

# The Price of Future Liquidity: Time-Varying Liquidity in the U.S. Treasury Market

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# The Price of Future Liquidity: Time-Varying Liquidity in the U.S. Treasury Market

**ABSTRACT.** This paper examines the price differences between very liquid on-the-run U.S. Treasury securities and less liquid off-the-run securities over the entire on/off cycle. By comparing pairs of securities as their relative liquidity varies over time we can disregard any cross-sectional differences between the securities. Since the liquidity varies predictably over time we are able to differentiate between current liquidity and expected future liquidity. We show that the more liquid security is priced higher on average, but that this difference depends on the amount of expected future liquidity over its remaining lifetime rather than its current liquidity. We measure future liquidity using both quotes and trades. The measures include bid-ask spread, depth and trading activity. Examining a variety of liquidity measures enables us to evaluate their relative importance and identify the liquidity proxies that most affect prices. Although all of the measures are highly correlated with one another, we find that quotes are more important when estimating the effect of the bid-ask spread and depth on the liquidity premium, while the number of trades and trading volume is a more important measure of market activity than the number of quotes.

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# 1 Introduction and Motivation

Liquidity, the ability to quickly and cheaply trade an asset at a fair price, is thought to be an important element that affects the value of securities. Ever since Amihud and Mendelson's (1986) seminal work, there have been a number of studies showing that an asset's liquidity is valued in the market place. These studies<sup>1</sup> often compare similar securities that differ in liquidity and show that the more liquid security has a higher price or lower return.

However, it is often difficult to isolate the price premium for liquidity from other effects when comparing securities. Securities that differ in liquidity usually have other differences that could confound efforts to isolate the price effect of liquidity. For example, the less liquid security might have additional market risk or credit risk. Less liquid securities might also be subject to more asymmetric information or they might be subject to differing tax treatments.<sup>2</sup> Therefore, cross-sectional studies are not able to easily distinguish liquidity effects from other security specific differences.

While theory would suggest that expected future liquidity should affect prices, the empirical literature has almost exclusively focused on current liquidity.<sup>3</sup> The empirical literature has, to date, implicitly assumed that a security's current liquidity will persist over time. Though this may be a valid assumption in many cases, little is known empirically about how expected *future* liquidity affects prices.

Moreover, the notion of liquidity itself is hard to pin down. Some use the term to describe the narrowness of the bid-ask spread, but it could also refer to market depth, volume, or other measures of activity in the market. If traders require the ability to

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<sup>1</sup>For example, Amihud and Mendelson (1991), Silber (1991), Brenner, Eldor & Hauser (2001), Dimson & Hanke (2001), Pastor and Stambaugh (2001) and others.

<sup>2</sup>For example, Amihud and Mendelson (1991) argue that the price difference between Treasury bills and close-to-maturity Treasury notes can be attributed to differences in liquidity. However, Kamara (1994) and Strebulaev (2001) show that there are other differences, including taxes, that affect the price difference.

<sup>3</sup>One exception is Amihud's (2001) analysis of stock returns.

transact small quantities immediately, then the quoted bid-ask spread can be used to measure the price of immediate execution. However, if traders are interested in transacting large quantities quickly, then measures of depth are more important. Market participants may be concerned about the amount of time it takes to arrange a trade. In this case, the number of daily trades, daily volume or similar measures of market activity may be more relevant.

While all of these notions of liquidity are valid, ultimately, our interest is in which among them most affect securities' prices.

In this paper we address these questions by comparing securities whose relative liquidity varies predictably over time. This allows us to distinguish between current liquidity and expected future liquidity. By measuring expected future liquidity using different measures, we determine the extent to which each of these aspects of liquidity affects prices. And by following the same securities over time, we may disregard any cross-sectional differences between securities.

Our purpose is to examine the effects of time-varying liquidity on securities' prices with a stress on distinguishing among different measures of liquidity. First, we show theoretically that the price of a security is affected by its expected liquidity over its entire life. Then, we study this empirically, by comparing on-the-run and off-the-run two-year U.S. Treasury notes over the issue cycle. U.S. Treasury securities are ideal for a study of this type since they go through predictable patterns of liquidity and illiquidity.

Two-year notes are auctioned monthly, so that at any time there are 24 issues outstanding. The most recently issued note is referred to as "on-the-run" and attracts most of the liquidity. Older notes are "off-the-run" and are much less liquid. In this study, we compare the prices of the "on-the-run" note with the most recent "off-the-run" note.

At the beginning of an issue cycle, the on-the-run note is very liquid. The buyer of such a note can easily sell it during this early period to another investor who will

pay a premium for the remaining liquidity. In contrast, towards the end of the cycle, although the market may still be very liquid, a buyer might expect to eventually sell the security when it is off-the-run and there is no longer a liquidity premium. So a buyer late in the cycle should pay less of a premium since he will benefit from a shorter time of liquidity. Thus, even if liquidity remains at a consistently high level throughout the on-the-run period, the liquidity premium in the price should decline over the period.

At each date, we measure the remaining expected liquidity over the life of the note using various liquidity measures. We document the patterns in prices and liquidity that occur over the issue cycle. Under all the measures, liquidity remains high throughout the month-long on-the-run period. Around the time the next note is issued, liquidity declines over a number of days until it reaches a new level. The note remains somewhat illiquid for the rest of its life. We show that the liquidity premium, the price difference between the on-the-run and the off-the-run notes, declines over the on-the-run cycle and is close to zero at the end of the month.

The measure of concern is the total, (or equivalently, the average) liquidity remaining over the asset's life. At the beginning of the issue cycle, there is a relatively large amount of expected liquidity remaining. By the end of the cycle, there is little future liquidity expected. We find that the liquidity premium in the price is closely related to the expected amount of remaining liquidity.

This shows that expected liquidity, rather than just the current level of liquidity, is priced in the Treasury market. When the difference in liquidity over the lives of two securities is expected to be large, there is a relatively wide difference in the price of the two securities. But as the expected difference in liquidity narrows over time, so does the price difference.

By comparing a pair of Treasury notes and following them through the cycle, we bypass any problems that might arise if the securities are not otherwise identical. For example, if the securities we are comparing are taxed differently (for example, due to

differing coupons), then there could be a resulting price difference. However, as long as these differences do not vary systematically over the issue cycle, then the analysis of the change in the liquidity premium over the cycle is not affected.

As mentioned above, we use various measures of liquidity in this study. These measures use quotes and trades to capture bid-ask spreads, depth, and the overall level of market activity. The measures are all correlated with each other and any one of them explains the changes in price as expected liquidity changes. Our method allows us to quantify the effect of illiquidity on a security's value. For example, we measure the expected (quoted) bid-ask spread over the life of the securities. We find that any change in the remaining average quoted bid-ask spread has more than a twenty-fold effect on the yield of the note. This compensates for all of the future trading costs over the life of the security.

We compare the various liquidity measures by testing which have further explanatory power beyond the other measures and which are subsumed by other liquidity measures when explaining the liquidity premium in prices. We find that the quoted spread and the quote size are more important than effective spread and traded size, respectively. This means that the value that investors place on immediacy – the ability to trade a quantity of securities quickly – is better measured by the quotes of market makers who supply liquidity, rather than the actual trade prices and trade sizes. However, as a measure of market activity, the number of trades and the trade volume is more related to the liquidity premium than the number of quotes.

## **Previous Literature**

Our study attempts to bridge the gap between two streams of existing literature on liquidity. The first stream of literature is on the impact of liquidity on asset prices and the second stream is on the behavior of different aspects of liquidity captured by different liquidity proxies.

Studies that belong to the first stream of literature include Amihud and Mendel-

son (1986), Eleswarapu and Reinganum (1993), Brennan and Subrahmanyam (1996), Barclay, Kandel and Marx (1997), Eleswarapu (1997), Chordia, Roll and Subrahmanyam (2000), Datar, Naik and Radcliffe (1998), Pastor and Stambaugh (2001) and Amihud (2001). These papers compare market liquidity to ex-post returns on equities. A number of studies also analyze the impact of liquidity on expected returns. Most of these studies examine the market for bonds and notes, notably Amihud and Mendelson (1991), Warga (1992), Daves and Ehrhardt (1993), Boudoukh and Whitelaw (1993), Kamara (1994), Krishnamurthy (2001) and Strebulaev (2000). Silber (1991) looks at restricted (non-traded) equities. Brenner, Eldor and Hauser (2001) examine currency options that are not traded until maturity and Dimson and Hanke (2001) examine equity-linked bonds.

Apart from relatively few exceptions (Eleswarapu and Reinganum (1993) and Barclay, Kandel and Marx (1997)) the general consensus of these studies is that less liquid securities have higher returns.

Also, the literature on repo markets has shown that U.S. Treasury repos are more likely to be “special” during the on-the-run period, i.e., there is an increased price for borrowing the security during this time period. This is consistent with a liquidity premium in the Treasury market as modeled by Duffie (1996) and as seen in the empirical results of Jordan and Jordan (1997) and Buraschi and Menini (2001).

The second stream of literature examines and compares different aspects of liquidity. Elton and Green (1998) find that trading volume as a proxy for liquidity has an effect on Treasury bond prices. Fleming (1997), Fleming and Remolona (1999) and Balduzzi, Elton and Green (2000) document intraday patterns of bid-ask spreads and trading volume but do not link those patterns to prices. Fleming (2001) examines a set of liquidity measures for the U.S. Treasury market and finds that price pressure is closely related to securities’ price changes over very short (five-minute) intervals. Huang, Cai and Song (2001) relate liquidity in the Treasury market to return volatility. They find that the number of trades is more correlated with volatility than is

trading volume. Jones, Kaul and Lipson (1994) have similar results for equity markets. They also find that trade size as a determinant of return volatility has little information beyond that contained in the number of trades.

In general, these studies show that different aspects of liquidity can be captured by different liquidity proxies. Most of the liquidity proxies are highly correlated with each other but some seem to capture the notion of liquidity better than others.

Studies that belong to this second stream of literature on liquidity suffer from two main limitations. First, they only examine the current liquidity rather than including expected future liquidity which should have the primary effect on prices. Contemporaneous liquidity measures should only have a significant impact to the extent that they are proxies for expected future liquidity. In the case of Treasuries, on-the-run liquidity differs considerably from off-the-run liquidity, so contemporaneous measures are not good proxies for expected liquidity. Second, when these studies compare two securities, it is difficult to isolate return variation due to liquidity changes from return variation caused by other factors. This study is an attempt to address these problems and to bridge the gap between the two streams of literature by relating a clean measure of the liquidity premium to various liquidity proxies.

The rest of this paper is organized as follows: Section 2 is a short theory of the effect of liquidity on asset prices. Section 3 describes the market and data. Section 4 gives an overview of how liquidity in the Treasury market varies over the on/off cycle. Section 5 describes the details of the methodology. Section 6 contains the empirical results and Section 7 concludes.

## **2 Theory of Liquidity and Bond Prices**

The theory presented below is based on Amihud and Mendelson (1986).

Illiquidity can be generally thought of as being measured by  $c$ , the cost to trade the security as a proportion of its value. This can represent the bid-ask spread, the

opportunity cost of waiting to trade, or any similar cost. Let us assume that this cost is borne by the seller of the security. Furthermore, suppose that an investor only trades when hit by an exogenous liquidity shock and let  $\lambda_i$  be the per-period probability of investor  $i$  being hit with such a liquidity shock.

We will first compare a fully liquid zero-coupon bond (i.e., one that has no trading costs) with a similar bond that has positive trading costs,  $c$ . We assume the existence of a risk-neutral marginal investor  $m$  who is indifferent between owning the two securities. This investor has a probability of  $\lambda_m$  of being hit with a liquidity shock each period.

The main results shown below are: (1) The value of an illiquid bond is reduced by the expected trading costs over the entire life of the asset. (2) The expected per-period proportional trading costs,  $\lambda_m c$ , can be viewed as a discount rate. Therefore, the yield of an illiquid bond is equal to the yield of a liquid bond plus  $\lambda_m c$ . (3) If two bonds have different trading costs (which may vary over time), the difference in their yields is equal to the difference in expected *average* trading costs to the marginal investor over the life of the securities.

Let  $f_t$  be the one period forward rate of interest from time  $t - 1$  to  $t$  for the perfectly liquid bond. Both the liquid and illiquid bond mature at time  $T$  at which time they each pay \$1.

At time  $T - 1$ , the value of the liquid bond is (by definition):

$$P_{T-1}^L = \frac{1}{1 + f_T}$$

and at any time  $t$ ,

$$P_t^L = \prod_{j=t+1}^T \left( \frac{1}{1 + f_j} \right).$$

At time  $T - 1$  the owner of the illiquid bond is no longer subject to future liquidity shocks before maturity and values his bond as

$$P_{T-1}^I = \frac{1}{1 + f_T}.$$

However, at time  $T - 2$ , the owner of the illiquid bond will be concerned about the probability  $\lambda_m$  that he will be hit with a liquidity shock at time  $T - 1$  and will have to pay  $cP_{T-1}^I$ . Therefore, the value of the illiquid security at  $T - 2$  is

$$\begin{aligned} P_{T-2}^I &= \frac{1}{1 + f_{T-1}} [(1 - \lambda_m) P_{T-1}^I + \lambda_m (1 - c) P_{T-1}^I] \\ &= \left( \frac{1}{1 + f_{T-1}} \right) (1 - \lambda_m c) P_{T-1}^I \\ &= (1 - \lambda_m c) P_{T-2}^L. \end{aligned}$$

This value is the expected value of the illiquid bond at  $T - 1$  (less the expected trading costs) discounted back to  $T - 2$ . More simply, the value of the illiquid bond is equal to the value of the liquid bond discounted by the expected trading costs. Similarly, at time  $T - 3$ , the value of the illiquid bond is

$$P_{T-3}^I = \left( \frac{1}{1 + f_{T-2}} \right) (1 - \lambda_m c) P_{T-2}^I = (1 - \lambda_m c)^2 P_{T-3}^L$$

and at any time  $t$ , the value of the illiquid bond is

$$P_t^I = (1 - \lambda_m c)^{T-t-1} P_t^L$$

or equivalently,

$$P_t^I = (1 - \lambda_m c)^{T-t-1} \prod_{j=t+1}^T \left( \frac{1}{1 + f_j} \right).$$

Until this point, we considered the discrete time case in which there is a point  $T - 1$  after which there are no longer liquidity shocks. However, if there is always a probability of a liquidity shock, it becomes simpler to consider the continuous time case. In continuous time, the value of the illiquid bond is

$$P_t^I = e^{-\int_t^T (f_\tau + \lambda_m c) d\tau} = e^{-\lambda_m c(T-t)} P_t^L \quad (1)$$

where  $f_t$  is now the instantaneous forward rate. Equation (1) can be rewritten using yields, where  $y_t^L$  and  $y_t^I$  are the yields to maturity for the liquid and illiquid bonds, respectively. So we have

$$P_t^I = e^{-y_t^I(T-t)} = e^{-(\lambda_m c + y_t^L)(T-t)}. \quad (2)$$

Thus, the relationship between the yields of the two bonds is simply

$$y_t^I = \lambda_m c + y_t^L. \quad (3)$$

In words, the yield on an illiquid bond exceeds the yield on a liquid bond simply by the proportional trading cost times the per-period probability of a liquidity shock to the marginal investor.

The fact that  $\lambda_m c$ , the expected per-period trading costs, is added to the bond's yield illustrates the similarity between expected transaction costs and interest rates. Just like an interest rate of  $r$  reduces a cash flow's value at a rate  $r$  per period, similarly, expected transaction costs of  $\lambda_m c$  per period reduce the value of a cash flow.

The preceding analysis can be generalized to a case in which both assets are somewhat illiquid (and now denoted as assets  $A$  and  $B$ ) with trading costs  $c^A$  and  $c^B$ , respectively. It is only necessary to assume that there exists a marginal investor that is indifferent between the two assets. In this case the relationship between the yields of the two assets is

$$y_t^B = \lambda_m (c^B - c^A) + y_t^A \quad (4)$$

Thus the yield spread between the two bonds is proportional to the difference in trading costs.

We can further generalize to allow for the possibility of transaction costs varying over time. This is particularly relevant for our study of U.S. Treasury notes, since the liquidity of the notes does vary systematically over time. We can easily generalize in this case by a simple adjustment to equation (1), which leads to equation (4) being rewritten as

$$y_t^B = \lambda_m E_t (\overline{c^B} - \overline{c^A}) + y_t^A \quad (5)$$

where  $\overline{c^i}$  is the average trading cost over the life of security  $i$ , and  $E_t$  is the expectations operator at time  $t$ . Now the difference between yields is proportional to the *average* difference between the trading costs of the two securities.

### **3 The Market for U.S. Treasury Securities**

#### **Description and Data**

The United States Treasury sells securities by auction on a regular schedule to finance the national debt. The empirical analysis in this study focuses on two-year notes which are auctioned monthly. Thus, at any time there are 24 issues outstanding. The issue size averages approximately \$16 billion. As explained above, the most recently issued security of a given maturity is referred to as “on-the-run” and older securities are referred to as “off-the-run”. The “on-the-run” security is considered to be the benchmark security, and as a result attracts most of the trade and liquidity.

The secondary market is predominantly an over-the-counter market with many brokers and dealers. During most of the period for which we have data, there were six major interdealer brokers who allow dealers to trade anonymously with each other.

Quotes are submitted to interdealer brokers who then display the quotes for all dealers to see. To effect a transaction, a dealer hits a bid or takes an ask that is displayed. Thus all trade occurs at quotes. However, price improvement effectively occurs when dealers improve on each other’s quotes while waiting for a counterparty.

In spite of the large number of dealers in the over-the-counter market, the vast majority of the quoting and trading activity is by less than 40 primary dealers. Primary dealers are those approved to transact directly with the Federal Reserve in its market operations. Primary dealers are also expected to participate in Treasury auctions as well as to make a market for customers.

The data set on the U.S. Treasury market that is used in this study is from GovPX. GovPX was set up in 1990 by all, except one, interdealer brokers in order to provide greater transparency in the U.S. Treasury market. The GovPX data set consists of all trades that are transacted through participating interdealer brokers. It includes the best bid and ask prices, trade prices, and the size of each trade and quote. There is no other data set for U.S. Treasury securities that covers a similarly

extensive period of intraday quotes and trading activity.<sup>4</sup> This study uses data from January 1994 to December 2000.

Because the GovPX data set is unique in its coverage of the Treasury securities secondary market, it is important to point out some of its limitations. First, as mentioned above, the data is from only five of the six interdealer brokers. It does not include trades and quotes routed through Cantor Fitzgerald – the largest of the interdealer brokers with a market share of about 30%. Cantor Fitzgerald is particularly strong at the “long end” of the Treasury maturity spectrum. Second, since the interdealer broker market is anonymous, it is impossible to identify the counterparties of a transaction or identify the brokers submitting quotations.

## 4 Overview of Treasury Market Liquidity

Examination of the various measures of liquidity and trading activity over the issue cycle for the two-year note reveals some interesting patterns. Figures 1 through 4 show how liquidity varies over the first 100 trading days of the securities. We measure time relative to the issue date of each security and average over the cross-section of securities. The first 22 trading days correspond, approximately, to the on-the-run period.

Figure 1 shows the average daily quoted and effective spreads (in yield space) averaged across the two-year notes in our sample for the first 100 days after issue. The quoted spread is the difference between the best bid and the best ask at any time and averaged over all quotes in a day. The effective spread is defined as twice the difference between each trade price and the most recent midquote. Since, all trades occur at the quotes, the effective spread can also be defined as the quoted spread immediately before a trade. The average effective spread is lower than the average

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<sup>4</sup>Prior to the availability of GovPX, studies either used quotes collected by the Federal Reserve Bank of New York from a daily survey of dealers, or small proprietary data sets.

quoted spread because trade tends to occur after a narrowing of the spread. During the first 15 trading days the effective spread is in the region of 0.4 basis points, while the quoted spread is about 0.6 basis points. Over the following week, in the run up to the issue of the next two-year note, spreads widen and continue to do so as the life of the security shortens. When the security is off-the-run, the effective spread is mostly above one basis point and the quoted spread averages more than two basis points. Off-the-run spreads are considerably more volatile than on-the-run spreads.

Figure 2 shows the average quote and trade sizes. During the on-the-run period, quotes average about \$20 million and the average transaction size is between \$10 million and \$15 million. In comparison, during the off-the-run period trade size averages about \$7 million while the average quote size falls much further to between \$2 million and \$3 million. Figure 3 shows the average numbers of quotes and trades per day. There are about 3000 quotes and 400 trades daily during the on-the-run period. During the off-the-run period, there are a few hundred quotes and as little as 15 trades daily. Figure 4 shows the daily volume which ranges from over \$6 billion per day during the on-the-run period to approximately \$100 million per day during the off-the-run period.

*Insert Figures 1, 2, 3 and 4*

## **5 Methodology**

Our empirical analysis studies the yield difference between on-the-run and off-the-run securities. In order to capture the portion of this difference that is due to liquidity we must first isolate it from the influence of other factors. We can then relate this yield difference to a variety of liquidity measures.

Over the period we study, there were 56 two-year Treasury notes that were both issued and matured during this time period. We group these 56 securities into 55

pairs of successive issues that were issued one month apart. We label the newer of the pair as the on-the-run and we label the older one as off-the-run. We align each pair of notes at the issue date of the on-the-run security, which is the day when the previous issue becomes off-the-run. Starting from the issue date of the on-the-run security we analyze the difference between the (bond equivalent) yields of the two securities day by day until the on-the-run security goes off the run one month later. By focusing on the time series aspect, we can safely ignore any fixed effects which cause the notes to have different yields.

However, there are several adjustments that we make to obtain cleaner comparisons. First, quotes for the two securities in a pair are not at exactly the same time of the day. We must control for asynchronous quotes so that intraday changes in interest rates do not affect our results. In order to overcome this problem, we use Amihud and Mendelson's (1991) linear weighting scheme, i.e., we match each off-the-run quote with the on-the-run quotes posted immediately before and immediately after the off-the-run quote. The theoretical on-the-run yield,  $y_t^{TH}$ , is the weighted average of the two actual on-the-run yields, i.e.,

$$y_t^{TH} = \frac{\delta_2}{\delta_2 + \delta_1} y_{t-\delta_1} + \frac{\delta_1}{\delta_2 + \delta_1} y_{t+\delta_2},$$

where  $\delta_1$  is the time between the off-the-run quote and the previous on-the-run quote; and  $\delta_2$  is the time between the off-the-run quote and the next on-the-run quote.

The on-the-run quote which is closer in time to the off-the-run quote gets more weight, reflecting the fact that it is a more relevant comparison. Comparing the off the run quotes to this weighted average of on-the-run quotes mitigates the problem of timing differences during the day and makes yields comparable.

A second problem is that successive issues normally have different coupons which affect their yields. Since bonds with different coupons naturally trade at different yields, we make an adjustment to the yield of the off-the-run note so that it will be comparable to a bond of the same maturity but with a coupon equal to the on-the-

run coupon. This coupon adjustment is simply the difference in yields between two hypothetical bonds (of the same liquidity) both with same maturity as the off-the-run security but with different coupons - one with same coupon as the off-the-run note and one with a coupon equal to that of the on-the-run note. We use zero-coupon bond price data to calculate the yields of these hypothetical securities to obtain the coupon adjustment. For example, suppose a 24-month on-the-run note has a 6% coupon and the 23-month off-the-run note has a 5.5% coupon. We use the zero-coupon price data to value a 23-month 5.5% note and a hypothetical 23-month 6% note. For each of these hypothetical prices we calculate yields. The difference between these two calculated yields is the coupon adjustment and is added to the actual quoted yield of the off-the-run note. Any small errors in the zero-coupon data appear in the yields of both hypothetical bonds and only have a negligible effect on the adjustment.

A potentially more serious problem is that the two notes that we compare, although very close in maturity, are not exactly at the same point on the yield curve. Hence, if the yield curve is not flat we would expect them to have different yields even in the absence of any liquidity effect. We solve this problem in a manner similar to the adjustment for the difference in coupons. An adjustment is added to the yield of the off-the-run security for being of a slightly shorter maturity. The adjustment is equal to the difference between two hypothetical yields: the yield of a security with a maturity equal to the maturity of the on-the-run and the yield of a security with a maturity equal to the maturity of the off-the-run. The hypothetical yields are obtained from a spline of zero-coupon bond prices. The spline excludes any strip that has a maturity close to that of the on-the-run security to bypass any liquidity premium in the zero-coupon data. Again, since the adjustment is a difference between two yields calculated using the same data, any small data errors have a negligible effect.

We define the yield effect at each time  $t$  for each pair of notes,  $YE_t$ , as the yield of the off-the-run security minus the yield of the on-the-run security (adjusted as

above).

The yield effect for each day of the on-the-run period, averaged over the cross-section of the 55 pairs of securities, is shown in Figure 5. At the beginning of the cycle, the liquidity effect is approximately 1.5 basis points and declines toward zero over the month. This is an economically significant effect considering the leverage often found in bond portfolios. Krishnamurthy (2001) finds a similar pattern, albeit of larger magnitude, for thirty year bonds.

According to the theory in Section 2, this yield effect should capture the difference between the lifetime liquidity of the on-the-run and the off-the-run notes. After the yield effect is calculated for each day of an issue cycle, we relate it to various measures of expected future liquidity. This allows us to show that the price effect can indeed be attributed to future liquidity differences and to determine which aspects of liquidity drives the price effect.

Theory predicts that the yield of a bond is equal to the yield of a perfectly liquid bond plus a term to capture future trading costs. Therefore, we propose the following econometric model to capture how the yield ( $y_{i,t}$ ) on a particular security  $i$  on date  $t$  is determined:

$$y_{i,t} = \alpha_i + \beta E_t(\bar{C}_i) + \varepsilon_{i,t} \quad (6)$$

where  $\alpha$  is the yield level of a perfectly liquid security that can be costlessly traded at any time.  $\beta$  corresponds to  $\lambda_m$  in the theory section – the probability that the marginal investor will experience a liquidity shock.  $E_t(\bar{C}_i)$  is a measure of the expected future costs associated with trading in security  $i$  over its life. One should keep in mind that the costs of trading should be loosely interpreted to include any direct or indirect trading costs such as the bid-ask spread, an inability to trade immediately or any other drawback of illiquidity. One of our objectives is to find measures of  $\bar{C}_i$  which are most closely related to  $y_{i,t}$ .

For comparing on-the-run and off-the-run securities, equation (6) and the definition of the yield effect,  $YE_t$ , yield the following expression:

$$Y E_t = \beta E_t (\overline{C}_{off} - \overline{C}_{on}) + u_t \quad (7)$$

which directly corresponds to equation (5) in the theory section.

For each day we calculate the following measures of liquidity:

- (a) the average quoted bid-ask spread (in price space),
- (b) the average effective bid-ask spread, (i.e. using the bid and ask quotes in price space immediately before each trade),
- (c) the average quote size (in million dollars, where the quote size is measured as the average of the bid and ask quantities),
- (d) the average trade size (in million dollars),
- (e) the number of quotes per day,
- (f) the number of trades per day, and
- (g) the daily volume (in million dollars).<sup>5</sup>

When we use the spread measures (a) and (b), the trading cost,  $C_{i,t}$ , is calculated each day as the average of all bid-ask spreads throughout the day. For the other measures, in order to interpret them as costs, we take (the natural logarithm of) their reciprocals.

It is an important concept in this paper that the yield effect reflects the expectation of all future trading costs. Because the on/off cycle is so regular and predictable, we set the average expected future costs,  $E_t(\overline{C}_i)$ , equal to the average actual cost

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<sup>5</sup>Datar, Naik and Radcliffe (1998) argue that turnover is a more relevant measure than liquidity. This would make little difference in our analysis since all note issues have similar amounts outstanding.

measured from time  $t$  until maturity.<sup>6</sup> Therefore, for notational simplicity, below we suppress the expectations operator and we replace it with a time subscript, i.e.,  $\bar{C}_{i,t}$ .

## 6 Empirical Results

### 6.1 Basic Regressions

In order to empirically test the relationship between the yield effect and the difference in expected future liquidity (i.e., equation (7)), we pool the data in a panel that includes the cross-section of 55 pairs of notes and a month-long time series for each pair of notes.<sup>7</sup> We use a fixed-effects panel-data model to regress the yield effect (i.e., the adjusted difference between the off-the-run and the on-the-run yields) on the difference in expected future trading costs,  $\bar{C}_{off,t} - \bar{C}_{on,t}$ , and a set of dummy variables (one for each on/off pair). We run individual regressions for each of the seven cost measures, (as listed at the end of the previous section), using the following regression model:

$$YE_t = \sum_{i=1}^{55} \alpha_i + \beta (\bar{C}_{off,t} - \bar{C}_{on,t}) + \varepsilon_t. \quad (8)$$

The 55 fixed-effects dummies in each regression are intended to isolate the impact of expected trading costs from unrelated cross-sectional differences between the securities.

The fact that we are using an average of trading costs on the right hand side of the equation introduces significant positive autocorrelation in the regression residuals. We adjust for autocorrelation in the residuals using a feasible generalized least squares (FGLS) model for panel data. The regression results for the first and second month

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<sup>6</sup>Because the data for the last few months before maturity is very noisy, we assume that the costs during the last six months before maturity are the same as the average over the previous year.

<sup>7</sup>We cannot use time series of longer than one month because the on-the-run security in one pair of securities becomes the off-the-run security for the next pair in the following month.

are shown in Table 1.

*Insert Table 1*

As shown in Panel A of Table 1, for the first month, the coefficients for each of the seven expected cost measures are positive and highly significant.<sup>8</sup> This shows that the yield difference between on-the-run and off-the-run notes is related to expected future liquidity regardless of which measure of trading cost we use. The t-statistics for all variables are similar as well. The fact that all of the cost measures give similarly significant results should not be surprising since they are highly correlated with each other.

If the bid-ask spread is interpreted as the cost of trading, then its coefficient is an estimate of the marginal investor's per-year probability of trading. So, for example, if the cost of trading is the effective spread, then the yield effect reflects a marginal investor trading more than 60 times per year. In particular, because the individual time series are run over the first month of the new security's life (although later costs are included in  $\bar{C}_i$ ), the coefficient should be interpreted primarily as the marginal investor's trading propensity over the first month.

Because the other cost measures are not literally costs, their coefficients do not lend themselves as easily to interpretation.

The intercepts (not reported) are significantly different from each other indicating that there are cross-sectional differences that are not caused by liquidity.

Because of concern for persistence in the construction of the right-hand-side variable, we repeat the analysis with both sides of the regression differenced along the time-series dimension which removes any first-order autocorrelation. Very similar results are obtained, except that the number of quotes is of only marginal statistical significance.

The analysis is repeated again using the Fama and MacBeth (1973) procedure

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<sup>8</sup>Since we hypothesize a positive relation between the yield effect and costs, the t-statistics should be interpreted in the context of a one-tailed test.

for which we run separate time-series regressions for each pair of securities and average the coefficients across the cross-section. Again, the results are similar and all coefficients are statistically significant.

The regressions in Panel A of Table 1 are run over the first month after the issue of the on-the-run security. In the first month, the difference in liquidity between the on-the-run and the off-the-run is striking. In the second month, after an even newer security is issued, neither security from the original pair is considered on-the-run and the liquidity difference (and the yield difference) between them is modest.<sup>9</sup> Panel B of Table 1 repeats the above analysis for the second month after the issue of the on-the-run security.

The basic regressions in the first column of Panel B of Table 1 show that while some of the trading cost measures are significantly related to the yield effect in the second month, a number of the measures are not. When we difference both sides of the regression in the time-series dimension, we no longer find a relationship between liquidity and the yield effect. Under the Fama-MacBeth technique, the results are mixed.

The fact that the model does a poorer job in relating the trading costs to the yield effect in the second month could be due to the noisier price data in the second month, and the fact that there is a much smaller yield effect to explain. However, it is also possible that the marginal investor changes between the first month and the second month. When comparing a new on-the-run with the most recent off-the-run, a marginal investor is one who trades frequently, values liquidity, and is indifferent between the more expensive liquid security and the cheaper less liquid security. However, in the second month, since there is a newer security that attracts most of the liquidity, the marginal investor may now be one who trades much less frequently, values liquidity less, and is choosing between the two securities both of

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<sup>9</sup>For consistency, we continue to refer to the newer of the two notes as on-the-run and the older as off-the-run, even though they are now actually off-the-run and off-off-the-run, respectively.

which are fairly illiquid. If this is the case, the coefficients in the Panel B regressions should be expected to be smaller than those in Panel A. For the remainder of the paper, we focus on only the first month.

## 6.2 Contemporaneous vs. Expected Future Liquidity

We have shown above that the yield effect is related to expected future trading costs. However, the previous literature has focused almost exclusively on current liquidity. We now separate contemporaneous liquidity and expected future liquidity to determine the extent to which each of them relate to asset prices. We do so by calculating  $C_{i,t}$ , the trading costs measured only on date  $t$ , and  $\bar{C}_{i,t+1}$ , the expected future trading costs excluding the current day. In order to capture the incremental explanatory power of the expected future costs beyond the current cost we orthogonalize the difference in future costs relative to the difference in contemporaneous costs and the fixed-effects dummies. If the contemporaneous costs already capture most of the variability in the yield effect, the orthogonalized expected cost coefficient should be statistically insignificant. This would also be true if the contemporaneous cost is a good proxy for expected costs. We test this with the following regression (run over the first month after the issue of the on-the-run security):

$$YE_t = \sum_{i=1}^{55} \alpha_i + \beta (C_{off,t} - C_{on,t}) + \gamma (\bar{C}_{off,t+1} - \bar{C}_{on,t+1})^{orth} + \varepsilon_t . \quad (9)$$

The results of this regression, for each of the seven cost measures, are reported in Table 2

*Insert Table 2*

In the second column of Table 2, we see that all the expected future cost coefficients are extremely significant indicating that future liquidity is indeed related to prices beyond that which is captured in current liquidity. Even when the variables are differenced almost all the future cost coefficients are significant. Contemporaneous

ous liquidity has mixed (and weaker) results reflecting the fact that current liquidity is only a small part of the lifetime liquidity and thus only has a small (if any) affect on prices. We must stress that due to the orthogonalization, any common component in contemporaneous and future costs is captured in the coefficient for the contemporaneous cost. This confirms the importance of expected future costs in explaining the yield effect.

### 6.3 Time vs. Expected Future Liquidity

It is possible that there is another effect, unrelated to liquidity, that depends upon the issue cycle – perhaps related to the Treasury auction or the repo market. We know that the expected future costs decrease over time, so it is conceivable that our results are simply due to correlation between the expected cost measures and time. If that were the case, our regression results would be spurious. We test whether this is true by including a time trend in the regressions which is simply the number of trading days since the issue of the on-the-run security<sup>10</sup>. We orthogonalize the expected trading cost measures against the time trend and the fixed-effect dummies to obtain the following regression model:

$$Y E_t = \sum_{i=1}^{55} \alpha_i + \beta \tau_t + \gamma (\bar{C}_{off,t} - \bar{C}_{on,t})^{orth} + \varepsilon_t, \quad (10)$$

where  $\tau_t$  denotes the number of trading days since issue of the on-the-run security at each day  $t$ . The coefficient  $\beta$  captures the effect of time on the yield effect whether or not due to changes in expected future liquidity. The coefficient  $\gamma$  captures any remaining effect of liquidity beyond that already captured in the time trend. The regression results are shown in Table 3

*Insert Table 3*

The regression coefficients for the time trend are all negative and very significant as a result of the downward slope in the yield effect. However, almost all of the

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<sup>10</sup>Sarig and Warga (1989), for example, use a time trend as one proxy for liquidity.

orthogonalized cost measures are also statistically significant. This indicates that these expected cost measures are not simply proxying for an unrelated time effect. However, trade size is only weakly significant and the number of quotes is not at all significant beyond what is already captured in the time trend.

## 6.4 Comparison of Expected Liquidity Measures

One of the main goals of this paper is to examine the importance of the different liquidity measures relative to each other as determinants of the yield effect. If certain aspects – or certain measures – of illiquidity are more detrimental to investors than others, then investors will require a higher yield on securities that have these characteristics.

The main difficulty in making this comparison is that our trading cost measures are correlated with each other. In order to examine the relative importance of each, we run the regression with pairwise combinations of cost measures. For each pair of cost measures, the difference in expected future costs (between the off-the-run and the on-the-run securities) using the second measure is orthogonalized relative to the difference in costs under the first measure as well as the fixed-effects dummies. The regression model is

$$YE_t = \sum_{i=1}^{55} \alpha_i + \beta \left( \overline{C}_{off,t}^j - \overline{C}_{on,t}^j \right) + \gamma \left( \overline{C}_{off,t}^k - \overline{C}_{on,t}^k \right)^{orth} + \varepsilon_t \quad (11)$$

*for  $j, k = 1, 2, \dots, 7$  and  $j \neq k$ ,*

where  $j$  and  $k$  refer to different cost measures.

Orthogonalizing the two regressors allows us to measure the incremental explanatory power of measure  $k$  beyond measure  $j$ . Given the results in Section 6.1, the coefficient of any measure  $j$  will certainly be significantly positive. The question though, is whether the orthogonalized measure  $k$  adds explanatory power or if it is subsumed by measure  $j$ . Since we have seven expected cost measures and we examine each permutation of pairs we have a total of 42 regressions. The regression results

are shown in Panels A and B of Table 4 and summarized in Panel C of Table 4.

*Insert Table 4*

In Panels A of Table 4 the measures listed along the vertical dimension are the nonorthogonalized (first) measures of trading cost, and the orthogonalized (second) measures appear along the horizontal dimension of the table. For each pair of expected cost measures, the regression coefficient and t-statistic of the nonorthogonalized measure is shown first, followed by the coefficient and t-statistic of the orthogonalized measure one line below. Coefficients of orthogonalized measures that are statistically significant (at the one-tailed 5% level) are highlighted in the table with asterisks. (Panel B repeats the analysis with differenced regressions.)

When examining the regression results in Panel A, certain patterns emerge. The measure that appears most robust in adding explanatory power is the average quoted spread. The quoted spread adds explanatory power relative to each of the other measures, and each of the other measures is subsumed by quoted spread (i.e., they do not add statistically significant explanatory power when orthogonalized relative to quoted spread). Average effective spread, the bid-ask spread immediately before trades, adds explanatory power relative to certain other measures (although not relative to quoted spread). Effective spread also subsumes most, but not all, other liquidity measures. So although both quoted and effective bid-ask spreads are measures of liquidity that significantly affect yields, the quoted spread appears stronger as it adds explanatory power relative to effective spread, while the reverse is not true.

Depth measures – average quote size and average trade size – only add explanatory power relative to the weakest of the other measures, nor do they subsume most of the other measures.

The measures of market activity are the number of quotes per day, the number of trades per day, and volume. The number of quotes per day is the weakest of our seven liquidity measures. It neither adds explanatory power relative to the other measures, nor does it subsume any other liquidity measure. In contrast, the

trade-based measures of market activity – the number of trades and volume – add explanatory power relative to most of the other measures and subsume most of the other measures. Although these measures are weakest relative to the quoted spread and relative to each other.

The results in Table 4, Panel B for differenced regressions are largely similar.

Panel C of Table 4 is a concise summary of the results in Panels A and B. For each of the liquidity measures, we count the number of times it adds statistically significant explanatory power (at the one-tailed 5% level) relative to other six measures. We also count the number of times the measure subsumes the other measures (i.e. that the other measures do not add statistically significant incremental explanatory power). From this summary we again see that quoted spread, number of daily trades and daily volume are most important in explaining the yield effect.

It is curious that when considering the effect of bid-ask spreads on the yields required by investors, quotes are more important. This may reflect the need for immediacy – the ability to trade a position at any time at the quoted spread without waiting for the spread to narrow. In contrast, as a measure of market activity, the number of trades and volume have more of an effect on prices than the number of quotes. This may capture the time required to find a counterparty to complete a trade at a fair price when immediacy is not needed.

## 7 Conclusion

This paper examines the effect of liquidity on on-the-run and off-the-run U.S. Treasury notes. Unlike the previous empirical literature, but in line with the theoretical literature, we focus on expected future liquidity rather than just the current liquidity. We are able to distinguish between current liquidity and expected future liquidity because liquidity varies systematically over the on/off cycle in the Treasury market. At the beginning of the cycle, the on-the-run note is very liquid and can be expected

to remain liquid for some time. At the end of the cycle, although the note is still very liquid it is expected to have little liquidity in the future. We find that the price premium for liquid securities does indeed depend on expected future liquidity.

Our paper also differs from other work in the literature in that we look at the differences in liquidity and yields of securities over time. Thus any cross-sectional difference between the securities is merely a fixed effect and so we are able to isolate the liquidity differences between the securities we are examining.

We measure liquidity using quoted and effective bid-ask spreads; quote and trade sizes; number of quotes and number trades; and volume. We find that each of these measures significantly explains the yield effect. When orthogonalized relative to each other, we find that the quoted spread and measures of market trading activity, (i.e., number of trades and volume) add the most incremental explanatory power relative to other measures. Depth measures (i.e. average quote and trade size) and especially the number of daily quotes adds little incremental explanatory power.

## References

- [1] Amihud, Yakov and Haim Mendelson, 1986, Asset pricing and the bid-ask spread, *Journal of Financial Economics* 17, 223-249
- [2] Amihud, Yakov and Haim Mendelson, 1991, Liquidity, maturity, and the yields on U.S. Treasury securities, *Journal of Finance* 46, 1411-1425.
- [3] Amihud, Yakov, 2001, Illiquidity and Stock Returns: Cross-Section and Time-Series effects, *Journal of Financial Markets* 5, 31-56.
- [4] Balduzzi, P., E. J. Elton and T. C. Green, 1997, Economic news and the yield curve, *Working paper*, New York University.
- [5] Barclay, Michael J., Eugene Kandel and Lesley Marx, 1998, The effects of transaction costs on stock prices and trading volume, *Journal of Financial Intermediation* 7, 130-150.
- [6] Boudoukh, Jacob and Robert F. Whitelaw, 1993, Liquidity as a choice variable: a lesson from the Japanese government bond market, *Review of Financial Studies* 6, 265-292.
- [7] Brennan, Michael J. and Avanidhar Subrahmanyam, 1996, Market microstructure and asset pricing: On the compensation for illiquidity in stock returns, *Journal of Financial Economics* 41, 441-464.
- [8] Brenner, Menachem, Rafi Eldor and Shmuel Hauser, 2001, The price of options illiquidity, *Journal of Finance*, forthcoming.
- [9] Buraschi, Andrea and Davide Menini, 2001, Liquidity risk and specialness, *Journal of Financial Economics*, forthcoming.
- [10] Chordia, Tarun, Richard Roll and A. Subrahmanyam, 2000, Market liquidity and trading activity, *Working paper*, UCLA.

- [11] Datar, Vinay, Naik, Narayan and Robert Radcliffe, 1998, Liquidity and stock returns: An alternative test, *Journal of Financial Markets* 1, 203-219.
- [12] Daves, Phillip R. and Michael C. Ehrhardt, 1993, Liquidity, reconstitution, and the value of U.S. Treasury strips, *Journal of Finance* 48, 1, 315-329.
- [13] Dimson, Elroy and Bernd Hanke, 2001, The expected illiquidity premium: evidence from equity index-linked bonds, *Working paper*, London Business School.
- [14] Duffie, Darrell, 1996, Special repo rates, *Journal of Finance* 51, 2, 493-526.
- [15] Eleswarapu, Venkat, 1997, Cost of transacting and expected returns in the Nasdaq market, *Journal of Finance* 52, 2113-2128.
- [16] Eleswarapu, Venkat and Marc Reinganum, 1993, The seasonal behavior of the liquidity premium in asset pricing, *Journal of Financial Economics* 34, 281-305.
- [17] Elton, E. J. and T. C. Green, 1998, Tax and liquidity effects in pricing government bonds, *Journal of Finance* 53, 1533-1562.
- [18] Fama, Eugene F. and James D. MacBeth, 1973, Risk, return and equilibrium: Empirical tests, *Journal of Political Economy* 81, 607-636.
- [19] Fleming, M. J., 1997, The round-the-clock market for U.S. Treasury securities, *Federal Reserve Bank of New York Economic Policy Review* (July), 9-32.
- [20] Fleming, M. J., 2001, Measuring Treasury Market Liquidity, *Working paper*, Federal Reserve Bank of New York.
- [21] Fleming, M. J. and E. M. Remolona, 1999, Price formation and liquidity in the U.S. Treasury market: The response to public information, *Journal of Finance*, 1901-1916.

- [22] Huang, Roger D., Jun Cai, and Xiaozu Wang, 2001, Inventory risk-sharing and public information-based trading in the Treasury note interdealer broker market, *Working paper*, University of Notre Dame and City University of Hong Kong.
- [23] Jones, Charles M., Gautam Kaul and Marc Lipson, 1994, Transactions, volume and volatility, *Review of Financial Studies* 7, 631-651.
- [24] Jordan, Bradford D. and Susan D. Jordan, 1997, Special repo rates: an empirical analysis, *Journal of Finance* 52, 5, 2051-2072.
- [25] Kamara, Avraham, 1994, Liquidity, taxes, and short-term Treasury yields, *Journal of Financial and Quantitative Analysis* 29(3), 403-417.
- [26] Krishnamurthy, Arvind, 2001, The bond/old-bond spread, *Journal of Financial Economics*, forthcoming.
- [27] Pastor, Lubos and Robert Stambaugh, 2001, Liquidity Risk and Expected Stock Returns, *Working paper*, University of Chicago.
- [28] Sarig, Oded, and Arthur Warga, 1989, Bond price data and bond market liquidity, *Journal of Financial and Quantitative Analysis* 24, 367-378.
- [29] Silber, William , 1991, Discounts on restricted stock: the impact of illiquidity on stock prices, *Financial Analysts Journal* 47, 60-64.
- [30] Strebulaev, Ilya, 2001, Market imperfections and pricing in the U.S. Treasury securities market, *Working paper*, London Business School.
- [31] Warga, Arthur, 1992, Bond return, liquidity, and missing data, *Journal of Financial and Quantitative Analysis* 27, 605-617.

FIGURE 1  
**Quoted Spread and Effective Spread**

This graph shows the average quoted spread and the average effective spread over the first 100 trading days of the two-year US Treasury notes in our sample. Both the quoted and the effective spreads are very low during the on-the-run period (averaging about 0.6 and 0.4 basis points, respectively) and considerably higher afterwards.

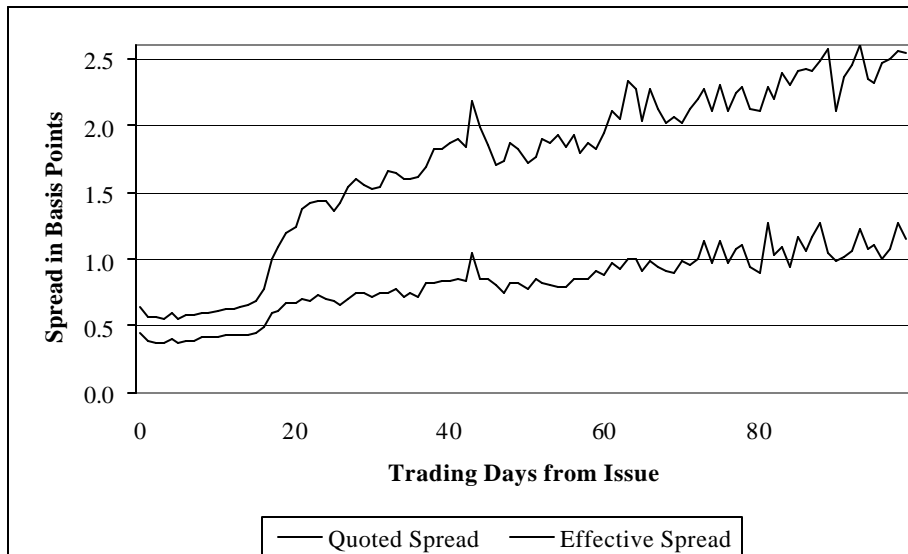


FIGURE 2  
**Quote Size and Trade Size**

This graph shows the average quote size and the average trade size over the first 100 trading days of the two-year US Treasury notes in our sample. Both quote and trade size are very high during the on-the-run period (averaging about \$20 million and \$13 million, respectively) and considerably lower afterwards (averaging about \$2.5 million and \$6 million, respectively). The quote size declines more rapidly than the trade size over time. While the average quote size exceeds the average trade size during the on-the-run period, it is lower during the off-the-run period.

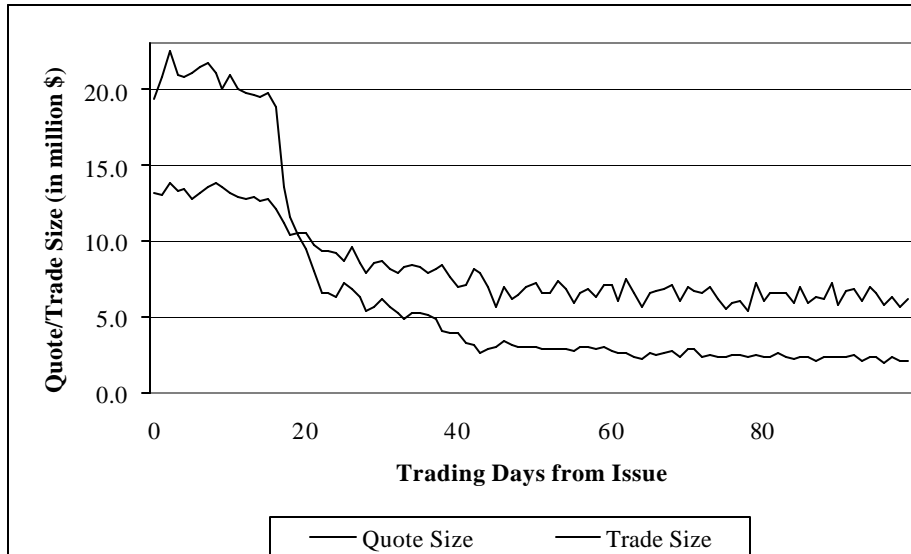


FIGURE 3

**Number of Quotes and Number of Trades per Day**

This graph shows the average number of quotes and the average number of trades per day over the first 100 trading days of the two-year US Treasury notes in our sample. Both the number of quotes and the number of trades are very high during the on-the-run period (averaging about 3,000 and 400 respectively) and considerably lower afterwards (averaging less than 400 and approximately 15, respectively).

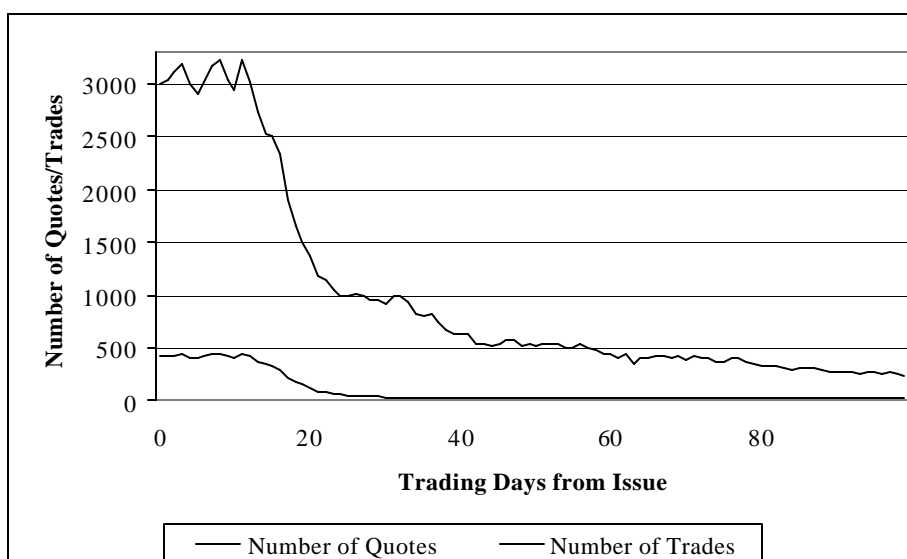


FIGURE 4  
**Volume per Day**

This graph shows the average volume per day over the first 100 trading days of the two-year US Treasury notes in our sample. Volume during the on-the-run period is extremely high compared to the off-the-run period (averaging over \$6 billion *vs.* approximately \$100 million). There is an abrupt decline in volume at the end of the on-the-run period.

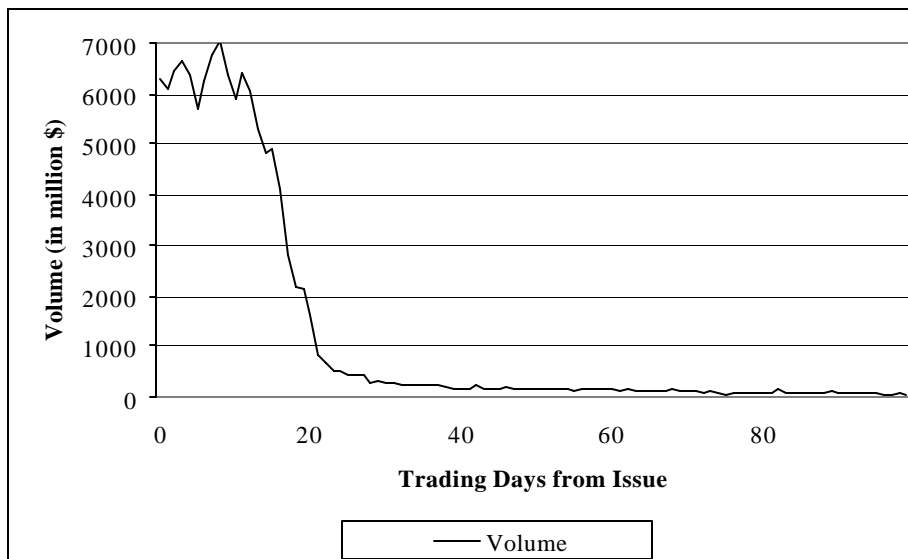


FIGURE 5

**Yield Effect:**

**Off-the-run yield minus on-the-run yield (adjusted)**

This graph shows the average difference between the yields of off-the-run and on-the-run two-year US Treasury notes in our sample. The yield effect is adjusted for differences in coupon and maturity between each pair of notes. The difference in yields declines over the month until a newer note is issued.

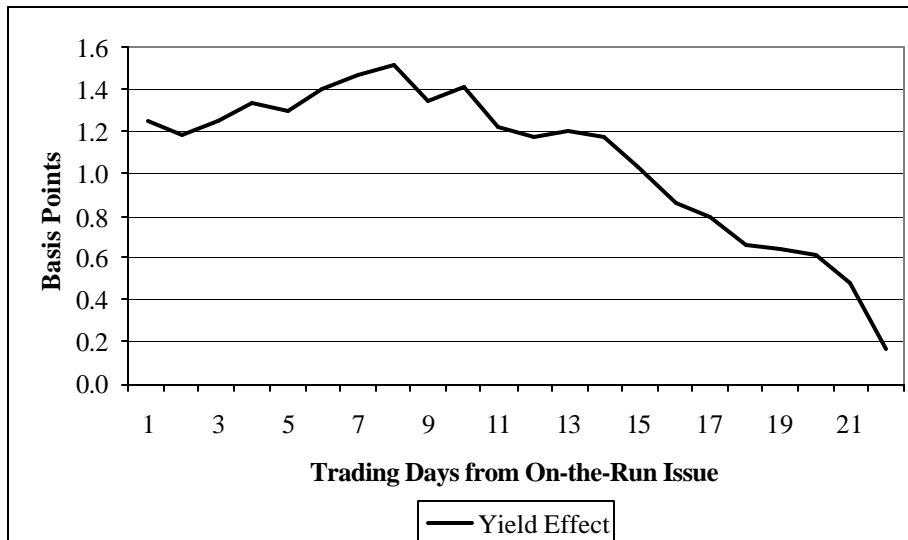


TABLE 1  
**Regression of Yield Effect on Expected Trading Cost Measures**

The first column of this table shows the results of autocorrelation-adjusted panel regressions of the yield effect ( $YE_t$ ) on the difference between the expected off-the-run and the expected on-the-run cost measures (run separately for each of the seven cost measures). Fifty-five fixed-effects dummies are included for each pair of securities in order to isolate cross-sectional differences other than liquidity from the impact of the cost measure. The regression equation is

$$YE_t = \sum_{i=1}^{55} \alpha_i + \beta_j \left( \overline{C}_{off,t}^j - \overline{C}_{on,t}^j \right) + \varepsilon_t \text{ for } j = 1, 2, \dots, 7.$$

In addition, the same regression is carried out in first differences with only one intercept. We also run the regressions separately for each pair of securities, average the regression coefficients, and calculate the t-statistics using the Fama and MacBeth (1973) procedure. In Panel A, the regressions are run over the first month from the issue of the on-the-run security. In Panel B, the regressions are run over the second month.

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**Panel A: First Month**

Cost Measure	Panel Regression	Panel Regression (Differences)	Fama-MacBeth
Quoted Spread	22.12 (10.8)	27.32 (2.6)	10.68 (2.1)
Effective Spread	66.77 (14.1)	42.46 (2.2)	35.78 (2.2)
Quote Size	0.16 (8.9)	0.40 (2.7)	0.09 (2.5)
Trade Size	0.43 (11.7)	0.29 (2.1)	0.20 (1.8)
# of Quotes	0.18 (7.8)	0.33 (1.6)	0.14 (2.1)
# of Trades	0.07 (8.8)	0.22 (3.0)	0.04 (2.4)
Volume	0.07 (9.1)	0.19 (3.2)	0.04 (2.3)

**Panel B: Second Month**

Cost Measure	Panel Regression	Panel Regression (Differences)	Fama-MacBeth
Quoted Spread	0.76 (0.8)	-1.09 (-0.6)	6.53 (1.4)
Effective Spread	35.43 (4.4)	8.59 (0.8)	1.34 (0.1)
Quote Size	0.05 (1.8)	-0.17 (-1.8)	0.23 (2.8)
Trade Size	0.16 (4.3)	-0.07 (-1.1)	0.34 (2.7)
# of Quotes	-0.00 (-0.2)	-0.10 (-0.9)	0.57 (1.6)
# of Trades	-0.05 (-1.5)	-0.08 (-1.5)	0.02 (0.1)
Volume	-0.01 (-0.4)	-0.07 (-1.8)	0.06 (0.8)

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TABLE 2  
**Regression of Yield Effect on Contemporaneous  
and Expected Future Trading Cost Measures**

This table shows the results of autocorrelation-adjusted panel regressions of the yield effect ( $YE_t$ ) on the contemporaneous trading cost difference and the expected future trading cost difference (orthogonalized) for each of the seven cost measures. Fixed-effects dummies are included to control for cross-sectional differences. The regression is run over the first month from the issue date of the on-the-run security. The regression equation is as follows:

$$YE_t = \sum_{i=1}^{55} \alpha_i + \beta_j (C_{off,t}^j - C_{on,t}^j) + \gamma_j (\bar{C}_{off,t}^j - \bar{C}_{on,t}^j)^{orth} + \varepsilon_t \text{ for } j = 1, 2, \dots, 7$$

The same regression is repeated in first differences with a single intercept. Autocorrelation-adjusted t-statistics are shown in parentheses.

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Cost Measure	Contemporaneous	Future Expected	Contemporaneous (Differences)	Future Expected (Differences)
Quoted Spread	0.0320 (2.3)	12.24 (8.3)	0.0026 (0.2)	12.28 (1.2)
Effective Spread	0.0326 (0.4)	41.01 (7.3)	-0.0674 (-0.9)	29.84 (2.4)
Quote Size	0.0003 (1.1)	0.10 (7.1)	0.0000 (0.0)	0.10 (2.7)
Trade Size	0.0002 (0.4)	0.22 (6.8)	-0.0003 (-0.5)	0.22 (3.1)
# of Quotes	0.0007 (2.2)	0.12 (6.4)	0.0005 (1.7)	0.13 (2.6)
# of Trades	0.0008 (3.3)	0.05 (7.4)	0.0004 (1.8)	0.06 (3.0)
Volume	0.0006 (2.6)	0.04 (7.3)	0.0002 (1.3)	0.05 (3.1)

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TABLE 3  
**Regression of Yield Effect on Time Trend  
and Expected Trading Cost Measures**

This table shows the results of autocorrelation-adjusted panel regressions of the yield effect ( $YE_t$ ) on a time trend, (i.e., the number of trading days since the issue of the on-the-run note), and the expected trading cost difference (orthogonalized) for each of the seven cost measures. Fixed-effects dummies are included to control for cross-sectional differences. The regression is run over the first month from the issue of the on-the-run security. Autocorrelation-adjusted t-statistics are shown in parentheses. The regression equation is as follows:

$$YE_t = \sum_{i=1}^{55} \alpha_i + \beta_j T_{i,t} + \gamma_j \left( \overline{C}_{off,t}^j - \overline{C}_{on,t}^j \right)^{orth} + \varepsilon_t \text{ for } j = 1, 2, \dots, 7.$$

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Cost Measure	Time Trend	Expected Cost
Quoted Spread	-0.0002 (-7.3)	22.24 (4.3)
Effective Spread	-0.0003 (-6.5)	40.44 (3.2)
Quote Size	-0.0002 (-6.8)	0.11 (2.1)
Trade Size	-0.0003 (-6.7)	0.13 (1.7)
Number of Quotes	-0.0003 (-6.7)	0.00 (0.0)
Number of Trades	-0.0003 (-7.7)	0.09 (3.5)
Volume	-0.0003 (-7.4)	0.06 (3.0)

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TABLE 4: PANEL A  
**Regression of Yield Effect on Pairs of Expected Trading Cost Measures**

This table reports the results of 42 regressions of the yield effect ( $YE_t$ ) on all permutations of pairs of expected trading cost differences, each with one cost measure orthogonalized relative to the other. Fixed-effects dummies are included to control for cross-sectional differences. Autocorrelation-adjusted t-statistics are shown in parentheses. The regressions are run over the first month from the issue date of the on-the-run security. The regression equation is as follows:

$$YE_t = \sum_{i=1}^{55} \alpha_i + \beta_j \left( \overline{C}_{off,t}^j - \overline{C}_{on,t}^j \right) + \gamma_j \left( \overline{C}_{off,t}^k - \overline{C}_{on,t}^k \right)^{orth} + \varepsilon_t \text{ for } j, k = 1, 2, \dots, 7 \text{ and } j \neq k.$$

The non-orthogonalized trading cost measures are shown along the vertical dimension of the table and the orthogonalized measures are shown along the horizontal dimension. The first set of numbers for each trading cost pair refers to the non-orthogonalized cost measure and the second set of number refers to the orthogonalized measure. Asterisks denote coefficients of the orthogonalized cost measures that are significant at the one-tailed 5% level.

	Quoted Spread (orthogonal)	Eff. Spread (orthogonal)	Quote Size (orthogonal)	Trade Size (orthogonal)	# of Quotes (orthogonal)	# of Trades (orthogonal)	Volume (orthogonal)
Quoted Spread		22.12 (10.8) -16.55 (-0.9)	21.87 (10.6) -0.14 (-2.1)	20.62 (10.1) -0.10 (-0.9)	22.28 (10.8) -0.35 (-3.4)	21.47 (10.1) -0.04 (-1.0)	21.30 (10.1) -0.04 (-1.2)
Eff. Spread	69.14 (14.6) 24.62 (3.9)*		66.60 (14.1) 0.04 (0.9)	65.69 (14.1) 0.08 (0.9)	66.46 (14.5) 0.00 (0.0)	67.01 (14.2) 0.04 (1.8)*	66.86 (14.2) 0.03 (1.6)
Quote Size	0.17 (9.7) 34.33 (4.4)*	0.16 (8.6) 35.33 (2.2)*		0.16 (8.8) 0.10 (0.8)	0.15 (8.6) -0.48 (-3.6)	0.17 (9.5) 0.19 (3.3)*	0.16 (9.1) 0.16 (3.0)*
Trade Size	0.47 (13.2) 20.42 (4.1)*	0.46 (12.8) 35.98 (2.8)*	0.44 (12.3) 0.10 (1.9)*		0.43 (11.58) 0.04 (0.6)	0.45 (12.8) 0.09 (3.5)*	0.45 (12.8) 0.08 (3.5)*
# of Quotes	0.21 (8.9) 48.0 (5.2)*	0.18 (7.4) 48.20 (2.9)*	0.18 (7.8) 0.48 (4.5)*	0.18 (7.7) 0.29 (2.4)*		0.20 (9.4) 0.38 (6.8)*	0.19 (8.7) 0.33 (6.7)*
# of Trades	0.08 (8.7) 26.08 (2.9)*	0.07 (8.0) 21.74 (1.3)	0.08 (9.0) -0.24 (-2.1)	0.07 (8.7) -0.02 (-0.2)	0.08 (10.2) -0.82 (-5.8)		0.07 (8.8) -0.07 (-0.6)
Volume	0.07 (9.2) 27.56 (3.1)*	0.06 (8.4) 23.13 (1.4)	0.07 (9.1) -0.24 (-1.9)	0.07 (9.2) -0.09 (-0.7)	0.07 (9.8) -0.86 (-5.6)	0.07 (9.3) 0.15 (1.2)	

**TABLE 4: PANEL B**  
**Regression of Yield Effect on Pairs of Expected Trading Cost Measures**  
(Differenced regressions)

This panel repeats the analysis of Panel A in first differences and with a single intercept.

	Quoted Spread (orthogonal)	Eff. Spread (orthogonal)	Quote Size (orthogonal)	Trade Size (orthogonal)	# of Quotes (orthogonal)	# of Trades (orthogonal)	Volume (orthogonal)
Quoted Spread		27.74 (2.7) 21.39 (0.9)	48.05 (3.1) 0.29 (1.8)*	33.51 (3.1) 0.23 (1.6)	30.60 (1.9) 0.06 (0.3)	47.52 (3.2) 0.16 (1.9)*	50.74 (3.5) 0.15 (2.2)*
Eff. Spread	66.54 (2.8) 20.95 (1.7)*		104.06 (3.0) 0.34 (2.2)*	59.74 (2.8) 0.25 (1.8)*	75.58 (2.0) 0.21 (1.0)	108.73 (3.3) 0.18 (2.4)*	114.81 (3.5) 0.17 (2.7)*
Quote Size	0.46 (3.0) 19.34 (1.7)*	0.42 (2.8) 30.64 (1.5)		0.41 (2.7) 0.18 (1.2)	0.43 (2.4) 0.06 (0.3)	0.52 (3.2) 0.16 (1.8)*	0.53 (3.3) 0.15 (2.0)*
Trade Size	0.56 (3.1) 24.29 (2.3)*	0.42 (2.7) 37.35 (1.9)*	0.71 (2.9) 0.34 (2.1)*		0.53 (2.0) 0.24 (1.1)	0.77 (3.2) 0.19 (2.5)*	0.79 (3.2) 0.20 (2.5)*
# of Quotes	0.35 (1.7) 25.72 (2.1)*	0.35 (1.7) 36.76 (1.8)*	0.54 (2.3) 0.38 (2.2)*	0.37 (1.7) 0.25 (1.7)*		0.53 (2.4) 0.22 (2.6)*	0.54 (2.5) 0.21 (2.9)*
# of Trades	0.22 (3.1) 15.02 (1.2)	0.22 (3.1) 26.82 (1.3)	0.26 (3.2) 0.21 (1.1)	0.22 (3.1) 0.18 (1.2)	0.21 (2.5) -0.04 (-0.2)		0.23 (3.2) 0.18 (1.2)
Volume	0.20 (3.4) 13.96 (1.2)	0.20 (3.3) 25.42 (1.3)	0.22 (3.3) 0.17 (0.9)	0.19 (3.1) 0.00 (0.0)	0.18 (2.6) -0.08 (-0.3)	0.20 (3.2) 0.02 (0.1)	

TABLE 4: PANEL C  
**Scoring of Trading Cost Measures**

This panel summarizes the information in Panels A and B of Table 4. In the previous panels each of the seven trading cost measures  $k$  is orthogonalized relative to each of the other cost measures  $j$ . If the orthogonalized measure  $k$  is statistically significant (at the one-tailed 5% level) in a regression with measure  $j$ , we say that measure  $k$  adds explanatory power relative to  $j$ . If not, we say that measure  $j$  subsumes measure  $k$ . For each measure of liquidity, we count the number of times (out of a possible six times) it adds explanatory power relative to the other liquidity measures. We also count the number of times it subsumes other measures (also out of a possible six times). The total score is the sum of these counts.

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Cost Measure	Adds Explanatory Power	Subsumes Other Measures	Adds Explanatory Power (Differences)	Subsumes Other Measures (Differences)	Total
Quoted Spread	6	6	4	3	19
Eff. Spread	3	4	2	1	10
Quote Size	2	2	4	3	11
Trade Size	1	1	2	1	5
# of Quotes	0	0	0	0	0
# of Trades	4	5	5	6	20
Volume	3	5	5	6	19

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