Michael J. Fleming

Measuring Treasury Market Liquidity

- U.S. Treasury securities are important to a range of market-related trading and analytical activities because of the securities' immense liquidity.
- Recently, the availability of high-frequency data has enabled detailed analyses of Treasury market liquidity. Measures such as the bid-ask spread, quote size, trade size, and price impact can now be used to assess and track liquidity more effectively.
- An examination of these and other liquidity measures for the U.S. Treasury market finds that the commonly used bid-ask spread—the difference between bid and offer prices—is a useful tool for assessing and tracking liquidity.
- Other measures, such as quote and trade sizes, prove to be only modest tools for assessing and tracking liquidity, while trading volume and frequency are in fact poor measures of liquidity.

1. Introduction

Many important uses of U.S. Treasury securities stem from the securities' immense liquidity. Market participants, for example, use Treasuries to hedge positions in other fixed-income securities and to speculate on the course of interest rates because they can buy and sell Treasuries quickly and with low transaction costs. The high volume of trading and narrow bid-ask spreads also help make Treasury rates reliable reference rates for pricing and analyzing other securities. In addition, the Federal Reserve System, foreign central banks, and depositary institutions hold Treasuries as a reserve asset in part because they can buy and sell them quickly with minimal market impact.[1]

The liquidity of the Treasury market has received particular attention in recent years. This heightened focus is partly attributable to the financial market turmoil in the fall of 1998, when liquidity was disrupted across markets and investors sought the safety and liquidity of Treasuries.[2] It is also attributable to concerns about liquidity arising from the federal government's reduced funding needs in the late 1990s and the resultant reduction in the supply of Treasuries.[3] Several debt management changes—such as the launch of the debt buyback program in January 2000—were motivated by the Treasury's desire to maintain liquidity in such an environment.[4]

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Historically, few studies have analyzed Treasury market liquidity—despite its importance.[5] Recently, however, the availability of high-frequency data has spurred several detailed analyses. Fleming (1997), for example, documents the intraday patterns of bid-ask spreads and trading volume in the round-the-clock interdealer market. Fleming and Remolona (1997, 1999), Balduzzi, Elton, and Green (2001), and Huang, Cai, and Wang (2002) analyze bid-ask spreads and trading activity around macroeconomic announcements. Fleming (2002), Strebulaev (2002), and Goldreich, Hanke, and Nath (2003) examine liquidity across subgroups of securities and over securities' life cycles and relate liquidity differences to price differences. Brandt and Kavajecz (2003), Cohen and Shin (2003), and Green (forthcoming) explore how order flow affects prices.

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This article adds to the literature by estimating and evaluating a comprehensive set of liquidity measures for the U.S. Treasury securities market. High-frequency data from the interdealer market allow for an analysis of trading volume, trading frequency, bid-ask spreads, quote sizes, trade sizes, price impact coefficients, and on-the-run/off-the-run yield spreads. The variables are analyzed relative to one another, across securities, and over time in an effort to assess how liquidity can best be measured and tracked.

The measurement and tracking of liquidity are of relevance to those who transact in the market, those who monitor market conditions, and those who analyze market developments. As a measure of trading costs, for example, liquidity affects the incentives of dealers, hedge funds, and others to engage in hedging and speculative activity. As a barometer of market conditions, liquidity signals to policymakers the willingness of market makers to commit capital and take risks in financial markets. Those interested in understanding the determinants of liquidity, the price formation process, and the effects of liquidity on prices are also naturally interested in how liquidity can be measured and tracked.

Our analysis reveals that the simple bid-ask spread—the difference between bid and offer prices—is a useful measure for assessing and tracking Treasury market liquidity. The bid-ask spread can be calculated quickly and easily with data that are widely available on a real-time basis. Nonetheless, the spread is highly correlated with the more sophisticated price impact measure and it is correlated with episodes of reported poor liquidity in the expected manner. The bid-ask spread thus increases sharply with 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.

Conversely, quote size, trade size, and on-the-run/off-the-run yield spread are found to be only modest proxies for market liquidity. These measures correlate less strongly with the episodes of reported poor liquidity and with the bid-ask spread and price impact measures. Furthermore, trading volume and trading frequency are weak proxies for market liquidity, as both high and low levels of trading activity are associated with periods of poor liquidity.

It is worth noting that this article complements work on the equity and foreign exchange (FX) markets (Goodhart and O'Hara [1997] and Madhavan [2000] survey the literature). The analysis of price impact coefficients, in particular, is related to studies of the FX market by Evans (1999), Payne (2000), and Evans and Lyons (2002), who find that a high proportion of exchange rate changes can be explained by order flow alone. We uncover a similar relationship between order flow and price changes in the Treasury market, with a simple model of price changes producing an R^2 statistic above 30 percent for the two-year note.

In addition, our analysis of liquidity measures complements studies that analyze commonality in liquidity in equity markets (Chordia, Roll, and Subrahmanyam 2000, Hasbrouck and Seppi 2001, and Huberman and Halka 2001) and between equity and Treasury markets (Chordia, Sarkar, and Subrahmanyam 2003). Commonality in liquidity across securities is likely to be strong in the Treasury market given the securities' common features. Moreover, the high volume of trading in the Treasury market and the absence of rules that limit price changes or bid-ask spreads to specified minimums or maximums make it relatively easy to estimate measures of liquidity precisely. Correlation coefficients across Treasuries are in fact found to be quite high for the various measures, indicating that the liquidity of one security can serve as a reasonable proxy for the market as a whole.

Our analysis proceeds as follows: Section 2 describes market liquidity and how it is typically measured in practice; Section 3 discusses the data and the sample period; Section 4 presents empirical results for the individual liquidity measures; Section 5 examines the relationships among the measures.

2. Measures of Liquidity

A liquid market is defined as one in which trades can be executed with no cost (O'Hara 1995; Engle and Lange 1997). In practice, a market with very low transaction costs is characterized as liquid and one with high transaction costs as illiquid. Measuring these costs is not simple, however, as they depend on the size of a trade, its timing, the trading venue, and the counterparties. Furthermore, the information needed to calculate transaction costs is often not available. As a consequence, a variety of measures are employed to evaluate a market's liquidity.

The bid-ask spread is a commonly used measure of market liquidity. It directly measures the cost of executing a small trade, with the cost typically calculated as the difference between the bid or offer price and the bid-ask midpoint (or one-half of the bid-ask spread). The measure can thus quickly and easily be calculated with data that are widely available on a real-time basis. However, a drawback of the bid-ask spread is that bid and offer quotes are good only for limited quantities and periods of time. The spread therefore only measures the cost of executing a single trade of limited size.

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The quantity of securities that can be traded at the bid and offer prices helps account for the depth of the market and complements the bid-ask spread as a measure of market liquidity. A simple estimate of this quantity is the quote size, or the quantity of securities that is explicitly bid for or offered for sale at the posted bid and offer prices. A drawback of this estimate, however, is that market makers often do not reveal the full quantities they are willing to transact at a given price, so the measured depth underestimates the true depth.

An alternative measure of market depth is trade size. Trade size is an ex-post measure of the quantity of securities that can be traded at the bid or offer price, reflecting any negotiation over quantity that takes place. Trade size also underestimates market depth, however, as the quantity traded is often less than the quantity that could have been traded at a given price. In addition, any measure of the quantity of securities that can be traded at the bid and offer prices does not, by definition, consider the cost of executing larger trades.

A popular measure of liquidity, suggested by Kyle (1985), considers the rise (fall) in price that typically occurs with a buyer-initiated (seller-initiated) trade. The Kyle lambda is defined as the slope of the line that relates the price change to trade size and is typically estimated by regressing price changes on net volume for intervals of fixed time. The measure is relevant to those executing large trades or a series of trades, and together with the bid-ask spread and depth measures provides a fairly complete picture of market liquidity. A drawback of this measure, though, is that the data required for estimation, including the side initiating a trade, are often difficult to obtain, particularly on a real-time basis.

A liquidity measure used in the Treasury market is the "liquidity" spread between more and less liquid securities, often calculated as the difference between the yield of an on-the-run security and that of an off-the-run security with similar cash flow characteristics.[6] Since liquidity has value, more liquid securities tend to have higher prices (lower yields) than less liquid securities, as shown by Amihud and Mendelson (1991) and Kamara (1994). A nice feature of the liquidity spread is that it can be calculated without high-frequency data. Moreover, because the spread reflects both the price of liquidity as well as differences in liquidity between securities, it provides insight into the value of liquidity not provided by the other measures. The spread can be difficult to interpret, however, for the same reason. In addition, factors besides liquidity can cause on-the-run securities to trade at a premium, confounding the interpretation of the spread.[7] Furthermore, the choice of an off-the-run benchmark against which to compare an on-the-run security can result in considerable estimation error.

Trading volume is an indirect but widely cited measure of market liquidity. Its popularity may stem from the fact that more active markets, such as the Treasury market, tend to be more liquid, and from theoretical studies that link increased trading activity with improved liquidity. The measure's popularity may also reflect its simplicity and availability, with volume figures regularly reported in the press and released by the Federal Reserve. A drawback of trading volume, however, is that it is also associated with volatility (Karpoff 1987), which is thought to impede market liquidity. The implications of changes in trading activity for market liquidity are therefore not always clear.

A closely related measure of market liquidity is trading frequency. Trading frequency equals the number of trades executed within a specified interval, without regard to trade size. Like trading volume, high trading frequency may reflect a more liquid market, but it is also associated with volatility and lower liquidity. In fact, Jones, Kaul, and Lipson (1994) show that the positive volume-volatility relationship found in many equity market studies reflects the positive relationship between the number of trades and volatility, and that trade size has little incremental information content.

3. Data and Sample Period Description

Our primary data source is GovPX, Inc. GovPX consolidates data from all but one of the major brokers in the interdealer market and transmits the data to subscribers in real time through on-line vendors.[8] The posted data include the best bid and offer quotes, the associated quote sizes, the price and size of each trade, and whether the trade was a "take" (buyer-initiated) or a "hit" (seller-initiated). We use a history of these postings, provided by GovPX, that includes the time of each posting to the second.

Because GovPX consolidates data from all but one of the major brokers, it provides a good, but not complete, picture of interdealer activity. Data reported to the Federal Reserve Bank of New York by the primary dealers indicate average daily trading of $108 billion in the interdealer broker market in the first quarter of 2000 (and $105 billion in the dealer-to-customer market). The comparable GovPX figure is $46 billion, implying market coverage of about 42 percent.[9] This share has been falling fairly quickly in recent years, averaging 65 percent in 1997, 57 percent in 1998, and 52 percent in 1999.

The decline in GovPX market coverage has been particularly severe among coupon securities, as noted by Boni and Leach (2002b). Estimated GovPX coverage of coupon securities with five years or less to maturity fell from 70 percent in 1997 to 39 percent in the first quarter of 2000. Estimated coverage of coupon securities with more than five years to maturity fell from 37 percent to 19 percent over the same period. In contrast, estimated GovPX bill coverage exceeded 90 percent in every year in the sample.

The incompleteness of the data can cause estimated liquidity measures to be biased measures of liquidity in the interdealer market as a whole, and to become more biased over time. Such a bias is obvious in the case of the trading activity measures, but it is also true for measures such as the bid-ask spread and the price impact coefficient. In the case of the bid-ask spread, for example, the spread between the best bid and the best offer prices based on a subset of activity in the interdealer market is never narrower, but sometimes wider, than the comparable spread for the complete interdealer market.

To mitigate the biases due to declining coverage, the measures for the coupon securities are adjusted and reported as if GovPX coverage was constant at its average levels over the sample period.[10] Note that the adjustment methodology, described in the box, does not attempt to correct for biases in the measures due to the *level* of GovPX coverage, but is instead intended to reduce biases due to *changes* in GovPX coverage.

Despite these data issues, the estimated liquidity measures are nonetheless highly informative about liquidity in the interdealer market. First, the incompleteness of GovPX coverage applies almost entirely to coupon securities, so that the liquidity measures estimated for bills are not appreciably biased. Second, as GovPX coverage of coupon securities deteriorates gradually over the sample period, the week-to-week changes in the liquidity measures are highly informative about short-term liquidity changes in the broader market.

An interesting feature of the interdealer market is the negotiation that takes place over quantities (Boni and Leach [2002a] provide a detailed analysis of this phenomenon). Trades often go through a "workup" process, in which a broker mediates an increase in trade size beyond the amount quoted. For these trades, the brokers' screens first indicate that a trade is occurring and then update the trade size until the trade's completion many seconds later. The GovPX data are processed and analyzed in a manner that treats the outcomes of these workup processes as single trades. The appendix discusses this and other data processing issues in detail.

[Our sample period] covers the Thai baht devaluation in July 1997, the equity market declines in October 1997, the financial market turmoil of fall 1998, and the Treasury's debt management announcements of early 2000.

In contrast to the negotiation over trade sizes, there is no price negotiation in the interdealer market, so trades only go off at posted bid or offer prices. As a result, quoted bid-ask spreads provide an accurate indication of the spreads facing market participants.[11]

This article focuses on the liquidity of the on-the-run bills and notes. Even though on-the-run securities represent just a small fraction of the roughly 200 Treasury securities outstanding, they account for 71 percent of activity in the interdealer market (Fabozzi and Fleming 2000). We exclude the three-year note from our analyses because the Treasury suspended issuance of

Adjusting the Liquidity Measures for Changes in GovPX Coverage

To adjust the liquidity measures for the coupon securities, we first calculate weekly GovPX trading volume coverage ratios for the different sectors of the Treasury market. The primary dealers report their trading activity through interdealer brokers by sector (bills, coupon securities with maturities of less than or equal to five years, and coupon securities with maturities of more than five years) on a weekly basis. We calculate GovPX trading volume for comparable sectors and weeks, and then calculate GovPX coverage ratios as twice the ratio of GovPX trading volume in a sector to dealers' reported interdealer broker volume in a sector (see endnote 9).

Trading volume and net trading volume for the coupon securities are then scaled up or down by the ratio of the GovPX coverage ratio in that sector over the entire sample period to the GovPX coverage ratio for that week. For example, GovPX coverage of coupon securities with less than or equal to five years to maturity equals 62 percent over the entire sample. In a week in which the ratio equals 52 percent, the raw volume numbers for the relevant securities (the two- and five-year notes) are multiplied by 1.19 (1.19 = 62 percent/52 percent).

The other measures are adjusted based on the results of regression analyses. We first regress weekly bid-ask spread, quote size, trade size, and price impact measures for each security on the share of that sector covered by GovPX, on price volatility in that security, and on a dummy variable equal to 1 for the week ending August 21, 1998, and thereafter. Because volume numbers are reported to the Federal Reserve for weeks ending Wednesday, we calculate a weighted-average GovPX coverage ratio for each calendar week using the coverage ratios of the two weeks that overlap the calendar week. Price volatility is calculated for the contemporaneous week in a manner similar to the way yield volatility is calculated in Chart 2.

The GovPX share variable is statistically significant (at the 5 percent level) for all notes for the bid-ask spread and price impact measures (and of the expected sign) and is significant for the ten-year note for the quote and trade size measures. Volatility and the dummy variable are mostly significant for the notes for the spread, quote size, and price impact measures. The share variables are never significant for the bills, probably because GovPX bill coverage is not declining (and is close to 100 percent) over the sample period. Accordingly, the liquidity measures for the bills are not adjusted.

The bid-ask spread, quote size, trade size, and price impact measures are then adjusted by adding to the raw measures the applicable regression coefficient multiplied by the difference between the GovPX coverage ratio for the whole sample and the GovPX coverage ratio for that week. For example, the regression coefficient for the bid-ask spread for the two-year note is -0.21 and the relevant GovPX coverage ratio for the entire sample is 62 percent. In a week in which the ratio equals 52 percent, the adjusted bid-ask spread equals the raw bid-ask spread -0.02 32nds (-0.02 = -0.21 * (0.62-0.52)).

Adjusted trading frequency figures are then calculated by dividing adjusted trading volume figures by adjusted trade size figures.

The adjusted liquidity measures are employed throughout this article, reported in the descriptive tables and charts, and used in the statistical analyses.[a] Adjusted numbers do not appear in Table 10 or Charts 1, 2, and 11, as yields, yield spreads, and volatilities are not adjusted (the measures that employ these variables should be relatively unaffected by changes in GovPX coverage). The data in Chart 3 are also not adjusted, as one purpose of that chart is to illustrate the decline in GovPX coverage.

The most significant effects on the results of these adjustments are the leveling out of the time series plots of the liquidity measures. In particular, adjusted trading volume and trading frequency exhibit less of a decline over time, and adjusted bid-ask spreads and price impact coefficients exhibit less of an increase. The results in the tables are relatively unaffected by the adjustments. As mentioned, the adjustment methodology is not intended to correct for biases in the measures due to the overall level of GovPX coverage, so one would not expect the descriptive statistics for the measures to change much.

[a]In particular, note that adjusted net trading volume and net trading frequency figures are employed in the regression analyses of Table 8 and endnotes 17 and 18. In contrast, the weekly price impact coefficients in Table 9 and Chart 10 are adjusted after having been estimated with unadjusted data.

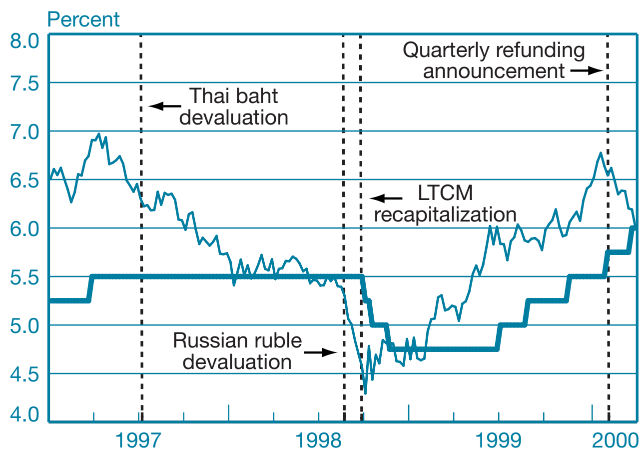
this security in 1998. Also excluded are the thirty-year bond, due to limited coverage by GovPX, and Treasury inflation-indexed securities, due to their limited trading activity.

Most of our analyses are conducted and presented at the daily and weekly level and are typically based on data from New York trading hours (defined as 7:30 a.m. to 5:00 p.m., eastern time).[12] The aggregation dampens some of the idiosyncratic variation in the liquidity measures and largely removes time-of-day patterns (and day-of-week patterns in the case of the weekly aggregated data). The limitation to New York trading hours prevents the relatively inactive overnight hours from having undue influence. The trading activity measures (volume, trading frequency, and trade size) are reported for the full day, however, for consistency with figures reported by the Federal Reserve and GovPX.

The sample period is December 30, 1996, to March 31, 2000. The sample thus covers the Thai baht devaluation in July 1997, the equity market declines in October 1997, the financial market turmoil of fall 1998, and the Treasury's debt management announcements of early 2000. Chart 1 illustrates some of these developments and plots the ten-year Treasury note yield and the fed funds target rate.

Chart 2 depicts the yield volatilities of the three-month bill and ten-year note, calculated weekly as the standard deviations of thirty-minute yield changes (computed using bid-ask midpoints). It reveals that volatilities of both securities reach their highest levels during the fall 1998 financial market turmoil (the week ending October 9). Both also spike to shorter peaks at the time of the October 1997 equity market declines (the week ending October 31) and at the time of the Treasury's February 2000 quarterly refunding meeting (the week ending February 4).

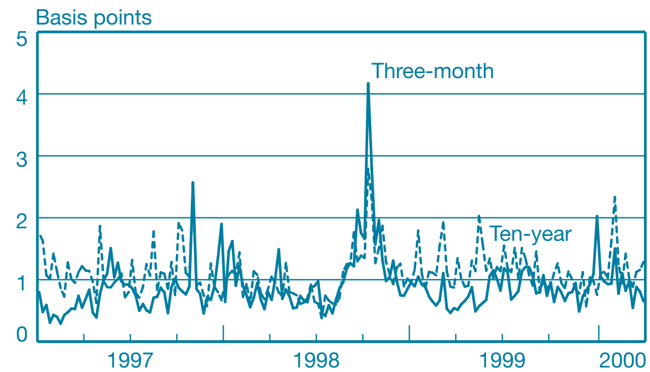
Chart 1
Ten-Year U.S. Treasury Note Yield and Fed Funds Target Rate



Source: Bloomberg.

Notes: The thin line represents the Treasury yield; the thick line represents the target rate. LTCM is Long-Term Capital Management.

Chart 2
Three-Month Bill and Ten-Year Note Yield Volatility



Source: Author's calculations, based on data from GovPX.

Note: The chart plots standard deviations of thirty-minute yield changes by week for the indicated on-the-run securities.

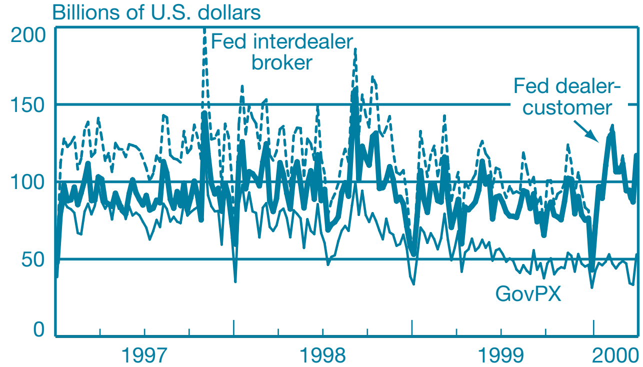
4. Empirical Results

4.1 Trading Volume

Chart 3 presents average daily trading volume by week using both GovPX data and data reported to the Federal Reserve by the primary dealers. As discussed, GovPX coverage of the interdealer market has been decreasing, causing GovPX volume to decline at a faster pace than interdealer broker volume reported to the Federal Reserve. Another long-term trend visible in Chart 3 is the stability of dealer-to-customer activity, even as interdealer activity has declined, causing the two series to converge in early 2000.

Looking at shorter term trends, we note that all three series drop off sharply in the final weeks of each year. This pattern likely reflects early holiday closes, lower staffing levels, and decreased willingness to take on new positions before year-end. Market participants characterize such low-volume periods as illiquid (*Wall Street Journal* 1997, 1998a). Volumes in all three series also rise together to peaks in late October 1997 and in the fall of 1998, when market volatility is quite high. These high-volume periods are also characterized by poor liquidity (*Wall Street Journal* 1998b; Committee on the Global Financial System 1999).

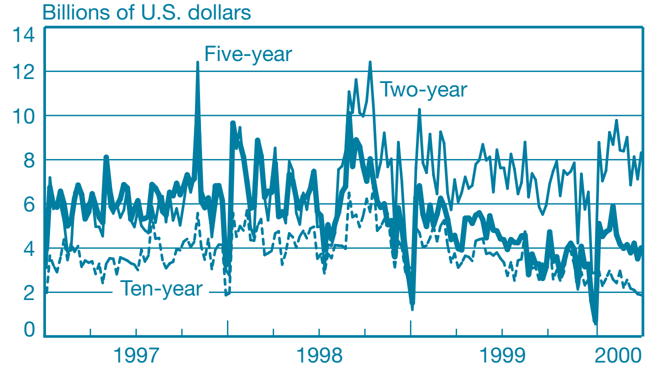
Chart 3
Daily Trading Volume of U.S. Treasury Securities



Source: Author's calculations, based on data from *Federal Reserve Bulletin* and GovPX.

Note: The chart plots mean daily trading volume by week for the indicated series.

Chart 4
Daily Trading Volume of U.S. Treasury Notes



Source: Author's calculations, based on data from GovPX.

Note: The chart plots mean daily interdealer trading volume by week for the on-the-run notes.

Daily GovPX trading volume descriptive statistics for each of the on-the-run bills and notes can be found in Table 1.[13] The two-year note is shown to be the most actively traded security among the brokers reporting to GovPX, with a mean (median) daily volume of $6.8 billion ($6.7 billion). The six-month bill is the least active, with a mean (median) daily volume of $0.8 billion ($0.8 billion).

Average daily note trading volume by week is plotted in Chart 4.[14] Activity for each of the notes tends to follow the patterns for total trading activity observed in Chart 3. Volume is positively correlated across securities, especially for notes, with the five- and ten-year notes the most correlated (correlation coefficient = 0.75).

4.2 Trading Frequency

Daily trading frequency descriptive statistics for the on-the-run bills and notes are reported in Table 2. The table shows that the most actively traded security in terms of volume—the two-year note—is only the third most actively traded in terms of frequency. The five-year note is the most frequently traded, with a mean (median) of 687 (678) trades per day. The six-month bill is again the least actively traded security, with a mean (median) of just forty-one (thirty-nine) trades per day.

Table 1
Daily Trading Volume of U.S. Treasury Securities

Issue	Mean	Median	Standard Deviation
Three-month bill	1.28	1.18	0.70
Six-month bill	0.84	0.76	0.51
One-year bill	2.01	1.82	0.99
Two-year note	6.81	6.67	2.53
Five-year note	5.54	5.46	1.98
Ten-year note	3.77	3.69	1.32

Source: Author's calculations, based on data from GovPX.

Notes: The table reports descriptive statistics on daily interdealer trading volume for the indicated on-the-run securities in billions of U.S. dollars. The sample period is December 30, 1996, to March 31, 2000.

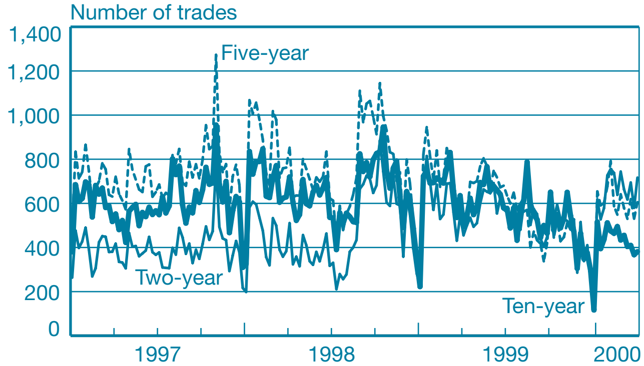
Table 2
Daily Trading Frequency of U.S. Treasury Securities

Issue	Mean	Median	Standard Deviation
Three-month bill	56.2	53	26.2
Six-month bill	41.4	39	19.8
One-year bill	107.7	98	48.9
Two-year note	482.9	463.7	177.6
Five-year note	687.5	677.7	225.5
Ten-year note	597.6	600.4	174.9

Source: Author's calculations, based on data from GovPX.

Notes: The table reports descriptive statistics on the daily number of interdealer trades for the indicated on-the-run securities. The sample period is December 30, 1996, to March 31, 2000.

Chart 5
Daily Trading Frequency of U.S. Treasury Notes



Source: Author's calculations, based on data from GovPX.

Note: The chart plots the mean daily number of interdealer trades by week for the on-the-run notes.

In Chart 5, we present average daily note trading frequency by week. The patterns there are quite similar to those for trading volume (Chart 4), although differences in trade size affect the ordering of the plotted lines. Trading frequency is also positively correlated across securities, with the five- and ten-year notes the most correlated (correlation coefficient = 0.85).

4.3 Bid-Ask Spreads

Table 3 reports descriptive statistics for average daily bid-ask spreads for the on-the-run bills and notes. Consistent with market quoting conventions, bill bid-ask spreads are reported in basis points, based on the discount rate, and note bid-ask spreads are reported in 32nds of a point, where one point equals 1 percent of par.[15] The longer maturity securities, which tend to be more volatile (in price terms), also have wider bid-ask spreads (in price terms). The ten-year note thus has an average spread of 0.78 32nds, whereas the two-year note has an average spread of 0.21 32nds. The one-year bill has the narrowest spread among the bills in terms of yield, at 0.52 basis point, but the widest spread among the bills in terms of price (the conversion from yield to price involves multiplying the yield by the duration of the security).

Chart 6 plots average note bid-ask spreads by week. The prominent features of the chart are the upward spikes in spreads that occur in late October 1997, October 1998, and February 2000, coinciding with the volatility spikes in Chart 2. The spreads also tend to widen in the final weeks of each year, albeit not as much for notes as for bills. Bid-ask spreads are positively correlated across securities, with the five- and ten-year notes again the most correlated (correlation coefficient = 0.88).

Table 3
Bid-Ask Spreads of U.S. Treasury Securities

Issue	Mean	Median	Standard Deviation
Three-month bill	0.71 bp	0.61 bp	0.45 bp
Six-month bill	0.74 bp	0.66 bp	0.34 bp
One-year bill	0.52 bp	0.48 bp	0.25 bp
Two-year note	0.21 32nds	0.20 32nds	0.03 32nds
Five-year note	0.39 32nds	0.37 32nds	0.10 32nds
Ten-year note	0.78 32nds	0.73 32nds	0.20 32nds

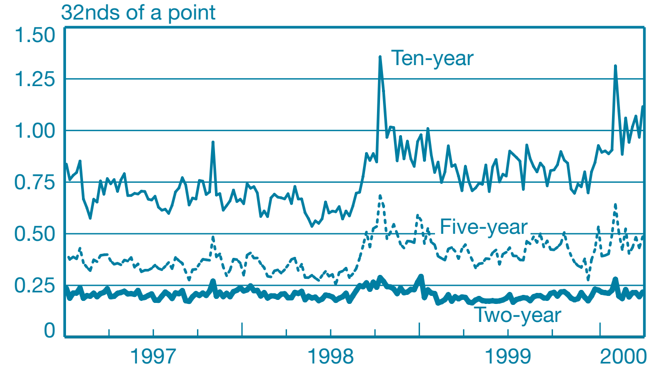
Source: Author's calculations, based on data from GovPX.

Notes: The table reports descriptive statistics on mean daily interdealer bid-ask spreads for the indicated on-the-run securities. The sample period is December 30, 1996, to March 31, 2000. bp is basis points; 32nds is 32nds of a point.

4.4 Quote Sizes

Descriptive statistics for average daily quote sizes for the on-the-run bills and notes appear in Table 4. The quote sizes are the quantity of securities bid for or offered for sale at the best bid and offer prices in the interdealer market (minimum quote sizes are $5 million for bills and $1 million for notes), and the averages are calculated using both bid and offer quantities.

Chart 6
Bid-Ask Spreads of U.S. Treasury Notes



Source: Author's calculations, based on data from GovPX.

Note: The chart plots mean interdealer bid-ask spreads by week for the on-the-run notes.

Table 4
Quote Sizes of U.S. Treasury Securities

Issue	Mean	Median	Standard Deviation
Three-month bill	16.9	14.9	8.6
Six-month bill	15.5	14.1	6.1
One-year bill	17.2	16.4	5.6
Two-year note	24.5	23.0	7.8
Five-year note	10.7	10.3	2.7
Ten-year note	7.9	7.6	2.2

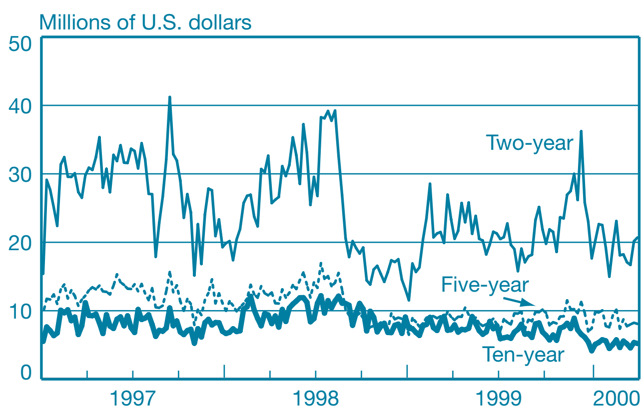
Source: Author's calculations, based on data from GovPX.

Notes: The table reports descriptive statistics on mean daily interdealer quote sizes for the indicated on-the-run securities in millions of U.S. dollars. Quote sizes are the quantity of securities bid for or offered for sale at the best bid and offer prices in the interdealer market; the mean daily figure is calculated with both bid and offer quantities. The sample period is December 30, 1996, to March 31, 2000.

Quote sizes are largest for the two-year note, with an average size of $24.5 million, and smallest for the ten-year note, with an average size of $7.9 million.

Chart 7 presents average quote sizes by week for the notes. It shows that quote sizes decline steeply during the financial market turmoil of fall 1998. Although they are not easy to identify amid somewhat volatile series, quote sizes also decline during the weeks ending October 31, 1997; October 9, 1998; and February 4, 2000 (when volatility and bid-ask spreads spike higher). Quote sizes are positively correlated across securities, especially for notes, with the two- and five-year notes the most correlated (correlation coefficient = 0.87).

Chart 7
Quote Sizes of U.S. Treasury Notes



Source: Author's calculations, based on data from GovPX.

Notes: The chart plots mean interdealer quote sizes by week for the on-the-run notes. Quote sizes are the quantity of securities bid for or offered for sale at the best bid and offer prices in the interdealer market; the mean weekly figure is calculated with both bid and offer quantities.

4.5 Trade Sizes

Table 5 reports descriptive statistics for average daily trade sizes for the on-the-run bills and notes. We see that average trade size decreases monotonically with security maturity, from $22.5 million for the three-month bill to $6.2 million for the ten-year note. As discussed in Section 3, trade sizes are calculated to reflect the quantity negotiation that occurs between counterparties in a workup process. Trades may therefore be for quantities in excess of the quoted size, although they can also be for quantities smaller than the quoted size. Empirically, average trade size exceeds average quote size for each of the bills, but average quote size exceeds average trade size for each of the notes.

Chart 8 plots average note trade sizes by week. Trade sizes are shown to decline in fall 1998, albeit less so than quote sizes. Furthermore, trade sizes decline only modestly or even increase in some of the most volatile weeks of the sample period. Trade sizes tend to be positively correlated across securities, with the two- and five-year notes the most correlated (correlation coefficient = 0.77).

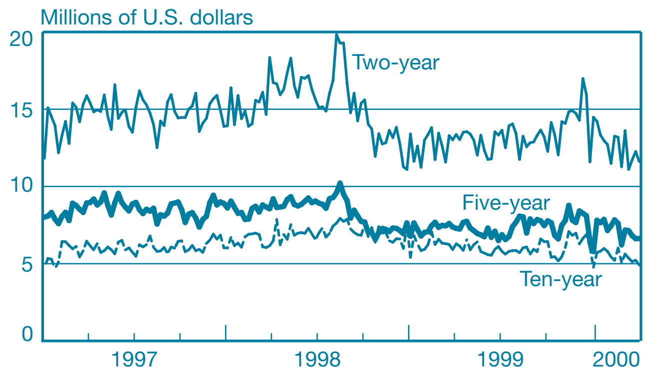
Table 5
Trade Sizes of U.S. Treasury Securities

Issue	Mean	Median	Standard Deviation
Three-month bill	22.5	22.0	6.3
Six-month bill	19.7	19.0	6.0
One-year bill	18.4	18.0	3.4
Two-year note	14.2	13.9	2.1
Five-year note	8.0	8.0	1.0
Ten-year note	6.2	6.2	0.8

Source: Author's calculations, based on data from GovPX.

Notes: The table reports descriptive statistics on mean daily interdealer trade sizes for the indicated on-the-run securities in millions of U.S. dollars. The sample period is December 30, 1996, to March 31, 2000.

Chart 8
Trade Sizes of U.S. Treasury Notes



Source: Author's calculations, based on data from GovPX.

Note: The chart plots mean interdealer trade sizes by week for the on-the-run notes.

Table 7
Daily Net Number of Trades of U.S. Treasury Securities

Issue	Mean	Median	Standard Deviation
Three-month bill	6.6	5	13.2
Six-month bill	1.4	1	9.9
One-year bill	-0.3	0	16.1
Two-year note	34.6	31.1	39.9
Five-year note	29.7	27.9	46.5
Ten-year note	18.2	17.2	38.0

Source: Author's calculations, based on data from GovPX.

Notes: The table reports descriptive statistics on the daily net number of interdealer trades for the indicated on-the-run securities. The net number of trades equals the number of buyer-initiated less seller-initiated trades. The sample period is December 30, 1996, to March 31, 2000.

4.6 Price Impact Coefficients

As discussed in Section 2, a popular measure of liquidity relates net trading activity to price changes. Net trading activity is typically defined—and is defined here—as buyer-initiated activity less seller-initiated activity. Descriptive statistics for daily net trading volume for the on-the-run bills and notes can be found in Table 6, while statistics on the daily net number of trades are offered in Table 7. In both tables, the means (medians) are positive for every security except the one-year bill, and the two-year note has the highest means (medians), with $0.30 billion ($0.24 billion) net volume per day and 34.6 (31.1) net trades per day. The predominance of buyer-initiated activity may reflect the tendency of dealers' customers to be net buyers and of dealers to offset customer trades in the interdealer market.[16]

Preliminary descriptive evidence relating net trading activity to price changes is shown in Chart 9. The chart plots the daily net number of trades against the daily price change for the on-the-run two-year note. As expected, the relationship is

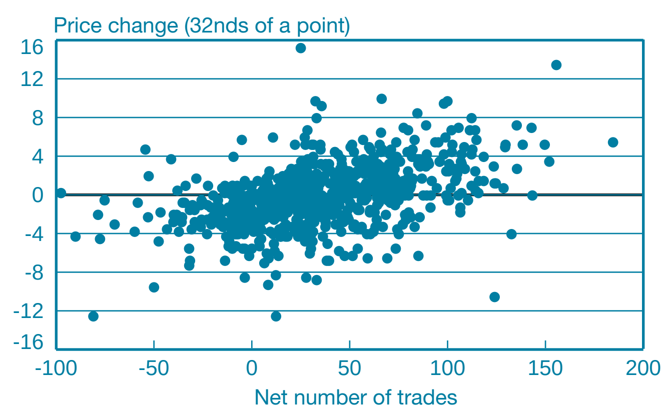
Table 6
Daily Net Trading Volume of U.S. Treasury Securities

Issue	Mean	Median	Standard Deviation
Three-month bill	0.16	0.09	0.44
Six-month bill	0.02	0.01	0.30
One-year bill	-0.04	-0.05	0.41
Two-year note	0.30	0.24	0.78
Five-year note	0.16	0.13	0.51
Ten-year note	0.11	0.10	0.38

Source: Author's calculations, based on data from GovPX.

Notes: The table reports descriptive statistics on daily net interdealer trading volume for the indicated on-the-run securities in billions of U.S. dollars. Net trading volume equals buyer-initiated less seller-initiated volume. The sample period is December 30, 1996, to March 31, 2000.

Chart 9
Net Number of Trades versus Price Change by Day for the Two-Year U.S. Treasury Note



Source: Author's calculations, based on data from GovPX.

Notes: The chart plots the daily net number of interdealer trades versus the daily price change for the on-the-run two-year note. The net number of trades equals the number of buyer-initiated less seller-initiated trades. Days on which a new two-year note was auctioned and for which the day's price change cannot be calculated are excluded. The sample period is December 30, 1996, to March 31, 2000.

positive, showing that buyer-initiated (seller-initiated) trades are associated with rising (falling) prices. A positive but weaker relationship is observed when daily net trading volume is plotted against the daily price change.

To examine more closely the relationship between price changes and net trading activity, we regress five-minute price changes, computed using bid-ask midpoints, on various measures of trading activity over the same interval. Analysis at this high frequency allows for a precise estimation of the relationship for the full sample, as well as for the relationship to be estimated fairly reliably on a weekly basis. At the same time, asynchronous arrival of trades and quotes, the commingling of data provided by different brokers, and the time lag between trade initiation and completion suggest that the data be aggregated to a certain extent, and not examined on a tick-by-tick basis.

The results from five regression models estimated over the entire sample period for the on-the-run two-year note are contained in Table 8. In model 1, price changes are regressed on the net number of trades. The slope coefficient is positive, as predicted, and highly significant. The coefficient of 0.0465 implies that about twenty-two trades, net, move the price of the two-year note by 1 32nd of a point. The adjusted R^2 statistic of 0.322 implies that more than 30 percent of the variation in price changes is accounted for by this one measure.

The high explanatory power of the model may seem somewhat surprising. Many of the sharpest price changes in this market occur with little trading upon the arrival of public information (Fleming and Remolona 1999). Nonetheless, studies of another market where much of the relevant information is thought to be public—the FX market—have found comparable or higher R^2 statistics. Evans and Lyons' (2002) model of daily exchange rate changes, for example, produces an R^2 statistic of more than 60 percent for the deutsche mark/dollar and more than 40 percent for the yen/dollar, with the explanatory power almost wholly due to order flow.

In model 2, we regress price changes on net trading volume, incorporating trade size into the analysis. The slope coefficient is again positive and highly significant, although less significant than in model 1. Net trading volume is therefore less effective at explaining price changes than is the net number of trades. The adjusted R^2 of the model is a much lower 0.138.

Price changes are regressed in model 3 on both the net number of trades and net trading volume. The coefficient on the net number of trades is similar to that in model 1, albeit slightly larger, but the coefficient on net trading volume is negative and significant. Controlling for the sign of a trade, we observe that larger trade sizes seem to be associated with smaller price changes. The explanatory power of the model is

Table 8
Price Impact of Trades for the Two-Year U.S. Treasury Note

Independent Variable	Model 1	Model 2	Model 3	Model 4	Model 5
Constant	-0.0169	-0.0055	-0.0178	-0.1898	0.0002
	(0.0009)	(0.0010)	(0.0009)	(0.0016)	(0.0017)
Net number of trades	0.0465		0.0528		
	(0.0004)		(0.0006)		
Net trading volume		0.0161	-0.0045		
		(0.0003)	(0.0003)		
Proportion of trades buyer-initiated				0.3575	
				(0.0023)	
Number of buyer-initiated trades					0.0432
					(0.0005)
Number of seller-initiated trades					-0.0505
					(0.0007)
Adjusted R^2	0.322	0.138	0.327	0.213	0.324
Number of observations	74,952	74,952	74,952	74,952	74,952

Source: Author's calculations, based on data from GovPX.

Notes: The table reports results from regressions of five-minute price changes on various measures of trading activity over the same interval for the on-the-run two-year note. Price changes are computed using bid-ask midpoints and are measured in 32nds of a point. The net number of trades equals the number of buyer-initiated less seller-initiated trades. Net trading volume equals buyer-initiated less seller-initiated volume and is measured in tens of millions of U.S. dollars. Heteroskedasticity-consistent (White) standard errors are reported in parentheses. The sample period is December 30, 1996, to March 31, 2000.

slightly better than that of model 1, with an adjusted R^2 of 0.327.

The relationship between trading volume and price changes is likely muddled by the endogenous nature of trade size. The observed trade size depends on the outcome of a negotiation that itself depends on the liquidity of the market. When the market is liquid, a dealer may well be able to execute a large trade at the best quoted price either because the quoted quantity is large or because the dealer can negotiate a larger quantity. When the market is illiquid, it is less likely that a dealer could execute a large trade at the best quoted price either because the quoted quantity is small or because the dealer is unable to negotiate a larger quantity. Large trades may therefore be a gauge of a liquid market, in which trades have less of a price impact.

The finding that trading frequency is more relevant than trading volume is consistent with the findings of other Treasury market studies.

The finding that trading frequency is more relevant than trading volume is consistent with the findings of other Treasury market studies. Green (forthcoming) finds that trade size has little influence on the price impact of trades around macroeconomic announcements. Cohen and Shin (2003) report lower R^2 statistics for models of price changes that incorporate trade size. Huang, Cai, and Wang (2002) examine the relationship between volatility and various measures of trading activity and find that volatility is positively correlated with trading frequency, but negatively correlated with trade size. A related equity market study by Jones, Kaul, and Lipson (1994) finds that trading frequency explains the relationship between volatility and trading volume, with trade size having little incremental information content.

We regress in model 4 price changes on the proportion of buyer-initiated trades. The coefficient is positive and highly significant, albeit less so than the net number of trades. The adjusted R^2 is 0.213.

Finally, in model 5, price changes are regressed on the number of buyer- and seller-initiated trades separately. Both coefficients are of the predicted sign and highly significant, with buys associated with price increases and sells with price decreases. Interestingly, the magnitude of the seller-initiated coefficient is larger, and significantly so, suggesting that sells have a greater effect on prices than buys. It was suggested earlier that dealers' customers tend to be buyers, reflecting dealers' underwriting role in the primary market. It may also follow that buys convey less information than sells because a certain proportion of buys simply reflects rollover by customers from maturing to newly issued securities.

Estimation results for the five models are qualitatively the same for the other on-the-run securities: the net number of trades is more important than net volume, the sign of the net volume coefficient flips in model 3, and sells have a greater price impact than buys. The results are also quite similar when the interval of analysis is expanded to ten minutes, fifteen minutes, or thirty minutes.[17] Finally, the results are qualitatively similar when model 1 is expanded to include the net number of trades in the previous interval, although the lags are statistically significant for some securities.[18]

To show how the price impact of trades varies over time, we use model 1 to estimate price impact coefficients on a weekly basis for each of the on-the-run bills and notes. Table 9 reports descriptive statistics for these coefficients. As with the bid-ask spreads, bill statistics are reported in basis points and note statistics in 32nds of a point (the reported bill coefficients are made positive by multiplying the actual coefficients by -1). The longer maturity securities, which tend to be more volatile (in terms of price), have the highest coefficients (in terms of price). The ten-year note thus has an average coefficient of 0.17 32nds. The shorter term securities have the highest coefficients in terms of yield, such that the three-month bill has an average coefficient of 0.15 basis point.[19]

Table 9

Price Impact Coefficients of U.S. Treasury Securities

Issue	Mean	Median	Standard Deviation
Three-month bill	0.15 bp	0.15 bp	0.07 bp
Six-month bill	0.14 bp	0.13 bp	0.05 bp
One-year bill	0.12 bp	0.11 bp	0.05 bp
Two-year note	0.04 32nds	0.04 32nds	0.01 32nds
Five-year note	0.10 32nds	0.09 32nds	0.02 32nds
Ten-year note	0.17 32nds	0.17 32nds	0.04 32nds

Source: Author's calculations, based on data from GovPX.

Notes: The table reports descriptive statistics on the weekly price impact coefficients for the indicated on-the-run securities. The coefficients come from regressions of five-minute price changes on the net number of trades over the same interval. Price changes are computed using bid-ask midpoints and are measured in yield terms (in basis points, or bp) for the bills and in price terms (in 32nds of a point) for the notes (the reported bill coefficients are made positive by multiplying the actual coefficients by -1). The net number of trades equals the number of buyer-initiated less seller-initiated trades. The sample period is December 30, 1996, to March 31, 2000.

The weekly price impact coefficients for the notes are illustrated in Chart 10. Except for the scale of the y-axis, the chart is almost indistinguishable from that of the bid-ask spreads (Chart 6). The price impact coefficients spike upward in late October 1997, October 1998, and February 2000, coinciding with the volatility spikes in Chart 2 and the bid-ask spread spikes in Chart 6. The coefficients also tend to increase in the final weeks of each year, as do the bid-ask spreads. The price impact coefficients are positively correlated across securities, especially for notes, with the five- and ten-year notes the most correlated (correlation coefficient = 0.84).

4.7 On-the-Run/Off-the-Run Yield Spreads

Table 10 provides descriptive statistics for daily on-the-run/off-the-run yield spreads. The spreads are calculated as the differences between the end-of-day yields of the on-the-run and first off-the-run securities.[20] Positive spreads indicate that on-the-run securities are trading with a lower yield, or higher price, than off-the-run securities. As expected, the table shows that average spreads for the coupon securities are positive, with the ten-year note having the highest mean (median) at 5.6 basis points (5.4 basis points). Bill spreads are negative, on average, probably reflecting a small liquidity premium for on-the-run bills along with an upward-sloping yield curve over the sample period.[21]

Table 10

On-the-Run/Off-the-Run Yield Spreads of U.S. Treasury Securities

Issue	Mean	Median	Standard Deviation
Three-month bill	-2.35	-2.00	3.22
Six-month bill	-1.43	-1.21	2.45
One-year bill	-2.07	-2.05	3.80
Two-year note	1.53	1.46	2.43
Five-year note	3.33	2.62	2.97
Ten-year note	5.63	5.44	3.66

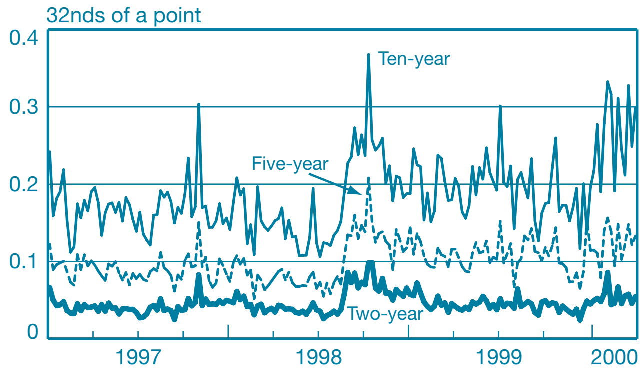
Source: Author's calculations, based on data from Bear Stearns and GovPX.

Notes: The table reports descriptive statistics on daily on-the-run/off-the-run yield spreads for the indicated securities. The spreads are calculated as the differences between the end-of-day yields of the on-the-run and first off-the-run securities. The sample period is December 30, 1996, to March 31, 2000.

Average daily on-the-run/off-the-run note yield spreads by week are plotted in Chart 11. The two- and five-year note spreads are shown to increase sharply during the financial market turmoil of fall 1998, peaking in the week ending October 16, 1998. Besides this episode, changes in the two spreads often diverge, and do not appear to be closely related to market developments. The ten-year-note spread behaves

Chart 10

Price Impact of U.S. Treasury Note Trades

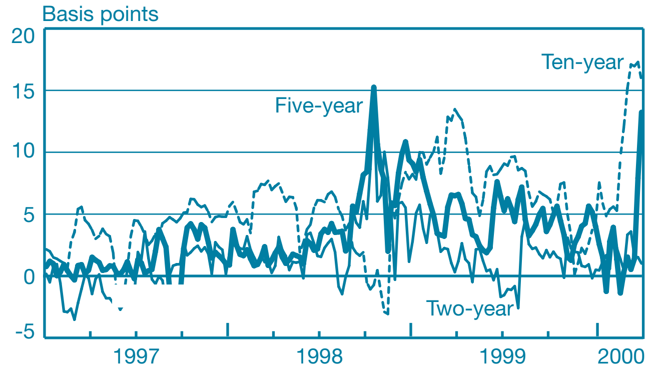


Source: Author's calculations, based on data from GovPX.

Notes: The chart plots the price impact of interdealer trades by week for the on-the-run notes. The price impact is measured as the slope coefficient from a regression of five-minute price changes on the net number of trades over the same interval. The net number of trades equals the number of buyer-initiated less seller-initiated trades.

Chart 11

On-the-Run/Off-the-Run Yield Spreads of U.S. Treasury Notes



Source: Author's calculations, based on data from Bear Stearns and GovPX.

Notes: The chart plots mean on-the-run/off-the-run yield spreads by week for the indicated securities. The spreads are calculated daily as the yield differences between the on-the-run and the first off-the-run notes.

independently of other securities' spreads, and decreases to its lowest level in the sample period during the fall 1998 financial market turmoil. This episode is indicative of the difficulties estimating liquidity spreads for the ten-year note.[22] The yield spreads are positively correlated across securities, with the one-year bill and two-year note the most correlated (correlation coefficient = 0.59).

5. Comparison of Liquidity Measures

An evaluation of the various liquidity measures is somewhat problematic because there is no single gauge of liquidity against which the measures can be definitively judged. That being said, there are ways in which the measures can be assessed. First, a liquidity measure that directly quantifies the cost of transacting is, a priori, likely a better measure of liquidity. Second, a liquidity measure should probably behave in a manner consistent with market participants' views about liquidity. Finally, a good liquidity measure should be easy to calculate and understand, and available to market participants on a real-time basis.

An evaluation of the various liquidity measures is somewhat problematic because there is no single gauge of liquidity against which the measures can be definitively judged. That being said, there are ways in which the measures can be assessed.

By the first two criteria, the bid-ask spread and price impact coefficient are superior liquidity measures. Both measures directly quantify the costs of transacting, with the bid-ask spread measuring the cost of executing a single trade of limited size and the price impact coefficient measuring the price effects of a trade. Both measures also correlate with episodes of reported poor liquidity in the expected manner, rising sharply during the market disruptions of October 1997, October 1998, and February 2000. On the last criterion, the bid-ask spread dominates the price impact coefficient. The spread is easy to calculate and understand, and available on a real-time basis. In contrast, estimating the price impact coefficient requires significant data and regression analysis, and it may not be estimable on a timely basis because of data limitations.

The other liquidity measures may be less informative than the bid-ask spread and price impact coefficient, yet may still contain useful information about liquidity. In particular, the other measures may serve as good proxies for liquidity and/or contain information about liquidity not present in the other measures. To describe the various measures and the extent to which one measure might be a suitable proxy for another, we compare them by using correlation and principal-components analyses.

5.1 Correlation Analysis

The correlation coefficients among the various measures, as calculated weekly for the on-the-run two-year note, are presented in Table 11. The table shows that the two preferred liquidity measures—the bid-ask spread and price impact coefficient—are highly correlated with one another (correlation coefficient = 0.73). (The correlation coefficients are even higher for the other on-the-run securities.) These results suggest that one measure is an excellent proxy for the other. Therefore, even if one prefers the price impact coefficient as a liquidity measure, the easy-to-calculate bid-ask spread is probably a good substitute.

Quote size, trade size, and on-the-run/off-the-run yield spread are correlated with the bid-ask spread, price impact coefficient, and one another in the expected manner (this correlation is generally true for the other on-the-run securities as well). Higher quote sizes, higher trade sizes, and narrower yield spreads are thus associated with narrower bid-ask spreads and smaller price impact coefficients. Quote size, in particular, is strongly correlated with the other measures. Trade size and yield spread, in contrast, are more modestly correlated with the other measures, suggesting that they are weaker liquidity proxies.

Even if one prefers the price impact coefficient as a liquidity measure, the easy-to-calculate bid-ask spread is probably a good substitute.

Table 11

Correlations of Liquidity Measures for the Two-Year U.S. Treasury Note

Measure	Trading Volume	Trading Frequency	Bid-Ask Spread	Quote Size	Trade Size	Price Impact	Yield Spread	Price Volatility
Trading volume	1.00	0.91	0.19	-0.44	0.00	0.60	0.41	0.69
Trading frequency	0.91	1.00	0.17	-0.64	-0.39	0.65	0.45	0.71
Bid-ask spread	0.19	0.17	1.00	-0.46	-0.08	0.73	0.32	0.54
Quote size	-0.44	-0.64	-0.46	1.00	0.64	-0.73	-0.45	-0.60
Trade size	0.00	-0.39	-0.08	0.64	1.00	-0.30	-0.17	-0.22
Price impact	0.60	0.65	0.73	-0.73	-0.30	1.00	0.56	0.84
Yield spread	0.41	0.45	0.32	-0.45	-0.17	0.56	1.00	0.50
Price volatility	0.69	0.71	0.54	-0.60	-0.22	0.84	0.50	1.00

Source: Author's calculations, based on data from GovPX.

Notes: The table reports correlation coefficients of liquidity measures and price volatility for the on-the-run two-year note. The measures are calculated weekly as mean daily trading volume, mean daily trading frequency, mean bid-ask spread, mean quote size, mean trade size, price impact coefficient, mean on-the-run/off-the-run yield spread, and standard deviation of thirty-minute price changes. The price impact coefficients come from regressions of five-minute price changes on the net number of trades over the same interval. Correlation coefficients with absolute values of 0.13 and higher, 0.15 and higher, and 0.20 and higher are significant at the 10 percent, 5 percent, and 1 percent levels, respectively. The sample period is December 30, 1996, to March 31, 2000.

Trading volume and trading frequency are the most correlated measures (correlation coefficient = 0.91). For the two-year note, their correlations with the other measures are generally consistent, such that higher trading activity is associated with lower liquidity. The correlations with the bid-ask spread are quite modest, however. Moreover, for the other on-the-run securities, the correlations are often inconsistent and close to zero. These results suggest that trading activity is not a reliable proxy for market liquidity.

Table 11 also reports correlations between our liquidity measures and price volatility. Price volatility is correlated with the liquidity measures in a consistent way, with higher volatility associated with lower liquidity. Moreover, the magnitudes of the correlation coefficients suggest that price volatility itself is a good liquidity proxy. In particular, price volatility appears to be an excellent proxy for the price impact coefficient given the high correlation between the two (correlation coefficient = 0.84).

5.2 Principal-Components Analysis

Results of the principal-components analysis for the on-the-run two-year note appear in Table 12. The reported eigenvalues of the principal components show that three components provide a good summary of the data, explaining 87 percent of the standardized variance (0.87 = (3.80+1.17+1.11)/7). The first component seems to measure variation in liquidity that is negatively related to trading activity, as it loads positively on trading volume and trading frequency, and it loads on the other variables in a manner suggesting lower liquidity. The second and third components seem to measure variation in liquidity that is positively related to trading activity, as they load positively on trading volume and trading frequency, and they generally load on the other variables in a manner suggesting higher liquidity. The other components are harder to interpret.

The first two principal components are represented in Chart 12. The plot of the first component looks somewhat similar to plots of volatility (Chart 2), bid-ask spreads (Chart 6), and price impact coefficients (Chart 10). Not surprisingly, the correlation between the first component and price volatility (for the two-year note) is quite high (correlation coefficient = 0.82). As a result, another way to interpret the first component is that it measures variation in liquidity that is correlated with volatility. The plot of the second component looks similar to plots of trading volume (Chart 4) and trading frequency (Chart 5). This component is more weakly correlated with price volatility (correlation coefficient = 0.16). As a result, another way to interpret the second component is that it measures variation in liquidity consistent with changes in trading activity, but not volatility. The third component (not shown) picks up a long-term deterioration of liquidity from late 1998 until mid-1999 and is also only weakly correlated with price volatility (correlation coefficient = 0.16).

Results from principal-components analyses on the other securities are reasonably similar. Across securities, one of the

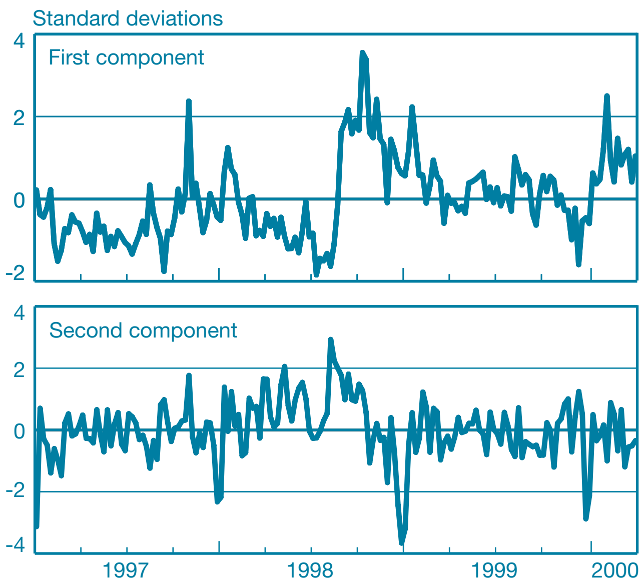
Table 12
Principal-Components Analysis of Liquidity Measures for the Two-Year U.S. Treasury Note

	Principal Components						
	1	2	3	4	5	6	7
Eigenvalue	3.80	1.17	1.11	0.63	0.19	0.10	0.00
Sensitivities							
Trading volume	0.74	0.63	0.16	-0.16	0.00	-0.05	-0.04
Trading frequency	0.85	0.32	0.38	-0.12	0.10	-0.05	0.05
Bid-ask spread	0.57	-0.25	-0.73	-0.22	0.10	-0.16	0.00
Quote size	-0.85	0.35	-0.13	0.06	0.36	0.03	0.00
Trade size	-0.47	0.69	-0.52	-0.02	-0.19	0.02	0.02
Price impact	0.91	-0.04	-0.30	-0.10	0.06	0.26	0.00
Yield spread	0.66	0.10	-0.16	0.73	0.02	-0.04	0.00

Source: Author's calculations, based on data from GovPX.

Notes: The table reports eigenvalues and sensitivities from a principal-components analysis of seven liquidity measures for the on-the-run two-year note. Sensitivities are calculated as the eigenvectors of the correlation matrix times the square root of the eigenvalues. The liquidity measures are calculated weekly as mean daily trading volume, mean daily trading frequency, mean bid-ask spread, mean quote size, mean trade size, price impact coefficient, and mean on-the-run/off-the-run yield spread. The price impact coefficients come from regressions of five-minute price changes on the net number of trades over the same interval. The sample period is December 30, 1996, to March 31, 2000.

Chart 12
First and Second Principal Components of Liquidity Measures for the Two-Year U.S. Treasury Note



Source: Author's calculations, based on data from GovPX.

Note: The chart plots the first and second standardized principal components of seven liquidity measures for the on-the-run two-year note.

first two components loads positively on the trading activity measures, the bid-ask spread, and the price impact coefficient, and one loads positively on the trading activity measures but negatively (or close to zero) on the other two measures.

6. Conclusion

Our estimation and evaluation of various liquidity measures for the U.S. Treasury market reveal that the simple bid-ask spread is a useful measure for assessing and tracking liquidity. The spread can be calculated quickly and easily with data that are widely available on a real-time basis, yet it is highly correlated with the more sophisticated price impact measure and is correlated with episodes of reported poor liquidity in the expected manner. The bid-ask spread thus 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.

By contrast, quote size, trade size, and the on-the-run/off-the-run yield spread are found to be only modest proxies for market liquidity. These measures correlate less strongly with the episodes of reported poor liquidity and with the bid-ask spread and price impact measures. Moreover, trading volume and trading frequency are weak proxies for market liquidity, as both high and low levels of trading activity are associated with periods of poor liquidity.

Additional findings obtained here complement those of recent FX and equity market studies. Consistent with results from the FX market, we find a strong relationship between order flow and price changes in the Treasury market, with a simple model of price changes producing an R^2 statistic above 30 percent for the two-year note. And in line with equity market studies, we find considerable commonality in liquidity in the U.S. Treasury market, across securities as well as measures.

More generally, our study illustrates the value of high-frequency data for assessing and tracking U.S. Treasury market liquidity. The availability of such data, combined with the market's importance and distinct organizational structure, make the Treasury market an appealing setting for continued work on securities liquidity.

Appendix : Data Cleaning and Processing

GovPX historical tick data files provide a complete history of the real-time trading information distributed to GovPX subscribers through on-line vendors. The format of these files necessitates that the data be processed before they are analyzed. Some data cleaning is also called for to screen out the interdealer brokers' posting errors that are not filtered out by GovPX.

Trades

As discussed in the text, trades in the interdealer market often go through a workup process in which a broker mediates an increase in the trade size beyond the amount quoted. For example, as of 9:36:38 a.m. on March 4, 1999, $1 million par was bid at 97.5625 (97-18) for the on-the-run five-year U.S. Treasury note.[23] At 9:38:06, the bid was "hit" for $1 million; the trade size was then negotiated up to $18 million through incremental trades of $9 million and $8 million.

The GovPX historical tick data files capture the richness of these transactions, as shown in the table and described below:

- As of 9:36:38, $1 million par is bid at 97.5625 (97-18) and $6 million par is offered at 97.578125 (97-18+). The last trade for this security was a $4 million "take" (a buyer-initiated trade, designated by the "T" in the Last Trade Side field) at 97.5625 (97-18). No trades are being executed at the time, as indicated by the zeros in the workup fields. Aggregate trading volume for this security since the beginning of the trading day is $2,258 million.
- At 9:37:32, the offer price improves to 97.5703125 (97-182) with an offer size of $9 million.
- At 9:38:06, the bid is "hit" for $1 million. The transaction price is recorded in the Current Hit Workup Price field and the size (at that point) is recorded in the Current Hit Workup Size field. The last trade side, price, and size have not yet changed to reflect this new trade.
- At 9:38:10, the offer size is increased to $10 million. The initial information about the aforementioned trade is repeated on this line.
- At 9:38:12, the negotiated size of the trade that started at 9:38:06 increases by $9 million, and at 9:38:14, it increases by another $8 million. As always, these additional quantities are transacted at the same price as the initial trade.
- At 9:38:24, the bid size is increased to $11 million. In the same second, the last trade side, price, and size are updated to reflect the $18 million total traded (in this

GovPX Historical Tick Data for the On-the-Run Five-Year U.S. Treasury Note
March 4, 1999, 9:36:38 a.m.–9:38:29 a.m.

					Last Trade			Current Hit		Current Take		
Time	Bid Price	Bid Size	Ask Price	Ask Size	Side	Price	Size	Workup Price	Workup Size	Workup Price	Workup Size	Aggregate Volume
9:36:38	97.5625	1	97.578125	6	T	97.5625	4	0	0	0	0	2258
9:37:32	97.5625	1	97.5703125	9	T	97.5625	4	0	0	0	0	2258
9:38:06	97.5625	1	97.5703125	9	T	97.5625	4	97.5625	1	0	0	2258
9:38:10	97.5625	1	97.5703125	10	T	97.5625	4	97.5625	1	0	0	2258
9:38:12	97.5625	1	97.5703125	10	T	97.5625	4	97.5625	9	0	0	2258
9:38:14	97.5625	1	97.5703125	10	T	97.5625	4	97.5625	8	0	0	2258
9:38:24	97.5625	11	97.5703125	10	T	97.5625	4	0	0	0	0	2258
9:38:24	97.5625	11	97.5703125	10	H	97.5625	18	0	0	0	0	2276
9:38:29	97.5625	13	97.5703125	10	H	97.5625	18	0	0	0	0	2276

Source: GovPX.

Note: In addition to the information presented, the tick data files include line counters, security-specific information (such as the CUSIP, security type, coupon rate, and maturity date), indicative prices, and the yields associated with each of the prices.

case, the price does not change because the previous trade was executed at the same price). The aggregate volume is updated at this point as well and the workup fields are cleared.

- At 9:38:29, the bid size is increased to $13 million. The last trade side, price, and size and the aggregate volume are repeated on this line, and continue to be repeated until another trade is completed.

The challenge in processing the data is to identify each trade accurately and uniquely. Unfortunately, uniquely identifying the incremental trades of the workup processes is difficult, if not impossible, given the repetition in the data set and the fact that trades of equal size sometimes follow one another. However, completed trades can be, and are, accurately and uniquely identified by the increases in aggregate volume. For the trade discussed, the $18 million increase in aggregate volume at 9:38:24 identifies a trade of that size at that time.[24]

The processed data set contains 1,597,991 trades for the on-the-run securities examined in our article, or an average of 1,958 trades per day.

Quotes

As we described, the GovPX historical tick data files are constructed in such a way that a change in any field results in a reprinting of every field on a subsequent line. This construction not only results in a repetition of trade information, but in a repetition of quote information as well. In the previously cited example, identical quote information appears at 9:38:10, 9:38:12, and 9:38:14, as new information regarding a trade is reported.

To prevent the same quote from being counted multiple times, the analysis of bid-ask spreads and quote sizes is limited to quotes for which the bid price, bid size, offer price, or offer size has changed from the previously listed quote for that security. A few instances in which the bid or offer quotations become erroneously "stuck" at stale values for extended periods of time are also excluded.[25]

The analysis of quote sizes is further limited by the screening out of quote sizes in excess of $1,250 million. Many of these quote sizes are likely to be erroneous, and they have significant influence on statistics summarizing the data.[26]

The processed data set contains 14,361,862 quote sizes (7,186,294 bid sizes and 7,175,568 offer sizes) for the on-the-run securities examined in our article, or an average of 17,600 per day.

The analysis of bid-ask spreads makes no use of one-sided quotes (quotes for which there is a bid or an offer, but not both). Bid-ask spreads that are calculated to be less than -2.5 basis points or more than 25 basis points are also excluded. Such extreme spreads are likely to be erroneous in a market where the average on-the-run spread is close to 0.5 basis point.[27] As spreads posted by the interdealer brokers do not include the brokerage fee charged to the transaction initiator, zero spreads (referred to as "locked" markets) are quite common and are retained in the data set. In addition, because GovPX posts the highest bid and the lowest offer from several brokers, even slight negative spreads can be posted momentarily and are thus also retained.

The processed data set contains 7,085,037 bid-ask spreads for the on-the-run securities examined here, or an average of 8,683 per day.

Price and Yield Changes

We calculate price and yield changes at five-minute, thirty-minute, and one-day intervals for various purposes. In all cases, the changes are calculated from the last observation reported for a given interval to the last observation for the subsequent interval (for example, from the last price in the 9:25-9:30 interval to the last price in the 9:30-9:35 interval). The changes are calculated using both transaction prices and bid-ask midpoint prices. Data thought to be erroneous in calculating the bid-ask spreads are excluded from the bid-ask midpoint calculations. The data are also checked by identifying differences of 10 basis points or more between transaction yield changes and bid-ask midpoint yield changes, and then screening out data thought to be erroneous.[28]

Data Gaps

The sample period of December 30, 1996, to March 31, 2000, covers 170 complete weeks, or 850 weekdays. After we exclude thirty-four holidays, we retain 816 trading days, including thirty-nine days on which the market closed early.[29] Gaps in coverage within New York trading hours occur on January 29, 1997, from 12:57 to 1:31 p.m.; on June 12, 1998, from 9:31 a.m. until the market's close; on August 13, 1998, from 1:58 to 2:35 p.m.; on November 18, 1998, from 3:39 to 4:12 p.m.; and on February 4, 1999, from the market's opening until 11:17 a.m. August 26, 1999, is missing completely for the two-year note.[30]

Endnotes

1. For a more extensive discussion of the uses and attributes of Treasuries, see Fleming (2000a, 2000b).

2. See, for example, *Wall Street Journal* (1998b) and Committee on the Global Financial System (1999).

3. See, for example, *Business Week* (1999), *Wall Street Journal* (2000), and *BondWeek* (2001).

4. The Treasury indicated that buybacks "enhance the liquidity of Treasury benchmark securities, which promotes overall market liquidity" (January 13, 2000, press release, posted at <http://www.treas.gov/press/releases/ls335.htm>). For discussions of recent debt management changes, see Dupont and Sack (1999), Bennett, Garbade, and Kambhu (2000), and U.S. General Accounting Office (2001).

5. Exceptions include Garbade and Rosey (1977) and Beim (1992), who model bid-ask spreads using low-frequency data. Other studies make inferences about Treasury liquidity or about the valuation implications of liquidity differences using such proxies for liquidity as security age (Sarig and Warga 1989), security type (Amihud and Mendelson 1991; Kamara 1994), on-the-run/off-the-run status (Warga 1992), and trading volume (Elton and Green 1998).

6. An on-the-run security is the most recently auctioned security of a given (original) maturity and an off-the-run security is an older security of a given maturity. Off-the-run securities are sometimes further classified as first off-the-run (the most recently auctioned off-the-run security of a given maturity), second off-the-run (the second most recently auctioned off-the-run security of a given maturity), and so on.

7. In particular, on-the-run securities may trade at a premium because of their "specialness" in the repurchase agreement (repo) market. Duffie (1996) explains how fee income from lending a security that is "on special" in the repo market can supplement the security's principal and interest payments, and hypothesizes that expectations of such fees increase the equilibrium price of a security. Jordan and Jordan (1997) confirm the hypothesis for Treasury notes, and Krishnamurthy (2002) provides corroborating evidence for bonds. The relationship between repo market specialness and liquidity is complicated, as the two tend to be positively correlated across securities (that is, securities that are on special tend to be liquid and vice versa), but can be negatively correlated over time, so that an increase in specialness is accompanied by a reduction in liquidity.

8. The contributing brokers are Garban-Intercapital, Hilliard Farber, and Tullett & Tokyo Liberty. The noncontributing broker is Cantor Fitzgerald/eSpeed, which is thought to be more active in the long end of the market. Another noncontributing broker, BrokerTec, was launched in June 2000 after the end of our sample period.

9. Trades brokered between primary dealers are reported to the Federal Reserve by both counterparties and are therefore double counted. To provide a more proper comparison, the reported GovPX figure also double counts every trade. The comparison is still not perfect, however, as a small fraction of GovPX trades have nonprimary dealers as counterparties.

10. Unadjusted measures are reported in the working paper version of this article (Fleming 2001), available at <http://www.newyorkfed.org/rmaghome/staff_rp/2001/sr133.html>.

11. In cases where the bid or offer is not competitive, a dealer may be able to transact at a price better than the quoted spread by posting a limit order inside the quoted spread and having that order hit immediately. Such a scenario is most likely to occur for securities that are less actively quoted and traded.

12. Fleming (1997) describes the round-the-clock market for Treasury securities, and finds that 95 percent of trading volume occurs during these hours.

13. Per-security trading activity measures are not double counted and should therefore be doubled before comparing them with the previously cited total trading volume measures.

14. Comparable charts for bills are available in the working paper version of this article (Fleming 2001).

15. The bid-ask spreads are also calculated on a comparable bond-equivalent yield basis. The means (and medians) in basis points for the on-the-run bills and notes in order of increasing maturity are 0.74 (0.63), 0.79 (0.70), 0.57 (0.52), 0.35 (0.34), 0.29 (0.28), and 0.33 (0.31).

16. The tendency of dealers' customers to be net buyers reflects the underwriting role of dealers in the primary market. Charts produced for the Treasury's August 2001 quarterly refunding indicate that dealers took down 82 percent of the ten-year note and 65 percent of the thirty-year bond at the three preceding auctions.

17. Even at the daily level, the basic relationship between order flow and price changes is quite similar. Estimating model 1 using daily data for the two-year note (plotted in Chart 9) produces a slope coefficient of 0.0363 and an adjusted R^2 of 0.213.

18. The models can also be expanded to include the order flow of other securities, following Hasbrouck and Seppi (2001). A model of price changes for the two-year note that includes the contemporaneous net number of trades of every on-the-run bill and note produces an adjusted R^2 of 0.409—and every coefficient is significant.

19. On a comparable bond-equivalent yield basis, the mean magnitude of the coefficients in basis points for the on-the-run bills and notes in order of increasing maturity are 0.16, 0.15, 0.13, 0.08, 0.07, and 0.07.

20. This method of calculating the liquidity spread is used in numerous studies (see, for example, Dupont and Sack [1999], Furfine and Remolona [2002], and Goldreich, Hanke, and Nath [2003]), although more sophisticated methods are sometimes used (see, for example, Reinhart and Sack [2002]).

21. Liquidity spreads typically are not calculated for bills, presumably because of the modest liquidity premia of on-the-run relative to off-the-run bills. They are included here for completeness.

22. Although the on-the-run ten-year note yield was unusually low during the fall 1998 financial market turmoil, the first off-the-run ten-year note yield was also unusually low, producing a yield difference close to zero. Yields of off-the-run ten-year notes have often been unusually low because of the absence of noncallable Treasury securities with slightly longer maturities. (In the fall of 1998, the oldest noncallable thirty-year bond had sixteen and a half years to maturity, so there was a gap in the yield curve between ten and sixteen and a half years.) This gap makes it difficult to estimate reliably the liquidity premium for the ten-year note and explains why studies that look at liquidity premia typically disregard this security. It is included here for completeness and to illustrate the difficulties estimating liquidity premia.

23. As indicated in the text, Treasury notes are quoted in 32nds of a point. The price of 97.5625 corresponds to 97 and 18/32, or 97-18. The 32nds themselves are often split into quarters by the addition of a 2, +, or 6 to the price, so that -182 indicates 18¼ 32nds, -18+ indicates 18½ 32nds, and -186 indicates 18¾ 32nds.

24. Use of this algorithm uncovers a small number of cases in which a security's aggregate volume *decreases*, potentially resulting in an inferred trade size that is negative. In a few of these cases, the aggregate volume counter does not reset at the beginning of the trading day, and the data processing is adjusted accordingly. More commonly, the decrease in aggregate volume follows, and is similar in magnitude to, an earlier trade of very large size. In these situations, the earlier trade size is scaled down on the assumption that it was reported erroneously and later corrected in the aggregate volume. For example, at 12:45 p.m. on July 22, 1998, GovPX reports a trade of $697 million for the two-year note. Eleven minutes (and six trades) later, GovPX reports a trade of $22 million, along with a decrease in aggregate volume of $665 million. When the data are processed, the size of the earlier trade is reduced to $10 million ($697 million - $665 million - $22 million).

25. This happens for bid quotations for the ten-year note on January 28, 1997, from 2:24 p.m. until the market's close. The same bid price and size are reported on every line for that security even as offer quotations are changing and seller-initiated trades are executed at prices substantively different from the reported bid price. Similar episodes occur for offer quotations for the one-year bill on November 6, 1997, from 10:04 a.m. until 2:19 p.m., and for the six-month bill on October 28, 1998, from 11:50 a.m. until the market's close.

26. One example of such a large quote size occurs at 4:41:24 p.m. on September 25, 1997, when the reported bid size for the ten-year note increases from $69 million to $2,619 million. Three seconds later, the size is revised down to $319 million. Note that a broker inadvertently entering "250" as "2550" could have caused the reported increase in the quantity bid (as 2,619 - 69 = 2,550 and 319 - 69 = 250).

27. An example of a bid-ask spread that is screened out occurs on March 7, 2000, at 10:57:55 a.m. The offer price for the three-month bill rises from 5.665 percent to 5.79 percent at that time, causing the inferred bid-ask spread to fall from 0.5 basis point to -12 basis points. Three seconds later, the offer price returns to 5.665 percent, causing the spread to return to 0.5 basis point.

28. For example, at 3:43 p.m. on May 29, 1997, the reported trade price of the one-year bill falls from 5.505 percent to 4.505 percent. Nineteen minutes (and three trades) later, the reported price rises from 4.505 percent to 5.505 percent. Bid and offer prices range from 5.50 percent to 5.51 percent over this entire period. This is clearly a case where trade prices are reported with "handle" errors, and these prices are thus excluded from the price change calculations.

29. Thirty-four of the early closes occurred at 2:00 p.m., two at 1:00 p.m., two at 3:00 p.m., and one at noon. Thirty-eight of these early closes are associated with holidays; the other early close occurred September 16, 1999, due to inclement weather in the New York metropolitan area associated with Hurricane Floyd.

30. The security is included in the data file for that day, but no new information is reported after 4:57 a.m.

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