First draft, September 28, 2001
This draft, March 6, 2002

Are Larger Treasury Issues More Liquid? Evidence from Bill Reopenings*

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Forthcoming, *Journal of Money, Credit and Banking*

Abstract

This paper makes use of a natural experiment of the U.S. Treasury Department to examine the relationship between Treasury security issue size and liquidity. Treasury bills that were first issued with fifty-two weeks to maturity and then reopened at twenty-six weeks are shown to be more liquid than comparable maturity bills that were first issued with twenty-six weeks to maturity. The relationship is less pronounced when bills are on-the-run (the most recently auctioned bills of a given maturity) than when they are off-the-run, and persists when controlling for other factors that affect liquidity. The reopened bills are found to have higher yields (lower prices) than comparable maturity bills, showing that the indirect liquidity benefits of reopenings are more than offset by the direct supply costs.

JEL classification: H63; G14; G12

Keywords: Treasury Market; Liquidity; Bid-ask spread; Trading volume; Issue size

* I thank Kenneth Garbade, Narasimhan Jegadeesh, Charles Jones, Tony Rodrigues, Joshua Rosenberg, Til Schuermann, Jason Seligman, an anonymous referee, and seminar participants at the Federal Reserve Bank of New York, the University of Kentucky, and the Federal Reserve Bank of Cleveland/*Journal of Money, Credit and Banking* conference on Declining Treasury Debt for helpful comments. Research assistance of April Bang is gratefully acknowledged. The views expressed here are those of the author and not necessarily those of the Federal Reserve Bank of New York or the Federal Reserve System.

I. Introduction

The U.S. government budget surpluses of recent years have led to a significant paydown of the federal debt, with marketable debt falling from $3.5 trillion on March 31, 1997 to $2.8 trillion on June 30, 2001.[1] The paydown has prompted a number of debt-management changes, including the elimination of some securities, reduced issuance frequency of other securities, commencement of a program to regularly "reopen" coupon securities (whereby the Treasury sells additional quantities of existing securities), and the launch of a program to buy back outstanding securities.[2] The stated reason for these changes has been to maintain Treasury security issue sizes, and hence liquidity.[3]

This paper uses high frequency data to analyze the relationship between Treasury security issue size and liquidity. To do so, it makes use of a natural experiment of the Treasury Department whereby, until recently, every fourth 26-week bill was a reopening of a security originally issued as a 52-week bill. Treasury bills that were first issued with 52 weeks to maturity, and then reopened at 26 weeks, are thus compared to bills that were first issued with 26 weeks to maturity. The primary metric of comparison is the bid-ask spread, but other measures of liquidity and trading activity are also examined, including quote size, quote frequency, trading volume, trade frequency, and trade size. Across every measure, 26- and 13-week bills that originated as 52-week bills are found to be more liquid and more actively traded than those that originated as 26-week bills.

Despite its importance, the relationship between security issue size and liquidity has not heretofore been studied so directly, presumably due to the lack of good data with which to estimate liquidity. Studies have instead tried to infer the relationship between issue size and liquidity by examining the relationship between issue size and yield. The presumption is that if larger issues are

[1] Nonmarketable Treasury debt on June 30, 2001 totaled $2.9 trillion. Of this, $2.4 trillion was non-public debt (held in government accounts), $0.2 trillion was held by private investors in the form of savings bonds, and $0.2 trillion was held in a special series by state and local governments (www.publicdebt.treas.gov/opd/opddload.htm).
[2] See U.S. General Accounting Office (2001) for a discussion of recent debt-management changes.
[3] In May 1998, for example, Treasury announced that it would discontinue issuance of 3-year notes and reduce the issuance frequency of 5-year notes from monthly to quarterly "in order to continue to assure large, liquid issues" (www.treas.gov/press/releases/pr2416.htm).

more liquid – and investors value liquidity – than they will have lower yields (higher prices). Crabbe and Turner (1995) find no relation between issue size and yield in the corporate market, suggesting that liquidity is not related to issue size. Mullineaux and Roten (2001) uncover mixed results for the relationship between issue size and yield in the corporate market, but find that yields tend to be lower for issues drawn from larger registration filings.

This paper examines the relationship between issue size and yield in the Treasury market, but under the presumption that issue size may have two opposing effects. As mentioned, the greater liquidity of larger issues might be expected to lead to lower yields for these securities. Such a liquidity effect in the Treasury market is found by Amihud and Mendelson (1991), Kamara (1994), Warga (1992), and Elton and Green (1998). In contrast, increases in issue size might lead to higher yields if demand curves for individual securities are downward sloping. Such a supply effect in the Treasury market is found by Simon (1991), Simon (1994), Duffee (1996), and Seligman (2001).

This paper finds that larger issues have higher yields (lower prices), so that the indirect liquidity benefits of additional supply are more than offset by the direct supply costs. Reopened bills thus trade with a yield spread to comparable maturity bills that averages 2.4 basis points for 26-week bills and 3.2 basis points for 13-week bills. The findings add to recent evidence (Elton and Green (1998), Strebulaev (2001)) that the liquidity effect is not as large as that found by earlier studies, perhaps because the liquidity effect has diminished over time, and perhaps because the effect's importance is overstated by earlier studies.

In addition to comparing liquidity, trading activity, and yield spreads averaged over the entire lives of bills, the paper compares such measures at various stages of bills' lives. The effects of reopenings on liquidity and trading activity are found to be most pronounced when bills are off-the-run, and are often insignificant when bills are on-the-run. Another contribution of the paper in carrying out this comparison is to document liquidity and trading activity patterns over bill life cycles. While it has long been known that fixed-income securities become less liquid as they age,

and that off-the-run securities are less liquid than on-the-run securities, the absence of suitable data has prevented a detailed description of this phenomenon.[4] This paper clearly and completely documents bid-ask spreads and trading volume over bill life cycles, showing the sharp widening of bid-ask spreads and decline in trading volume that occur as bills go off-the-run.

The paper also estimates models of bid-ask spreads, trading volume, and yield spreads that control for other factors that might affect these variables, and that allow for a more explicit estimate of the effects of issue size. Twenty-six and 13-week bills that originated as 52-week bills continue to have narrower bid-ask spreads, higher trading volume, and higher yields than bills that originated as 26-week bills when controlling for these other factors. Furthermore, the importance of issue size is found to be related to the timing of issuance, such that the marginal quantity of securities issued at 13 weeks is more important to 13-week bill liquidity than the marginal quantity issued at 26 weeks (for the same security).

The paper proceeds as follows: Section II reviews the methodology and relevant institutional detail. Section III discusses the issuance and market data. Section IV presents the empirical results, including the basic univariate results, results over bills' life cycles, the model results, and the valuation results. Section V concludes.

[4] Brandt, Edelen, and Kavajecz (2001) document liquidity and trading activity at several stages in the lives of Treasuries in a paper that focuses on market behavior around Treasury and Federal Reserve announcements. This paper, using the same dataset, provides a higher frequency (day by day) analysis of liquidity over bill life cycles. Strebulaev (2001) performs a similar analysis for the number of quotes per day.

II. Methodology

A. Treasury Bill Reopenings

Until recently, the Treasury issued three bills on a regular basis: 52-week bills, 26-week bills, and 13-week bills.[5] Fifty-two week bills were issued every four weeks, and 26- and 13-week bills were (and are) issued weekly. Every 52-week bill was reopened as a 26-week bill at 26 weeks to maturity, and every 26-week bill was reopened as a 13-week bill at 13 weeks to maturity. As a result, every fourth 26-week bill was a reopening of (and thus fungible with) a bill with an original maturity of 52 weeks, while three of four 26-week bills were "new." Every 13-week bill was a reopening of a previously issued bill, with every fourth a reopening of a bill with an original maturity of 52 weeks (and thus reopened twice) and three of four reopenings of bills with original maturities of 26 weeks (and thus reopened once).

Reopenings of bills originally issued as 52-week bills thus occurred systematically, every four weeks, for both 26- and 13-week bills, independent of any economic or financial market developments, and independent of any (other) calendar patterns.[6] The quantity of securities auctioned at 26 and 13 weeks, as well as the timing and manner of such auctions, was also unrelated to whether the bill was originally issued as a 52-week bill or not. Treasury's practice of reopenings thus represented a natural experiment whereby securities with otherwise similar characteristics differed with regard to whether the securities had previously been issued, and thus had a significantly larger issue size than other securities. The even dispersal of bill reopenings over time made it a

[5] In addition to its regular offerings of bills, the Treasury issues cash-management bills (CMBs) on an *ad hoc* basis to meet temporary financing needs. Such bills have original maturities ranging from a single day to several months and may be new securities or reopenings of previously issued bills. The number of CMBs auctioned per year ranged from 7 to 14 between 1996 and 2000.

[6] From June 1983 through September 1997, settlement of the 13-week Treasury bill futures contract required delivery of the bill originally issued as a 52-week bill. Since October 1997, and for most of this paper's sample period, the contract's settlement has been independent of the 52-week auction cycle. Moreover, this contract has been relatively unimportant since the introduction of the eurodollar futures contract in the early 1980s (Stigum (1990, p. 757) McCauley (2001)).

particularly good experiment, as it reduced the likelihood of any other variable being correlated with such reopenings by chance.

The approach of the paper is to examine whether, and the extent to which, reopened bills are more liquid than new bills (or, in the case of 13-week bills, whether twice-reopened bills are more liquid than once-reopened bills). As the reopenings occurred independently of any other variables that might affect liquidity, a simple univariate comparison of reopened and new bills gives an unbiased estimate of the effect of reopenings, and hence larger issue sizes, on liquidity. Average effects are measured over the lives of 26- and 13-week bills, as well as at various stages in the bills' lives. Models of liquidity controlling for other variables are also estimated to more precisely ascertain the effects of reopenings, to directly relate issue size to liquidity, and to determine the effects of other variables on liquidity. The effects of reopenings on security value (relative to the value of comparable maturity securities) are assessed in a similar manner.

Securities with larger issue sizes are hypothesized to be more liquid due to reduced inventory holding costs. Inventory holding costs arise because of the risk to marketmakers of holding inventory, which is needed to provide trading immediacy to customers (e.g., Demsetz (1968), Stoll (1978), and Ho and Stoll (1981)). Such risk increases with the length of time that positions are held. The holding period presumably decreases with issue size because larger issues are more actively traded and/or because it is less costly for marketmakers to solicit offsetting trades from investors.

In fact, the reopening of 52-week bills was specifically introduced by Treasury to improve bill liquidity. From 1972 to 1979, 52-week bills were issued every four weeks on a Tuesday to mature 52 weeks later on a Tuesday. Such bills were therefore not fungible with subsequent issues of 26- and 13-week bills, which were issued and matured on Thursdays. In November 1979, Treasury announced that future 52-week bills would mature on Thursdays, and would be fungible with 26- and 13-week bills that had the same maturity date. Treasury said the change would "reduce

the number of separate bills outstanding, facilitate market trading, and improve liquidity for the 52-week bills."[7]

A factor that might mitigate the effects of reopenings on liquidity is that dealers tend to buy a large fraction of Treasury issues at auction, and then sell off the securities as they age.[8] By the time a security is reopened, the effective (tradable) supply of the existing issue might be quite small if much of it is held by buy-and-hold investors who are reluctant to sell (or lend) the security. In such a case, the relationship between issue size and liquidity might depend on the timing of issuance, with the quantity issued at the most recent auction more relevant than the quantity issued at earlier auctions (this hypothesis is tested). Nonetheless, as long as the effective supply from earlier auctions is greater than zero – and effective supply affects liquidity – then reopened securities should be more liquid.

Reopenings could also be expected to affect bill valuation, both because of a direct supply effect and because of an indirect liquidity effect.[9] The liquidity effect pertains to the hypothesis that more liquid securities will have lower yields (higher prices) if investor demand for these securities is greater, all else equal. Such an effect is found in several Treasury market studies. Amihud and Mendelson (1991) thus find that more liquid bills have average yields 43 basis points lower than less liquid notes with the same cash flows. Kamara (1994) also finds a significant yield differential (averaging 34 basis points) between bills and notes with the same cash flows, which he attributes to

[7] Treasury Bulletin (November 1979, p. VII). Bennett, Garbade, and Kambhu (2000, p. 91) provide a more detailed description of the 52-week bill's history in a paper that makes suggestions to improve Treasury market liquidity.
[8] Charts produced for the Treasury's August 2001 Quarterly Refunding indicate that dealers took down 82% of the 10-year note and 65% of the 30-year bond at the three preceding auctions (figures for shorter-term securities are not reported). Such purchases at auction are partially offset by dealers' pre-auction sales to investors.
[9] Reopenings might also be expected to affect the cost of borrowing bills in the repurchase agreement (repo) market, which in turn might affect bill value (see, for example, Duffie (1996) and Jordan and Jordan (1997)). Repo data available for a subset of the paper's sample (starting July 14, 1999) shows that bills are not typically "on special" and that specialness is not related to whether a bill was first issued as a 52-week bill or not. The spread between the general collateral rate and the specific borrowing rate averages 9.4 basis points for on-the-run 26-week bills that are reopened, insignificantly *higher* than the 9.1 basis point average for bills that are new (9:00 a.m. quote data from GovPX is used). On-the-run 13-week bills that are twice reopened have an average spread of 13.0 basis points, insignificantly lower than the 14.7 basis point average for those that are only once reopened.

tax as well as liquidity differences. Warga (1992) finds that less liquid off-the-run bonds are priced to return an average premium of 55 basis points over more liquid, but otherwise equivalent, on-the-run bonds.

Recent studies find a more modest liquidity effect, perhaps because the liquidity effect has diminished over time, and perhaps because the effect's importance is overstated by earlier studies. Elton and Green (1998) find that more liquid Treasuries (as proxied by trading volume) have lower yields, but that the range of yield differences is on the order of 13 basis points (from the lowest to the highest volume deciles). Strebulaev (2001) finds average yield differences between bills and notes with identical cash flows of just 10 basis points, and finds insignificant yield differences between Treasury coupon securities with identical cash flows but differing liquidity.

The supply effect pertains to the hypothesis that larger issues will have higher yields (lower prices) if demand curves for individual issues are downward sloping, all else equal. While demand curves for individual bills may be relatively flat, as transaction costs are low and many close substitutes are available (thereby facilitating arbitrage), bills are not perfect substitutes for one another, and certain investors have a preference for bills maturing on certain days due to cash-management needs. Park and Reinganum (1986) thus find that bills maturing at the end of the month have significantly lower yields than bills maturing at the beginning of the next month. Ogden (1987) uncovers a similar phenomenon, which he attributes to institutions' month-end concentration of payments.

Such a supply effect is found in several Treasury market studies. Simon (1991) and Seligman (2001) find that announcements of cash-management bills (CMBs), which represent additional (and largely unexpected) supplies of outstanding bills, cause the yields on these bills to rise significantly. Simon (1994) finds that differences in supplies of 13- and 12-week bills have significant effects on their yield differentials, with each $1 billion increase in issue size associated

with a yield increase of 0.4 basis points. Duffee (1996) finds evidence that supply is positively related to yields for 1- and 2-month bills in a study of bill market segmentation.

This paper uses recent data (1996 to 2000) to assess the relationship between issue size and yield. The value of liquidity may have increased in recent years with the reductions in new Treasury issuance and with the fall 1998 financial market turmoil and associated "flight-to-liquidity" (Committee on the Global Financial System (1999), Fleming (2000a, 2000b)). In contrast, the evidence from other studies (Elton and Green (1998) and Strebulaev (2001)) suggests that the value of liquidity may actually be lower than that found by earlier work.

In February 2000, the Treasury reduced the issuance frequency of the 52-week bill from every four weeks to every 13 weeks, and in February 2001 it eliminated issuance of the bill altogether. Neither of these changes directly affects the paper's analyses. Furthermore, the paper's analyses remain relevant for several reasons. First, the Treasury could decide to reintroduce the 52-week bill if its financing needs increase in future years. Second, the decision of whether securities should be reopened or not arises in other contexts, most recently with the introduction of the 4-week bill, announced in July 2001. (The 4-week bill is offered weekly, as a reopening of previously issued bills.) Finally, the broader issue as to the relationship between issue size, liquidity, and value is relevant to a wide range of Treasury debt-management decisions and also has implications for other markets.

B. Treasury Bill Life Cycle

All regularly issued bills in the paper's sample period are issued on a Thursday and mature on a Thursday 52, 26, or 13 weeks later (barring holidays). Twenty-six and 13-week bills are auctioned on the Monday preceding their issuance, while 52-week bills are auctioned on the Tuesday preceding their issuance (again, barring holidays). As mentioned, the most recently auctioned securities of a given maturity are called "on-the-run." Twenty-six and 13-week bills are thus on-the-run from Tuesday, the day following auction, through the following Monday, the day of the next

auction. Securities that are no longer on-the-run are called "off-the-run," with the most recently issued off-the-run security called "first off-the-run," the second most recently issued called "second off-the-run," etc.

Treasury securities also trade before they are issued on a "when-issued" basis. When-issued trading starts when securities are first announced for auction and proceeds through the day preceding issuance. Twenty-six and 13-week bills thus trade when-issued from the Thursday preceding auction – at which time the bills are announced for auction – through the Wednesday after auction.[10] Before August 20, 1998, such bills were announced for auction on the Tuesday preceding auction and the when-issued period was thus two days longer. While most Treasury market trades settle the next trading day, when-issued trades settle on issuance day.

As every 26-week bill is reopened as a 13-week bill, 26-week bills are labeled as such from the announcement of the 26-week bill auction through two trading days preceding the issuance at 13 weeks to maturity. After that day, trading in the old 26-week bill and the new 13-week bill is fungible, and the security is labeled a 13-week bill. Thirteen-week bills are labeled as such from the announcement of the 13-week bill auction through the trading day preceding maturity (there is no trading on the maturity day). There is thus a period of several days (from the announcement of the 13-week auction through two days preceding issuance) over which a security trades as both an old 26-week bill and a new 13-week bill, reflecting the differing settlement days for the two types of trades.[11]

[10] Bills are thus both when-issued and on-the-run on the Tuesday and Wednesday following an auction but before issuance. In this paper (and following market convention), bills are labeled on-the-run on these days, with the when-issued label reserved for trading before, and on, auction day.

[11] On Mondays, for example, the auctioned 13-week bill trades in the when-issued market for settlement on Thursday (the issuance day). The same security trades as an off-the-run 26-week bill that day for settlement on Tuesday (the next trading day). As of Wednesday, the next trading day is the issuance day, so there is no longer a distinction between the old 26-week bill and the new 13-week bill.

C. Interdealer Broker Market

The secondary market for U.S. Treasury securities is a multiple-dealer over-the-counter market.[12] Trading takes place around-the-clock during the week, although 95% of it occurs during New York hours, roughly 7:30 a.m. to 5:00 p.m. (Fleming (1997)). The predominant marketmakers are the primary government securities dealers – those dealers with whom the Federal Reserve Bank of New York interacts directly in the course of its open market operations.[13] The dealers trade with the Fed and their customers, and they trade with one another. The core of the Treasury market and the source of our data is the interdealer broker market, which accounts for nearly all interdealer trading. During the first half of 2001, the dealers traded an average of $296 billion per day in Treasuries: $154 billion through interdealer brokers and $142 billion otherwise.[14]

The interdealer brokers facilitate information flows in the market while providing anonymity to the dealers. They offer proprietary electronic screens (and lately web sites) that post the best bid and offer prices of the dealers, along with the associated quantities bid or offered. Minimum trade sizes for bills are $5 million (face value), with additional amounts in increments of $5 million. The quotes are binding until and unless they are withdrawn. Dealers execute trades by notifying brokers (by phone, and lately electronically), who then post the resulting trade price and size. In compensation for their services, the brokers charge a small fee. The major brokers are BrokerTec, Cantor Fitzgerald/eSpeed, Garban-Intercapital, Hilliard Farber, and Tullett & Tokyo Liberty.

An interesting feature of the interdealer broker market is the negotiation that takes place over quantities (Boni and Leach (2001) provide a detailed analysis of this phenomenon). Trades often go through a "work-up" process in which a broker mediates an increase in the trade size beyond the

[12] For more detailed descriptions of the Treasury market, see Dupont and Sack (1999) and Fabozzi and Fleming (2000).
[13] There were 25 primary dealers as of September 15, 2001. The list of dealers is available at www.newyorkfed.org/pihome/news/opnmktops/.
[14] There is some double-counting in the figures, especially for interdealer broker trading, as trades between primary dealers are reported by both parties. Trading volume statistics are available at www.newyorkfed.org/pihome/statistics/.

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. In contrast to the negotiation over trade size, 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 bid-ask spreads provide an accurate indication of the spreads facing market participants.

D. Liquidity and Valuation Measures

The primary variable used to compare the liquidity of bills is the bid-ask spread. The bid-ask spread directly measures the cost of executing a trade (albeit a single trade of limited size). Furthermore, an analysis of Treasury market liquidity by Fleming (2001) finds that the bid-ask spread is highly correlated with a more sophisticated measure (suggested by Kyle (1985)) that considers the rise (fall) in price that typically occurs with a buyer-initiated (seller-initiated) trade. A secondary measure of liquidity employed is the average quote size, which refers to the quantity of securities that dealers are willing to buy or sell at quoted prices. Several measures of trading activity are also employed, including trading volume, trade frequency, trade size, and quote frequency.

The valuation of bills is assessed using butterfly spreads. Butterfly spreads are calculated by comparing security yields to the interpolated yields of securities with maturities longer and shorter than that of the given security. For example, the butterfly spread of a bill with twelve weeks to maturity is calculated by comparing its yield to the average yield of the bills with eleven and thirteen weeks to maturity. Butterfly spreads allow for a cleaner test of valuation effects than yields alone, as they control for yield levels. While the spreads do not account for curvature in the yield curve, the average curvature is controlled for by differencing the spreads between the treatment group (bills originated as 52-week bills) and the control group (bills originated as 26-week bills).

III. Data Description

A. Issuance Data

The paper examines every regularly issued bill maturing over the 4½-year period from July 1, 1996 to December 31, 2000. The sample thus encompasses 235 bills, 58 of which were originally issued as 52-week bills (and later reopened as 26-week bills), and 177 of which were originally issued as 26-week bills. As described earlier, all 235 bills were later reopened as 13-week bills. All 235 bills were auctioned under the regime by which every fourth 26-week bill and every fourth 13-week bill were reopenings of bills originally issued as 52-week bills.[15]

The first 26-week bill in the sample was announced for auction on December 26, 1995, auctioned on January 2, 1996, issued on January 4, 1996, and matured on July 5, 1996. The first 13-week bill in the sample was a reopening of this same bill – announced for auction on March 26, 1996, auctioned on April 1, 1996, issued on April 4, 1996, and matured on July 5, 1996. The last 26-week bill in the sample was announced for auction on June 22, 2000, auctioned on June 26, 2000, issued on June 29, 2000, and matured on December 28, 2000. The last 13-week bill in the sample was a reopening of this same bill – announced for auction on September 21, 2000, auctioned on September 25, 2000, issued on September 28, 2000, and matured on December 28, 2000.

The sample includes bills that were later reopened as CMBs. The Treasury auctioned CMBs on 41 occasions for maturity during the sample period, with maturities ranging from 1 to 80 days. Twenty of these 41 auctions involved a security originally issued as a CMB, one of which had previously and originally been issued as a CMB. Two of the 41 auctions were reopenings of bills that were originally issued as 52-week bills. The remaining 19 of the 41 auctions were reopenings of bills that were originally issued as 26-week bills, five of which had already been reopened once as

[15] As the Treasury reduced the issuance frequency of the 52-week bill in February 2000, the last bill issued under the old regime was auctioned February 29, 2000 and matured March 1, 2001. This last bill became costly to borrow in the repo market, illiquid relative to previous 52-week bills, and expensive relative to Treasuries with similar maturities (Fleming (2000b)).

CMBs. Sixteen bills that were later reopened as CMBs are thus included in the sample, 2 of which were originally issued as 52-week bills, and 14 of which were originally issued as 26-week bills.

Table 1 reports auction and issue size statistics for the bills in the sample.[16] Average auction sizes of reopened and new 26-week bills are nearly the same, at $11.9 and $12.0 billion, respectively. The amounts previously issued for the reopened 26-week bills reflect the original issue amounts for these securities at 52 weeks, and the total issue sizes for these bills reflect the original issue amounts plus the amounts auctioned at 26 weeks. Average auction sizes for twice- and once-reopened 13-week bills are also quite similar, at $11.7 and $11.9 billion, respectively. In both cases, previously issued amounts include the amounts issued at 26 weeks, and in the case of the twice-reopened bills, such amounts include the amounts issued at 52 weeks.

B. Market Data

The paper's source for market data is GovPX, Inc. GovPX consolidates data from several of the brokers in the interdealer market and transmits the data to subscribers in real time through online vendors.[17] GovPX data is particularly good for examining Treasury bills as virtually all bill market activity through interdealer brokers is reported by GovPX, even though the share of coupon trading reported by GovPX has declined (Boni and Leach (forthcoming)). 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). The paper uses a history of these postings, provided by GovPX, that includes the time of each posting to the second.

The data is cleaned and processed as follows: First, due to the manner in which the data is recorded, completed trade sizes are inferred from reported increases in aggregate daily volume for

[16] Auction and issue sizes are from the U.S. Treasury (www.publicdebt.treas.gov/of/ofaicqry.htm). They include amounts sold to all parties, including Federal Reserve Banks, foreign and international monetary authorities, and TreasuryDirect customers.

[17] The contributing brokers (as of the end of the sample period) are Garban Intercapital, Hilliard Farber, and Tullett & Tokyo Liberty. One non-contributing broker is Cantor Fitzgerald/eSpeed, which is thought to be more active in the long end of the market. Another non-contributing broker is BrokerTec, which was launched in June 2000 near the end of the paper's sample period.

each security. Second, to prevent the same quote from being counted multiple times, the analysis of quotes is limited to those for which the bid price, bid size, offer price, or offer size is different from the previous listed quote for that security. To exclude suspect data, the analysis of quote sizes is further limited to quote sizes of $1,250 million or less, and the analysis of bid-ask spreads is limited to spreads between -2.5 and 75 basis points. Suspect prices are also excluded, identified by day to day price (bid-ask midpoint) changes of 80 basis points or more that are immediately followed by similar sized (within 15%) changes of the opposite sign.[18]

The market data is analyzed from the day the first security is announced for auction (December 26, 1995) through the trading day preceding the maturity of the last security (December 28, 2000). (As mentioned, there is no trading on maturity day.) The sample thus covers 262 weeks, and 1307 weekdays. After excluding 51 holidays, 1256 trading days remain in the sample.

C. Estimating Liquidity and Valuation Measures

The liquidity and trading activity measures presented in the paper are derived from daily measures. Daily trading volume, the daily number of trades, and daily average trade size are self-explanatory. The daily number of quotes is defined as the number of two-sided quotes per day (a quote is two-sided if there is a bid and an offer price posted at the same time). The daily bid-ask spread is defined as the average spread between bid and offer rates for two-sided quotes. (Bills are quoted in terms of a discount rate; this yield measure is used throughout the paper.) The daily quote size is defined as the average quantity of securities bid for or offered for sale at the best bid and offer prices for one- or two-sided quotes.

[18] The data cleaning and processing closely follows that of Fleming (2001), which has a detailed data appendix. Two differences in data cleaning from that paper are as follows: First, the upper threshold for excluding bid-ask spreads is 75 basis points here (versus 25 basis points), and second, the screen for suspect price data is an 80 basis point change here (versus a 10 basis point differential in changes). Both differences come from the fact that this paper examines short-term Treasury bills for which bid-ask spreads and price changes can be quite high (in yield terms).

The butterfly spreads used to assess valuation are computed by comparing bill yields to the interpolated yields of the bills with maturities one week longer and one week shorter than that of the given bill. Such spreads are calculated for every bill and every possible day in the sample, but are not calculated when a bill has a week to maturity or less (when there is not a shorter-term bill outstanding) or when a 26-week bill has been trading for less than a week (when there is not a longer-term 26-week bill). They are also not calculated when yields are missing, which sometimes occurs because of missing data, but more often occurs because a security was not traded or quoted on a given day.[19] To minimize the number of missing spreads, and to mitigate problems associated with "bid-ask bounce," the calculations are performed with (closing) bid-ask midpoints (results are quite similar using transaction yields).

After calculating the various measures for each bill on a daily basis, per security averages are then calculated over the lives of the bills or at particular stages of bills' lives. Per security averages are only calculated for the subperiods that bills are labeled as 26-week bills or 13-week bills. In particular, 26-week bill averages are calculated from the time the 26-week auction is announced through two trading days prior to the bill's issuance at 13 weeks, but not over the period that the bill trades as a 13-week bill. Subgroup averages for bills that originated as 52-week bills and those that originated as 26-week bills are then calculated and presented in several of the tables. Alternatively, for several of the figures, the measures are instead averaged by days to maturity (across bills) for bills that originated as 52-week bills and for those that originated as 26-week bills.

[19] On average, 26-week bills in the sample are outstanding for 68 trading days (including the when-issued period), have two-sided quotes for 62 of those days, and trade on 51 of those days. Thirteen-week bills are outstanding for 68 trading days, have quotes for 67 days, and trade on 64 days.

IV. Empirical Results

A. Effects of Reopenings on Liquidity

The basic results on the effects of reopenings are presented in Table 2. Panel A shows that bid-ask spreads average 1.8 basis points for reopened 26-week bills, 0.4 basis points (17%) narrower than the 2.2 basis point average for new 26-week bills. The difference is significantly different from zero at the 1% level. Average quote sizes are also significantly different for reopened bills and new bills, at $9.0 million versus $8.3 million, respectively. Similar results are presented for 13-week bills in Panel B. Bid-ask spreads average 4.2 basis points for twice-reopened 13-week bills, 1.6 basis points (28%) narrower than the 5.7 basis point average for once-reopened 13-week bills. Quote sizes are also larger, at $10.0 million for twice-reopened bills versus $9.5 million for once-reopened bills. The evidence for both liquidity measures and bills is thus consistent: bills with larger issue sizes – having been originally issued as 52-week bills – are more liquid.

Reopened bills are also more actively quoted and traded. Quotes per day, daily trading volume, and trades per day are all significantly higher for reopened versus new 26-week bills and for twice- versus once-reopened 13-week bills. Daily trading volume, for example, averages $208 million for reopened 26-week bills and $154 million for new 26-week bills, with the $54 million difference statistically significant at the 1% level. Trade size is the one variable that is not significantly different between the subgroups for both sets of bills. Trade size thus averages $20.6 million for reopened 26-week bills, insignificantly higher than the $20.4 million average for new 26-week bills. The difference in average trade size is statistically significant for 13-week bills (at the 5% level), with trade size averaging $22.2 million for twice-reopened bills versus $21.3 million for once-reopened bills.

B. Reopening Effects over Bills' Life Cycles

The effects of reopenings on liquidity are not necessarily constant over Treasury bills' life cycles. Figure 1 thus compares bid-ask spreads for the two subsets of 26- and 13-week bills by days

to maturity. It shows that bid-ask spreads tend to be at their narrowest when bills are on-the-run (and on auction day, when they trade when-issued) and that they widen as bills age. The spreads become quite wide as bills approach maturity, although (annualized) yield spreads translate into smaller and smaller price differences as time to maturity decreases. The figure also shows that bills that originated as 52-week bills have narrower spreads over their entire lives, on average, with the possible exception of the times that bills are when-issued and on-the-run. Finally, a day-of-week pattern is evident, with spreads wider on Mondays and Fridays.[20]

Bid-ask spreads over bills' life cycles are more formally compared in Table 3. Spreads are seen to be significantly different for every off-the-run interval for both 26- and 13-week bills. Spreads are not significantly different during the when-issued period for either bill, or during the on-the-run period for 13-week bills. The when-issued results for the 26-week bill are somewhat surprising as one might expect that bid-ask spreads would be narrower when a security with identical cash flows is already trading in the market (and has been for six months). Nonetheless, the results suggest that the additional supply is of most relevance when securities are off-the-run. This may arise because dealers have ready and adequate access to on-the-run securities since they are so actively traded. In contrast, dealers may need to secure off-the-run securities from investor accounts to cover positions taken in these securities, a process that is quicker and less costly when the investor base holds a larger supply.

Figure 2 shows a comparison of trading volume over bills' life cycles. Bills are most actively traded when they are on-the-run (and on auction day, when they trade when-issued). Trading falls off sharply as the securities go off-the-run, but soon stabilizes. As with spreads, a day-of-week pattern is evident, with trading lowest on Mondays and Fridays. Also like spreads, differences between the subsets of bills are most distinct when the securities are off-the-run for both 26- and 13-

[20] The figures that plot measures by days to maturity exclude bills with Friday maturities so that a given number of days to maturity maps into the same weekday for every included bill.

week bills. Table 4, Panel A shows that the differences are significantly different for the when-issued interval and for every off-the-run interval for 26-week bills, but not for the on-the-run interval. Table 4, Panel B shows that the differences are statistically significant for the on-the-run interval and for six of the twelve off-the-run intervals, but not for the when-issued interval.[21]

Figures for trades per day and quotes per day look quite similar, and quote sizes fairly similar, to those for trading volume.[22] The differences between the subsets of bills are quite evident when the bills are off-the-run (although less so for quote sizes), and barely evident when the bills are when-issued and on-the-run. The patterns for trade sizes look quite different. Trade sizes are relatively constant across bills' life cycles, although they appear somewhat higher when bills are when-issued (and on-the-run for 13-week bills). There are no distinct differences between the subsets of bills for either 26- or 13-week bills, with the exception of the last three weeks before maturity, when trade sizes are larger for twice- versus once-reopened bills.

C. Models of Bid-Ask Spreads and Trading Volume

As discussed earlier, models of liquidity controlling for other variables are estimated to more precisely ascertain the effects of reopenings, to directly relate issue size to liquidity, and to determine the effects of other variables on liquidity. Figure 3 suggests two control variables to include in such models. The figure plots bill bid-ask spreads by auction date, delineating between bills originated as 52-week bills and those originated as 26-week bills. For both 26- and 13-week bills, spreads tend to be wider for bills outstanding during the fall 1998 financial market turmoil. This was a period of high volatility and wide bid-ask spreads more generally (Committee on the Global Financial System (1999), Fleming (2000a, 2001)). The figure also shows a general uptrend in spreads over time,

[21] The differences are statistically significant for every off-the-run interval when bills reopened as CMBs are excluded. The multivariate analysis in the next subsection controls for the issuance of CMBs.
[22] These additional figures are available from the author.

which might be explained by the fall 1998 financial market turmoil, Y2K, the federal debt paydown, and/or other factors.

Two control variables included in the regression models are thus volatility and a trend term. Higher volatility leads to wider bid-ask spreads in inventory models, and has been found to be correlated with bid-ask spreads in numerous studies (e.g., Benston and Hagerman (1974), Branch and Freed (1977), and Garbade and Rosey (1977)). There is also an extensive literature on the positive relationship between volatility and trading volume (Karpoff (1987) provides a review). The specific volatility measure used is the standard deviation of daily yield changes for the on-the-run 2-year note (calculated for the days that the given bill is traded). Two-year note volatility is used as a proxy for market volatility, rather than the volatility of the bills in the sample, as bill volatility could itself be influenced by bill liquidity. The trend term is defined to be one for the first bill in the sample, and increases by one (weekly) for each subsequent bill. One other control variable for the off-the-run 13-week bills is a dummy variable equal to one if the bill was reopened as a CMB, and equal to zero otherwise.[23]

The bid-ask spread regression results are presented in Table 5. As spreads were shown to differ across bills' life cycles, results are presented separately for the when-issued, on-the-run, and subsequent off-the-run stages. Two models are estimated for each of these stages, one of which includes a dummy variable equal to one if a bill was originated as a 52-week bill (and equal to zero otherwise), and one of which includes the 52-week auction size (set equal to zero for bills first issued at 26 weeks).[24] The 26-week auction size enters as a separate independent variable from 52-week

[23] In the sample, every reopening of a regularly issued bill as a CMB occurred when the bill was an off-the-run 13-week bill, so it is in this subgroup that one would expect the dummy variable to be (most) significant.

[24] The first model is of interest as it allows for a direct comparison between the dummy variable coefficient and the differences presented in Table 3. The second model is of interest as it allows for a comparison of the effects of auction size across auctions at different maturities. As the two variables are so highly correlated (correlation coefficient = 0.992) they tend to be individually insignificant when included in the same model.

auction size in the second model (and from 13-week auction size in Panel B) to allow the effects of size to differ depending on the time of issuance.

The results show that reopenings have a strong effect on bid-ask spreads of off-the-run bills, but a modest or insignificant effect on spreads of when-issued and on-the-run bills (consistent with the univariate results). Similar significance levels are seen when the reopening dummy variable is replaced by the actual quantity of securities auctioned at 52 weeks. In addition, the quantity of securities auctioned at 26 weeks significantly affects spreads of 26-week bills (along with spreads of off-the-run 13-week bills), and the quantity of securities auctioned at 13 weeks significantly affects spreads of 13-week bills. Furthermore, the effects of issue size seem to differ depending on the time of issuance. For off-the-run 13-week bills, for example, a $1 billion increase in issue size is associated with an average spread reduction of 0.67, 0.31, or 0.12 basis points, depending on whether the additional issuance comes at 13, 26, or 52 weeks, respectively. The hypothesis that all three coefficients are equal is rejected at the 1% level (using a Wald test). Such results lend credence to the hypothesis that Treasuries get sold off by dealers as they age and that their effective supply thereby declines. Finally, spreads are shown to increase with 2-year note volatility across the board, consistently widen over the sample period, and are significantly narrower for off-the-run 13-week bills that are reopened as CMBs.

Trading volume regression results are presented in Table 6. Again, the results show that reopenings have a strong effect for off-the-run bills, but a modest or insignificant effect for when-issued and on-the-run bills (consistent with the univariate results). The quantity auctioned at 26-weeks significantly affects trading volume of 26-week bills (along with that of when-issued and off-the-run 13-week bills), and the quantity auctioned at 13 weeks significantly affects trading volume of off-the-run 13-week bills. The effects of issue size seem to differ depending on the time of issuance, but the results are weaker here. For off-the-run 13-week bills, for example, a $1 billion increase in issue size is associated with an average increase in daily trading of $7 million, $5 million, or $4

million, depending on whether the additional issuance comes at 13, 26, or 52 weeks, respectively. The hypothesis that all three coefficients are equal is not rejected here (p-value = 0.22). Finally, volume is shown to increase with 2-year note volatility for all but off-the-run 26-week bills, decreases over the sample period for all but when-issued 13-week bills, and is significantly higher for off-the-run 13-week bills that are reopened as CMBs.

D. Valuation Effects of Reopenings

The basic valuation results are presented in Table 7. The table compares the average butterfly spread of bills originally issued as 52-week bills to the average spread of those originally issued as 26-week bills. As with the liquidity measures, per security averages are first calculated by averaging the daily measure across the bills' lives (or stages of their lives), and group averages are then calculated by averaging across bills. As mentioned, the spreads are not calculated when a 26-week bill has been trading for less than a week (or when a bill has a week to maturity or less) and are thus absent for the when-issued period of 26-week bills. The univariate statistics are calculated only for bills for which both of the bracketing securities were originally issued as 26-week bills.

As shown in Panel A of Table 7, butterfly spreads average 2.2 basis points over the lives of reopened 26-week bills and -0.3 basis points over the lives of new 26-week bills. The 2.4 basis point difference is significantly different from zero at the 1% level. As shown in Panel B, butterfly spreads average 5.4 basis points over the lives of twice-reopened 13-week bills and 2.1 basis points over the lives of once-reopened 13-week bills with the 3.2 basis point difference significantly different from zero at the 1% level. Bills with larger issue sizes – having been originally issued as 52-week bills – have higher yields, consistent with the findings of Simon (1991, 1994), Duffee (1996), and Seligman (2001).

To assess how reopenings affect valuation over bills' life cycles, differences in butterfly spreads are plotted by days to maturity in Figure 4. Shaded and solid circles indicate whether the differences are significantly different from zero at the 5% and 1% levels, respectively. The average

differences are always positive for the 26-week bill, usually significantly so, and show no clear trend over time. The differences for the 13-week bill are also always positive, albeit usually insignificantly so during the off-the-run period, and increase sharply as maturity nears. As noted earlier, (annualized) yield spreads translate into smaller and smaller price differentials as time to maturity decreases.

As with bid-ask spreads and trading volume, butterfly spreads are modeled to depend on reopenings, auction sizes, and other variables that are suspected to affect the spread. Following Park and Reinganum (1986), Ogden (1987), and Simon (1994), the models include dummy variables to control for the prospect that bills maturing near the end of the month have lower yields (the dummy variable equals one if the given bill is the last one maturing in a month and zero otherwise). As with the earlier models, a trend term is included to control for any changes in the spread over time that are not explained by the other independent variables. A CMB dummy variable is also included for 13-week bills.[25] The independent variables (except the trend term) are adjusted to account for the fact that the dependent variable is calculated not only with the yield of the given bill, but with the yields of the adjacent bills.[26] This adjustment allows the multivariate analysis to be carried out cleanly on the full sample of bills.

The butterfly spread regression results are presented in Table 8. The results show that reopenings have a positive and significant effect on yields (consistent with the univariate results). However, the quantity of securities auctioned at 26-weeks is insignificant for both 26- and 13-week bills and the quantity auctioned at 13 weeks is insignificant for 13-week bills. The end-of-month

[25] Even though CMBs were only issued during the off-the-run stage of 13-week bills' lives, the variable is included for all three stages as CMBs are at least partially predictable. The variable was also tested in specifications for the 26-week bill: the coefficient was insignificant in the on-the-run specifications and significant at the 10% level (but of the opposite sign to the predicted one) in the off-the-run specifications.

[26] To illustrate, if reopenings are associated with lower yields, then the predicted yields on adjacent bills should be higher than otherwise (since predicted yields are calculated using adjacent yields). The reopening dummy variable is thus defined to be one for reopened bills, -0.5 for adjacent bills, and 0 otherwise. The other variables are adjusted accordingly.

maturity coefficient is negative for all specifications (and significantly so for all but off-the-run 13-week bills) indicating that bills maturing near the end of the month have lower yields (consistent with the findings of earlier studies). The CMB variable is significantly positive for on-the-run and off-the-run 13-week bills, showing that bills reopened as CMBs tend to have higher yields. The trend term is insignificant for all but when-issued 13-week bills.

V. Conclusion

This paper makes use of a natural experiment of the U.S. Treasury Department to examine the relationship between Treasury security issue size and liquidity. Treasury bills that were first issued with 52 weeks to maturity, and then reopened at 26 weeks, are shown to be more liquid than comparable maturity bills that were first issued with 26 weeks to maturity. Reopened 26-week bills thus have an average bid-ask spread 0.4 basis points (17%) narrower than new 26-week bills (over their lives), and twice-reopened 13-week bills have an average bid-ask spread 1.6 basis points (28%) narrower than once-reopened bills. The effects of issue size on liquidity are particularly pronounced when bills are off-the-run, and persist when controlling for other factors that affect liquidity.

The greater liquidity of reopened securities does not result in lower yields (higher prices) for these securities. In fact, reopened 26-week bills trade with a statistically significant yield spread of 2.4 basis points (on average) to new 26-week bills, and twice-reopened 13-week bills trade with a yield spread of 3.2 basis points to once-reopened 13-week bills. These results show that the indirect liquidity benefits of reopenings are more than offset by the direct supply costs, and thus add to recent evidence suggesting that the implications of liquidity for security valuation may not be as great as previously thought.

As reopened securities are more liquid than new securities, the findings support efforts to make Treasury securities fungible in cases where maturity dates coincide. Holding the quantity of maturing securities fixed, fungibility increases liquidity and should lead to higher prices and lower

Treasury borrowing costs. However, the findings also show that concentrating the maturities of Treasuries has costs. At some point, larger-sized issues have lower prices, increasing Treasury's borrowing costs, as the direct costs of additional supply outweigh the indirect benefits of improved liquidity. These results suggest that efforts to improve liquidity that also concentrate Treasury security payments on fewer and fewer dates should proceed cautiously.

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TABLE 1
AUCTION AND ISSUE SIZES

	26-WEEK BILL		13-WEEK BILL	
	Reopened (n=58)	New (n=177)	Twice Reopened (n=58)	Once Reopened (n=177)
Mean				
Auction size	11.9	12.0	11.7	11.9
Previously issued	17.8	-	29.7	12.0
Issue size	29.7	12.0	41.5	23.9
Median				
Auction size	11.6	11.7	11.6	11.6
Previously issued	18.4	-	29.8	11.7
Issue size	29.8	11.7	40.8	23.6
Standard deviation				
Auction size	1.2	1.2	1.5	1.6
Previously issued	2.0	-	2.6	1.2
Issue size	2.6	1.2	2.9	2.3
Minimum				
Auction size	9.6	9.0	8.7	8.8
Previously issued	14.8	-	14.8	9.0
Issue size	25.2	9.0	35.6	19.5
Maximum				
Auction size	15.6	16.4	14.6	15.8
Previously issued	21.0	-	21.0	16.4
Issue size	34.4	16.4	46.6	30.1

SOURCE: Author's calculations, based on data from the U.S. Treasury.
NOTES: Auction and issue size statistics are reported for bills originally issued as 52-week bills and for those originally issued as 26-week bills for both 26- and 13-week bills. The auction size refers to the quantity sold at the noted maturity of that bill. The previously issued amount refers to the quantity sold at all earlier auctions of that bill. The issue size refers to the total quantity sold through the issuance at the noted maturity of that bill. All amounts are in billions of U.S. dollars (face value).

TABLE 2
EFFECTS OF REOPENINGS ON LIQUIDITY AND TRADING ACTIVITY

	PANEL A: REOPENED VS. NEW 26-WEEK BILLS		
	Reopened	New	Difference
Bid-ask spread	1.84 (0.56)	2.23 (0.70)	-0.39*** [0.06]
Quote size	8.97 (1.39)	8.30 (1.07)	0.67*** [0.15]
Quotes per day	58.6 (19.3)	45.9 (14.7)	12.7*** [1.8]
Daily trading volume	208 (80)	154 (57)	54*** [8]
Trades per day	9.45 (3.23)	7.21 (2.43)	2.24*** [0.32]
Trade size	20.6 (2.3)	20.4 (3.2)	0.3 [0.3]

	PANEL B: TWICE REOPENED VS. ONCE REOPENED 13-WEEK BILLS		
	Twice Reopened	Once Reopened	Difference
Bid-ask spread	4.16 (1.66)	5.75 (2.72)	-1.59*** [0.22]
Quote size	9.97 (1.77)	9.54 (2.56)	0.43* [0.25]
Quotes per day	77.7 (19.5)	65.7 (19.0)	12.0*** [2.2]
Daily trading volume	318 (99)	271 (123)	47*** [14]
Trades per day	13.6 (3.6)	11.4 (3.7)	2.2*** [0.4]
Trade size	22.2 (3.0)	21.3 (3.5)	1.0** [0.4]

SOURCE: Author's calculations, based on data from GovPX.
NOTES: Means and standard deviations (in parentheses) of various liquidity and trading activity measures are reported for bills originally issued as 52-week bills and for those originally issued as 26-week bills for both 26- and 13-week bills. The mean differences between the subgroups are also reported with heteroskedasticity- and autocorrelation-consistent (Newey-West) standard errors (in brackets). The bid-ask spread is in basis points, and the quote size, daily trading volume, and trade size are in millions of U.S. dollars (face value). One, two, and three asterisks indicate significance at the 10%, 5%, and 1% levels, respectively.

TABLE 3
EFFECTS OF REOPENINGS ON BID-ASK SPREADS

PANEL A: REOPENED VS. NEW 26-WEEK BILLS

	When-Issued	On-the-Run	First Off-the-Run	Second Off-the-Run	Third Off-the-Run	Fourth Off-the-Run	Fifth Off-the-Run
Reopened	1.22	0.67	1.28	1.62	1.87	1.82	2.04
New	1.28	0.72	1.45	1.98	2.23	2.32	2.57
Difference	-0.05	-0.05**	-0.17**	-0.36***	-0.36***	-0.51***	-0.53***
Standard error	0.08	0.02	0.07	0.09	0.11	0.11	0.16

	Sixth Off-the-Run	Seventh Off-the-Run	Eighth Off-the-Run	Ninth Off-the-Run	Tenth Off-the-Run	Eleventh Off-the-Run	Twelfth Off-the-Run
Reopened	2.14	2.25	2.04	2.16	2.16	2.24	2.19
New	2.62	2.60	2.84	2.77	2.88	2.92	2.62
Difference	-0.49***	-0.36***	-0.80***	-0.61***	-0.72***	-0.68***	-0.42***
Standard error	0.14	0.12	0.14	0.18	0.20	0.17	0.12

PANEL B: TWICE REOPENED VS. ONCE REOPENED 13-WEEK BILLS

	When-Issued	On-the-Run	First Off-the-Run	Second Off-the-Run	Third Off-the-Run	Fourth Off-the-Run	Fifth Off-the-Run
Twice reopened	1.36	0.68	1.49	2.16	2.42	2.64	2.87
Once reopened	1.44	0.69	1.78	2.47	3.00	3.17	3.75
Difference	-0.07	-0.01	-0.29***	-0.31***	-0.57***	-0.53***	-0.87***
Standard error	0.09	0.04	0.08	0.12	0.17	0.16	0.19

	Sixth Off-the-Run	Seventh Off-the-Run	Eighth Off-the-Run	Ninth Off-the-Run	Tenth Off-the-Run	Eleventh Off-the-Run	Twelfth Off-the-Run
Twice reopened	3.36	3.52	3.76	4.48	5.96	7.58	12.83
Once reopened	4.14	4.35	4.67	6.62	8.92	11.22	20.38
Difference	-0.78**	-0.83***	-0.91**	-2.14***	-2.97***	-3.64***	-7.55***
Standard error	0.31	0.22	0.36	0.47	0.58	0.60	1.23

SOURCE: Author's calculations, based on data from GovPX.
NOTES: Mean bid-ask spreads (in basis points) are reported for bills originally issued as 52-week bills and for those originally issued as 26-week bills for various stages in the lives of both 26- and 13-week bills. The twelfth off-the-run stage includes up to two days when the bill might more appropriately be described as thirteenth off-the-run. The mean differences between the subgroups are also reported along with heteroskedasticity- and autocorrelation-consistent (Newey-West) standard errors. One, two, and three asterisks indicate significance at the 10%, 5%, and 1% levels, respectively.

TABLE 4
EFFECTS OF REOPENINGS ON TRADING VOLUME

PANEL A: REOPENED VS. NEW 26-WEEK BILLS

	When-Issued	On-the-Run	First Off-the-Run	Second Off-the-Run	Third Off-the-Run	Fourth Off-the-Run	Fifth Off-the-Run
Reopened	594	985	290	169	113	105	84
New	470	941	203	95	68	70	52
Difference	124***	44	87***	74***	44***	35***	33***
Standard error	43	42	18	12	10	8	10

	Sixth Off-the-Run	Seventh Off-the-Run	Eighth Off-the-Run	Ninth Off-the-Run	Tenth Off-the-Run	Eleventh Off-the-Run	Twelfth Off-the-Run
Reopened	84	92	86	89	105	94	113
New	43	43	39	45	41	45	57
Difference	41***	49***	47***	44***	64***	49***	56***
Standard error	8	9	10	9	9	9	14

PANEL B: TWICE REOPENED VS. ONCE REOPENED 13-WEEK BILLS

	When-Issued	On-the-Run	First Off-the-Run	Second Off-the-Run	Third Off-the-Run	Fourth Off-the-Run	Fifth Off-the-Run
Twice reopened	683	1354	381	207	185	197	194
Once reopened	667	1280	324	188	154	148	119
Difference	17	74*	57**	18	31	50*	75***
Standard error	36	41	24	20	40	27	20

	Sixth Off-the-Run	Seventh Off-the-Run	Eighth Off-the-Run	Ninth Off-the-Run	Tenth Off-the-Run	Eleventh Off-the-Run	Twelfth Off-the-Run
Twice reopened	176	184	258	299	168	176	132
Once reopened	140	167	206	181	132	139	103
Difference	37	17	52**	117***	36	37	29**
Standard error	37	30	25	26	22	24	13

SOURCE: Author's calculations, based on data from GovPX.
NOTES: Mean daily trading volume (in millions of U.S. dollars, face value) is reported for bills originally issued as 52-week bills and for those originally issued as 26-week bills for various stages in the lives of both 26- and 13-week bills. The twelfth off-the-run stage includes up to two days when the bill might more appropriately be described as thirteenth off-the-run. The mean differences between the subgroups are also reported along with heteroskedasticity- and autocorrelation-consistent (Newey-West) standard errors. One, two, and three asterisks indicate significance at the 10%, 5%, and 1% levels, respectively.

TABLE 5
BID-ASK SPREAD REGRESSIONS

	PANEL A: 26-WEEK BILLS					
	When-Issued		On-the-Run		Off-the Run	
Independent Variable	Model (1)	Model (2)	Model (1)	Model (2)	Model (1)	Model (2)
Constant	1.33***	1.33***	0.74***	0.74***	2.76***	2.79***
	(0.45)	(0.45)	(0.15)	(0.15)	(0.66)	(0.66)
26-week auction size	-0.06*	-0.06*	-0.04***	-0.04***	-0.18***	-0.18***
	(0.03)	(0.03)	(0.01)	(0.01)	(0.05)	(0.05)
Originally issued as 52-week bill	-0.05	-	-0.04*	-	-0.48***	-
	(0.08)		(0.02)		(0.07)	
52-week auction size	-	-0.003	-	-0.002*	-	-0.03***
		(0.004)		(0.001)		(0.00)
2-year note volatility	0.04***	0.04***	0.04***	0.04***	0.21***	0.21***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.05)	(0.05)
Trend/10	0.04***	0.04***	0.02***	0.02***	0.06***	0.05***
	(0.01)	(0.01)	(0.00)	(0.00)	(0.01)	(0.01)
Adjusted R^2	0.25	0.25	0.50	0.50	0.45	0.45
Number of observations	234	234	235	235	235	235

	PANEL B: 13-WEEK BILLS					
	When-Issued		On-the-Run		Off-the Run	
Independent Variable	Model (1)	Model (2)	Model (1)	Model (2)	Model (1)	Model (2)
Constant	2.69***	2.69***	0.64***	0.64***	12.41***	12.57***
	(0.52)	(0.52)	(0.24)	(0.24)	(1.86)	(1.87)
13-week auction size	-0.12***	-0.12***	-0.03**	-0.03**	-0.66***	-0.67***
	(0.03)	(0.03)	(0.01)	(0.01)	(0.15)	(0.15)
26-week auction size	-0.04	-0.04	-0.01	-0.01	-0.31**	-0.31**
	(0.04)	(0.04)	(0.02)	(0.02)	(0.15)	(0.15)
Originally issued as 52-week bill	-0.10	-	-0.02	-	-2.15***	-
	(0.09)		(0.03)		(0.22)	
52-week auction size	-	-0.004	-	-0.002	-	-0.12***
		(0.005)		(0.002)		(0.01)
Issued as cash-management bill	-	-	-	-	-3.80***	-3.79***
					(0.36)	(0.37)
2-year note volatility	0.05**	0.05**	0.04***	0.04***	0.82***	0.82***
	(0.02)	(0.03)	(0.01)	(0.01)	(0.20)	(0.19)
Trend/10	0.03***	0.03***	0.02***	0.02***	0.13***	0.13***
	(0.01)	(0.01)	(0.00)	(0.00)	(0.03)	(0.03)
Adjusted R^2	0.19	0.19	0.33	0.33	0.53	0.53
Number of observations	234	234	235	235	235	235

SOURCE: Author's calculations, based on data from Bloomberg, GovPX, and the U.S. Treasury.
NOTES: The table reports results from regressions of bid-ask spreads on various explanatory variables for three stages in the lives of 26- and 13-week bills. Coefficients are reported with heteroskedasticity- and autocorrelation-consistent (Newey-West) standard errors (in parentheses). Bid-ask spreads and two-year note volatility are in basis points and auction sizes are in billions of U.S. dollars (face value). The trend variable is equal to one for the first bill in the sample and increases by one (weekly) for each subsequent bill. One, two, and three asterisks indicate significance at the 10%, 5%, and 1% levels, respectively.

TABLE 6
TRADING VOLUME REGRESSIONS

	PANEL A: 26-WEEK BILLS					
	When-Issued		On-the-Run		Off-the Run	
Independent Variable	Model (1)	Model (2)	Model (1)	Model (2)	Model (1)	Model (2)
Constant	-195	-194	50	48	29	25
	(396)	(394)	(257)	(257)	(36)	(36)
26-week auction size	60**	60**	84***	84***	6**	6**
	(29)	(29)	(19)	(19)	(3)	(3)
Originally issued as 52-week bill	134***		65		53***	
	(42)	-	(41)	-	(5)	-
52-week auction size		7***		4		3.1***
	-	(2)	-	(2)	-	(0.2)
2-year note volatility	16***	16***	38***	38***	-0.3	-0.03
	(6)	(6)	(7)	(7)	(1.8)	(1.72)
Trend/10	-12**	-11**	-27***	-27***	-2.3***	-2.1***
	(5)	(5)	(4)	(4)	(0.4)	(0.4)
Adjusted R^2	0.21	0.21	0.51	0.51	0.54	0.57
Number of observations	235	235	235	235	235	235

	PANEL B: 13-WEEK BILLS					
	When-Issued		On-the-Run		Off-the Run	
Independent Variable	Model (1)	Model (2)	Model (1)	Model (2)	Model (1)	Model (2)
Constant	-167	-168	1393***	1390***	-8	-14
	(280)	(281)	(270)	(270)	(48)	(48)
13-week auction size	11	11	14	15	7***	7***
	(16)	(16)	(15)	(15)	(2)	(2)
26-week auction size	44**	44**	-6	-7	6*	5*
	(21)	(21)	(22)	(22)	(3)	(3)
Originally issued as 52-week bill	21		70*		66***	
	(35)	-	(40)	-	(6)	-
52-week auction size		1		4*		4***
	-	(2)	-	(2)	-	(0)
Issued as cash-management bill					419***	419***
	-	-	-	-	(43)	(43)
2-year note volatility	21***	21***	30***	30***	7*	7*
	(6)	(6)	(9)	(9)	(4)	(4)
Trend/10	6	6	-30***	-29***	-4***	-3***
	(4)	(4)	(4)	(4)	(1)	(1)
Adjusted R^2	0.08	0.08	0.33	0.33	0.77	0.78
Number of observations	235	235	235	235	235	235

SOURCE: Author's calculations, based on data from Bloomberg, GovPX and the U.S. Treasury.
NOTES: The table reports results from regressions of daily trading volume on various explanatory variables for three stages in the lives of 26- and 13-week bills. Coefficients are reported with heteroskedasticity- and autocorrelation-consistent (Newey-West) standard errors (in parentheses). Trading volume is in millions of U.S. dollars (face value), auction sizes are in billions of U.S. dollars (face value), and two-year note volatility is in basis points. The trend variable is equal to one for the first bill in the sample and increases by one (weekly) for each subsequent bill. One, two, and three asterisks indicate significance at the 10%, 5%, and 1% levels, respectively.

TABLE 7
EFFECTS OF REOPENINGS ON BUTTERFLY SPREADS

	PANEL A: REOPENED VS. NEW 26-WEEK BILLS		
	Reopened	New	Difference
On-the-run	1.91	-0.09	2.00***
	(2.22)	(1.96)	[0.38]
Off-the-run	2.18	-0.29	2.48***
	(2.19)	(2.72)	[0.40]
Overall	2.15	-0.28	2.43***
	(2.13)	(2.56)	[0.38]

	PANEL B: TWICE REOPENED VS. ONCE REOPENED 13-WEEK BILLS		
	Twice Reopened	Once Reopened	Difference
When-issued	3.28	1.72	1.55***
	(1.94)	(2.63)	[0.43]
On-the-run	2.45	0.71	1.75***
	(1.93)	(1.93)	[0.33]
Off-the-run	5.76	2.31	3.44**
	(7.64)	(7.98)	[1.35]
Overall	5.36	2.15	3.22***
	(6.71)	(7.02)	[1.19]

SOURCE: Author's calculations, based on data from GovPX.
NOTE: Means and standard deviations (in parentheses) of butterfly spreads are reported in basis points for bills originally issued as 52-week bills and for those originally issued as 26-week bills for various stages in the lives of both 26- and 13-week bills. The mean differences between the subgroups are also reported with heteroskedasticity- and autocorrelation-consistent (Newey-West) standard errors (in brackets). One, two, and three asterisks indicate significance at the 10%, 5%, and 1% levels, respectively.

TABLE 8
BUTTERFLY SPREAD REGRESSIONS

	PANEL A: 26-WEEK BILLS			
	On-the-Run		Off-the Run	
Independent Variable	Model (1)	Model (2)	Model (1)	Model (2)
Constant	0.09	0.10	-0.01	-0.01
	(0.14)	(0.14)	(0.11)	(0.11)
26-week auction size	0.39	0.36	0.20	0.16
	(0.25)	(0.24)	(0.24)	(0.23)
Originally issued as 52-week bill	1.82***	-	1.99***	-
	(0.28)		(0.32)	
52-week auction size	-	0.10***	-	0.12***
		(0.01)		(0.02)
End of month maturity	-1.49***	-1.49***	-2.26***	-2.25***
	(0.31)	(0.31)	(0.43)	(0.42)
Trend/10	-0.01	-0.01	0.00	0.00
	(0.01)	(0.01)	(0.01)	(0.01)
Adjusted R^2	0.38	0.39	0.41	0.43
Number of observations	234	234	235	235

	PANEL B: 13-WEEK BILLS					
	When-Issued		On-the-Run		Off-the Run	
Independent Variable	Model (1)	Model (2)	Model (1)	Model (2)	Model (1)	Model (2)
Constant	-0.21	-0.20	0.41*	0.41*	-0.01	-0.002
	(0.31)	(0.31)	(0.22)	(0.21)	(0.37)	(0.372)
13-week auction size	0.34	0.34	0.31	0.30	0.80	0.74
	(0.23)	(0.22)	(0.30)	(0.29)	(1.05)	(1.06)
26-week auction size	-0.05	-0.09	0.12	0.08	1.12	1.01
	(0.15)	(0.14)	(0.15)	(0.14)	(0.76)	(0.74)
Originally issued as 52-week bill	1.80***	-	1.91***	-	6.46***	-
	(0.30)		(0.30)		(1.00)	
52-week auction size	-	0.11***	-	0.11***	-	0.36***
		(0.02)		(0.02)		(0.05)
Issued as cash-management bill	0.55	0.51	1.70***	1.65***	16.27***	16.14***
	(0.67)	(0.66)	(0.60)	(0.59)	(2.12)	(2.11)
End of month maturity	-1.27***	-1.27***	-0.82**	-0.81**	-1.43	-1.44
	(0.28)	(0.27)	(0.34)	(0.33)	(1.31)	(1.30)
Trend/10	0.15***	0.15***	0.02	0.02	-0.005	-0.01
	(0.03)	(0.03)	(0.02)	(0.02)	(0.031)	(0.03)
Adjusted R^2	0.35	0.37	0.29	0.30	0.39	0.40
Number of observations	231	231	234	234	235	235

SOURCE: Author's calculations, based on data from GovPX and the U.S. Treasury.
NOTES: The table reports results from regressions of butterfly spreads on various explanatory variables for various stages in the lives of 26- and 13-week bills. Coefficients are reported with heteroskedasticity- and autocorrelation-consistent (Newey-West) standard errors (in parentheses). Butterfly spreads are in basis points and auction sizes are in billions of U.S. dollars (face value). The trend variable is equal to one for the first bill in the sample and increases by one (weekly) for each subsequent bill. One, two, and three asterisks indicate significance at the 10%, 5%, and 1% levels, respectively.

Figure 1A: Bid-Ask Spreads of 26-Week Bills by Days to Maturity

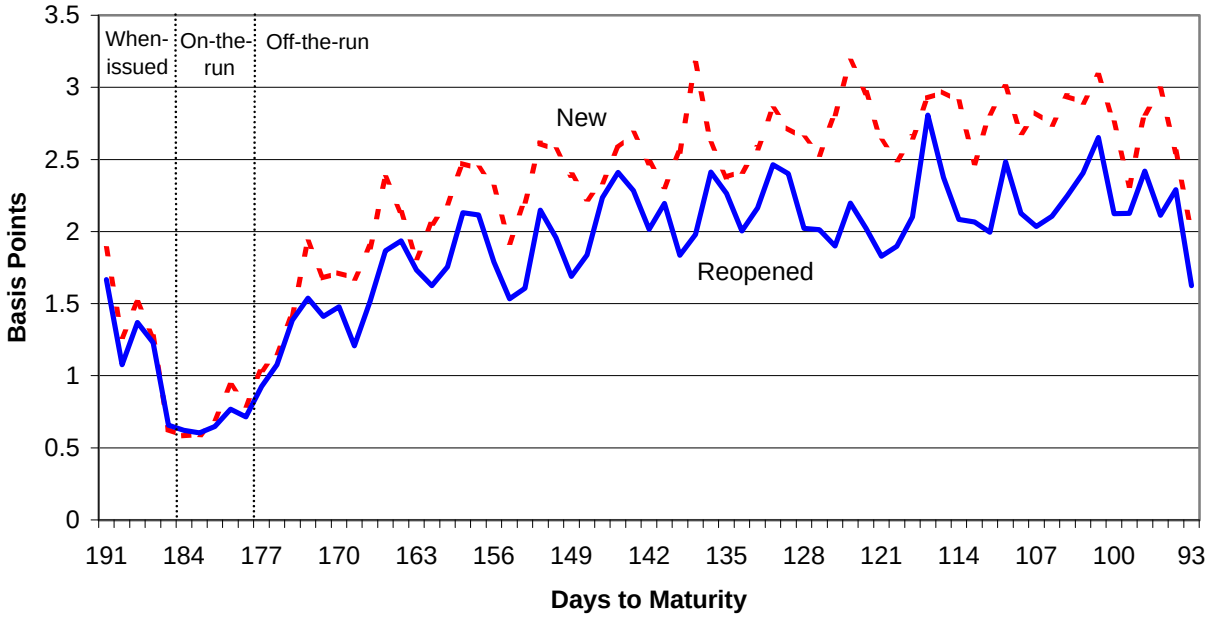
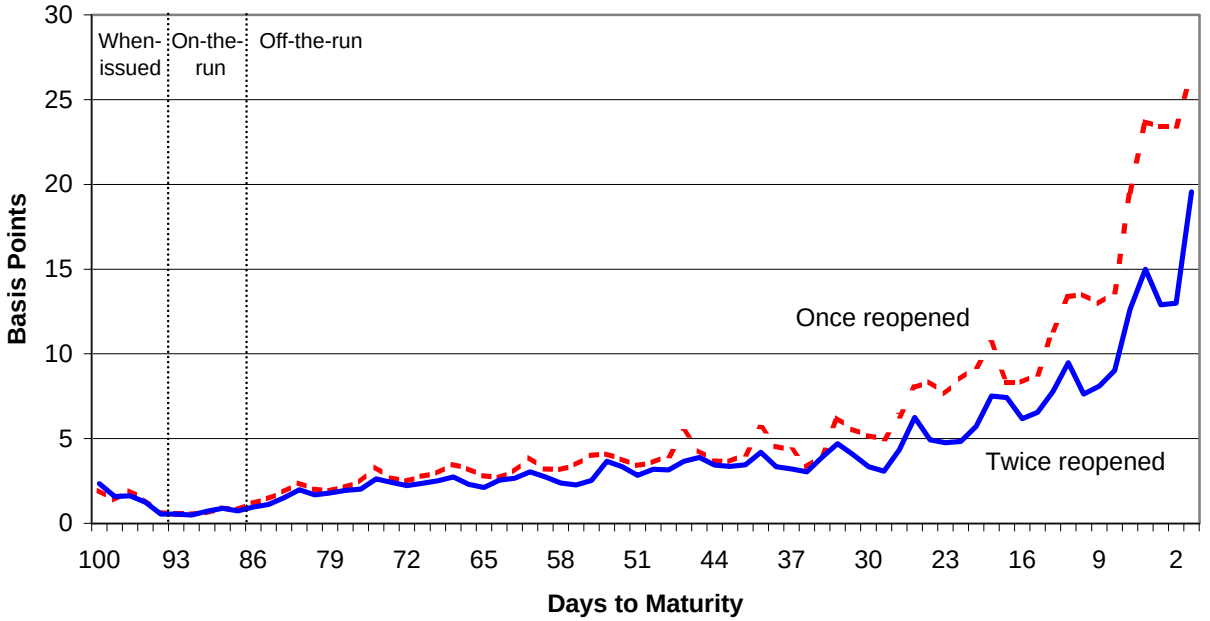


Figure 1B: Bid-Ask Spreads of 13-Week Bills by Days to Maturity



Source: Author's calculations, based on data from GovPX.
Notes: The figure plots mean bid-ask spreads by days to maturity for bills originally issued as 52-week bills and for those originally issued as 26-week bills for both 26- and 13-week bills. Bills maturing on a Friday are excluded.

Figure 2A: Daily Trading Volume of 26-Week Bills by Days to Maturity

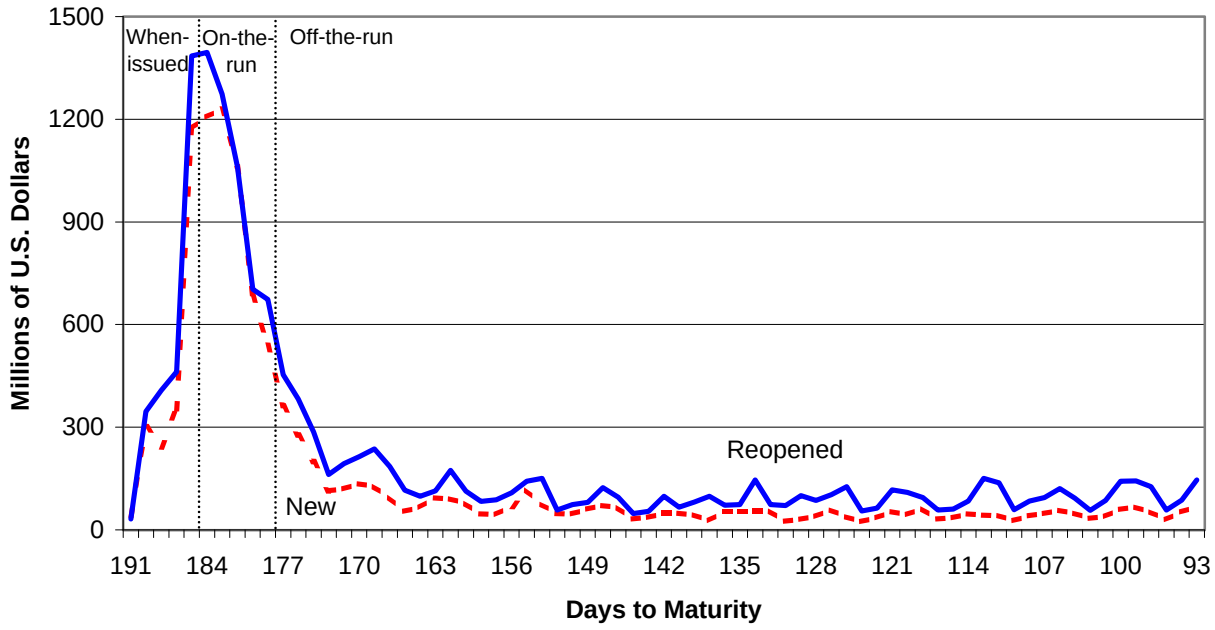
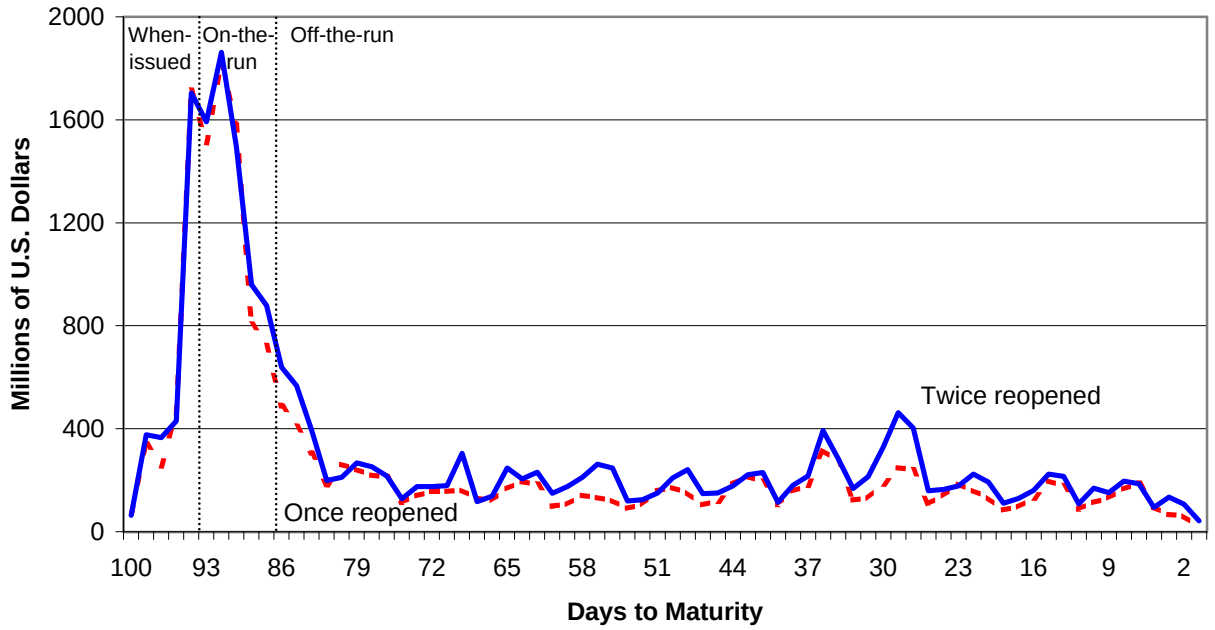


Figure 2B: Daily Trading Volume of 13-Week Bills by Days to Maturity



Source: Author's calculations, based on data from GovPX.
Notes: The figure plots mean daily trading volume by days to maturity for bills originally issued as 52-week bills and for those originally issued as 26-week bills for both 26- and 13-week bills. Bills maturing on a Friday are excluded.

Figure 3A: Bid-Ask Spreads of 26-Week Bills by Auction Date

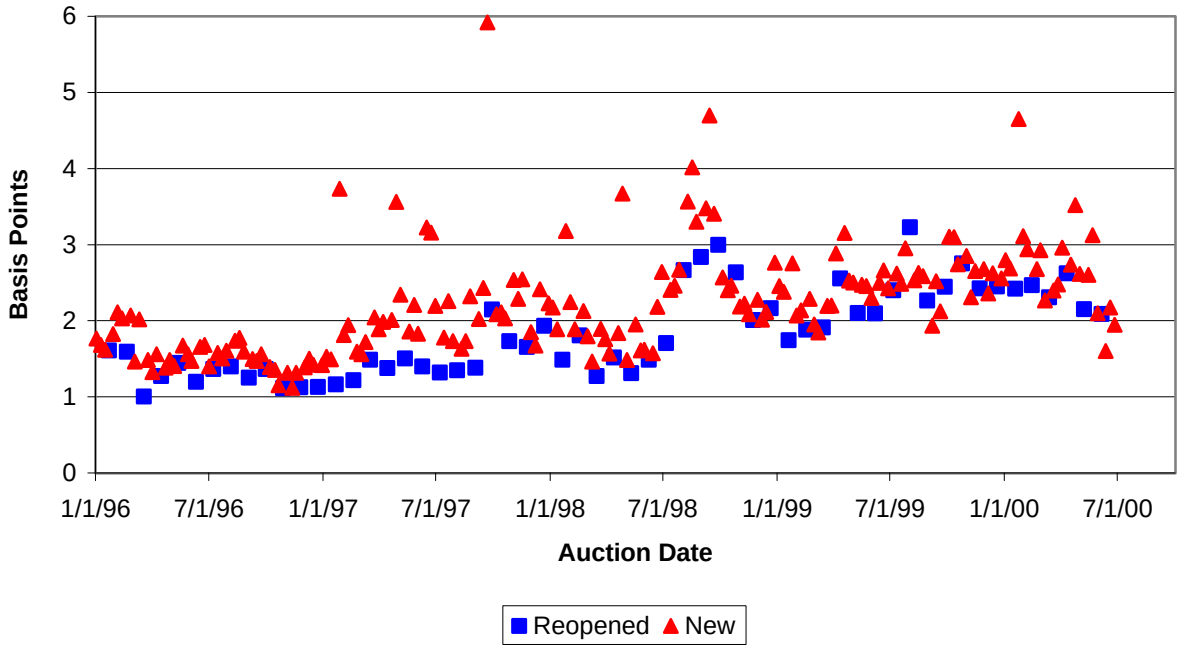
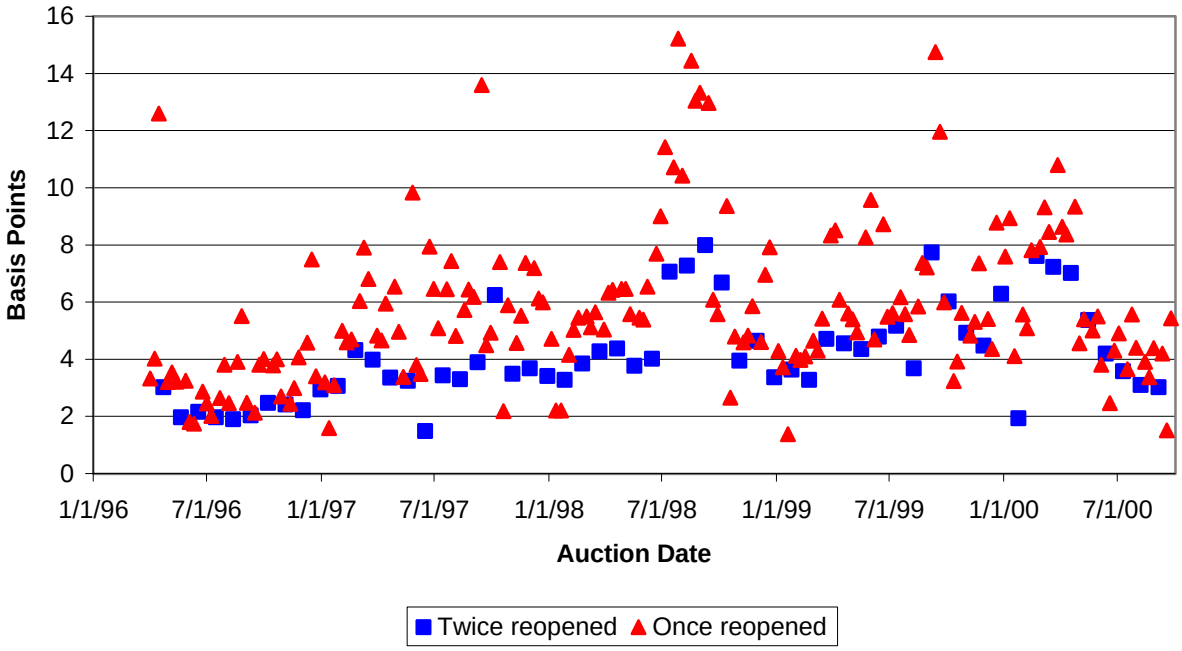


Figure 3B: Bid-Ask Spreads of 13-Week Bills by Auction Date



Source: Author's calculations, based on data from GovPX.
Note: The figure plots mean bid-ask spreads by auction date for bills originally issued as 52-week bills and for those originally issued as 26-week bills for both 26- and 13-week bills.

Figure 4A: Butterfly Spreads of Reopened less New 26-Week Bills

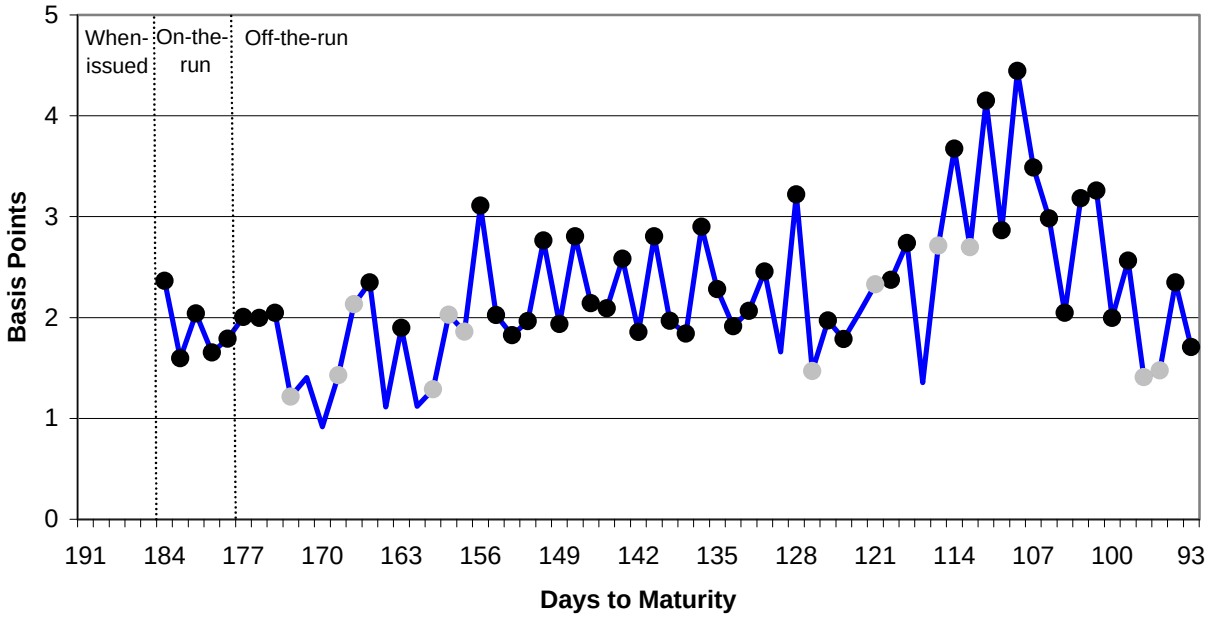
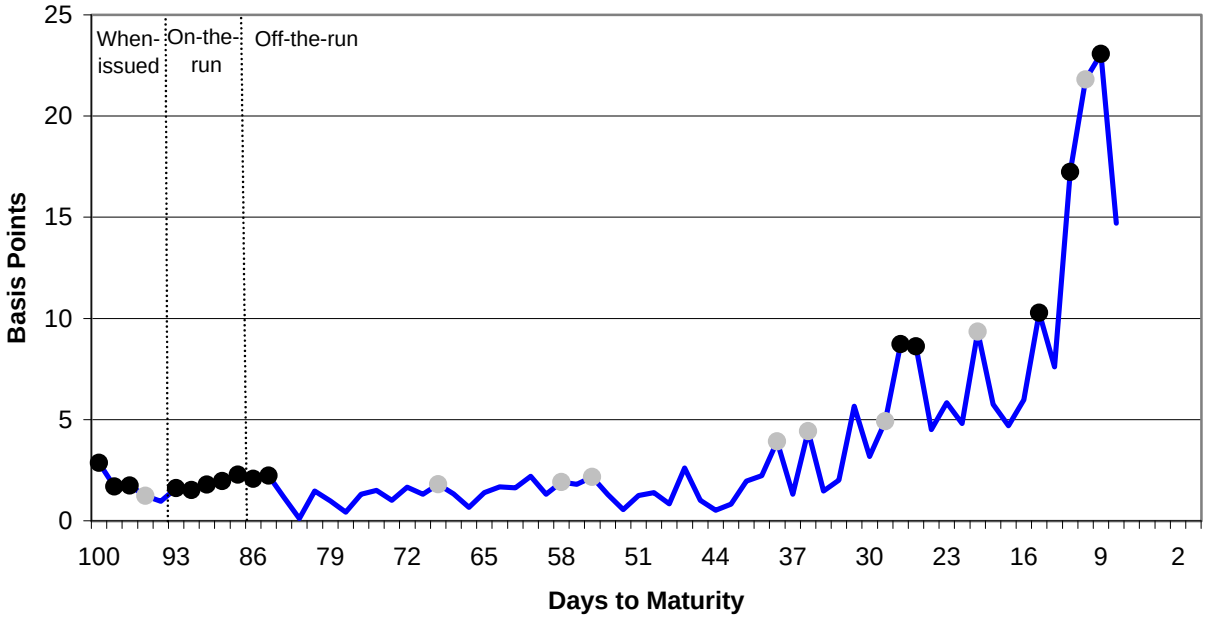


Figure 4B: Butterfly Spreads of Twice less Once Reopened 13-Week Bills



Source: Author's calculations, based on data from GovPX.
Notes: The figure plots differences in butterfly spreads between bills originally issued as 52-week bills and those originally issued as 26-week bills by days to maturity for both 26- and 13-week bills. Shaded and solid circles indicate differences significant at the 5% and 1% levels, respectively. Bills maturing on a Friday are excluded.