50.63
		(-1.86)*		(2.11)$^{+}$			(-3.53)$^{\#}$		(-1.33)
AM	0.000		0.000		AV	0.003		-0.002	
	(-0.26)		(0.52)			(2.59)$^{\#}$		(-2.32)$^{+}$	
E[AM]		0.000		0.000	E[AV]		0.002		-0.006
		(0.35)		(0.89)			(0.53)		(-0.96)
AbnAM		0.000		0.000	AbnAV		0.003		-0.003
		(0.51)		(0.54)			(2.50)$^{+}$		(-2.24)$^{+}$
Bao	0.001		0.005		Roll	0.028		-0.032	
	(1.41)		(5.98)$^{\#}$			(2.69)$^{\#}$		(-0.92)	
E[Bao]		0.117		-0.146	E[Roll]		4.784		-0.097
		(1.45)		(-1.46)			(2.90)$^{\#}$		(-0.06)
AbnBao		0.679		4.714	AbnRoll		0.032		-0.032
		(1.34)		(5.99)$^{\#}$			(3.23)$^{\#}$		(-0.92)
PD	0.000		-0.001						
	(-3.95)$^{\#}$		(-5.99)$^{\#}$						
E[PD]		0.001		0.004					
		(0.25)		(1.08)					
AbnPD		-0.538		-0.909					
		(-4.86)$^{\#}$		(-5.81)$^{\#}$					
Age	0.002	0.002	0.002	0.001	Age	0.002	0.004	0.002	0.002
	(47.46)$^{\#}$	(7.89)$^{\#}$	(40.65)$^{\#}$	(3.52)$^{\#}$		(16.55)$^{\#}$	(5.55)$^{\#}$	(15.21)$^{\#}$	(2.57)$^{+}$
Coupon	-0.016	-0.016	0.006	0.006	Coupon	-0.015	-0.016	0.004	0.004
	(-8.61)$^{\#}$	(-8.59)$^{\#}$	(2.74)$^{\#}$	(2.82)$^{\#}$		(-2.78)$^{\#}$	(-2.93)$^{\#}$	(0.82)	(0.80)
Amount	0.074	0.076	0.044	0.044	Amount	0.075	0.077	0.048	0.048
	(9.07)$^{\#}$	(9.35)$^{\#}$	(5.23)$^{\#}$	(5.29)$^{\#}$		(3.48)$^{\#}$	(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
	(0.27)	(0.16)	(2.45)$^{+}$	(2.11)$^{+}$		(0.90)	(0.29)	(-1.90)*	(-2.02)$^{+}$
Level	-2.084	-1.898	1.809	1.813	Level	-2.024	-1.668	1.932	1.926
	(-1.90)*	(-1.74)*	(3.62)$^{\#}$	(3.62)$^{\#}$		(-0.93)	(-0.79)	(2.66)$^{\#}$	(2.65)$^{\#}$
Slope	3.937	4.043	1.831	1.857	Slope	3.506	3.156	4.932	4.899
	(2.28)$^{+}$	(2.35)$^{+}$	(1.80)*	(1.82)*		(0.80)	(0.73)	(2.76)$^{\#}$	(2.74)$^{\#}$
Curvature	-1.887	-1.808	21.239	21.238	Curvature	-5.064	-5.182	14.868	14.957
	(-0.25)	(-0.24)	(8.32)$^{\#}$	(8.32)$^{\#}$		(-0.31)	(-0.32)	(3.10)$^{\#}$	(3.13)$^{\#}$
SP500	0.000	0.000	0.000	0.000	SP500	0.000	0.000	0.000	0.000
	(5.18)$^{\#}$	(5.35)$^{\#}$	(-5.84)$^{\#}$	(-5.84)$^{\#}$		(2.07)$^{+}$	(2.20)$^{+}$	(-4.01)$^{\#}$	(-4.02)$^{\#}$
VIX	0.002	0.002	-0.001	-0.001	VIX	0.002	0.002	-0.001	-0.001
	(4.86)$^{\#}$	(4.84)$^{\#}$	(-2.06)$^{+}$	(-2.08)$^{+}$		(3.78)$^{\#}$	(4.02)$^{\#}$	(-1.73)*	(-1.77)*
BBB-AAA	-0.126	-0.126	0.027	0.027	BBB-AAA	-0.165	-0.133	-0.026	-0.026
	(-4.09)$^{\#}$	(-4.11)$^{\#}$	(2.19)$^{+}$	(2.19)$^{+}$		(-2.79)$^{\#}$	(-2.16)$^{+}$	(-1.29)	(-1.27)
AAA-10yTr	-0.082	-0.075	0.042	0.042	AAA-10yTr	-0.118	-0.106	0.091	0.091
	(-3.11)$^{\#}$	(-2.87)$^{\#}$	(4.83)$^{\#}$	(4.83)$^{\#}$		(-1.90)*	(-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
	(2.63)$^{\#}$	(2.51)$^{+}$	(3.95)$^{\#}$	(3.98)$^{\#}$		(3.35)$^{\#}$	(3.52)$^{\#}$	(4.44)$^{\#}$	(4.41)$^{\#}$
Adj. R^2	0.546	0.551	0.619	0.478	Adj. R^2	0.560	0.571	0.456	0.455
#Obs	2,864	2,634	2,864	2,634	#Obs	1,967	1,843	1,967	1,843