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Measuring Treasury Market Liquidity*

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Abstract

This paper examines a comprehensive set of liquidity measures for the U.S. Treasury market. The measures are analyzed relative to one another, across securities, and over time. I find highly significant price impact coefficients, such that a simple model that explains price changes with net order flow produces an R^2 statistic above 30% for the two-year note. The price impact coefficients are highly correlated with bid-ask spreads and with episodes of reported poor liquidity (such as the fall 1998 financial markets turmoil). Quote and trade sizes correlate modestly with these episodes and with the other liquidity measures, as do yield spreads between on-the-run and off-the-run securities. In contrast, trading volume and trading frequency are only weakly correlated with these other measures, suggesting that they are poor liquidity proxies. The various measures are positively correlated across securities, almost without exception, especially for Treasury notes.

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I. Introduction

While numerous studies have examined the liquidity of the equity and foreign exchange (FX) markets (Goodhart and O'Hara (1997) and Madhavan (forthcoming) survey the literature), relatively few have examined the liquidity of the U.S. Treasury securities market. Exceptions include Tanner and Kochin (1971) and Garbade and Rosey (1977), who model Treasury bid-ask spreads, and Amihud and Mendelson (1991), Kamara (1994), and Elton and Green (1998), who explain valuation differences among Treasuries using proxies for liquidity. More recent exceptions, using high frequency data, include Fleming (1997), who documents intraday patterns of bid-ask spreads and trading volume, and Fleming and Remolona (1999) and Balduzzi, Elton, and Green (forthcoming), who analyze spreads and trading volume around economic announcements.

Interest in the market's liquidity is increasing as the Treasury Department implements debt management changes to address the federal government's decreased funding needs.[1] Recent changes include reductions in issuance sizes and frequencies in the primary market and the introduction of a program to buy back outstanding securities in the secondary market.[2] As most of the remaining public debt is projected to be retired within the next decade (Congressional Budget Office (2001)), further debt management changes are assured, and interest in the liquidity of the market is only likely to increase.

This paper examines a comprehensive set of liquidity measures for the U.S. Treasury securities market. Detailed high frequency data from the interdealer broker market allows an analysis of trading volume, trading frequency, bid-ask spreads, quote sizes, trade sizes, price

[1] See, for example, Business Week (1999), Wall Street Journal (2000), and BondWeek (2001).
[2] See the Treasury's website for announcements of debt management changes (http://www.treas.gov/press/) and Dupont and Sack (1999) and U.S. General Accounting Office (2001) for a discussion of recent changes.

impact coefficients, and on-the-run/off-the-run yield spreads for the most active Treasury securities. The liquidity measures are analyzed relative to one another, across securities, and over time.

The analysis of price impact coefficients is related to studies of the FX market by Lyons (1995), Yao (1997), and others, that find evidence of order flow affecting prices. Evans (1999), Payne (2000), and Evans and Lyons (forthcoming), in particular, find that a high proportion of exchange rate changes can be explained by order flow alone. Evans and Lyons, for example, find that their model of daily deutsche mark/dollar rate changes produces an R^2 statistic above 60% (and that the explanatory power is almost wholly due to order flow). In this paper, I find a strong relationship between net order flow and price changes in the U.S. Treasury market, with a simple model of price changes producing an R^2 statistic above 30% for the two-year note.

I also find that it is the net number of trades that matters, with trade size having little incremental power to explain price changes. Green (2001) uncovers similar findings in a related Treasury market study that examines the effects of trades on prices around macroeconomic announcements. The results are also consistent with Huang, Cai, and Song's (2001) findings that the number of trades is more correlated with Treasury volatility than trading volume. Jones, Kaul, and Lipson (1994) also find that it is the number of trades that explains the relationship between volatility and trading volume in equity markets, with trade size having little information content beyond that contained in the number of trades.

The analysis of liquidity measures is related to recent equity market studies that analyze commonality in liquidity (Chordia, Roll, and Subrahmanyam (2000), Hasbrouck and Seppi (2001) and Huberman and Halka (forthcoming)) and market liquidity over time

(Chordia, Roll, and Subrahmanyam (2001)). Commonality in liquidity across securities is likely to be strong in the Treasury market given the securities' common features, and, in fact, correlation coefficients across securities are found to be quite high for various measures, especially for Treasury notes. For instance, the correlation of weekly price impact coefficients between the five- and ten-year Treasury notes is 94%.

Similarly, the tremendous level of activity in the Treasury market combined with the absence of rules that limit price changes or bid-ask spreads to specified minimums or maximums makes it relatively easy to precisely estimate measures of liquidity. Such precision facilitates the analysis of liquidity over time and the comparison of different measures. I find that the liquidity measures change substantially over time, that they are correlated, and that they correlate with episodes of reported poor liquidity. Accordingly, both price impact coefficients and bid-ask spreads increase sharply with equity market declines in October 1997, with the financial markets turmoil in fall 1998, and with the Treasury's Quarterly Refunding announcement in February 2000.

Quote and trade sizes correlate modestly with the other liquidity measures and with the episodes of poor liquidity in the expected manner, as do yield spreads between on-the-run and off-the-run securities. In contrast, trading volume and trading frequency are only weakly correlated with the other measures, suggesting that they are poor proxies of liquidity. In fact, both high and low levels of trading activity are associated with periods of poor liquidity.

The paper proceeds as follows: Section II discusses market liquidity and how it is typically measured in practice. Section III discusses the data and the sample period. Section IV presents the empirical results for the various liquidity measures and looks at how they correlate with one another. Section V concludes.

II. 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 of a trade. Furthermore, the information needed to calculate transaction costs is often not available. As a consequence, a variety of measures have been employed to evaluate a market's liquidity.

The bid-ask spread, or difference between bid and offer prices, 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 distance between the bid or offer price and the bid-ask midpoint (or one-half of the bid-ask spread). A drawback of the bid-ask spread is that bid and offer quotes are only good for limited quantities and periods of time. The spread therefore only measures the cost of executing a single trade of limited size.

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 is that market makers often do not reveal the full quantities they are willing to transact at a given price so that the measured depth underestimates the true depth.

An alternative measure of market depth is the trade size. The 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 is that the data required for estimation, including the side initiating a trade, is often difficult to obtain.

A liquidity measure used in the Treasury market is the yield spread between more and less liquid securities. 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). The yield spread is 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.[3] A drawback of this measure is that it necessarily reflects both the price of liquidity as well as differences in liquidity between securities. In addition, specialness in the repo market may also cause on-the-run securities to trade at a premium (Duffie (1996) and Jordan and Jordan (1997)), confounding the interpretation of the spread. Furthermore, the choice of an off-the-run benchmark against which to compare an on-the-run security introduces potentially significant estimation error. Conversely, the spread provides insight

[3] On-the-run securities are the most recently issued securities of a given maturity whereas off-the-run securities are older securities of a given maturity.

into the value of liquidity not provided by the other measures and it can be calculated without high frequency data.

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.

III. Data and Sample Period Description

The paper's 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.[4] The posted data include the best bid and offer quotes, the

[4] The contributing brokers are Garban-Intercapital, Hilliard Farber, and Tullett & Tokyo Liberty. The non-contributing broker is eSpeed, which is thought to be more active in the long end of the market.

associated quote sizes, the price and size of each trade, and whether the trade was a "take" (buyer-initiated) or a "hit" (seller-initiated). The paper uses a history of these postings, provided by GovPX, that includes the time of each posting to the second.

As GovPX consolidates data from all but one of the major brokers, it provides a good, but not complete, picture of interdealer broker 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%.[5] This share has been falling fairly quickly in recent years, averaging 65% in 1997, 57% in 1998, and 52% in 1999. Caution should therefore be used in interpreting the paper's liquidity measures, particularly in how they have changed over time.

An interesting feature of the interdealer market is the negotiation that takes place over trade sizes. Trades often go through a "work-up" 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 several seconds later. The GovPX data is processed and analyzed in a manner that treats the outcomes of these work-up processes as single trades. The appendix discusses this and other data processing issues in detail.

In contrast to the negotiation over trade sizes, there is no price negotiation in the interdealer market, so that trades only go off at posted bid or offer prices. As a result, quoted

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Another non-contributing broker, BrokerTec, was launched in June 2000 after the end of the paper's sample period.

[5] 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 non-primary dealers as counterparties.

bid-ask spreads provide an accurate indication of the spreads facing market participants and effective spreads need not be calculated.

The paper 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 more than 200 Treasury securities outstanding, they account for 71% of activity in the interdealer market (Fabozzi and Fleming, 2000). The three-year note is excluded from the paper's analyses as the Treasury stopped issuing this security in 1998. Also excluded from the analyses is the thirty-year bond. GovPX coverage of the bond is limited and trending downward, making inference particularly difficult for this security. Similarly, Treasury Inflation-Indexed Securities are excluded from the analyses due to their limited level of trading activity.

Most of the paper's 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).[6] 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, equity market declines in October 1997, the financial markets turmoil of fall 1998, and the Treasury's debt management announcements of early

[6] Fleming (1997) describes the round-the-clock market for Treasury securities and finds that 95% of trading volume occurs during these hours.

2000. Chart 1 notes some of these developments along with plots of the ten-year Treasury note yield and the fed funds target rate.

Chart 2 plots the yield volatilities of the three-month bill and the ten-year note, calculated weekly as the standard deviations of 30-minute yield changes (computed using bid-ask midpoints). Volatilities of both securities reach their highest levels during the fall 1998 financial markets turmoil (in the week ending October 9). Both also spike to shorter peaks at the time of the October 1997 equity market declines (week ending October 31) and at the time of the Treasury's February 2000 Quarterly Refunding meeting (week ending February 4).

IV. Empirical Results

A. Trading Volume

Chart 3 plots average daily trading volume by week according to 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 Fed. 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, all three series drop off sharply in the final weeks of each year. This 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, 1998c)).

Table 1, Panel A reports daily GovPX trading volume descriptive statistics for each of the on-the-run bills and notes.[7] The two-year note is the most actively traded security among the brokers reporting to GovPX, with a mean (median) daily volume of $6.7 ($6.4) billion. The six-month bill is the least active with a mean (median) daily volume of $0.8 ($0.8) billion. Five of the six minimum volumes occur on days of early holiday closes, with the minimum three-month volume of zero occurring on Good Friday 1999.[8]

Table 1, Panel B reports correlation coefficients of daily trading volume across securities. Trading is positively correlated for every pairwise comparison, particularly so for Treasury notes. The five- and ten-year notes are most correlated, with a coefficient of 0.88.

Charts 4A and 4B plot average daily trading volume by week. Bill activity appears fairly erratic, while note activity tends to follow the patterns for total trading activity observed in Chart 3. The high correlations of volume across the notes, documented in Panel B of Table 1, are clearly evident. The decline in trading of the five- and ten-year notes over the last half of the sample may largely reflect decreased coverage of these securities by GovPX rather than decreased interdealer broker trading.

B. Trading Frequency

Table 2, Panel A reports daily trading frequency descriptive statistics for each of the on-the-run bills and notes. It shows that the most actively traded security in terms of volume

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[7] 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.

[8] The Bond Market Association usually recommends that the market be closed on Good Friday, but recommended trading with a noon close in 1999 due to the release of the monthly employment report that day.

– 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 693 (697) trades per day. The six-month bill is again the least actively traded security, with a mean (median) of just 41 (39) trades per day.

Table 2, Panel B reports correlation coefficients of daily trading frequency across securities. The coefficients are again all positive and with only two exceptions are higher than the corresponding correlation coefficients for trading volume. The most correlated securities are again the five- and ten-year notes, with a coefficient of 0.92.

Charts 5A and 5B plot average daily trading frequency by week. The patterns are quite similar to those seen in Charts 4A and 4B, although differences in trade size affect the ordering of the plotted lines for the notes.

C. Bid-Ask Spreads

Table 3, Panel A reports descriptive statistics of 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 one percent of par).[9] 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 points, but the widest spread among the

[9] 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 (0.27), and 0.33 (0.30).

bills in terms of price (the conversion from yield to price involves multiplying the yield by the duration of the security).

Table 3, Panel B reports correlation coefficients of average daily bid-ask spreads across securities. All securities are positively correlated and the most correlated are again the five- and ten-year notes, with a coefficient of 0.91.

Charts 6A and 6B plot average bid-ask spreads by week. Prominent features of both charts are the upward spikes in spreads that occur in late October 1997, October 1998, and February 2000, coinciding with the volatility spikes observed in Chart 2. The spreads also tend to widen in the final weeks of each year, particularly for the bills.

D. Quote Sizes

Table 4, Panel A reports descriptive statistics of average daily quote sizes for the on-the-run bills and notes. 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. Quote sizes are largest for the two-year note, with an average of $24.5 million, and smallest for the ten-year note, with an average of $7.9 million.

Table 4, Panel B reports correlation coefficients of average daily quote sizes across securities. Quote sizes are positively correlated for all securities and particularly so for Treasury notes. The two- and five-year notes are most correlated, with a coefficient of 0.77.

Charts 7A and 7B plot average quote sizes by week. Quote sizes decline steeply during the financial markets turmoil of fall 1998 and never return to pre-turmoil levels. Quote sizes for the two-year note, for example, average $29.1 million in the sample through August 28, 1998, and $19.6 million after that. While not easy to identify amid somewhat volatile series, quote sizes of all plotted securities decline during the weeks ending October 31, 1997, October 9, 1998, and February 4, 2000 (when volatility and bid-ask spreads spike higher).

E. Trade Sizes

Table 5, Panel A reports descriptive statistics of average daily trade sizes for the on-the-run bills and notes. Average trade sizes decrease 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 the data section, trade sizes are calculated to reflect the quantity negotiation that occurs between counterparties in a work-up process. As a result, average trade sizes actually exceed average quote sizes for each of the bills. Trades may also be for less than the posted quantities, however, so that average trade sizes are less than average quote sizes for each of the notes.

Table 5, Panel B reports correlation coefficients of average daily trade sizes across securities. All of the coefficients are positive, except for those between the three-month bill and the two- and ten-year notes. Trade sizes among the notes are particularly correlated and the most correlated are the two- and five-year notes, with a coefficient of 0.54.

Charts 8A and 8B plot average trade sizes by week. Trade sizes decline in fall 1998 for Treasury notes, albeit less so than quote sizes. Trade sizes for the two-year note, for example, average $15.2 million in the sample through August 28, 1998, and $13.2 million after that. Trade sizes for bills do not show a clear decline at all in fall 1998. Furthermore, trade sizes decline only modestly or even increase for some securities in some of the most volatile weeks of the sample period.

F. Price Impact Coefficients

As discussed in Section II, 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. Table 6, Panel A reports descriptive statistics on daily net trading volume for the on-the-run bills and notes. The means (medians) are positive for every security except the one-year bill, and the two-year note has the highest mean (median), with daily net volume of $0.30 ($0.23) billion. The predominance of buyer-initiated volume may reflect the tendency of dealers' customers to be net buyers, and of dealers to offset customer trades in the interdealer broker market.[10]

Table 6, Panel B reports correlation coefficients of daily net trading volume across securities. The coefficients are positive and tend to be higher for the notes. The most correlated are the five- and ten-year notes, with a coefficient of 0.28.

Table 7, Panel A reports descriptive statistics on the daily net number of trades for the on-the-run bills and notes. The same pattern as Table 6 is evident in that the means (medians) are positive for every security except the one-year bill. The two-year note also has the highest mean (median) here, with 34.1 (31) net trades per day.

Table 7, Panel B reports correlation coefficients of the daily net number of trades across securities. With one exception, the coefficients are again all positive, and with two exceptions, the coefficients are higher than the corresponding correlation coefficients for net trading volume. The most correlated are the two- and five-year notes, with a coefficient of 0.46.

[10] The tendency of dealers' customers to be net buyers reflects dealers' underwriting role in the primary market. Charts produced for the Treasury's May 2001 Quarterly Refunding indicate that dealers took down 88% of the ten-year note and 65% of the thirty-year bond at the three preceding auctions (the latest charts are posted at: http://www.treas.gov/domfin/2toc.htm).

Charts 9A and 9B plot the average daily net number of trades by week. No clear patterns or trends are evident in the series, although the greater prevalence of buyer-initiated trades for most securities is evident in lines that are generally above zero.

Preliminary descriptive evidence relating net trading activity to price changes is shown in Chart 10. 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 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 more closely examine the relationship between price changes and net trading activity, five-minute price changes (computed using bid-ask midpoints) are regressed 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, and it allows 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, suggests that the data be aggregated to a certain extent (and not examined on a tick-by-tick basis).

Table 8 presents results from five regression models estimated over the entire sample period for the on-the-run two-year note. 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 0.0478 implies that just under 21 trades, net, moves the price of the two-year note by one 32nd of a point. The adjusted R^2 of 0.317 implies that over 30% 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' (forthcoming) model of daily exchange rate changes, for example, produces an R^2 statistic of over 60% for deutsche mark/dollar and over 40% for yen/dollar (with the explanatory power almost wholly due to order flow).

In Model (2), price changes are regressed on net trading volume, incorporating trade size into the analysis. The slope coefficient is again positive and highly significant, albeit 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 0.137.

In Model (3), price changes are regressed 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 here negative and significant. Controlling for the sign of a trade, larger trade sizes seem to be associated with smaller price changes. The explanatory power of the model is slightly better than that of Model (1), with an adjusted R^2 of 0.322.

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 is able to 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.

Other Treasury market studies find a similar relationship between trade size and price impact. Green (2001) examines the effects of trades around macroeconomic announcements, distinguishing between order processing and adverse selection costs. He finds no support that these costs increase with trade size, and, in fact, finds some evidence that adverse selection costs decrease with trade size. Huang, Cai, and Song (2001) examine the relationship between volatility and various measures of trading activity and find that volatility is more correlated with trading frequency than trading volume, and that trade size is negatively correlated with volatility. 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.

In Model (4), price changes are regressed 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 are less meaningful than sells because a certain proportion of buys simply reflect customers' rollover from maturing to newly issued securities.

Estimation results from 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 10 minutes, 15 minutes, or 30 minutes.[11] Finally, the results are qualitatively the same 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.[12]

To understand how the price impact of trades varies over time, Model (1) is used to estimate price impact coefficients on a weekly basis for each of the on-the-run bills and notes. Table 9, Panel A 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 negative one). 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 0.19 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 points.[13]

[11] 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 10) produces a slope coefficient of 0.0387 and an adjusted R^2 statistic of 0.223.

[12] 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 statistic of 0.483 – and every coefficient is significant.

[13] 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, 0.08, and 0.08.

Table 9, Panel B reports correlation coefficients of weekly price impact coefficients across securities. The price impact coefficients are positively correlated for every pairwise comparison, and particularly so for Treasury notes. The five- and ten-year notes are most correlated, with a coefficient of 0.94.

The weekly price impact coefficients are plotted in Charts 11A and 11B. Except for the scales of the y-axes, the charts are virtually indistinguishable from those of the bid-ask spreads (Charts 6A and 6B). 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 Charts 6A and 6B. The coefficients also tend to increase in the final weeks of each year for the bills (as do the bid-ask spreads).

G. On-the-Run/Off-the-Run Yield Spreads

Table 10, Panel A reports descriptive statistics of daily on-the-run/off-the-run curve yield spreads for the bills and notes. The spreads are calculated as the differences between the actual yields of the on-the-run securities and the yields predicted for those securities from a yield curve estimated with off-the-run prices.[14] Positive spreads indicate that on-the-run securities are trading at a yield discount (or price premium) to off-the-run securities. The bills have the widest spreads, largely reflecting their price premiums over coupon securities (since the predicted yields are estimated with off-the-run coupon securities as well as bills).

Table 10, Panel B reports correlation coefficients of daily yield spreads across securities. The coefficients among the notes and the one-year bill are positive, except for

[14] The yield curve is estimated using a flexible functional form proposed by Fisher, Nychka, and Zervos (1995) in which a set of simple functions (cubic splines) covering different maturity ranges are used to describe the zero curve. The model is estimated to fit Treasury bid prices excluding the two most recently issued securities of a given maturity, securities with less than 31 days to maturity, callable bonds, flower bonds, and inflation-indexed securities. End-of-day data from Bear Stearns and GovPX is used in the on-the-run/off-the-run calculations.

that between the two- and ten-year notes. The one- and five-year securities are most correlated, with a coefficient of 0.68. The three- and six-month bill spreads are positively correlated, but negatively correlated with the five- and ten-year note spreads.

Charts 12A and 12B plot average daily on-the-run/off-the-run curve yield spreads by week. The three- and six-month bill spreads are seen to be fairly volatile, although a distinct increase in the fall of 1998 is discernible. The one-year bill spread is somewhat less volatile and tends to track the spreads of the notes. The note spreads increase fairly sharply during the financial markets turmoil of fall 1998, generally peaking in the week ending October 16, 1998. Most of the spreads remain high through most of 1999, decline in December 1999 and January 2000, and then increase in February 2000. In spite of the sharp widening in fall 1998, the spread movements are modest and inconsistent in sign in the most volatile weeks of the sample.

The yield spreads across the notes also diverge distinctly at times. In November 1998, for example, the ten-year spread falls below zero and remains there for about six weeks while other spreads remain high. This episode stems from the difficulty in estimating a theoretical off-the-run yield for an on-the-run security. The low yield of the second off-the-run ten-year note at this time pulls the yield curve down in that sector, causing the predicted yields to be unusually low. Spread estimation for the two- and five-year notes is somewhat more reliable, as these shorter-term notes are surrounded by off-the-run securities. Nevertheless, the spreads for these securities also diverge at times.

Due to the difficulties in estimating theoretical off-the-run yields, a more straightforward method of estimating on-the-run/off-the-run yields is also examined. Charts 13A and 13B plot spreads that compare yields of on-the-run securities to those of second off-the-run securities. Bill spreads are much lower here, reflecting the comparison of bills to other bills, as well as the upward slope of the bill curve during most of the sample period. The note spreads are reasonably similar, although the upward slope of the yield curve causes two-year spreads to be often negative. The low yield spread of the second off-the-run ten-year note in late 1998, mentioned earlier, is also a problem with this methodology, albeit somewhat less so.

H. Comparison of Liquidity Measures

To this point, the liquidity measures have largely been discussed in isolation. An explicit comparison of the measures may lead to a better understanding of the measures and of the extent to which one measure might be a suitable proxy for another. The correlation coefficients of the various liquidity measures, as calculated weekly for the on-the-run two-year note, are presented in Table 11.

Trading volume and trading frequency are the most correlated measures, with a coefficient of 0.90. Trading volume's correlations with the other liquidity measures are relatively weak and inconsistent, however, suggesting that trading volume is not a reliable indicator of market liquidity. Trading volume is negatively correlated with the bid-ask spread and positively correlated with trade size, suggesting that higher trading volume is associated with greater liquidity. However, trading volume is also negatively correlated with quote size and positively correlated with the price impact coefficient and the yield spread, suggesting that higher trading volume is associated with lower liquidity.

Trading frequency's correlations with the other liquidity measures are consistent, but often small. Trading frequency is associated with higher bid-ask spreads, lower quote and trade sizes, larger price impact coefficients, and wider yield spreads, all indicative of lower market liquidity. The correlation coefficient with the bid-ask spread is a modest 0.08, however, and rises up to 0.49 for the yield spread.

The bid-ask spread is strongly and consistently correlated with the other liquidity measures (excluding the trading activity measures). In fact, the second highest correlation coefficient among the measures, of 0.82, occurs between the bid-ask spread and the price impact coefficient. The simple bid-ask spread, based on widely available data, thus appears to be a good proxy for the relatively complicated price impact coefficient, which can be difficult to estimate on a timely basis due to data limitations. The bid-ask spread is also negatively correlated with quote and trade size, and positively correlated with the yield spread.

Quote and trade size are both consistently correlated with the other liquidity measures (excluding the trading activity measures). Higher quote (trade) sizes are associated with lower bid-ask spreads, higher trade (quote) sizes, smaller price impact coefficients, and lower yield spreads, all indicative of higher market liquidity. Comparing quote and trade sizes, quote size strictly dominates as a proxy for the other measures, with greater magnitude correlation coefficients.

Like the bid-ask spread, the price impact coefficient is strongly and consistently correlated with the other liquidity measures (excluding the trading activity measures). In fact, its correlations with quote and trade size are slightly stronger than those of the bid-ask spread with these measures, and its correlation with the yield spread is substantially stronger. Lastly, the yield spread is consistently correlated with the other liquidity measures, although the correlations are generally weaker than those among the other measures.

V. Conclusion

Interest in the liquidity of the U.S. Treasury securities market is increasing as debt management changes are implemented to address the federal government's decreased funding needs. This paper uses high frequency data from the interdealer broker market to examine a comprehensive set of liquidity measures for the Treasury market, including trading volume, trading frequency, bid-ask spreads, quote sizes, trade sizes, price impact coefficients, and on-the-run/off-the-run yield spreads. The measures are analyzed relative to one another, across securities, and over time.

I find a strong relationship between net order flow and price changes in the U.S. Treasury market, consistent with findings from the FX market. For the two-year note, a simple model with price changes depending on order flow alone produces an R^2 statistic above 30%. I also find that it is the net number of trades that matters, with trade size having little incremental power to explain price changes. This result is likely explained by the endogenous determination of trade size in a market with quantity, but not price negotiation, and concurs with findings from other studies of the Treasury market.

I also find that the liquidity measures change substantially over time, that they are correlated, and that they correlate with episodes of reported poor liquidity. Accordingly, both price impact coefficients and bid-ask spreads increase sharply with equity market declines in October 1997, with the financial markets turmoil in fall 1998, and with the Treasury's Quarterly Refunding announcement in February 2000. These results highlight the relevance of tracking liquidity over time and the ability of simple liquidity measures, such as bid-ask spreads, to proxy for more complicated measures, such as price impact coefficients.

Quote and trade sizes correlate modestly with the other liquidity measures and with the episodes of poor liquidity in the expected manner, as do yield spreads between on-the-run and off-the-run securities. In contrast, trading volume and trading frequency are only weakly correlated with the other measures, suggesting that they are poor proxies of liquidity. In fact, both high and low levels of trading activity are associated with periods of poor liquidity.

The paper's findings suggest several attractive areas for future research. The correlations of the liquidity measures across securities suggest that commonality in liquidity and price determination is prevalent in the Treasury market, so that models of price changes should account for cross-security order flow (following Hasbrouck and Seppi (2001)). Such models could also be expanded to include macroeconomic variables as well as order flow (following Evans and Lyons (forthcoming)) to improve understanding of how prices are determined and of why order flow is so relevant. Lastly, an analysis of the determinants of liquidity – including the role of issuance sizes and frequencies – might provide useful policy guidance as the Treasury adjusts its debt management policies in the coming years.

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 it is analyzed. Some data cleaning is also called for to screen out posting errors made by the interdealer brokers that are not filtered out by GovPX.

A. Trades

As discussed in the text, trades in the interdealer broker market often go through a work-up 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.[15] 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 accompanying 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 start 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)

[15] As mentioned 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.

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

Time	Bid Price	Bid Size	Ask Price	Ask Size	Last Trade Side	Last Trade Price	Last Trade Size	Current Hit Workup Price	Current Hit Workup Size	Current Take Workup Price	Current Take 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 presented information, the tick data files include line counters, security specific information (including the cusip, security type, coupon rate, and maturity date), indicative prices, and the yields associated with each of the prices.

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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 case, the price does not change as 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 accurately and uniquely identify each trade.

Unfortunately, uniquely identifying the incremental trades of the work-up processes is difficult, if not impossible, given the repetition in the dataset 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.[16]

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

B. Quotes

As indicated, the GovPX historical tick data files are constructed such that a change in any field results in a reprinting of every field on a subsequent line. This 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 previous 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.[17]

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[16] 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. In processing the data, the size of the earlier trade is reduced to $10 million ($697 million - $665 million - $22 million).

[17] This happens for bid quotations for the ten-year note on January 28, 1997 from 2:24 p.m. until the

The analysis of quote sizes is further limited by screening out quoted 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.[18]

The processed dataset 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 the paper, 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 one-half basis point.[19] 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 retained in the dataset. In addition, since 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 dataset contains 7,085,037 bid-ask spreads for the on-the-run securities examined in the paper, or an average of 8,683 per day.

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market 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 close.

[18] 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).

[19] 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 to 5.79% at that time, causing the inferred bid-ask spread to fall from 0.5 basis points to -12 basis points. Three seconds later, the offer price returns to 5.665% causing the spread to return to 0.5 basis points.

C. Price and yield changes

Price (and yield) changes are calculated at five-minute, 30-minute, and one-day intervals for various purposes in the paper. In all cases, the changes are calculated from the last observation reported for a given interval to the last observation for the subsequent interval (e.g., 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 is excluded from the bid-ask midpoint calculations. The data is 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.[20]

D. Data gaps

The sample period of December 30, 1996 to March 31, 2000 covers 170 complete weeks, or 850 weekdays. After excluding 34 holidays, 816 trading days are retained, including 39 days on which the market closed early.[21] 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 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 open until 11:17 a.m. August 26, 1999 is missing completely for the two-year note.[22]

[20] For example, at 3:43 p.m. on May 29, 1997, the reported trade price of the one-year bill falls from 5.505 to 4.505%. Nineteen minutes (and three trades) later, the reported price rises from 4.505 to 5.505%. Bid and offer prices range from 5.50 to 5.51% 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.
[21] 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 from Hurricane Floyd.
[22] 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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Table 1: Daily Trading Volume of U.S. Treasury Securities

Panel A: Descriptive Statistics

Issue	Mean	Median	Std. Dev.	Minimum	Maximum
3-month bill	1.28	1.18	0.70	0	4.48
6-month bill	0.84	0.76	0.51	0.05	5.27
1-year bill	2.01	1.82	0.99	0.02	5.61
2-year note	6.65	6.43	2.48	0.86	18.03
5-year note	5.63	5.51	2.42	0.27	14.48
10-year note	3.81	3.77	1.60	0.19	9.14

Panel B: Correlation Coefficients

Issue	3-month	6-month	1-year	2-year	5-year	10-year
3-month bill	1	0.53	0.39	0.38	0.36	0.37
6-month bill	0.53	1	0.36	0.39	0.33	0.34
1-year bill	0.39	0.36	1	0.55	0.68	0.63
2-year note	0.38	0.39	0.55	1	0.71	0.59
5-year note	0.36	0.33	0.68	0.71	1	0.88
10-year note	0.37	0.34	0.63	0.59	0.88	1

Source: Author's calculations, based on data from GovPX.
Notes: Panel A reports descriptive statistics of daily interdealer trading volume for the indicated on-the-run securities in billions of U.S. dollars. Panel B reports correlation coefficients of daily trading volume across securities. The sample period is December 30, 1996 to March 31, 2000.

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

Panel A: Descriptive Statistics

Issue	Mean	Median	Std. Dev.	Minimum	Maximum
3-month bill	56.2	53	26.2	0	164
6-month bill	41.4	39	19.8	2	116
1-year bill	107.7	98	48.9	3	273
2-year note	467.2	460	158.0	72	1043
5-year note	693.1	697	273.8	47	1632
10-year note	593.3	603.5	209.6	45	1247

Panel B: Correlation Coefficients

Issue	3-month	6-month	1-year	2-year	5-year	10-year
3-month bill	1	0.63	0.49	0.44	0.48	0.49
6-month bill	0.63	1	0.50	0.46	0.45	0.44
1-year bill	0.49	0.50	1	0.58	0.77	0.73
2-year note	0.44	0.46	0.58	1	0.70	0.56
5-year note	0.49	0.45	0.77	0.70	1	0.92
10-year note	0.49	0.44	0.73	0.56	0.92	1

Source: Author's calculations, based on data from GovPX.
Notes: Panel A reports descriptive statistics of the daily number of interdealer trades for the indicated on-the-run securities. Panel B reports correlation coefficients of the daily number of trades across securities. The sample period is December 30, 1996 to March 31, 2000.

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

Panel A: Descriptive Statistics

Issue	Mean	Median	Std. Dev.	Minimum	Maximum
3-month bill	0.71 bp	0.61 bp	0.45 bp	0.13 bp	5.64 bp
6-month bill	0.74 bp	0.66 bp	0.34 bp	0.27 bp	3.16 bp
1-year bill	0.52 bp	0.48 bp	0.25 bp	0.15 bp	3.12 bp
2-year note	0.21 32nds	0.20 32nds	0.04 32nds	0.13 32nds	0.46 32nds
5-year note	0.40 32nds	0.36 32nds	0.14 32nds	0.20 32nds	1.18 32nds
10-year note	0.78 32nds	0.71 32nds	0.25 32nds	0.42 32nds	2.99 32nds

Panel B: Correlation Coefficients

Issue	3-month	6-month	1-year	2-year	5-year	10-year
3-month bill	1	0.69	0.72	0.57	0.58	0.57
6-month bill	0.69	1	0.67	0.58	0.59	0.57
1-year bill	0.72	0.67	1	0.71	0.80	0.77
2-year note	0.57	0.58	0.71	1	0.80	0.71
5-year note	0.58	0.59	0.80	0.80	1	0.91
10-year note	0.57	0.57	0.77	0.71	0.91	1

Source: Author's calculations, based on data from GovPX.
Notes: Panel A reports descriptive statistics of mean daily interdealer bid-ask spreads for the indicated on-the-run securities. Panel B reports correlation coefficients of mean daily bid-ask spreads across securities. The sample period is December 30, 1996 to March 31, 2000.

Table 4: Quote Sizes of U.S. Treasury Securities

Panel A: Descriptive Statistics					
Issue	Mean	Median	Std. Dev.	Minimum	Maximum
3-month bill	16.9	14.9	8.6	6.4	120.5
6-month bill	15.5	14.1	6.1	6.0	53.2
1-year bill	17.2	16.4	5.6	6.6	42.0
2-year note	24.5	23.0	8.1	6.6	54.5
5-year note	10.7	10.3	2.8	4.3	23.1
10-year note	7.9	7.7	2.7	2.0	16.2

Panel B: Correlation Coefficients						
Issue	3-month	6-month	1-year	2-year	5-year	10-year
3-month bill	1	0.48	0.24	0.33	0.30	0.21
6-month bill	0.48	1	0.31	0.38	0.29	0.19
1-year bill	0.24	0.31	1	0.40	0.30	0.13
2-year note	0.33	0.38	0.40	1	0.77	0.63
5-year note	0.30	0.29	0.30	0.77	1	0.72
10-year note	0.21	0.19	0.13	0.63	0.72	1

Source: Author’s calculations, based on data from GovPX.
Notes: Panel A reports descriptive statistics of 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 and the mean daily figure is calculated with both bid and offer quantities. Panel B reports correlation coefficients of mean daily quote sizes across securities. The sample period is December 30, 1996 to March 31, 2000.

Table 5: Trade Sizes of U.S. Treasury Securities

Panel A: Descriptive Statistics					
Issue	Mean	Median	Std. Dev.	Minimum	Maximum
3-month bill	22.5	22.0	6.3	7.6	72.0
6-month bill	19.7	19.0	6.0	7.5	86.7
1-year bill	18.4	18.0	3.4	5.7	44.2
2-year note	14.2	13.9	2.1	9.3	23.6
5-year note	8.0	8.0	0.9	5.0	10.9
10-year note	6.2	6.3	1.0	3.2	9.7

Panel B: Correlation Coefficients						
Issue	3-month	6-month	1-year	2-year	5-year	10-year
3-month bill	1	0.13	0.16	-0.01	0.01	-0.03
6-month bill	0.13	1	0.08	0.09	0.06	0.09
1-year bill	0.16	0.08	1	0.14	0.14	0.05
2-year note	-0.01	0.09	0.14	1	0.54	0.45
5-year note	0.01	0.06	0.14	0.54	1	0.53
10-year note	-0.03	0.09	0.05	0.45	0.53	1

Source: Author’s calculations, based on data from GovPX.
Notes: Panel A reports descriptive statistics of mean daily interdealer trade sizes for the indicated on-the-run securities in millions of U.S. dollars. Panel B reports correlation coefficients of mean daily trade sizes across securities. The sample period is December 30, 1996 to March 31, 2000.

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

Panel A: Descriptive Statistics

Issue	Mean	Median	Std. Dev.	Minimum	Maximum
3-month bill	0.16	0.09	0.44	-1.20	3.01
6-month bill	0.02	0.01	0.30	-0.98	2.52
1-year bill	-0.04	-0.05	0.41	-1.73	1.89
2-year note	0.30	0.23	0.77	-2.41	3.70
5-year note	0.17	0.12	0.52	-1.22	2.35
10-year note	0.13	0.10	0.38	-1.71	3.38

Panel B: Correlation Coefficients

Issue	3-month	6-month	1-year	2-year	5-year	10-year
3-month bill	1	0.25	0.10	0.10	0.12	0.01
6-month bill	0.25	1	0.12	0.18	0.12	0.11
1-year bill	0.10	0.12	1	0.17	0.20	0.09
2-year note	0.10	0.18	0.17	1	0.28	0.19
5-year note	0.12	0.12	0.20	0.28	1	0.28
10-year note	0.01	0.11	0.09	0.19	0.28	1

Source: Author's calculations, based on data from GovPX.
Notes: Panel A reports descriptive statistics of daily net interdealer trading volume for the indicated on-the-run securities in billions of U.S. dollars. Net trading volume equals buyer-initiated volume less seller-initiated volume. Panel B reports correlation coefficients of daily net trading volume across securities. The sample period is December 30, 1996 to March 31, 2000.

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

Panel A: Descriptive Statistics

Issue	Mean	Median	Std. Dev.	Minimum	Maximum
3-month bill	6.6	5	13.2	-32	67
6-month bill	1.4	1	9.9	-35	39
1-year bill	-0.3	0	16.1	-60	85
2-year note	34.1	31	38.7	-81	208
5-year note	30.7	26	49.1	-92	301
10-year note	19.2	17	37.6	-108	165

Panel B: Correlation Coefficients

Issue	3-month	6-month	1-year	2-year	5-year	10-year
3-month bill	1	0.41	0.24	0.22	0.17	-0.00
6-month bill	0.41	1	0.30	0.27	0.20	0.11
1-year bill	0.24	0.30	1	0.34	0.36	0.18
2-year note	0.22	0.27	0.34	1	0.46	0.30
5-year note	0.17	0.20	0.36	0.46	1	0.40
10-year note	-0.00	0.11	0.18	0.30	0.40	1

Source: Author’s calculations, based on data from GovPX.
Notes: Panel A reports descriptive statistics of 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. Panel B reports correlation coefficients of the daily net number of trades across securities. The sample period is December 30, 1996 to March 31, 2000.

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	-0.0170	-0.0057	-0.0180	-0.1898	0.0016
	(0.0009)	(0.0010)	(0.0009)	(0.0016)	(0.0017)
Net number of trades	0.0478		0.0545		
	(0.0004)		(0.0006)		
Net trading volume		0.0164	-0.0047		
		(0.0003)	(0.0003)		
Proportion of trades buyer-initiated				0.3575	
				(0.0023)	
Number of buyer-initiated trades					0.0441
					(0.0005)
Number of seller-initiated trades					-0.0523
					(0.0007)
Adjusted R^2	0.317	0.137	0.322	0.213	0.319
No. 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.

Table 9: Price Impact Coefficients of U.S. Treasury Securities

Panel A: Descriptive Statistics					
Issue	Mean	Median	Std. Dev.	Minimum	Maximum
3-month bill	0.15 bps	0.15 bps	0.07 bps	0.05 bps	0.69 bps
6-month bill	0.14 bps	0.13 bps	0.05 bps	0.06 bps	0.39 bps
1-year bill	0.12 bps	0.11 bps	0.05 bps	0.05 bps	0.30 bps
2-year note	0.05 32nds	0.04 32nds	0.02 32nds	0.02 32nds	0.12 32nds
5-year note	0.10 32nds	0.09 32nds	0.04 32nds	0.05 32nds	0.33 32nds
10-year note	0.19 32nds	0.18 32nds	0.07 32nds	0.09 32nds	0.51 32nds

Panel B: Correlation Coefficients						
Issue	3-month	6-month	1-year	2-year	5-year	10-year
3-month bill	1	0.76	0.71	0.58	0.46	0.46
6-month bill	0.76	1	0.76	0.72	0.57	0.57
1-year bill	0.71	0.75	1	0.82	0.76	0.75
2-year note	0.58	0.72	0.82	1	0.85	0.84
5-year note	0.46	0.57	0.76	0.85	1	0.94
10-year note	0.46	0.57	0.75	0.84	0.94	1

Source: Author's calculations, based on data from GovPX.
Notes: Panel A reports descriptive statistics of 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) 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 negative one). The net number of trades equals the number of buyer-initiated less seller-initiated trades. Panel B reports correlation coefficients of the weekly price impact coefficients across securities. The sample period is December 30, 1996 to March 31, 2000.

Table 10: On-the-Run/Off-the-Run Curve Yield Spreads of U.S. Treasury Securities

Panel A: Descriptive Statistics

Issue	Mean	Median	Std. Dev.	Minimum	Maximum
3-month bill	16.7	16.3	6.6	-11.5	39.6
6-month bill	13.6	13.6	5.2	-2.9	33.3
1-year bill	17.0	16.4	5.2	7.6	32.8
2-year note	3.7	3.1	3.7	-3.0	25.0
5-year note	9.7	7.2	7.3	-1.0	25.4
10-year note	9.9	8.6	5.5	-4.3	22.4

Panel B: Correlation Coefficients

Issue	3-month	6-month	1-year	2-year	5-year	10-year
3-month bill	1	0.26	0.00	0.00	-0.25	-0.14
6-month bill	0.26	1	0.08	0.05	-0.21	-0.15
1-year bill	0.00	0.08	1	0.47	0.68	0.48
2-year note	0.00	0.05	0.47	1	0.59	-0.03
5-year note	-0.25	-0.21	0.68	0.59	1	0.42
10-year note	-0.14	-0.15	0.48	-0.03	0.42	1

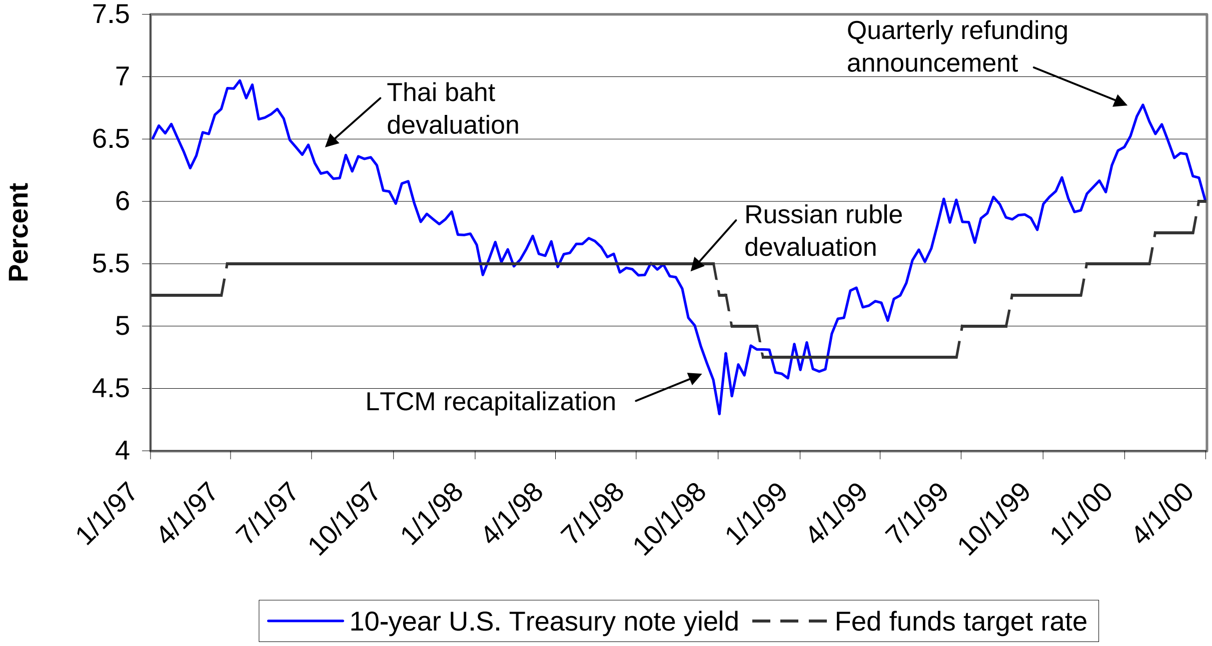
Source: Author’s calculations, based on data from Bear Stearns and GovPX.
Notes: Panel A reports descriptive statistics of daily on-the-run/off-the-run curve yield spreads for the indicated securities. The spreads are calculated as the differences between the actual end-of-day yields of the on-the-run securities and the yields predicted for those securities from a yield curve estimated with off-the-run prices. Panel B reports correlation coefficients of daily on-the-run/off-the-run curve yield spreads across securities. The sample period is December 30, 1996 to March 31, 2000.

Table 11: Correlations of Liquidity Measures for the Two-Year U.S. Treasury Note

	Trading Volume	Trading Frequency	Bid-Ask Spread	Quote Size	Trade Size	Price Impact	Yield Spread
Trading volume	1	0.90	-0.04	-0.13	0.28	0.32	0.36
Trading frequency	0.90	1	0.08	-0.41	-0.15	0.48	0.49
Bid-ask spread	-0.04	0.08	1	-0.68	-0.33	0.82	0.37
Quote size	-0.13	-0.41	-0.68	1	0.65	-0.78	-0.52
Trade size	0.28	-0.15	-0.33	0.65	1	-0.38	-0.22
Price impact	0.32	0.48	0.82	-0.78	-0.38	1	0.59
Yield spread	0.36	0.49	0.37	-0.52	-0.22	0.59	1

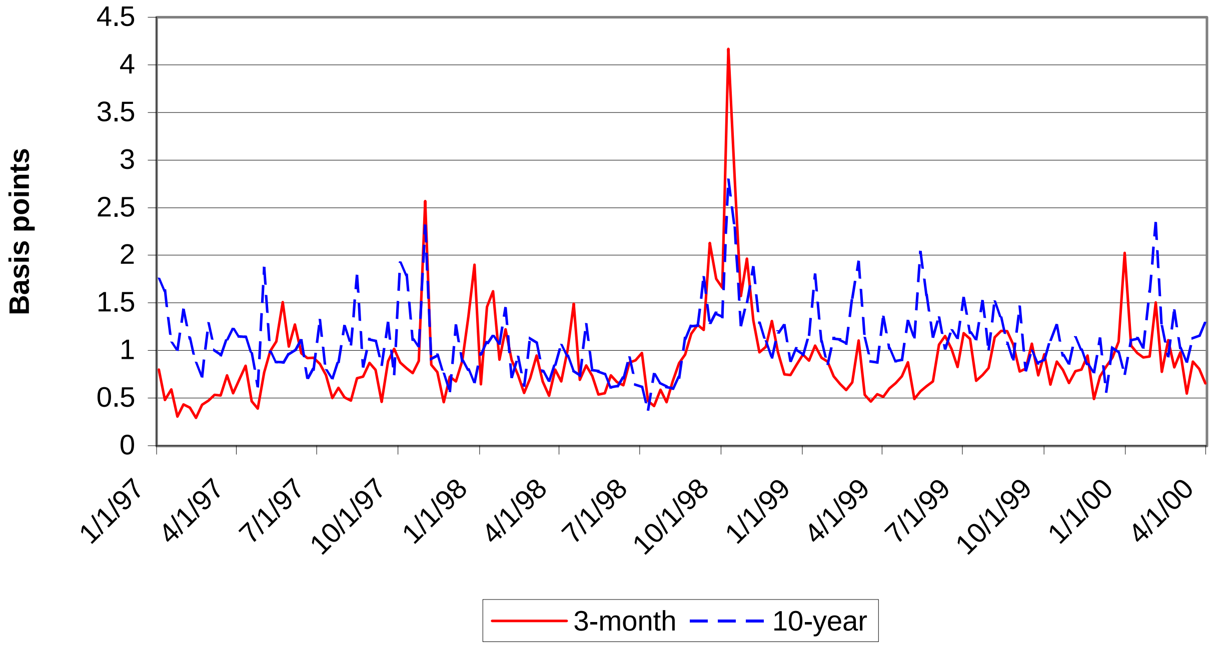
Source: Author's calculations, based on data from GovPX and Bear Stearns.
Notes: The table reports correlation coefficients of liquidity measures for the on-the-run two-year note. The measures are calculated weekly as mean daily trading volume, mean daily trading frequency, mean bid-ask spread, mean quote size, mean trade size, price impact coefficient, and mean on-the-run/off-the-run curve 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 yield spreads are calculated as the differences between the actual yields of the on-the-run securities and the yields predicted for those securities from a yield curve estimated with off-the-run prices. The sample period is December 30, 1996 to March 31, 2000.

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



Source: Bloomberg.

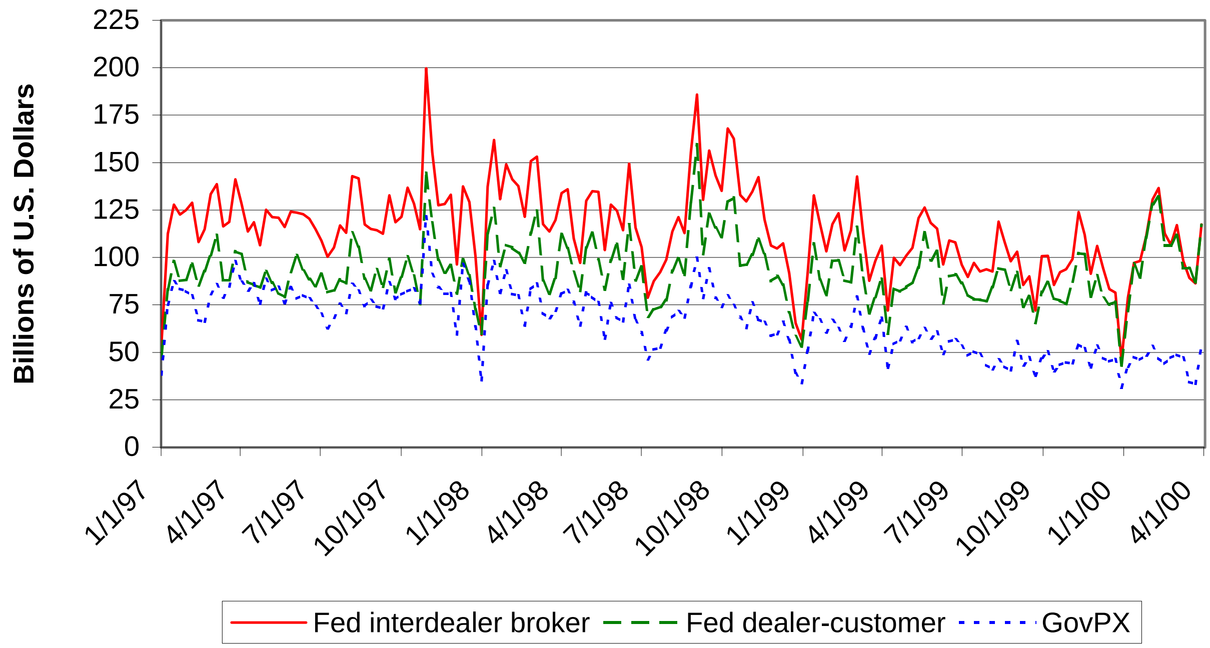
Chart 2: Three-Month Bill and Ten-Year Note Yield Volatility



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

Note: The chart plots standard deviations of 30-minute yield changes by week for the indicated on-the-run securities.

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



Source: Author's calculations, based on data from the Federal Reserve Bulletin and GovPX.
Note: The chart plots mean daily trading volume by week for the indicated series.

Chart 4A: Daily Trading Volume of U.S. Treasury Bills

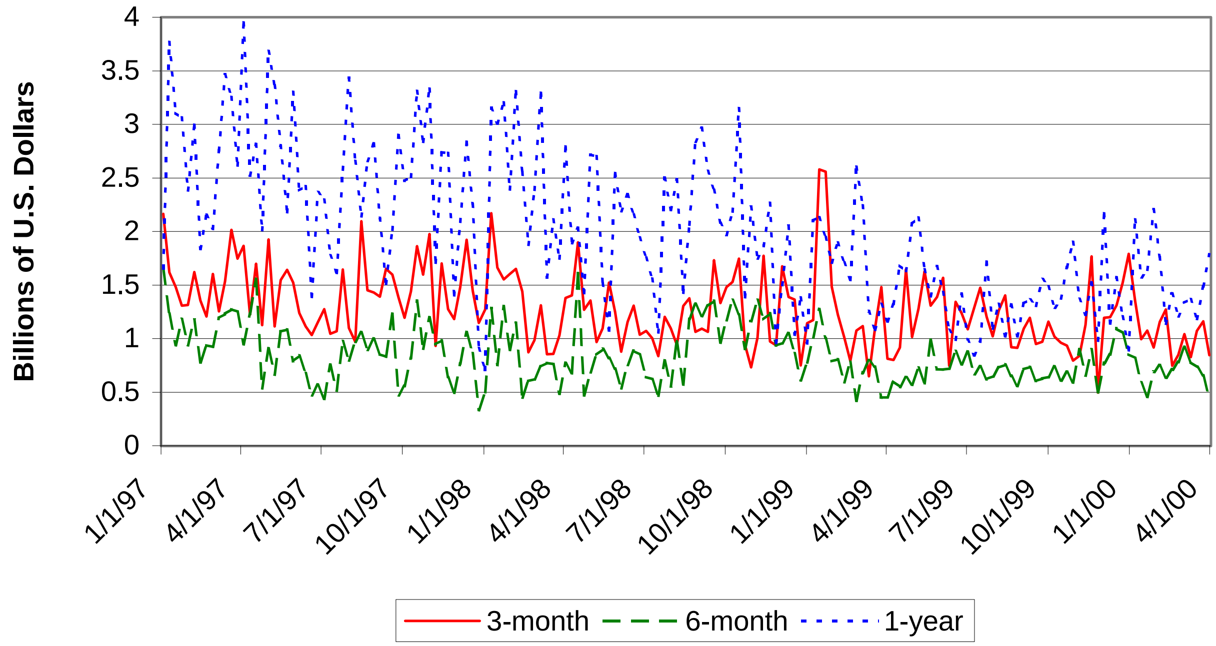
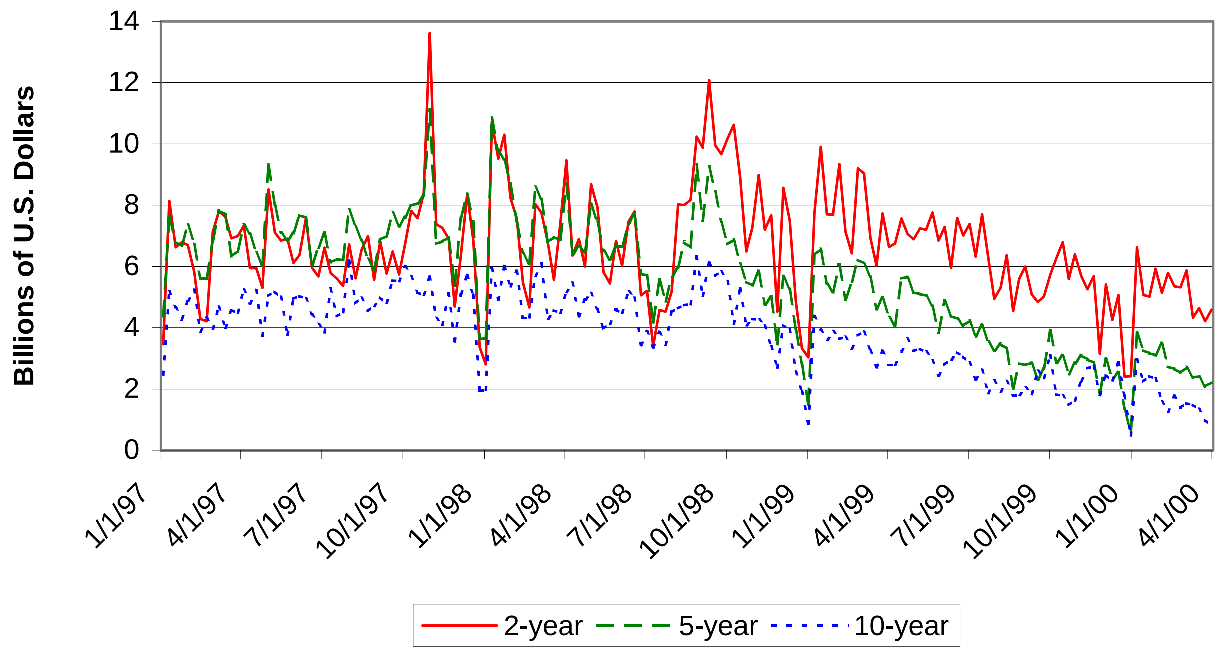


Chart 4B: Daily Trading Volume of U.S. Treasury Notes



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

Note: The charts plot mean daily interdealer trading volume by week for the indicated on-the-run securities.

Chart 5A: Daily Trading Frequency of U.S. Treasury Bills

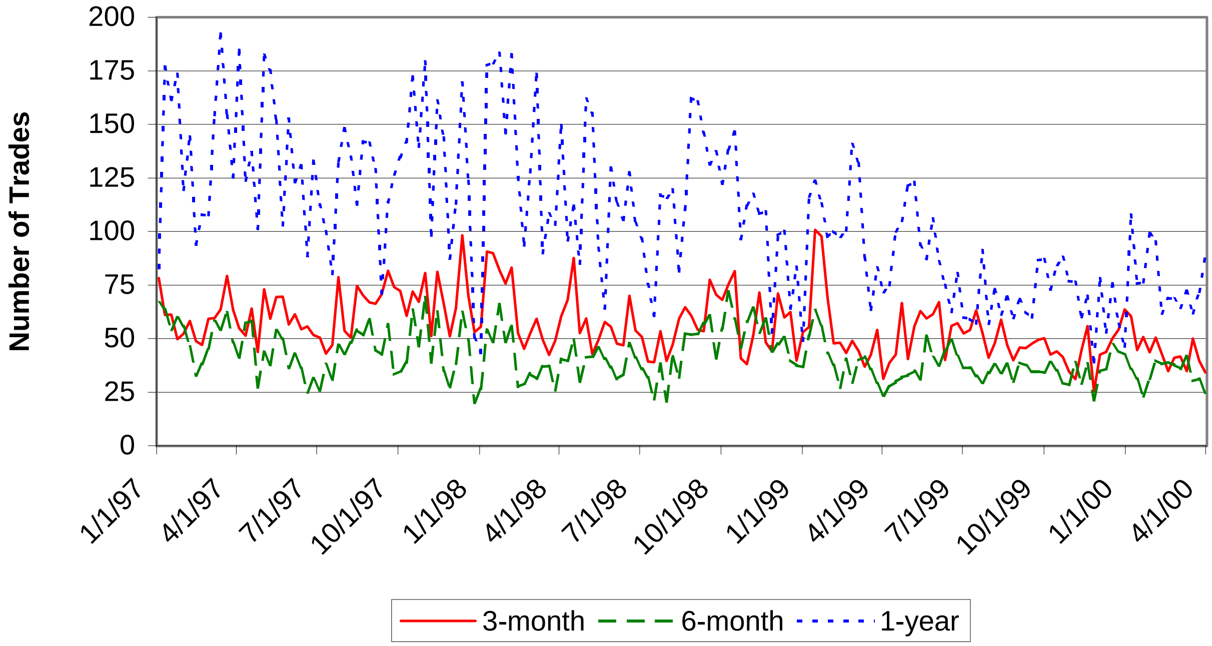
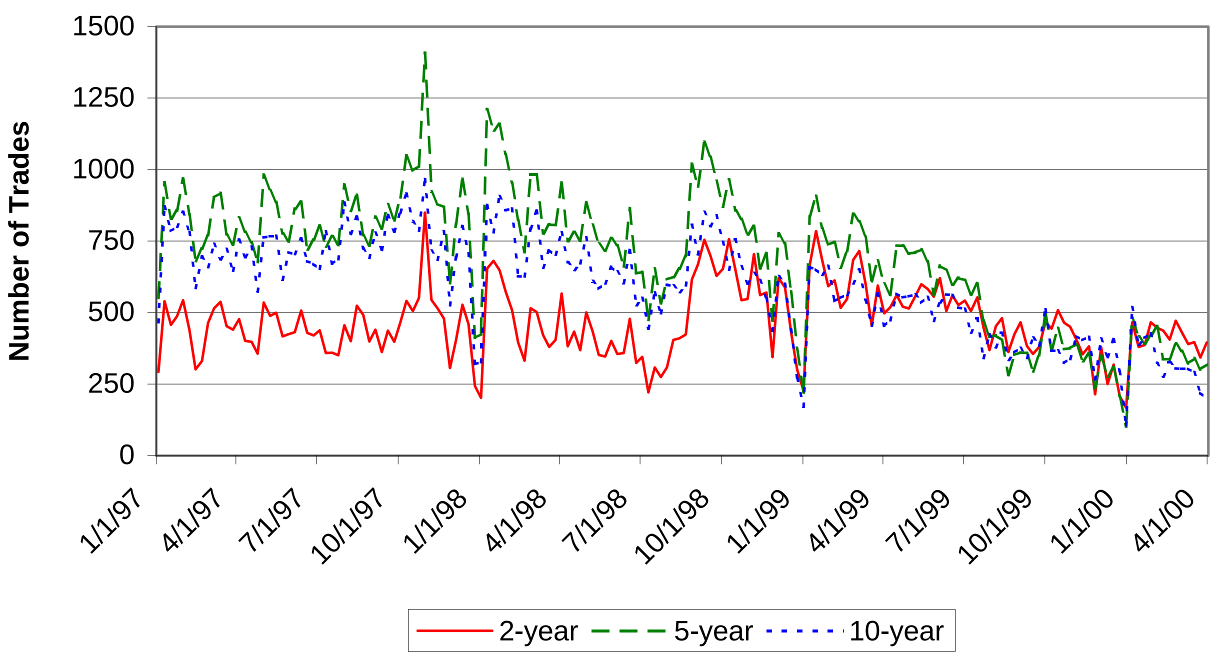


Chart 5B: Daily Trading Frequency of U.S. Treasury Notes



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

Note: The charts plot the mean daily number of interdealer trades by week for the indicated on-the-run securities.

Chart 6A: Bid-Ask Spreads of U.S. Treasury Bills

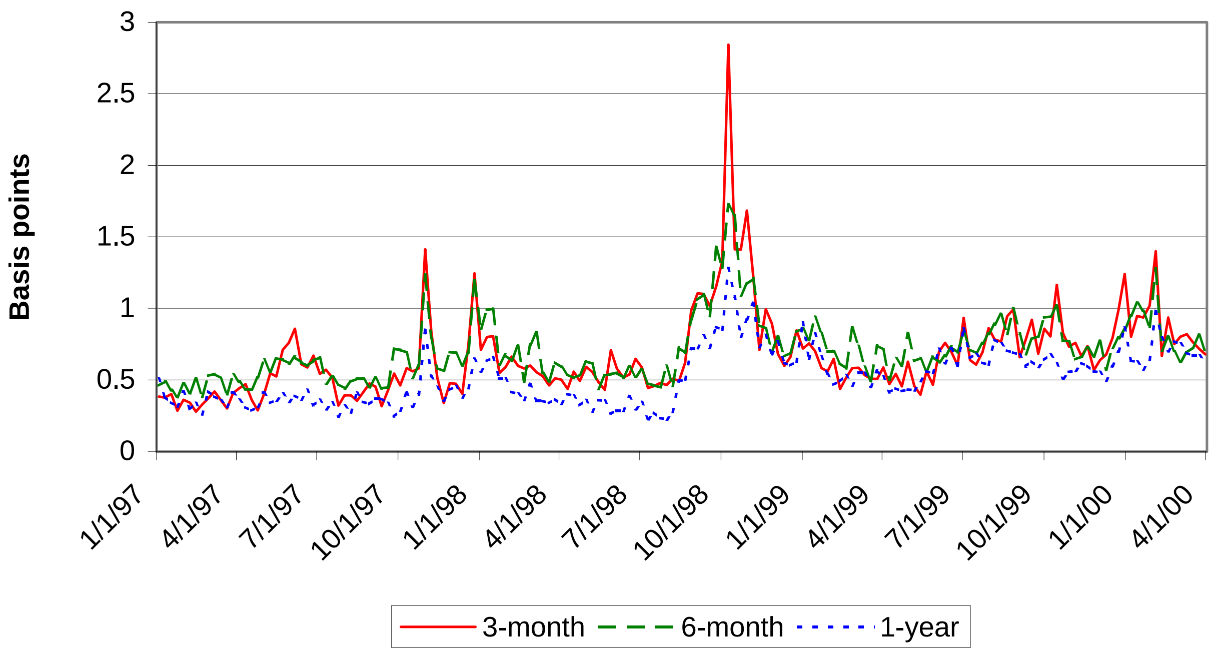
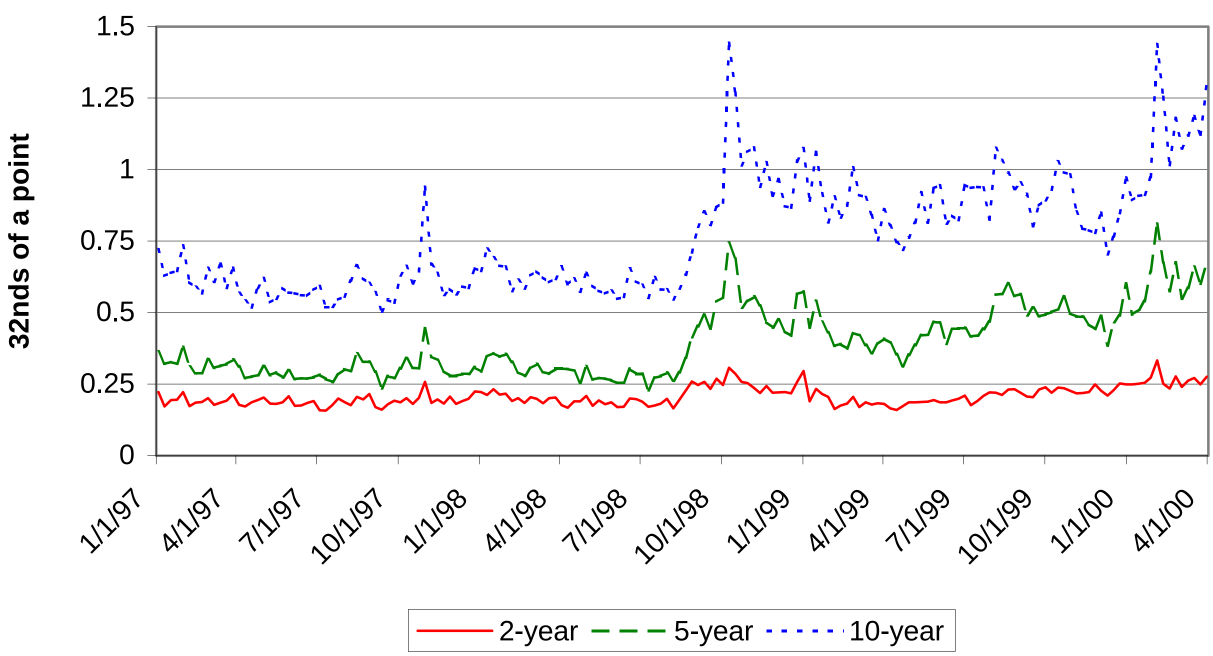


Chart 6B: Bid-Ask Spreads of U.S. Treasury Notes



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

Note: The charts plot mean interdealer bid-ask spreads by week for the indicated on-the-run securities.

Chart 7A: Quote Sizes of U.S. Treasury Bills

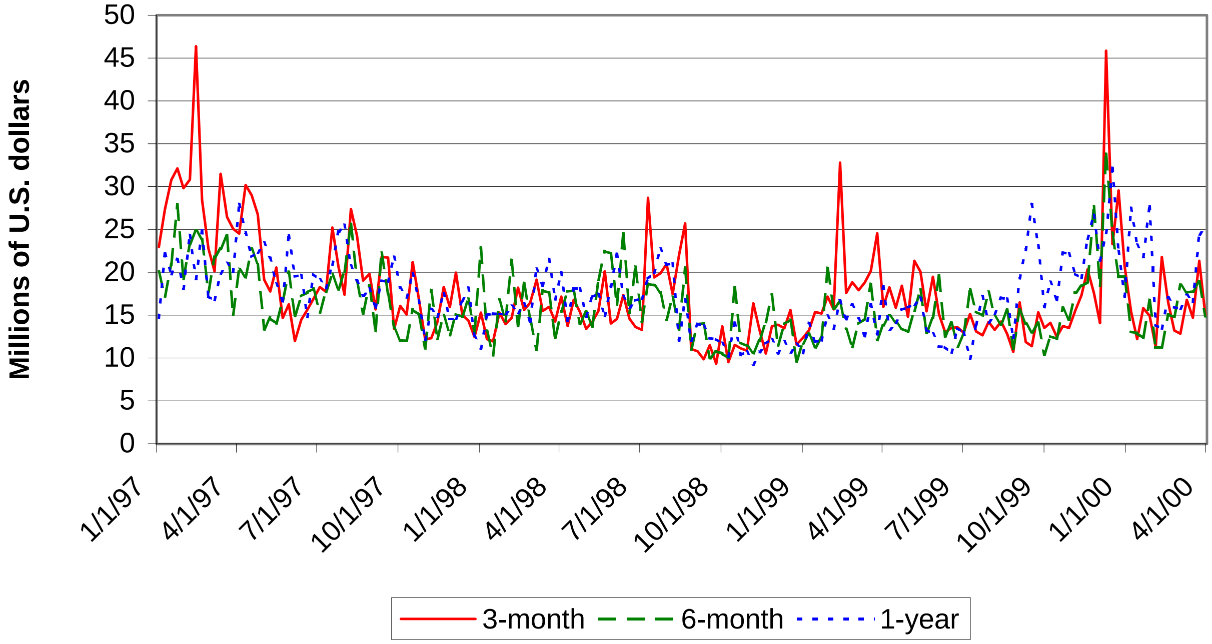
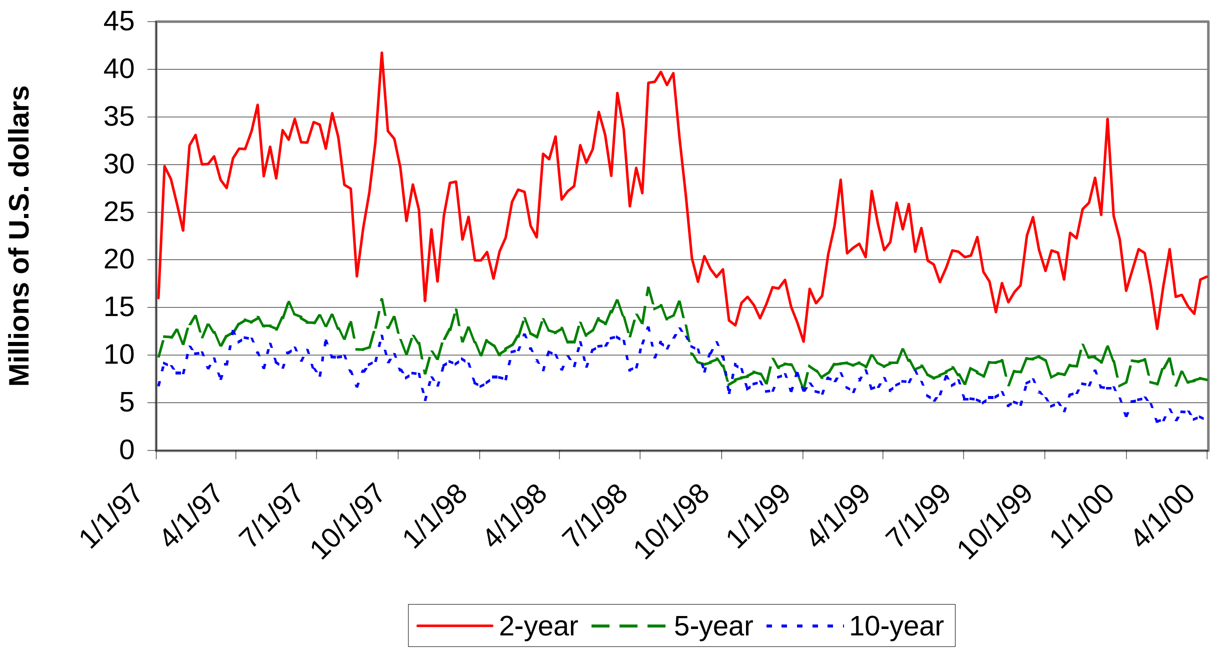


Chart 7B: Quote Sizes of U.S. Treasury Notes



Source: Author's calculations, based on data from GovPX.
Notes: The charts plot mean interdealer quote sizes by week for the indicated on-the-run securities. Quote sizes are the quantity of securities bid for or offered for sale at the best bid and offer prices in the interdealer market and the mean weekly figure is calculated with both bid and offer quantities.

Chart 8A: Trade Sizes of U.S. Treasury Bills

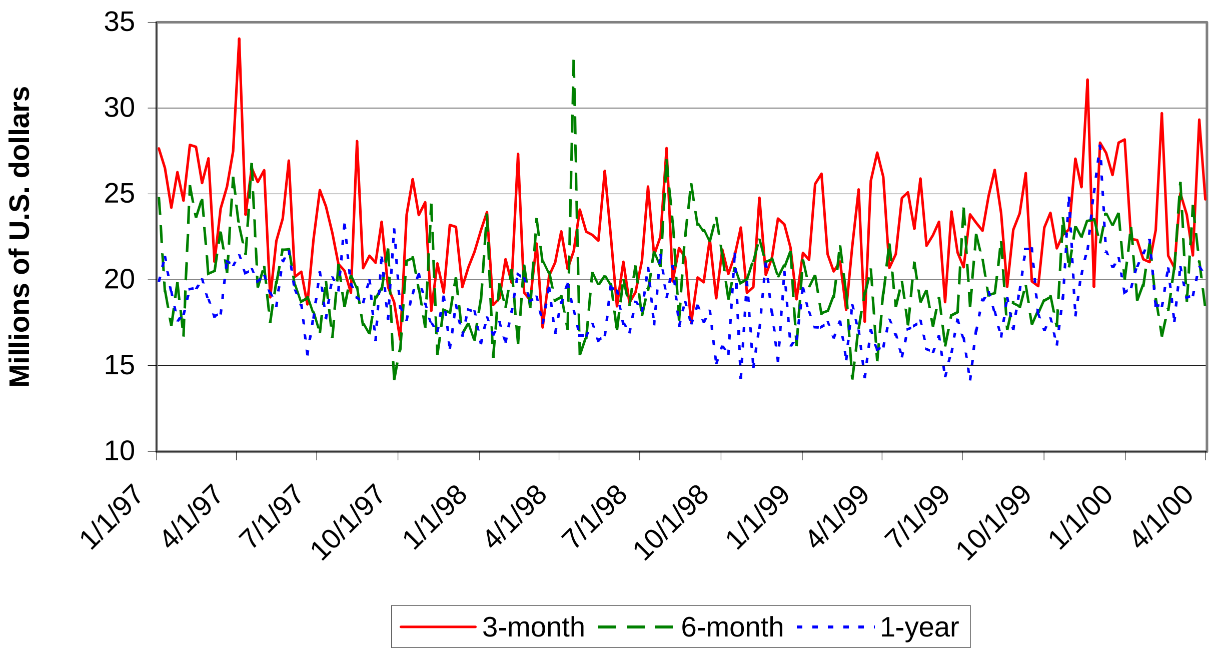
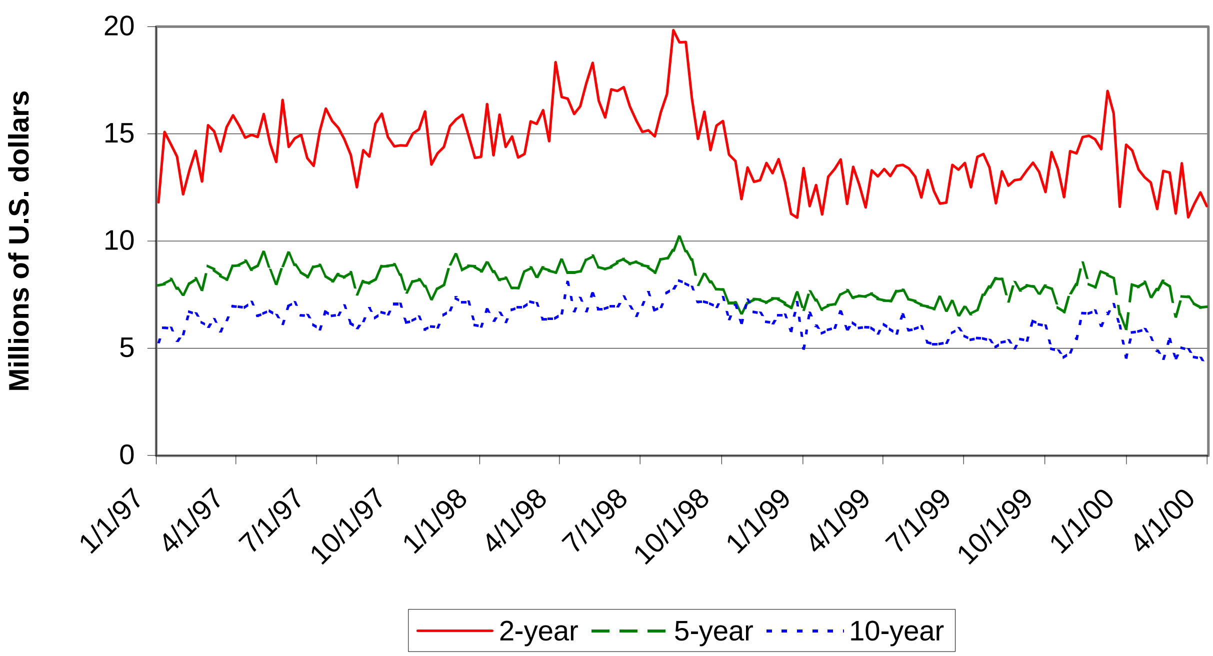


Chart 8B: Trade Sizes of U.S. Treasury Notes



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

Note: The charts plot mean interdealer trade sizes by week for the indicated on-the-run securities.

Chart 9A: Daily Net Number of Trades of U.S. Treasury Bills

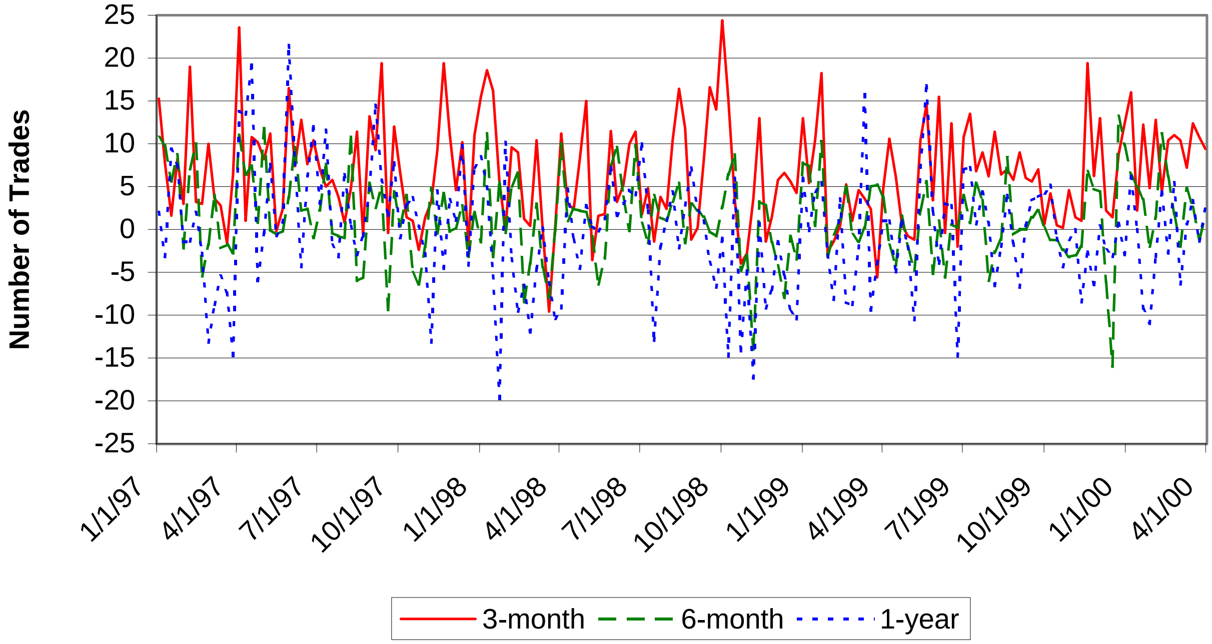
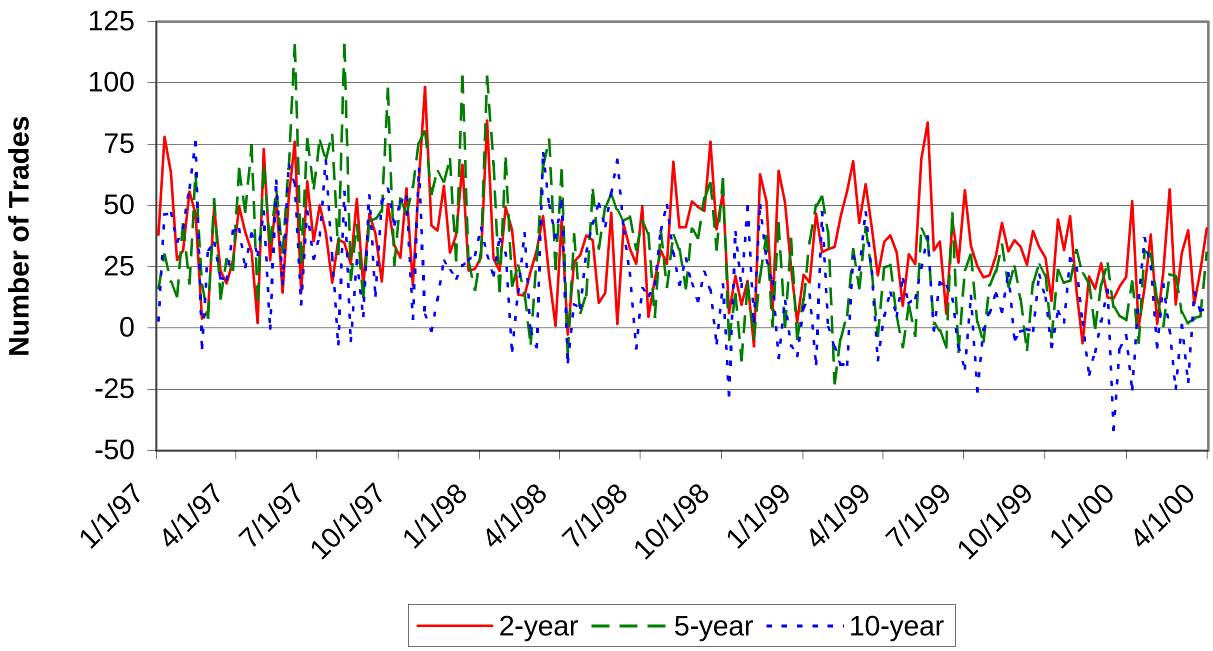


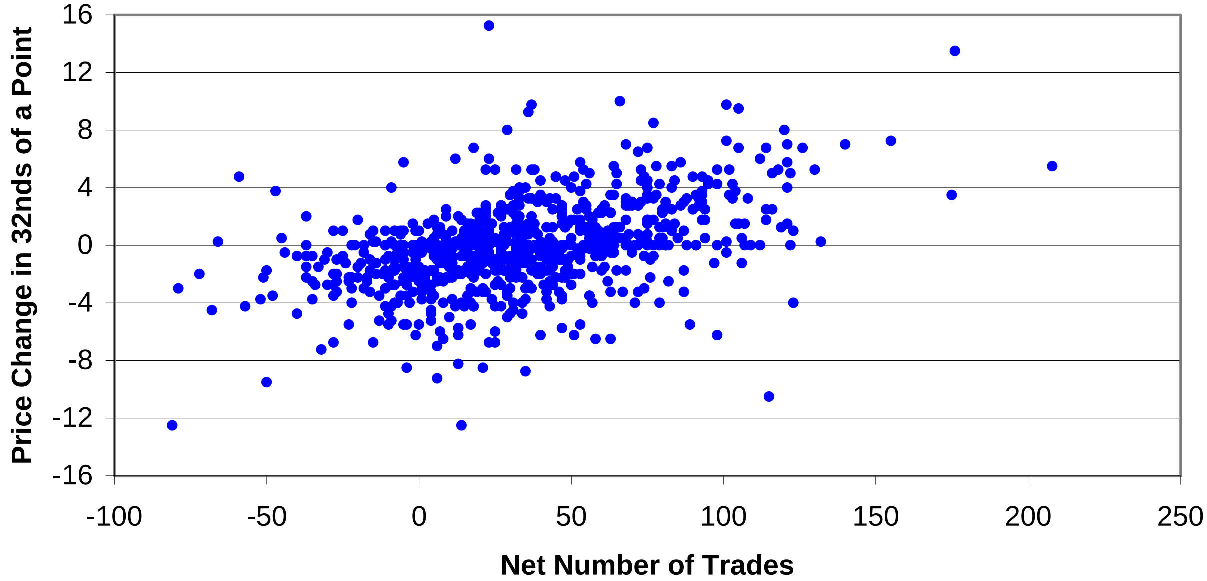
Chart 9B: Daily Net Number of Trades of U.S. Treasury Notes



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

Notes: The charts plot the mean daily net number of interdealer trades by week for the indicated on-the-run securities. The net number of trades equals the number of buyer-initiated less seller-initiated trades.

Chart 10: Net Number of Trades versus Price Change by Day for 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.

Chart 11A: Price Impact of U.S. Treasury Bill Trades

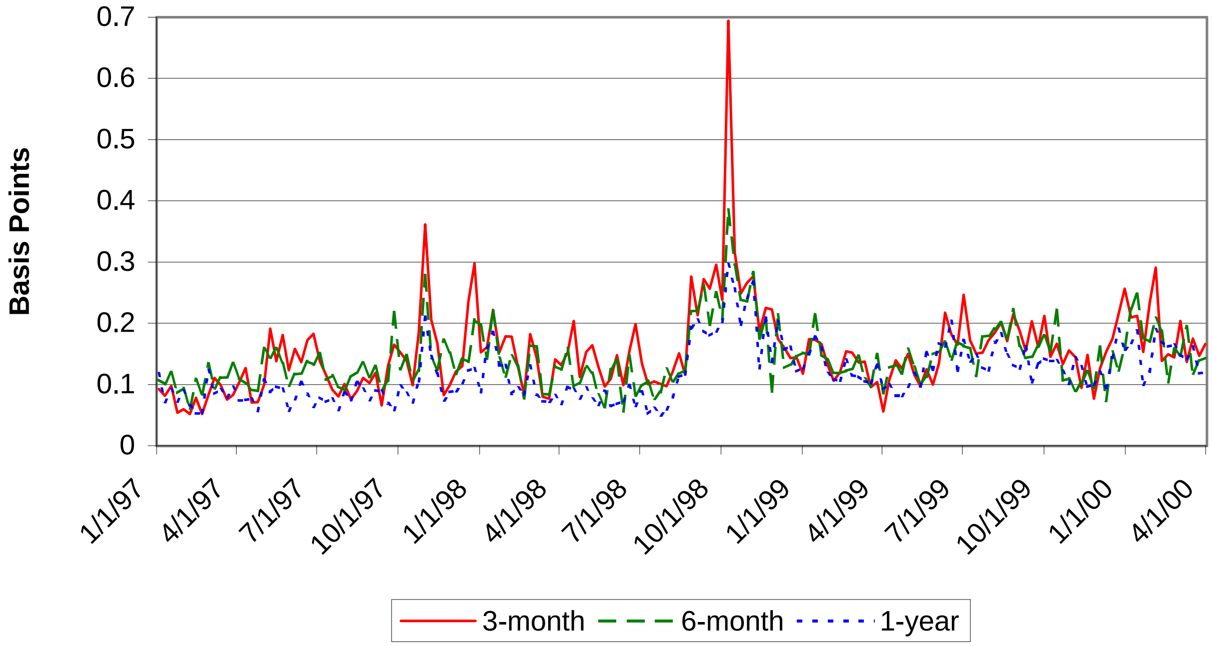
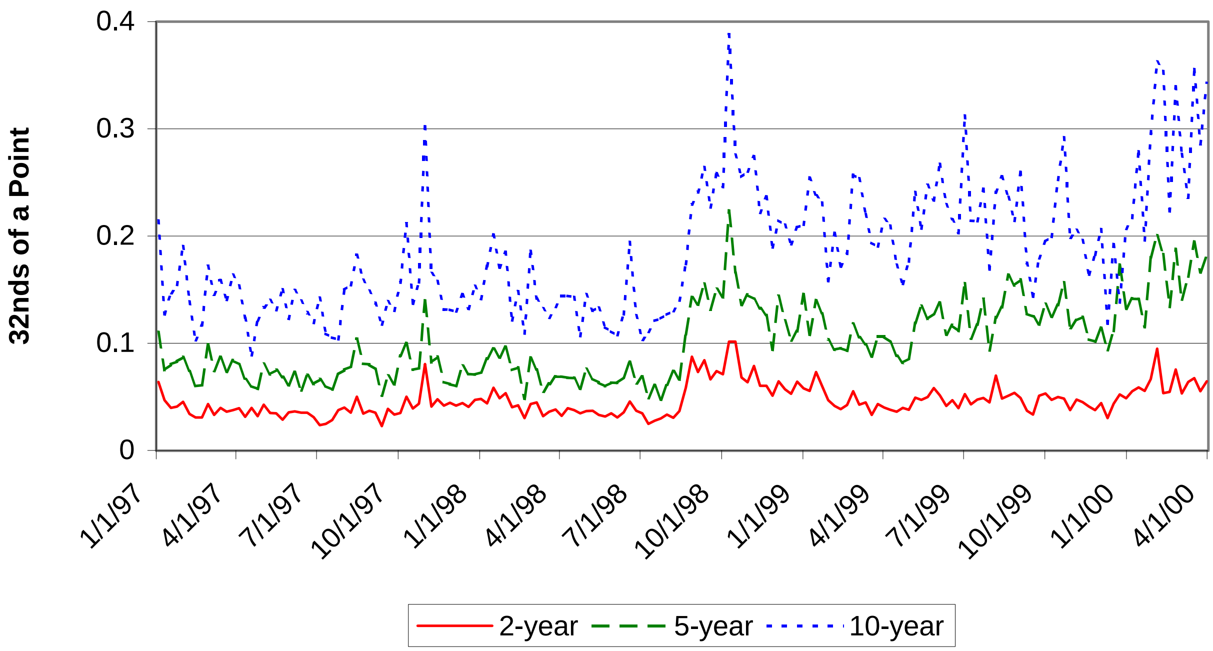


Chart 11B: Price Impact of U.S. Treasury Note Trades



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

Notes: The charts plot the price impact of interdealer trades by week for the indicated on-the-run securities. 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 reported bill coefficients are the actual coefficients multiplied by negative one). The net number of trades equals the number of buyer-initiated less seller-initiated trades.

Chart 12A: On-the-Run/Off-the-Run Curve Yield Spreads of Treasury Bills

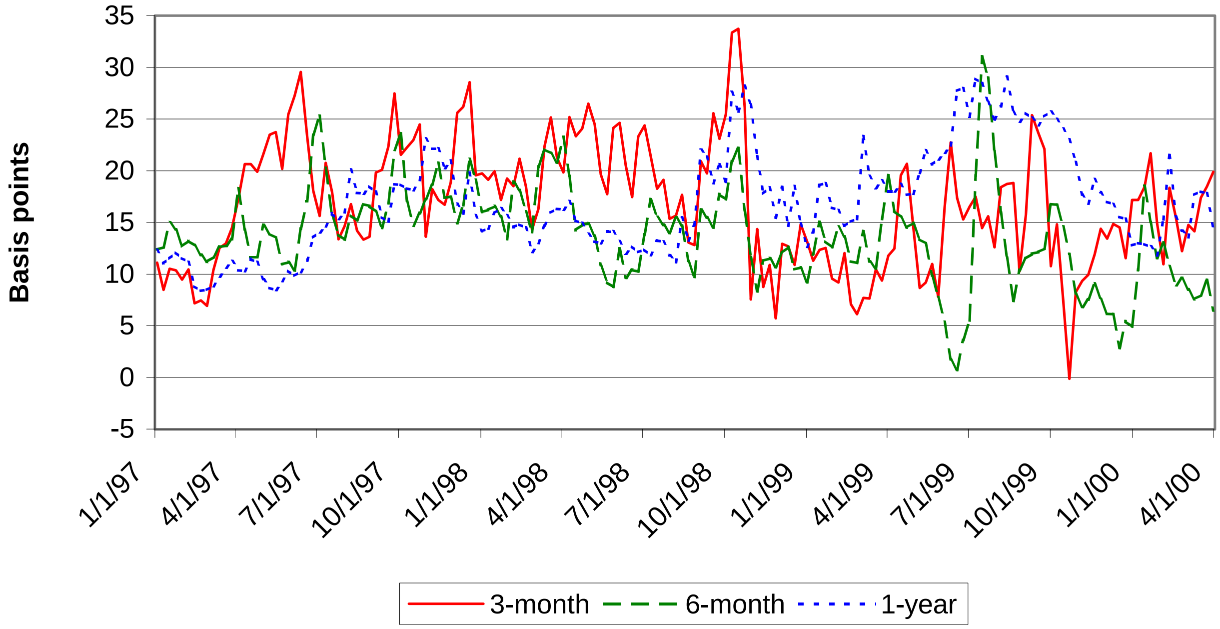
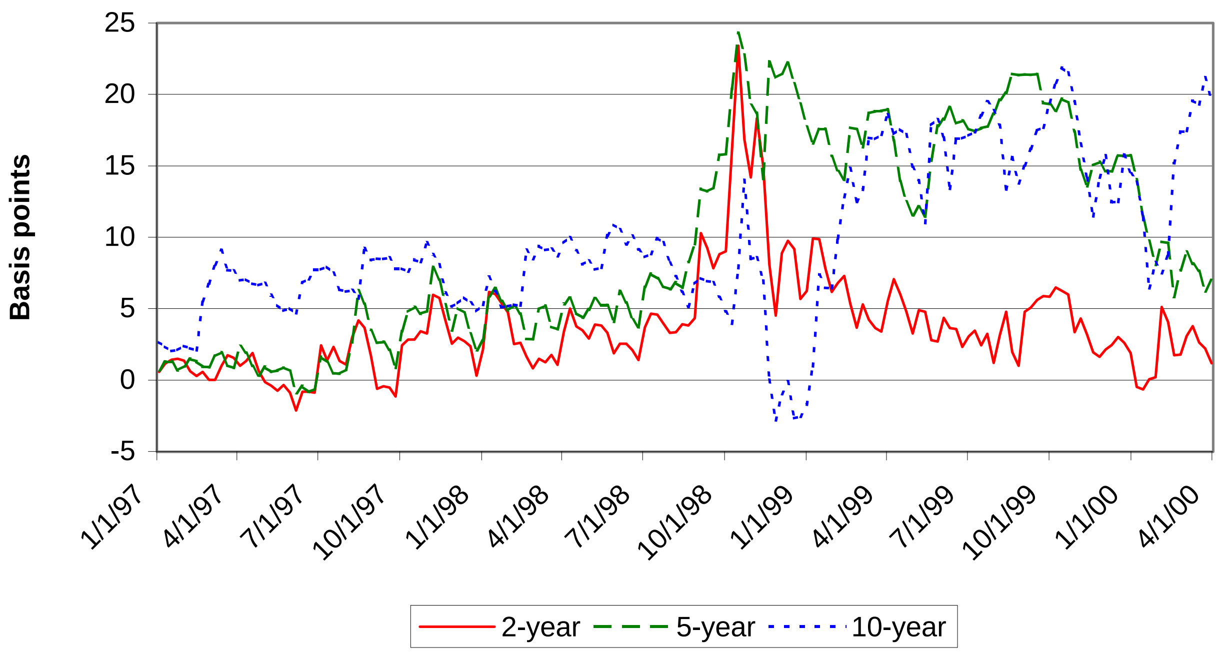


Chart 12B: On-the-Run/Off-the-Run Curve Yield Spreads of Treasury Notes



Source: Author's calculations, based on data from Bear Stearns and GovPX.
Notes: The charts plot mean on-the-run/off-the-run curve yield spreads by week for the indicated securities. The spreads are calculated daily as the differences between the actual yields of the on-the-run securities and the yields predicted for those securities from a yield curve estimated with off-the-run prices.

Chart 13A: On-the-Run/Second Off-the-Run Yield Spreads of Treasury Bills

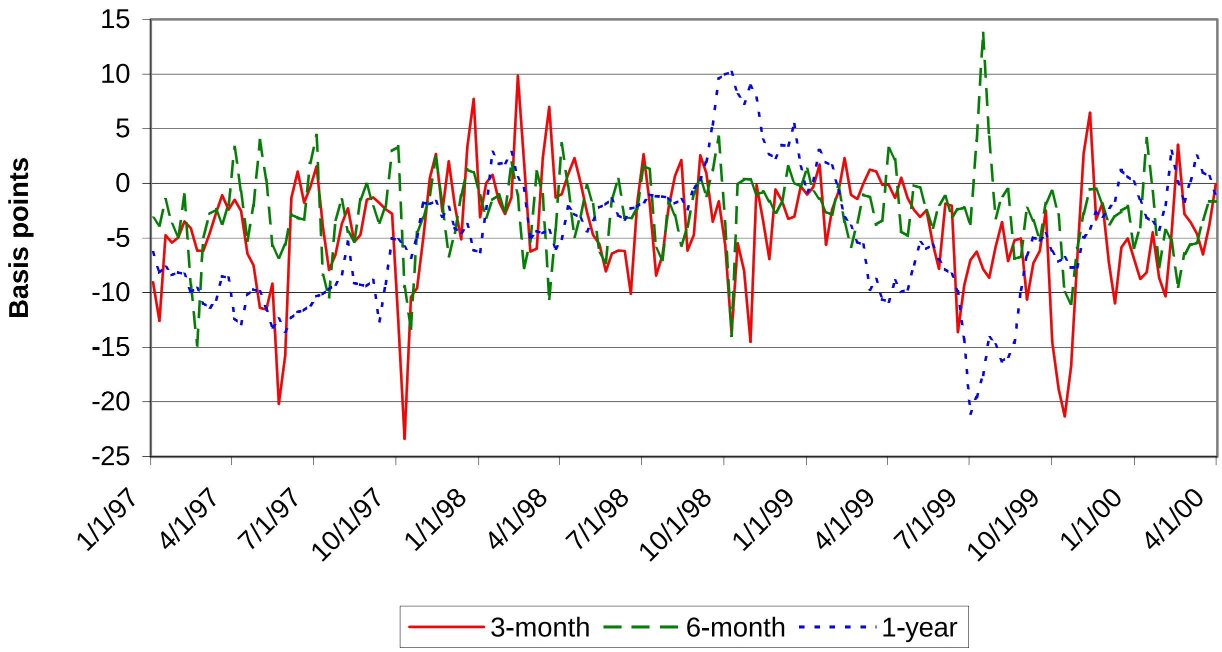
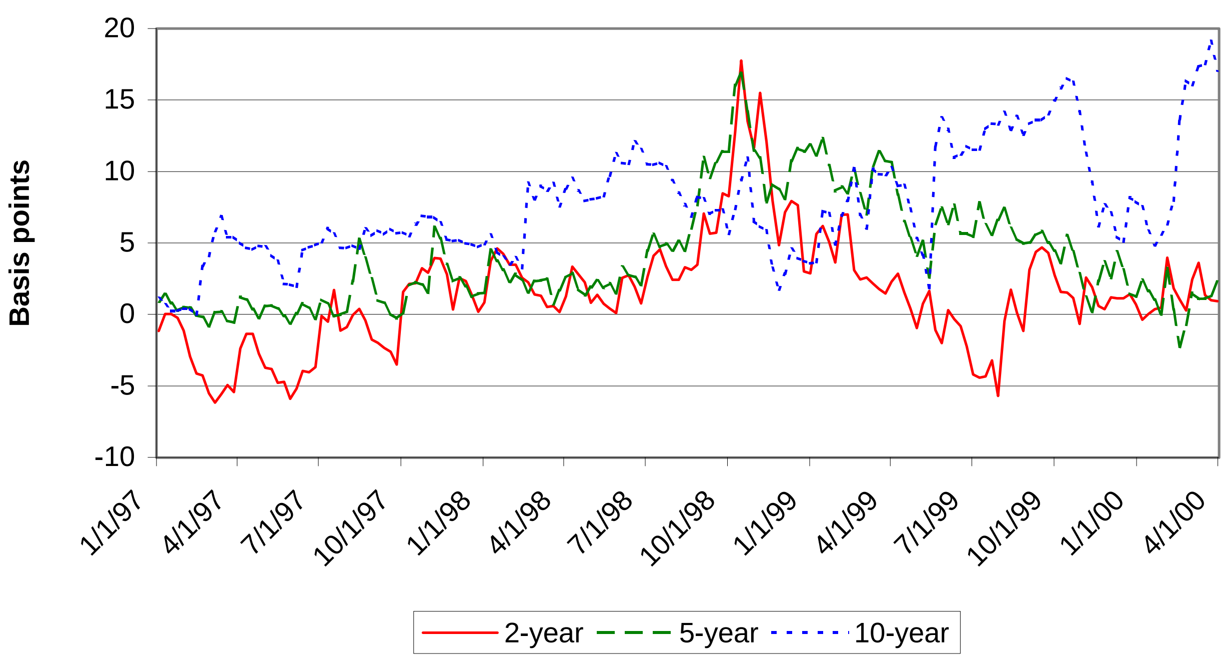


Chart 13B: On-the-Run/Second Off-the-Run Yield Spreads of Treasury Notes



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

Notes: The charts plot mean on-the-run/second 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 second off-the-run securities.