Intraday Pricing and Liquidity Effects of U.S. Treasury Auctions[*]

Michael J. Fleming, Federal Reserve Bank of New York

Weiling Liu, Harvard University

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Abstract

We examine the intraday effects of U.S. Treasury auctions on the pricing and liquidity of the most recently issued notes. We find that prices decrease in the hours preceding auction and recover in the hours following. The magnitude of the price changes is positively correlated with bid-ask spreads, price impact, volatility, and other measures of financial stress. We further find that liquidity tends to be better right before an auction, albeit worse at auction time and thereafter. Our results provide high frequency evidence of supply shocks causing price pressure effects and show dealers' limited risk-bearing capacity helps explain such effects.

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[*] Fleming: michael.fleming@ny.frb.org, (212) 720-6372); Liu: weilingliu90@gmail.com. The authors are grateful to Tobias Adrian, Charles Jones, and seminar participants at the Bank for International Settlements (Asian Office), Bank of Thailand, Board of Governors of the Federal Reserve System, Centre for Advanced Financial Research and Learning, First International Conference on Sovereign Bond Markets, and FTG Summer School for helpful comments. Ron Yang provided excellent research assistance. Views expressed are those of the authors and not necessarily those of the Federal Reserve Bank of New York or the Federal Reserve System.

1. Introduction

The extant literature shows that security supply matters to prices, even in a market as liquid as the U.S. Treasury securities market. Studies such as Simon (1991), Simon (1994a), Duffee (1996), and Fleming (2002) show that the price of a given Treasury security is related to its supply. More recently, especially with the introduction of the Federal Reserve's large-scale asset purchases (LSAPs), studies have shown a broader linkage between aggregate Treasury supply and prices. For example, Gagnon, Raskin, Remache, and Sack (2011) find that the LSAPs resulted in meaningful and long-lasting reductions in longer term interest rates on a broad range of securities, and D'Amico and King (2013) find that LSAPs have both a stock (long-run) and a flow (same-day) effect. More generally, Krishnamurthy and Vissing-Jorgensen (2012) show that the government debt-to-GDP ratio is negatively correlated with corporate spreads, which reflect a convenience yield attributable to Treasury securities.

Of most relevance to this paper are studies that show that government security supply shocks, even when fully anticipated, have temporary inventory-related effects on prices. Using weekly data, Fleming and Rosenberg (2007) show that secondary Treasury security prices tend to decline during the weeks of Treasury auctions and increase in the following weeks. Using daily data, Lou, Yan, and Zhang (2013) show that Treasury security prices decrease in the few days before auctions and recover shortly thereafter. Beetsma, Giuliodori, deJong, and Widijanto (2016) uncover a similar pattern using daily data in the Italian public bond market.

The argument behind the V-shaped price pattern around auctions is that investors have imperfect capital mobility and dealers have limited risk-bearing capacity. Dealers tend to buy securities at auction and sell them off over adjacent weeks, but they need to be compensated for the risk associated with the auction-driven inventory changes. Consistent with this hypothesis, Lou, Yan, and Zhang (2013) find that the extent of this return behavior is positively and significantly related to implied equity and implied interest rate volatility, and negatively and significantly related to broker-dealer leverage growth.

In this paper, we assess price and liquidity patterns around U.S. Treasury security auctions using intraday data, in contrast to the lower frequency data used in earlier studies.

With intraday data, we can zoom in on the hours surrounding auctions so that our results are not confounded by the immediate effects of major macroeconomic announcements, which are released earlier in the day. Moreover, because we look at behavior within the same day, factors important to daily price patterns, such as the evolving capitalized value of repo specialness, are not relevant, simplifying the analyses and clarifying the inferences.

In looking at the intraday data, we demonstrate the same pattern as past studies, whereby prices decline heading into auctions and increase after auctions. A similar pattern is not observed on non-auction days, suggesting that it is the auctions themselves leading to the price pattern. Moreover, we not only observe this pattern for the on-the-run 2-, 5-, and 10-year notes, as in Lou, Yan, and Zhang (2013), but for the shorter duration 13- and 26-week bills, and for securities trading in the when-issued market.[1]

We further explore the cross-sectional determinants of this supply effect. We utilize some of the same market-wide variables as Lou, Yan, and Zhang (2013), such as implied Treasury volatility and implied equity volatility. In addition, we use new variables, including a measure of the dispersion of yields around a smoothed yield curve, similar to the noise measure examined by Hu, Pan, and Wang (2013). We find all of these variables to be positively correlated with the price pressure effect for each of the 2-, 5-, and 10-year notes (with the coefficients often statistically significant), consistent with the hypothesis of limited dealer risk-bearing capacity.

In addition to the market-wide measures, we utilize our intraday data to generate measures of bid-ask spread, quoted depth, price impact, and realized price volatility for each Treasury note in our sample, measured as of the day or week preceding each auction. We show that the price pressure effect tends to be positively correlated with bid-ask spread, price impact, and realized volatility, and negatively correlated with depth. This provides further corroboration for the idea that limited risk-bearing capacity helps explain the supply effect.

In addition to the striking price pattern we observe around auctions, we also examine the behavior of volatility and liquidity around these events. While numerous studies have

[1] When-issued securities are those which have been announced for auction, but not yet issued. On-the-run securities are the most recently auctioned securities of a given maturity.

documented such behavior around macroeconomic releases (e.g., Fleming and Remolona (1999) and Balduzzi, Elton, and Green (2001)) and Federal Open Market Committee (FOMC) announcements (e.g., Fleming and Piazzesi (2005)) there is limited evidence of such behavior around Treasury auctions.[2] We find that volatility and bid-ask spreads spike higher and depth plunges lower around such announcements (consistent with past announcement studies), but that liquidity is better in the hours preceding auctions (in contrast to past announcement studies).

While liquidity on Treasury auction days overall is good, liquidity costs are still appreciable relative to the V-shaped auction price pattern. We consider a potential trading strategy to exploit the observed price behavior. Specifically, we suppose that an investor first shorts at the bid price one to four hours in advance of an auction and closes out the position at the ask price right before auction; then, he buys at the ask price right after auction and closes out the position at the bid price one to four hours later. Average returns to this strategy are only significantly positive for the 10-year note, illustrating the importance of trading costs relative to the observed auction price pattern.

Our key findings are illustrated in Figure 1 for each of the 2-, 5-, and 10-year notes. The black lines illustrate the evolution of the average yield relative to the yield at the auction closing time, showing that yields tend to rise in the hours before auction and fall in the hours after auction.[3] The blue shaded area illustrates the evolution of the average depth at the inside tier, showing that depth declines sharply at the time of auction but quickly recovers 1-2 minutes after. Lastly, the red diamonds illustrate average underpricing, calculated as the yield at auction minus the yield of the auctioned security in the secondary market at the auction close. Underpricing has been examined in numerous prior studies and is not our focus, but it provides a nice comparison to the price pressure effect we document. Over our sample, the observed degree of underpricing is of similar magnitude to the intraday price pressure effect for the 10-year note, but smaller for the 5- and especially 2-year notes.

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[2] Some studies have reported selected liquidity/trading activity measures for limited time intervals around Treasury auctions (see, for example, Nyborg and Sundaresan (1996) and Goldreich (2007)). Fleming and Krishnan (2012) document the behavior of volatility and liquidity around auctions of Treasury inflation-protected securities.

[3] Recall that yields move inversely to prices, so the V-shaped pattern of prices around auctions corresponds to an inverted V-shaped pattern of yields.

Our paper proceeds as follows. In Section 2, we provide background on the Treasury market and the associated literature on auction effects. In Section 3, we discuss our auctions and market data. In Section 4, we present our main results concerning intraday price patterns of on-the-run notes and some of the factors that influence those patterns. In Section 5, we present various additional results on price pressure effects in other securities. Section 6 concludes.

2. Background on Treasury Market and Auction Effects

The U.S. Treasury securities market is one of the largest and most liquid financial markets in the world, with marketable debt outstanding of $13.9 trillion as of December 31, 2016.[4] Because of their liquidity, Treasuries are commonly used to price and hedge positions in other fixed-income securities and to speculate on the course of interest rates. The securities' creditworthiness and liquidity also make them a key instrument of monetary policy and a key store of value.

A. Primary Market

Marketable Treasury securities are sold in the primary market via auction. Each auction is announced one or more days in advance by means of a Treasury Department press release. The announcement provides details of the offering, including the offering amount and the term and type of security being offered, and describes some of the auction rules and procedures. Competitive bids must be made in terms of yield and must typically be submitted by 1:00 p.m. eastern time on auction day. Noncompetitive bids must typically be submitted by noon on auction day.[5]

All noncompetitive bids from the public up to $5 million are accepted. The lowest yield (i.e., highest price) competitive bids are then accepted up to the yield required to cover the amount offered (less the amount of noncompetitive bids). The highest yield accepted is

[4] From Monthly Statement of the Public Debt of the United States: http://www.treasurydirect.gov/govt/reports/pd/mspd/mspd.htm

[5] These are the auction times for Treasury notes and bonds. The usual competitive and noncompetitive deadlines for Treasury bills are 11:00 am and 11:30 am, respectively.

called the stop-out yield. All accepted tenders (competitive and noncompetitive) are awarded at the stop-out yield. There is no maximum acceptable yield, and the Treasury does not add to or reduce the size of the offering according to the strength of the bids.

Historically, the Treasury auctioned securities through multiple-price (discriminatory) auctions. With multiple-price auctions, the Treasury accepted the lowest-yielding bids up to the yield required to sell the amount offered (less the amount of noncompetitive bids), but accepted bids were awarded at yields specific to the winning bidders, rather than at the stop-out yield. Noncompetitive bids were awarded at the weighted-average yield of the accepted competitive bids rather than at the stop-out yield. In September 1992, the Treasury started conducting single-price auctions for the 2- and 5-year notes, and in November 1998, the Treasury adopted the single-price method for all auctions.

Shortly after the auction deadline, the Treasury announces the auction results. Announced results include the stop-out yield, the associated price, and the proportion of securities awarded to those investors who bid exactly the stop-out yield. For notes and bonds, the announcement includes the coupon rate of the new security. The coupon rate is set to be the rate (in increments of 1/8 of one percent) that produces the price closest to, but not above, par when evaluated at the yield awarded to successful bidders.

While Treasury auctions are open to all investors, the primary government securities dealers – dealers with a trading relationship with the Federal Reserve Bank of New York – are required to participate. The primary dealers have historically bought most securities sold at auction, although this share has declined in recent years (Fleming and Myers (2013)). The next largest categories of buyers at auction are investment funds and foreign and international investors.

To minimize uncertainty surrounding auctions, and thereby reduce borrowing costs, the Treasury offers securities on a regular, predictable schedule. Two-year notes, for example, are announced for auction in the second half of each month, auctioned a few days later, and then issued on the last day of the month. Treasury also tries to maintain a stable issue size for issues of a given maturity. Issue sizes for the 2-year note, for example, were a constant $35 billion between October 2010 and July 2013, before inching down $1 billion a month to $32 billion in October 2013, where they remained through April 2014.

B. Secondary Market

Secondary trading in Treasury securities occurs in a multiple-dealer over-the-counter market rather than through an organized exchange. Trading takes place around the clock during the week, although the vast majority of trading takes place during New York trading hours, roughly 7:30 a.m. to 5:00 p.m. eastern time (Fleming (1997)). The primary dealers are the principal market makers, buying and selling securities from customers for their own accounts at their quoted bid and ask prices. In the first half of 2017, primary dealers reported daily trading activity in the secondary market that averaged $526 billion per day.[6]

In addition to trading with their customers, the dealers trade among themselves through interdealer brokers. The brokers offer the dealers proprietary electronic screens or trading platforms that post the best bid and offer prices of the participating firms, along with the associated quantities bid or offered (minimums are $5 million for bills and $1 million for notes and bonds). The firms execute trades by notifying the brokers (by phone or electronically), who then post the resulting trade price and size. Interdealer brokers thus facilitate information flows in the market while providing anonymity to the trading firms.

A notable development in the trading of Treasury securities is the migration of activity from voice-assisted brokers to electronic platforms (Mizrach and Neely (2006)). Voice-assisted brokers provide dealers with screens that post the best bid and offer prices called in by dealers, with dealers executing trades by calling the brokers. In contrast, electronic platforms are fully electronic, with buyers matched to sellers without human intervention. The two predominant electronic platforms are eSpeed, introduced in 1999, and BrokerTec, introduced in 2000. Nearly all interdealer trading of on-the-run securities occurs via these platforms (Barclay, Hendershott, and Kotz (2006)).

C. Price Pressure Effects

As mentioned earlier, some studies use daily or weekly data to show that government security prices tend to decline in the period leading to an auction and increase in the period

[6] From Federal Reserve Bank of New York (www.newyorkfed.org/markets/statrel.html). As the data is collected from the primary dealers but no other entities, trades between primary dealers are counted twice, and trades between firms that are not primary dealers are not counted at all.

after. Lou, Yan, and Zhang (2013) is the most comprehensive of these, assessing price behavior around auctions of the 2-, 5-, and 10-year Treasury notes from January 1980 to June 2008. They find that yields rise 2-3 basis points in the days leading up to and including the auction day, and then decline about 2 basis points over the subsequent days. While the study examines a 20-day window around auction day, most of the rise and fall seem to occur within 3-4 days of the auction. About half of their reported cumulative yield changes are statistically different from zero, with stronger effects for the 2-year note and weaker effects for the 10-year note.

While the findings in past studies are compelling, there are several reasons why it is worth revisiting price behavior around auctions using intraday data. One reason concerns repo market specialness. On-the-run Treasury securities tend to trade special in the repo market. Duffie (1996) explains how this repo market specialness offers owners of the securities an additional return beyond the securities' cash flows. The return should be capitalized into prices and dissipate over time as securities age. Most of the premium should dissipate by the time of the next auction because securities fall off-the-run the day following auction and off-the-run securities trade special to a much lesser extent. Repo specialness is thus consistent with price declines before auction (but steady – and not increasing – prices after auction).

A second reason to consider the use of intraday data concerns the long downward trend in Treasury yields. Two-year yields peaked at almost 17% in 1981 and ended 2008 at less than 1%. The average decline in yields over this period was thus more than one basis point per week. Naturally, this decline cannot explain the increase in yields observed before auction, but it can perhaps explain a share of the decrease observed after auction. More importantly, this long-term decline together with an increase in yields before auction due to dissipating repo specialness could together create an inverted V-shaped pattern of yields around auction.

A final reason concerns month-end dynamics. Some Treasury securities are regularly auctioned near the end of the month.[7] At the same time, the market efficiency literature identifies various pricing anomalies, some concerning return behavior around the turn of the month. Ariel (1987), for example, shows that equity returns are unusually high over the last day and first half of the month, which Ogden (1990) argues is consistent with the standardization of payments in the United States at the turn of each month. Some of the return behavior around auctions could thus conceivably be related to month-end dynamics.

The use of intraday data eliminates or mitigates each of the possible concerns with analyzing supply effects using lower frequency data. First, repo specialness is irrelevant to intraday returns because the settlement of Treasuries is independent of the time of day at which a trade occurs. A security that is shorted at 11:00 a.m. and bought back at 1:00 p.m. does not need to be borrowed to cover the short position over that interval. Settlement of both trades, if they are not netted, would occur the following day by 3:00 p.m.[8]

Complications associated with month-end dynamics and trending Treasury yields are also mitigated by the use of intraday data. The use of intraday data allows us to focus in on the interval immediately around auction and avoid other times of significant information arrival (such as the 8:30 a.m. release time of major macroeconomic announcements). While some other information may be released during the period around auctions, and while month-end dynamics may affect intraday patterns, it is hard to imagine how such factors would produce a V-shaped pattern of prices centered around auction time.

This is not to say that the use of intraday data does not have its drawbacks. One drawback is that intraday data is harder to come by, so our sample period is necessarily shorter than what can be conducted with daily data. Moreover, earlier studies suggest that the price pressure effect occurs over several days. If that is the case, then our intraday analysis will be measuring just a fraction of the total price pressure effect. It follows that our analysis is intended to cleanly identify whether there is a price pressure effect, but is not

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[7] In our sample, 97% of the 2-year notes, 74% of the 5-year notes, and 1% of the 10-year notes are auctioned in the last third of a calendar month (between the 21st and the 30th).
[8] Most Treasury security trades are for next-day settlement. Trades of when-issued securities settle on the issuance day.

suited to identifying the magnitude of the price pressure effect to the extent it occurs over multiple days.

D. Underpricing

It is important to distinguish the price pressure effect examined in this paper from the underpricing phenomenon. Underpricing refers to the fact that Treasury securities tend to be sold in the primary market at prices lower than the contemporaneous secondary market prices. Such underpricing is documented by numerous studies including Cammack (1991), Spindt and Stolz (1992), and Simon (1994b). Simon (1994c), Nyborg and Sundaresan (1996), and Goldreich (2007) relate underpricing to auction technique, be it single-price or multiple-price.

3. Data

A. Primary Market

Our analysis focuses on the on-the-run 2-, 5-, and 10-year Treasury notes between January 1, 1992 and December 31, 2012. The 2-, 5-, and 10-year notes are the only three coupon-bearing securities regularly issued over our entire sample period.[10] We focus on the on-the-run securities in particular because of data availability and because the on-the-run securities are the most liquid securities of a given maturity. That said, we include robustness tests for a shorter sample using data for when-issued securities and for 13- and 26-week bills.

The primary market information we use in our analyses comes from the Treasury Department's TreasuryDirect website. In particular, the auction date and security information is from the historical archive whereas the auction closing time for competitive bids (usually

[10] While the Treasury currently also issues 3-, 7-, and 30-year coupon securities, issuance of the 3-year note was suspended between May 2007 and November 2008, issuance of the 7-year note was suspended between April 1993 and February 2009 and issuance of the 30-year bond was suspended between August 2001 and February 2006.

1:00 p.m.) is gleaned from individual auction announcements.[11] The Treasury note auction information is summarized in Table 1, Panel A.

Figure 2 shows the amount issued by calendar month for each of the Treasury notes examined in the paper. New issue amounts are shown in blue and scheduled reopenings (which tend to be smaller) are shown in red.[12] With rare exception, issues of a given maturity occur at a monthly frequency or lower, so the figure effectively show issuance frequency differences across securities and over time as well as the increase in issuance sizes over time.[13]

The figure shows that the 2-year note is newly issued on a monthly basis over our entire sample. The 5-year note is also newly issued on a monthly basis for most of our sample, but was sold quarterly between 1998 and 2003, with several of the quarterly auctions being reopenings. Finally, issuance frequency of the 10-year note has increased over time, with Treasury currently selling a new 10-year note once a quarter, followed by reopenings of the note one and two months later. In total, our sample includes 252 2-year auctions, 8 of which were multiple price, 212 5-year auctions (including 6 reopenings), 8 of which were multiple price, and 140 10-year auctions (including 69 reopenings), 29 of which were multiple price.

B. Secondary Market

To analyze intraday prices and liquidity, we rely on tick data from both GovPX and BrokerTec. GovPX is a data vendor that consolidates price and volume data from voice-

[11] For 10 auctions in our sample, the auction closing time for competitive bids was earlier than 1:00 p.m., with four of these auctions closing at 11:00 a.m., and the remainder closing at 11:30 a.m.
[12] A reopening occurs when the Treasury Department sells an additional amount of an outstanding security. Such reopenings are "scheduled" when the reopening is planned and anticipated (for example, currently, a new 10-year note is issued quarterly and then reopened one and two months after its initial issuance). In some cases, the scheduled issuance of a new security ends up as a reopening by chance because an issue's maturity date and market-determined coupon rate happen to match those of an outstanding issue. We classify these happenstance reopenings as new issues. Lastly, over our sample, there were five unscheduled reopenings of the 10-year note in which the Treasury deviated from its usual practice of regular and predictable issuance to alleviate the shortage of a particular issue. We exclude such *ad hoc* reopenings from our analysis.
[13] In one month in our sample – April 1996 – there were two auctions each of the 2- and 5-year notes because planned issuance of the notes the preceding month was postponed pending Congressional action on the debt limit.

assisted brokers, whereas BrokerTec is an electronic trading platform. Because trading activity has migrated in recent years from the voice-assisted brokers to the electronic platforms, as mentioned earlier, the representativeness of the databases changes over time. To illustrate, Figure 3 plots the quote incidence over time on GovPX (blue line) and BrokerTec (black line), calculated as the percent of time between 7:00 a.m. and 5:00 p.m. in which there was a quote in the on-the-run 10-year note according to the respective database.[14] The figure shows that GovPX coverage is high early in the sample, but falls sharply in 2000 and 2001. In contrast, BrokerTec coverage starts modestly in 2001, but has extremely high coverage for recent years. The shifting coverage of the datasets motivates our decision to use mid 2001 as a transition point (indicated by the red line in the figure), so that we use historical tick data from GovPX between January 1992 and June 2001 and from BrokerTec between July 2001 and December 2012.

The GovPX database contains information for when-issued, on-the-run, and off-the-run Treasury bills, notes, and bonds, whereas the BrokerTec database contains information for on-the-run Treasury notes and bonds only. The GovPX database contains information on prices and (since July 1994) depth at the inside tier of the limit order book, as well as trade prices and (until April 2001) volume. In contrast, the BrokerTec database contains a complete record of every order placed on the platform. Prices and depth at the inside tier are generated from a full reconstruction of the limit order book.

For tractability, we pull one-minute snapshots of the limit order book from GovPX and BrokerTec for each of the notes. The snapshots are generally taken from the end of each minute (but we take a snapshot from earlier in the minute if there was a two-sided quote then but not at the end of the minute).[15] To give an idea of the thoroughness of our data, our final dataset contains prices/yields in the minute preceding the auction close for 249 out of 252 2-year auctions, 208 out of 212 5-year auctions, and 134 out of 140 10-year auctions.

[14] While not shown here due to space constraints, the 2- and 5- year notes show a similar pattern.
[15] We employ several screening mechanisms for the one-minute snapshots to remove notable outliers or undesired quotes. The screens employed include: negative spreads, one-sided quotes, prices accidentally quoted in yields, and any other observation outside a 10-standard deviation band around the daily sample mean.

In addition to prices and yields, we also track several intraday liquidity and volatility measures for the on-the-run notes including bid-ask spread, depth, price impact, and price volatility. Bid-ask spread is calculated for each five-minute interval as the average difference between the best bid and ask prices at the end of each minute and is measured in 32nds of a point. Depth is calculated for each five-minute interval as the average quantity quoted at the best bid and ask prices at the end of each minute and is measured in millions of dollars (par value).[16] Price impact is estimated from weekly regressions of five-minute price changes on the signed (buyer initiated minus seller initiated) number of trades over the same interval. Finally, price volatility is calculated as the standard deviation of five-minute changes in the bid-ask midpoint and is measured in 32nds of a point. These measures are summarized, as of the day preceding each auction (week preceding auction in case of price impact), in Table 1, Panel B.

C. Broad Financial Conditions

To explain supply effects over time, we use some security-specific liquidity and volatility measures, as described above, as well as other broad financial measures as in Lou, Yan, and Zhang (2013). Our broad measures include:

- The Merrill Lynch Option Volatility Estimate index (MOVE), a measure of implied Treasury volatility (source: Bloomberg),
- The Chicago Board Options Exchange Volatility Index (VIX), a measure of implied equity volatility (source: Bloomberg),
- Moody's Baa-Aaa corporate credit spread, a measure of flight to safety (Hakkio and Keeton (2009)) (source: U.S. Economics Database in Haver),
- The TED (Treasury-eurodollar) spread, a measure of financial market stress, calculated as the spread between 3-month LIBOR and the 3-month Treasury bill rate (source: Federal Reserve Bank of St. Louis).
- The average absolute yield curve fitting error from the Nelson-Siegel-Svensson model of Gurkaynak, Sack, and Wright (2007), a measure of dealers' risk bearing

[16] Note that depth is not recorded in our GovPX data before July 1994, so its sample is limited to July 1994 through December 2012.

capacity (see Hu, Pan and Wang (2013); source: Board of Governors of the Federal Reserve System).

These broad measures are summarized, as of the day preceding each auction, in Table 1, Panel C.

4. Empirical Results

A. Intraday Yield/Return Behavior

To assess the effect of Treasury auctions on intraday prices, we compare secondary market quotes to each other around the time of auction. We first calculate the average yield difference for each on-the-run note in the eight-hour window surrounding the auction of the next issue (of the same original maturity). Yield difference is measured as the yield t minutes away from auction minus the yield at time of auction, where t ranges from -240 (four hours before auction) to 240 (four hours after auction). Table 2 reports average yield differences by note in 30-minute intervals, along with the corresponding t-statistics. The black lines in Figure 4 illustrate these average yield differences in one-minute increments around the time of auction, and the dotted blue lines show the corresponding 95% confidence interval.

The results show that yields tend to be significantly higher at time of auction than in the hours around auction (that is, the yield differences are negative) and that these differences increase in magnitude with time. Across all three notes, the yield differences are negative and significant at the 10% level or better in the interval of 90 to 180 minutes before auction. For the 2- and 5-year notes, the yield differences following auction are generally negative but not significant. In contrast, the 10-year note shows negative and significant yield differences after as well as before auction.

Next, we examine cumulative returns for the on-the-run security for various time windows around auction. This measure, which follows a similar approach as Lou, Yan, and Zhang (2013), combines the price pressure effect on both sides of the auction, and is thus a more robust measure of the supply effect than yield differences. The cumulative return at t minutes from auction is calculated as the cumulative return in the t minutes after auction less the cumulative return in the t minutes before auction:[17]

$$return(t) = \left(\frac{midprice(t+10) - midprice(10)}{midprice(10)}\right) - \left(\frac{midprice(0) - midprice(-t)}{midprice(-t)}\right)$$

Table 3 reports the average cumulative returns around time of auction in 30-minute increments. Figure 5 further depicts the average return around auction in one minute increments, with the 95% confidence interval shaded in light blue.

Across all three notes, we find positive average intraday returns surrounding auction (left-side graphs). In fact, in the one to three hours around auction, returns are significant for all notes at the 1% level or better. In contrast, on non-auction days (right-side graphs), returns in the same window around the usual 1:00 p.m. auction time are miniscule and never significantly different from 0. Thus, the pricing patterns we observe are unique to auction days and centered around auction time. Moreover, similar to the yields analysis, the magnitude of the price pressure effect grows as the window over which the returns are cumulated gets larger.

Our findings are similar to those of Lou, Yan, and Zhang (2013) in terms of the V-shape price patterns and the statistical significance of the findings. The magnitudes of the returns are not directly comparable, however, because of the differing intervals of analysis. Nonetheless, for the most closely matched intervals, covering four-hour intervals in our case and one-day intervals in the case of their study, the returns are of the same order of magnitude. Returns for our four-hour intervals are thus 1.5, 2.5 and 12.5 bps for the 2-, 5-, and 10-year notes, respectively, whereas returns for the one-day intervals in Lou, Yan, and Zhang (2013) are 3.7, 2.0, and 8.6 bps, respectively.[18]

[17] Since there is high price volatility shortly after auction due to information contained in the auction results, we calculate returns from 10 minutes after auction.

[18] Aside from differing intervals of analysis, our sample period also differs from that of Lou, Yan, and Zhang (2013). To assess the importance of this point, we calculate returns with daily data following their approach but using our shorter sample period. Those results, reported in Appendix Table A1, show returns that are quite close to theirs for the 2- and 5-year notes, but appreciably smaller for the 10-year note for several intervals.

B. Drivers of Supply Effects

In this section, we attempt to explain the observed supply effect using both broad market conditions as well as security-specific measures from the day or week before auction. Lou, Yan, and Zhang (2013) suggest that pricing patterns in the secondary market around auction days can be explained by dealers' limited risk-bearing capacity. In order to incorporate large amounts of new issuance into their balance sheets, dealers must take short positions in the secondary market, driving prices down. From this reasoning, we expect price pressure to be greater when dealers' risk-bearing capacity is weaker and when market stability and liquidity are lower. Similar to past literature, we use measures of implied equity and Treasury volatility as explanatory variables, but we also incorporate other measures of risk-bearing capacity and financial stress, such as the average absolute yield curve fitting error (as in Hu, Pan, and Wang (2013)). In addition, utilizing our secondary market data, we test several security-specific liquidity measures and a realized volatility measure.

In Table 4, we regress price pressure effects, measured as cumulative returns three hours from auction, on a set of broad market metrics: the MOVE, the VIX, the Baa-Aaa yield spread, the TED spread, the average absolute yield curve fitting error, and a broker-dealer leverage factor.[19] Overall, we find that our measures of market uncertainty and stress are consistently and positively correlated with price pressure effects. More specifically, higher volatility as measured by the MOVE and VIX indices, higher flight-to-safety premium as measured by a wider Baa-Aaa spread, higher financial market stress as measured by a wider TED spread, lower dealer risk-bearing capacity as measured by larger absolute yield curve fitting errors, and higher funding risk as measured by rising broker-dealer leverage, are associated with higher returns around auction.[20]

[19] For the regression analysis, we exclude observations from days on which there was a scheduled FOMC announcement, because FOMC statements for much of our sample period were released around 2:15 pm, not long after the typical auction close of 1:00 p.m.

[20] Note that the positive coefficients for broker-dealer leverage are opposite in sign from what Lou, Yan, and Zhang (2013) find. Our results are mainly driven by salient observations in the summer of 2008 when prior growth in leverage had been extremely high, but extant funding conditions were extremely poor. If we restrict our sample to ending in June 2008, as in Lou, Yan, and Zhang (2013), our broker-dealer leverage coefficient is negative but insignificant for the 2- and 10-year notes, and positive but insignificant for the 5-year note.

In terms of statistical significance, the TED spread and average yield curve fitting error are significantly correlated with returns across all three maturities, the MOVE and VIX are significantly correlated with returns for the 5- and 10-year notes, the Baa-Aaa spread is significantly correlated with returns for 2- and 10-year notes, and the leverage factor is significantly correlated with returns for the 5-year note. Using the 10-year note as an example, we find that a one standard deviation increase in the MOVE (26.68), VIX (8.81), Baa-Aaa spread (47.87), TED-spread (40.27), average yield curve fitting error (2.52), or broker-dealer leverage (66.68) is associated with a 6.53, 5.99, 5.26, 3.62, 3.57, or 1.33 bps increase in three-hour cumulative returns, respectively.

Next, in Table 5, we regress price pressure effects on a common set of liquidity and volatility measures from the secondary market. These consist of: bid-ask spread, depth, price impact, and price volatility and are calculated as of the day before auction for most measures and the week before auction in the case of price impact. In addition, we also add the auction's offering amount, which proxies for the balance sheet burden of the dealers. Consistent with the preceding analysis, we find that liquidity and volatility are strongly and consistently correlated with price pressure effects. More specifically, returns are higher when bid-ask spreads are wider, depth is lower, price impact is higher, price volatility is higher, and when the offering amount is higher.[21] For the 5-year note, the price volatility and offering amount coefficients are both positive and significant. For the 10-year note, the bid-ask spread and price impact coefficients are both positive and significant. To demonstrate the relative magnitude of their effects, a one standard deviation increase in depth (0.02), price impact (0.49), spread (0.36), price volatility (0.62), or offering amount (5.47) for the 10-year note is associated with a -2.59, +43.25, +4.14, +0.25, or +1.01 bps change in three-hour cumulative returns respectively.

C. Intraday Patterns

Liquidity and price volatility in the secondary market have been shown to respond quickly to public information in the form of scheduled macroeconomic announcements (for

[21] The only deviation from this pattern is price volatility for the 2-year note which is negative but insignificant.

example, see Fleming and Remolona (1999) and Balduzzi, Elton, and Green (2001)). In contrast, there has been limited study on the effects of Treasury auctions. Nyborg and Sundaresan (1996) look at when-issued Treasury securities between 1992 and 1993, documenting some evidence of low depth in the secondary market right before auction and Goldreich (2007) shows that pricing patterns in the form of underpricing are positively correlated with bid-ask spreads and yield volatility in the secondary market 30 minutes prior to auction. However, no study to our knowledge has documented intraday liquidity and volatility patterns for on-the-run Treasury notes in a sizable window around auction. Moreover, as with macroeconomic announcements, it is natural to expect strong microstructure patterns around Treasury auctions because Treasury auctions are large in size, are scheduled well in advance, and occur with a regular frequency. Furthermore, any strategy which attempts to exploit the pricing pattern on auction day would need to take contemporaneous liquidity and volatility movements into consideration.

We examine three different measures of intraday liquidity and volatility on days with a 2-, 5-, or 10-year Treasury note auction: bid-ask spread, depth, and price volatility. First, in Figure 6, we compare intraday price volatility on auction days (black line) and non-auction days (blue line).[25] For each five-minute interval between 7:00 a.m. and 5:00 p.m., price volatility is calculated as the standard deviation of all five-minute mid-price changes. In general, the level of volatility on auction days is similar to that on non-auction days. For both auction and non-auction days, we see notable spikes in volatility around 8:30 a.m. and 10:00 a.m., corresponding to the times of macroeconomic announcements and consistent with previous studies on the Treasury market (for example, see Fleming and Remolona (1997)). Importantly, we see an additional spike between 1:00-1:10 p.m. for the auction-day series alone, suggesting a unique effect from Treasury auctions. Using the Brown and Forsythe F-test of sample variances, we find that the auction-day and non-auction day volatilities are significantly different at the 1% level (denoted by a shaded diamond) for all three maturities at time of auction as well as for a short time after auction.

[25] Non-auction days are defined as trading days on which no nominal, coupon-bearing securities were auctioned.

Next, Figure 7 compares the average bid-ask spread on auction days (black line) and non-auction days (blue line). As with volatility, spreads are generally similar on auction and non-auction days, with noticeable jumps around the time of 8:30 a.m. and 10:00 a.m. macroeconomic announcements.[26] On auction days, we find that liquidity is a little better (the spread is a little narrower) leading up to auction time across all maturities. However, there is also a salient rise in the spread starting at the time of the auction close, and it generally stays elevated until late in the trading day. A two-sided t-test shows that while spreads at time of auction are not significantly wider on auction days they are significantly wider for many of the 5-minute intervals following auction between 1:30 p.m. and 3:00 p.m.

Finally, Figure 8 compares depth (the average of quoted depth at the best bid and ask prices) for auction days (black line) and non-auction days (blue line). One again sees roughly similar patterns on auction and non-auction days, with noticeable dips around the time of 8:30 a.m. and 10:00 a.m. macroeconomic announcements. However, depth on auction days, generally exceeds that non-auction day levels in the hours preceding the auction close, but then drops roughly 50% at time of auction. Depth then quickly rebounds to a level comparable to non-auction days for the 5-and 10-year notes and to a somewhat higher level for the 2-year note. A two-sided t-test shows that the depth on auction days is significantly greater than on non-auction days in the period leading up to auction time, when it becomes significantly lower, but then significantly greater again for roughly two hours after auction for the 2-year note.

D. Profiting from Intraday Supply Effects

While liquidity on auction days overall is good, transaction costs may still be appreciable relative to the magnitude of the intraday supply effect we document. Thus, we next use our order book data to test a simple trading strategy that tries to take advantage of the observed price patterns. First, we suppose that an investor sells the on-the-run security t minutes before auction at the best bid price, and buys back the security at auction time at the best ask price. Next, the investor buys the security 10 minutes after auction (see footnote 17)

[26] There is also some indication of another jump shortly at 2:15 p.m., especially for the 2- and 5-year notes, consistent with the fact that FOMC statements were typically released around 2:15 pm for most of our sample period.

at the best bid price, and then sells it t minutes after auction at the best ask price. We allow t to take on values of 60, 120, 180, and 240 minutes. The estimated profit per security is calculated as the sum of the ask prices minus the sum of the bid prices.

Table 6 summarizes the average returns per security using this simple trading strategy. We find that the strategy loses money for the 2-year note, has positive but statistically insignificant returns for the 5-year note, but positive and statistically significant returns for the 10-year note (for the strategies with the 60-, 120-, and 180-minute windows). That is, transaction costs are large relative to the intraday supply effect for shorter term maturities, precluding systematically positive profits from trying to exploit the price pattern and underscoring the importance of considering market frictions when evaluating trading strategies.

5. Additional Tests

A. Yield/Return Behavior of Treasury Bills

One advantage of our intraday data is that we are able to also examine price pressure effects of bill issuance for the part of our sample covered by GovPX (January 1992 – June 2001). Most Treasury bills are auctioned on a weekly basis, precluding similar forms of multiday analysis as in past work.[27] We choose to study the 13-week and 26-week bills, which are auctioned at the same time each Monday. The weekly frequency of these auctions provides for a large number of observations and thus more precise estimates.[28] Moreover, because they are auctioned at the same time, their supply effect is synchronized and strengthened by each other.

Table 7 summarizes intraday yield changes by 30 minute intervals for the on-the-run 13- and 26-week bills around the auction of the next issues (of the same maturities). We see

[27] That is, if we studied a 20-day window around weekly auctions (the same window width as in Lou, Yan, and Zhang (2013)), our results would be confounded by the effects of other auctions of the same maturity security in the preceding and following weeks.

[28] The Treasury also auctions 4-week bills on a weekly basis, but these have only been sold since July 2001. Fifty-two-week bills are auctioned every four weeks, and issuance frequency was reduced and then suspended for part of our sample. Cash-management bills are sold infrequently on an *ad hoc* basis.

that the effect of the auction is especially strong leading up to the auction so that the yield change is negative and significant at the 5% level or better from 180 minutes before auction to 30 minutes after auction for both the 13- and 26-week bills, but is not significantly different from zero thereafter. The significant yield changes for the 26-week bill are usually larger than those for the 13-week bill. Similar to the notes analysis, we find some evidence that the effect of the auction gets stronger as we move further from the time of auction. Figure 9 depicts the yield changes in finer, one-minute intervals.

Next, Table 8 summarizes cumulative returns in the eight-hour window around auction by 30 minute intervals for on-the-run bills. We find that the 13- and 26-week bills both have very significant (at the 1% level) auction day effects in all of the 8 hours around auction. The magnitude of the auction effect for 26-week bills (0.12 to 0.29 bps) is about 2-3 times that of the 13-week bills (0.05 to 0.16 bps).

Figure 10 summarizes returns in one-minute intervals and compares the returns pattern on auction days to that on non-auction days. We see that the auction-day returns are consistently positive and highly significant in the eight-hour window around auction. On non-auction days, however, the returns tend to oscillate around zero and are not significantly different from zero. That is, the intraday price pattern for bills is unique to auction days, consistent with the idea that the effect is driven by the new security supply.

B. When-Issued vs. On-the-Run Behavior

Our intraday data also allows us to examine price pressure effects in the when-issued market for the part of our sample covered by GovPX (January 1992 – June 2001). If anything, one might expect supply effects to be more pronounced in this market because we are here examining the yields/returns of the actual security being issued, as opposed to the yields/returns of a close substitute (i.e., the on-the-run security) as in our earlier analysis.

Table 9 shows the average when-issued yield difference for the 2-, 5-, and 10-year notes in the six-hour window surrounding auction. Consistent with on-the-run analysis, we find an inverted V-shaped pattern for 2- and 5-year notes. Many of the yield changes before auction are statistically significant for the 2- and especially 5-year notes, but only a few yield changes after auction are significant for these notes. In the case of the 10-year note, for which the sample is quite small, the yield changes are negative before auction and positive after auction, but none of the observed yield changes are statistically significant.

Table 10 summarizes cumulative returns in the eight-hour window around auction by 30 minute intervals for the auctioned 2-, 5-, and 10-year notes. For the 5-year note, we find returns that are statistically significant and of somewhat greater magnitude than those for the on-the-run securities reported in Table 3. For the 2-year note, we find returns similar in magnitude to those for the on-the-run note, but the coefficients here tend to be marginally significant or insignificant. For the 10-year note, in contrast, returns here are generally negative, albeit insignificant. The weak results for the 10-year may be due to the small sample size of these when-issued notes.[29]

Figure 11 summarizes the returns in one-minute intervals and also compares the returns for when-issued securities (black line) to those for the on-the-run securities (red line). In this figure, the sample period for the on-the-run securities is limited to match that for the when-issued securities: January 1, 1992 to June 30, 2001. We see that for the 2-, 5-, and 10-year notes, the when-issued returns closely track those of the on-the-run notes. This suggests that the supply effect of Treasury note auctions affects the on-the-run and when-issued securities similarly.

6. Conclusion

We assess price behavior around Treasury auctions using intraday data and find that prices tend to decline in advance of auction and increase following auction. While our results are consistent with evidence uncovered using lower frequency data, we argue that analysis of intraday data avoids some of the possible confounding factors that affect lower-frequency analyses. Finding a price pressure effect with intraday data thus increases confidence in the findings of the lower frequency analyses.

We relate the price pressure effect to various exogenous variables and find support for the hypothesis that investors have imperfect capital mobility and dealers have limited

[29] Note that this 10-year sample includes only the first issue of each security, while the prior analysis also includes reopenings.

risk-bearing capacity. In particular, we find that implied Treasury volatility, implied equity volatility, the Baa-Aaa corporate yield spread, the TED spread, and a measure of the dispersion of yields around a smoothed yield curve, are all positively correlated to the price pressure effect for each of the 2-, 5-, and 10-year notes. We further find that the price pressure effect is positively correlated with bid-ask spread, price impact, and realized price volatility, and negatively correlated with depth.

We further examine the intraday behavior of volatility and liquidity around Treasury auctions. We find that volatility and bid-ask spreads spike higher, and depth plunges lower, around announcements of auction results, but that liquidity is generally better in the hours before such announcements. Despite generally good liquidity on Treasury auction days, returns from a trading strategy that seeks to exploit the price pressure effect are only significantly positive for one of the three maturities examined, illustrating the importance of trading costs relative to the observed auction price pattern.

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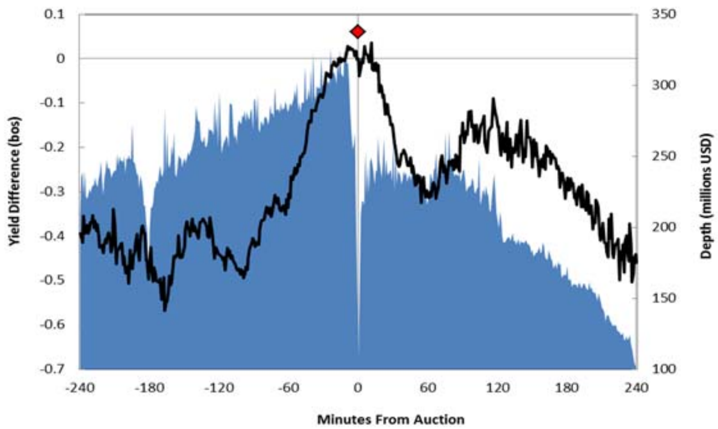
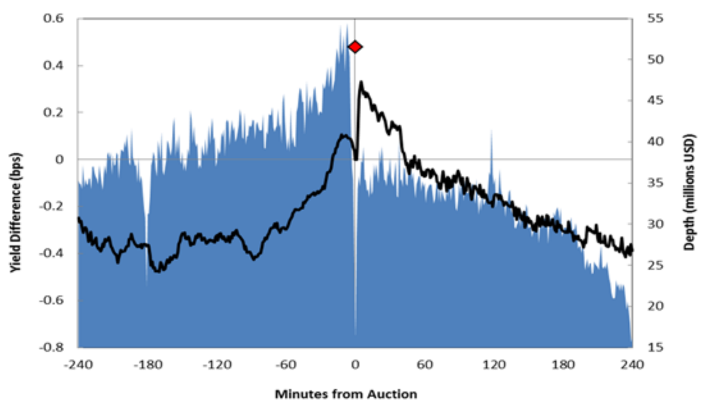
Figure 1. Yields, liquidity, and underpricing around Treasury auctions

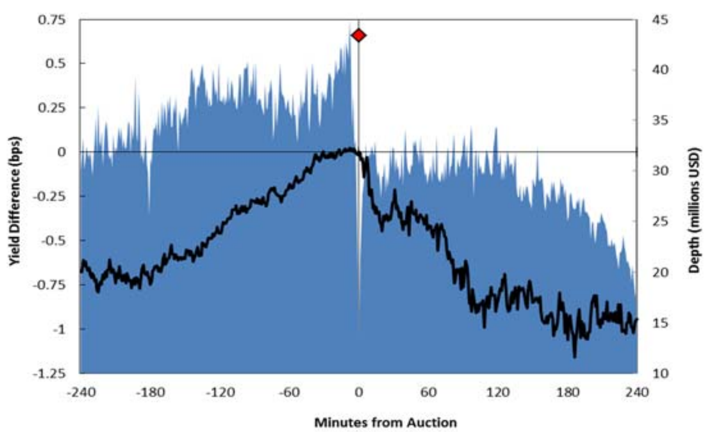
Panel A. 2-Year Note



Panel B. 5-Year Note



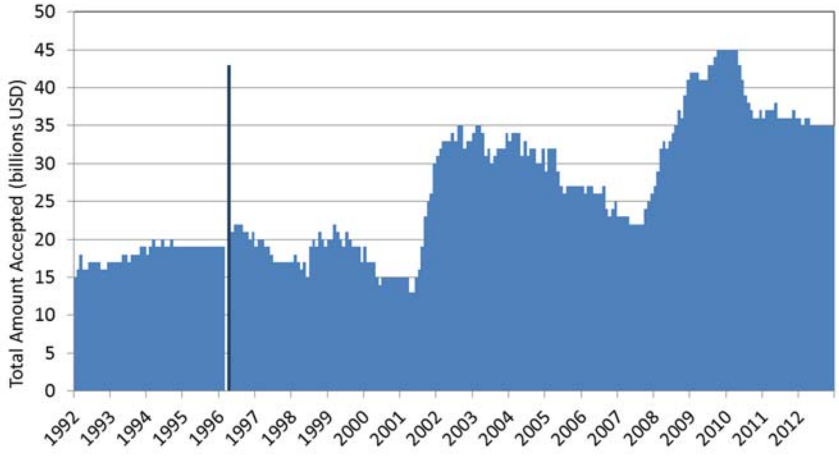
Panel C. 10-Year Note



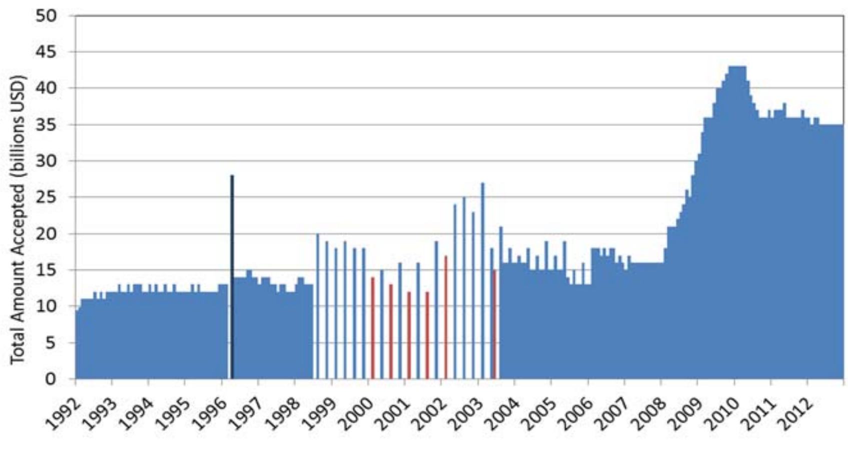
Notes: Panels A-C show average yield change (black line), depth (shaded blue area), and underpricing (red diamond) in one-minute intervals for the eight-hour window around auction time from January 1, 1992 to December 31, 2012. Yield change is calculated using the difference of on-the-run mid-quotes (the average of the best bid and ask quotes) t minutes from auction and at the time of auction. t ranges from -240, or four hours before auction, to 240, or four hours after auction. Depth is calculated as the average of depth at the best bid and ask prices for the corresponding on-the-run security. Underpricing is calculated as the difference between the stop-out yield in the primary market and the last observed when-issued mid-yield in the secondary market before the auction close. Between January 1, 1992 and June 30, 2001, depth and on-the-run yield quotes come from GovPX. Between July 1, 2001 and December 31, 2012, they come from BrokerTec. When-issued quotes for underpricing come solely from GovPX.

Figure 2. Treasury note issuance amounts by month

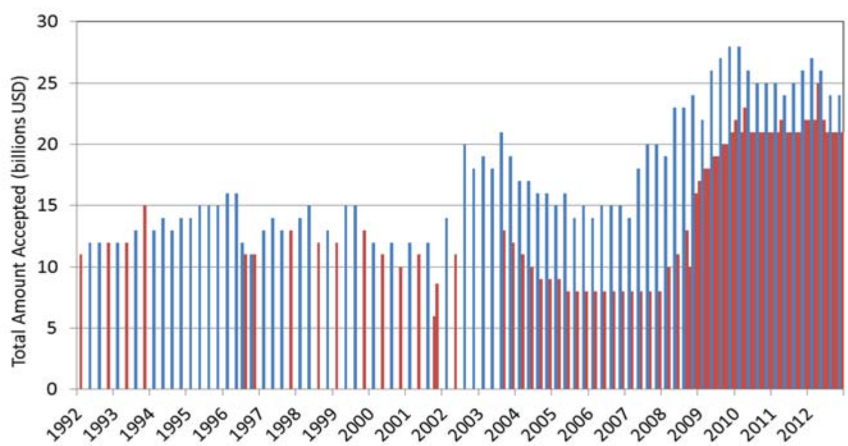
Panel A. 2-Year Note



Panel B. 5-Year Note

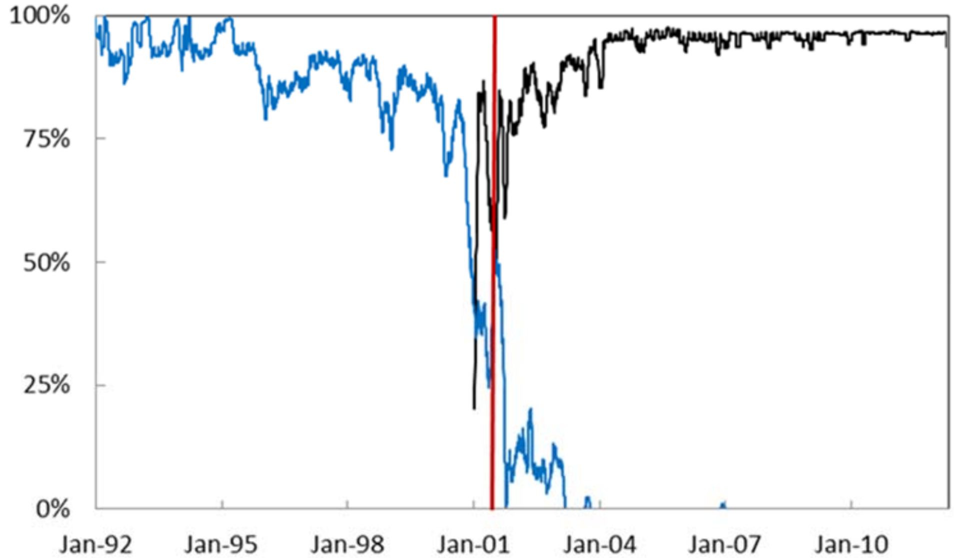


Panel C. 10-Year Note



Notes: The figure shows the total amount issued by month for each of the 2-, 5-, and 10-year Treasury notes between January 1992 and December 2012. Amounts from reopenings are in red and instances of more than one auction in a month (April 1996) are in dark blue.

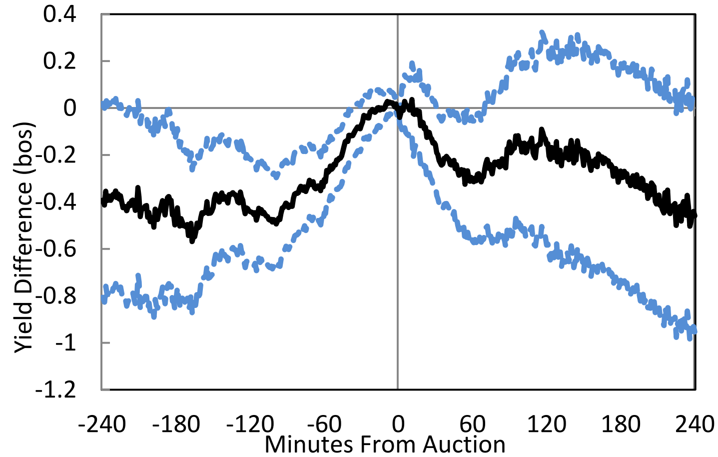
Figure 3. Quote incidence of 10-Year Treasury note



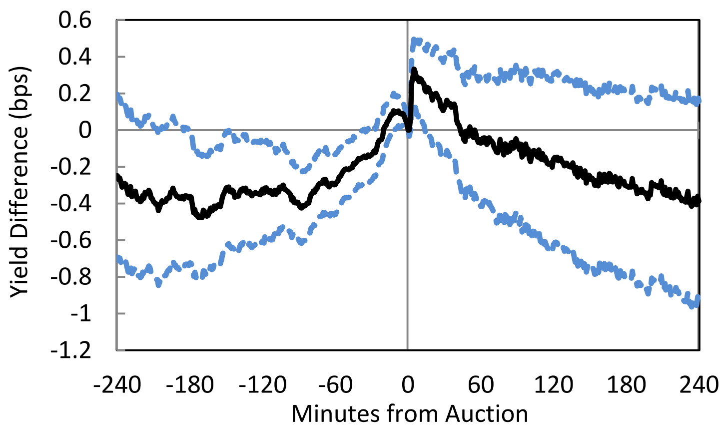
Notes: The figure shows the incidence of quotes for the 10-year note on GovPX (blue line) and BrokerTec (black line) between January 1, 1992 and December 31, 2012. Quote incidence is calculated as the percent of time on trading days between 7:00 a.m. and 5:00 p.m. in which there was a quote in the order book at either the bid or ask. The red vertical line marks July 1, 2001, the transition date at which we stop using GovPX data and start using BrokerTec data.

Figure 4. Yield changes around subsequent auctions for on-the-run notes

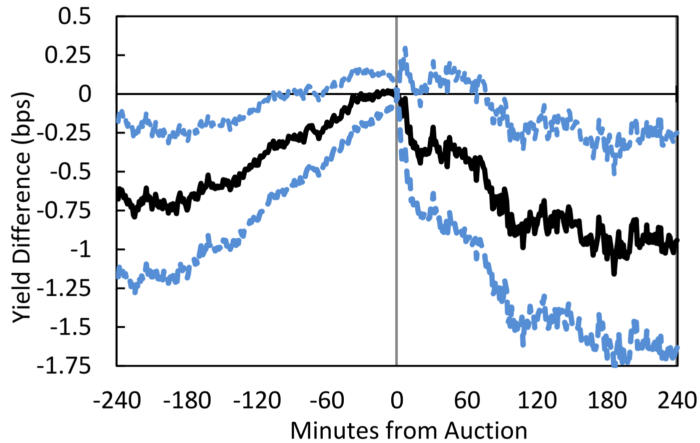
Panel A. 2-Year Note



Panel B. 5-Year Note



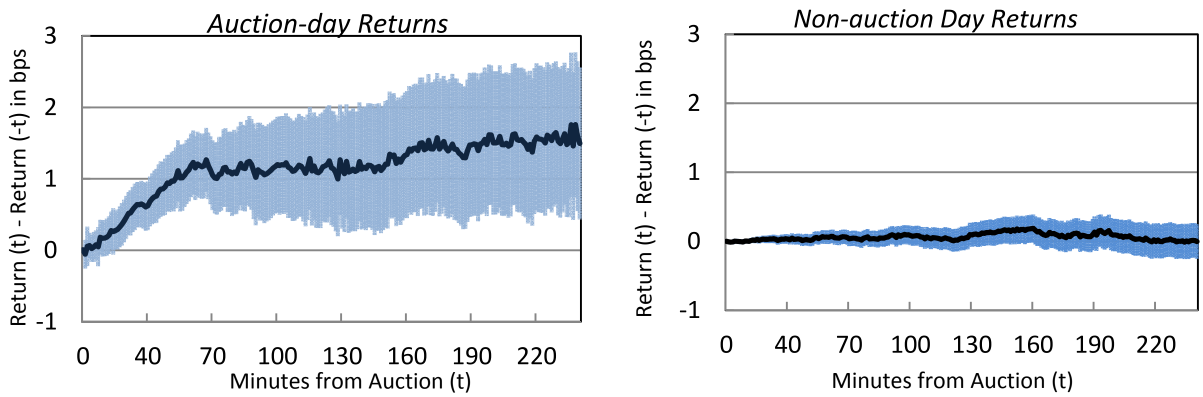
Panel C: 10-Year Note



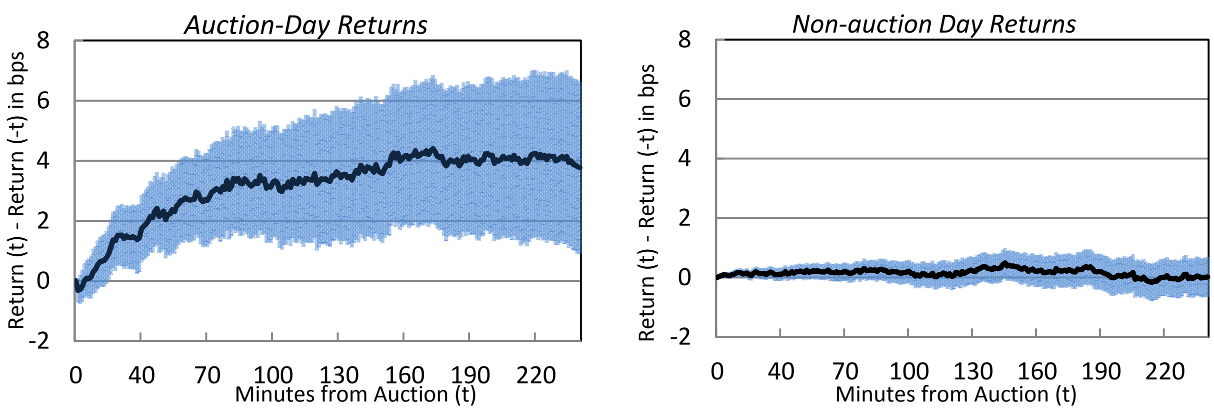
Notes: Panels A-C show the average yield change in the eight-hour window around time of auction for the 2-, 5-, and 10-year on-the-run Treasury notes between January 1, 1992 and December 31, 2012. Yield change is calculated as the difference between on-the-run mid-quotes (the average of the best inside bid and ask quotes) t minutes from auction and at the time of auction. t ranges from -240, or four hours before auction, to 240, or four hours after auction. Between January 1, 1992 and June 30, 2001, yield quotes come from GovPX. Between July 1, 2001 and December 31, 2012, they come from BrokerTec. The dotted blue lines indicate the 95% confidence interval around the sample mean constructed using a t-test.

Figure 5. Cumulative returns around subsequent auctions for on-the-run notes

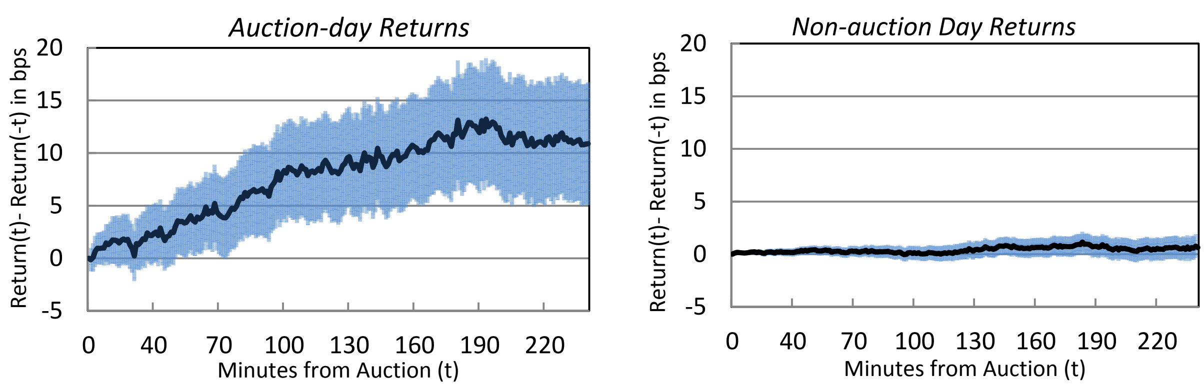
Panel A. 2-Year Note



Panel B. 5-Year Note



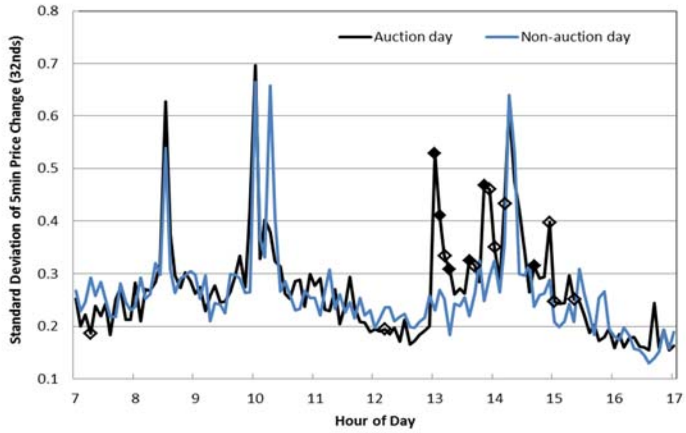
Panel C. 10-Year Note



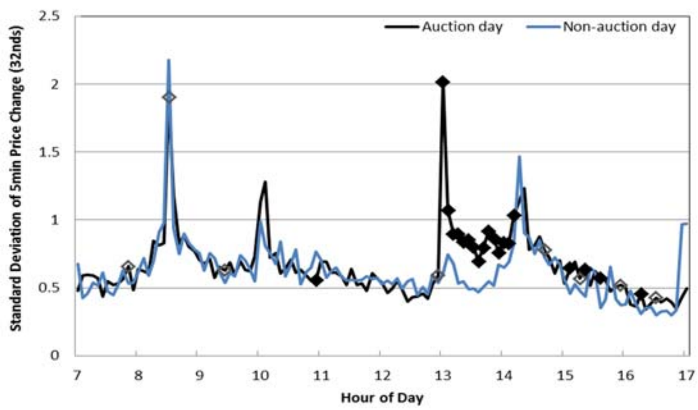
Notes: Panels A-C show the average return in the eight-hour window around time of auction for the 2-, 5-, and 10-year on-the-run Treasury notes between January 1, 1992 and December 31, 2012. In each panel, the left graph represents the average return t minutes from time of auction on days with a Treasury auction of the specific security; the right graph represents the average return t minutes from 1:00 p.m., the regular time of auction, on days in which no Treasury note or bond is auctioned. Cumulative return t minutes from time of auction (left graph) or 1:00 p.m. (right graph) is calculated as: ((mid-price(t+10)-mid-price(10))/(mid-price(10))-(mid-price(0)-mid-price(-t))/(mid-price(-t))). Mid-price is calculated as the average of the best bid and ask prices. The shaded blue band shows the 95% confidence interval for the sample mean constructed using a t-test.

Figure 6. Intraday price volatility on auction and non-auction days

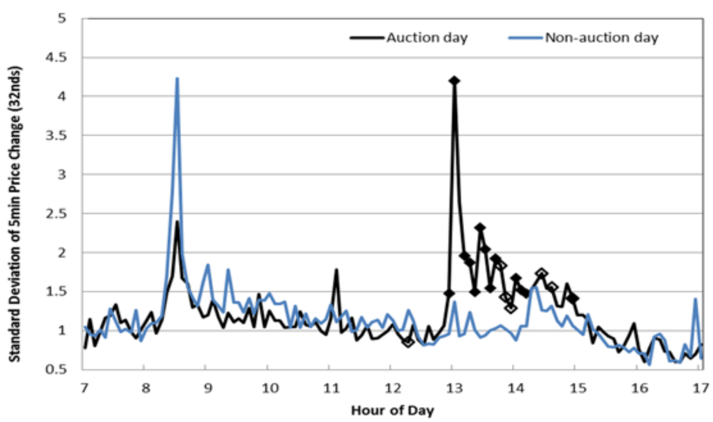
Panel A. 2-Year Note



Panel B. 5-Year Note



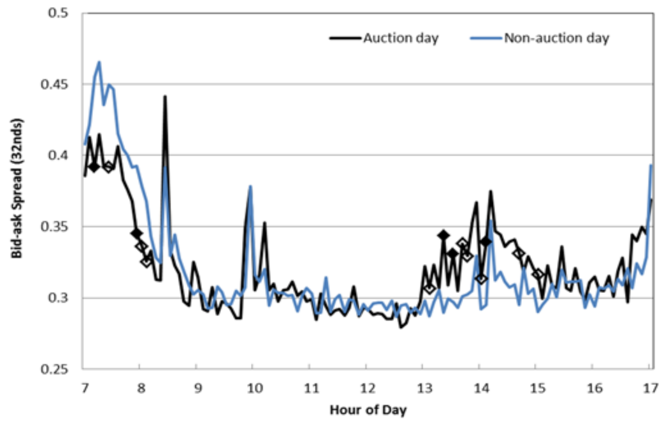
Panel C. 10-Year Note



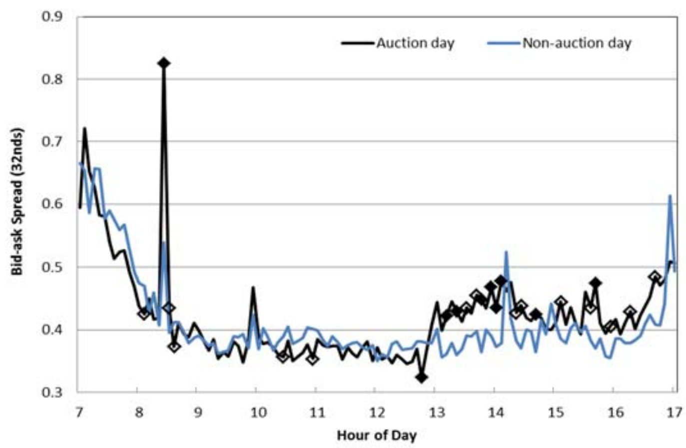
Notes: Panels A-C show price volatility between the trading hours of 7:00 a.m. and 5:00 p.m. on 1:00 p.m. auction days (black line) and non-auction days (blue line) for 2-, 5-, and 10-year Treasury notes respectively between January 1, 1992 and December 31, 2012. Price volatility is calculated as the standard deviation of five-minute changes in mid-price (the average of the best bid and ask quotes) of the on-the-run security and is measured in 32nds of a price point. Between January 1, 1992 and June 30, 2001, the quotes come from GovPX. Between July 1, 2001 and December 31, 2012, the quotes come from BrokerTec. An open (shaded) diamond marks a five-minute interval in which auction day volatility is significantly different from non-auction day volatility at the 5% (1%) significance level using the Brown and Forsythe F-test.

Figure 7. Bid-ask spread on auction and non-auction days

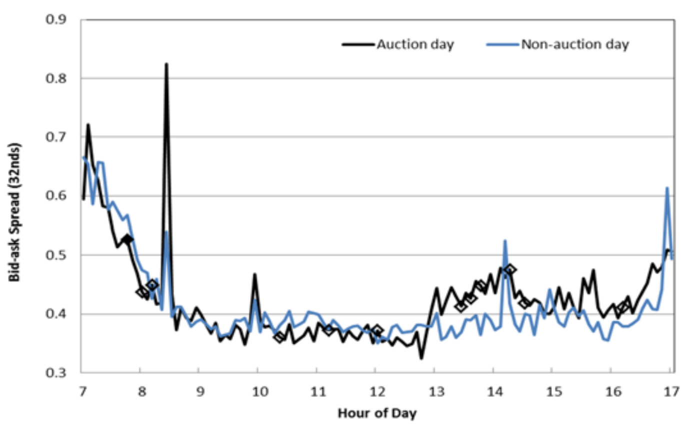
Panel A. 2-Year Note



Panel B. 5-Year Note



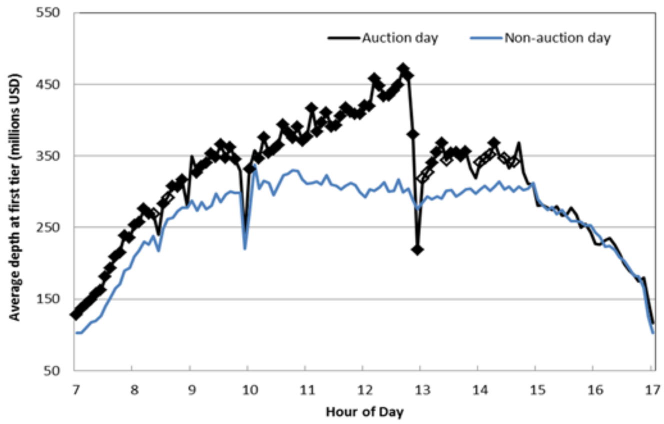
Panel C. 10-Year Note



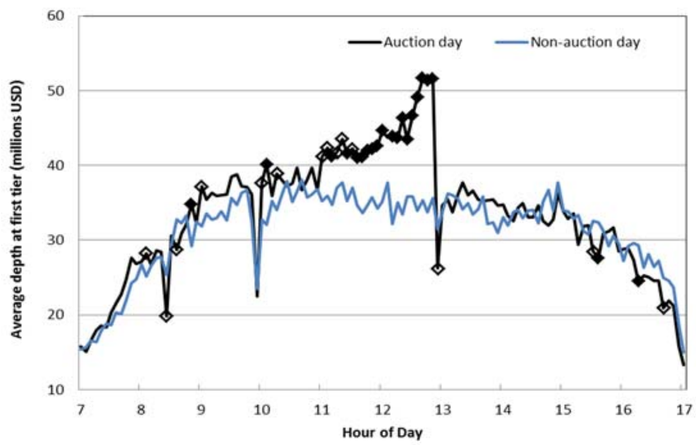
Notes: Panels A-C show the average bid-ask spread between trading hours 7:00 a.m. and 5:00 p.m. on 1:00 p.m. auction days (black line) and non-auction days (blue line) for 2-, 5-, and 10-year Treasury notes respectively between January 1, 1992 and December 31, 2012. Bid-ask spread is calculated as the difference of the best bid and ask prices across trading days and is measured in 32nds of a point. Between January 1, 1992 and June 30, 2001, observations come from GovPX. Between July 1, 2001 and December 31, 2012, observations come from BrokerTec. An open (shaded) diamond marks a five-minute interval in which auction-day spread is significantly different from non-auction spread at the 95% (99%) confidence level using a two-sample t-test.

Figure 8. Depth on auction and non-auction days

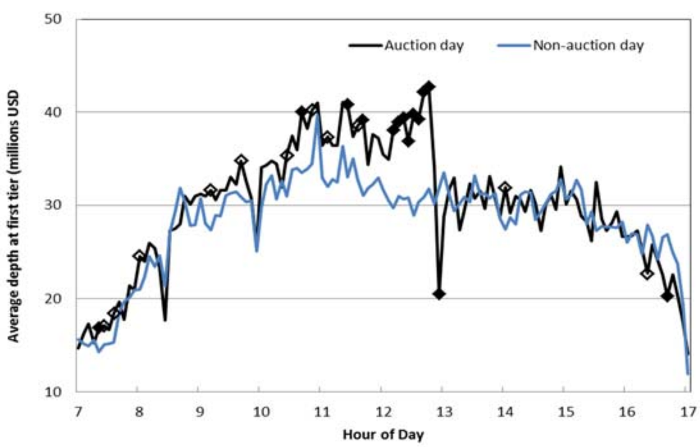
Panel A. 2-Year Note



Panel B. 5-Year Note



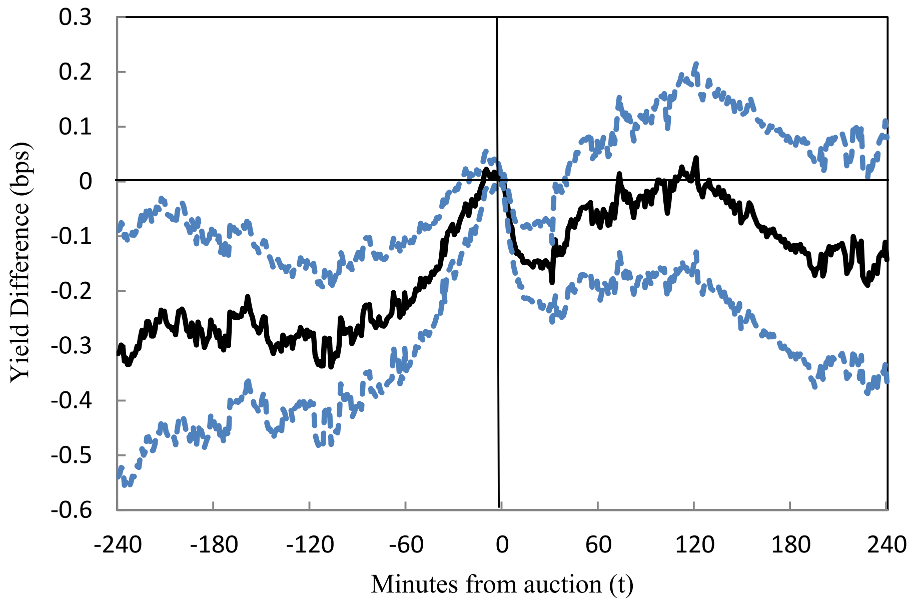
Panel C. 10-Year Note



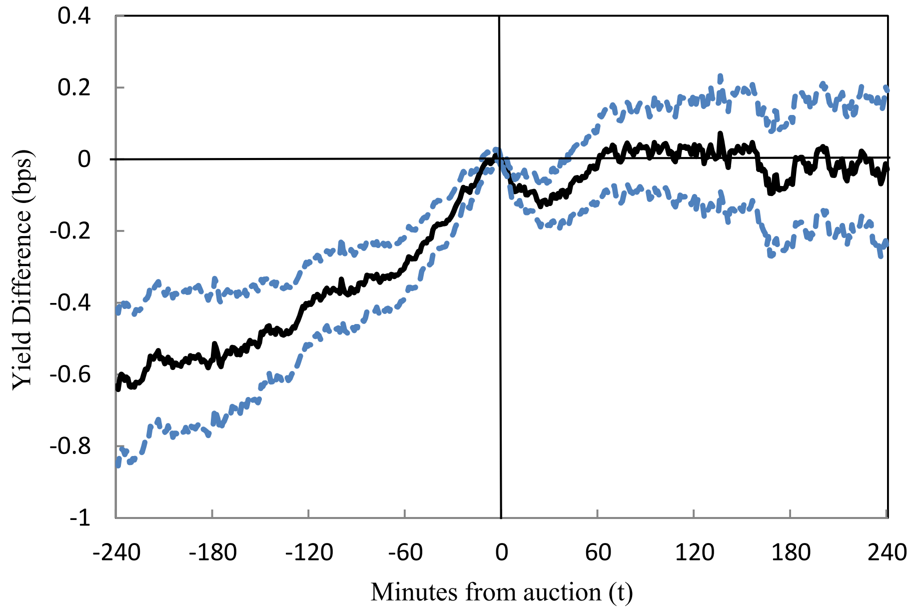
Notes: Panels A-C show average depth between trading hours 7:00 a.m. and 5:00 p.m. on 1:00 p.m. auction days (black line) and non-auction days (blue line) for 2-, 5-, and 10-year Treasury notes respectively between January 1, 1992 and December 31, 2012. Depth is calculated as the average of depth at the best bid and ask prices and then averaged across trading days by hour of day. Between January 1, 1992 and June 30, 2001, observations come from GovPX. Between July 1, 2001 and December 31, 2012, observations come from BrokerTec. An open (shaded) diamond marks a five-minute interval in which auction-day depth is significantly different from non-auction depth at the 95% (99%) confidence level using a two-sample t-test.

Figure 9. Yield changes around subsequent auction for on-the-run bills

Panel A. 13-Week Bill



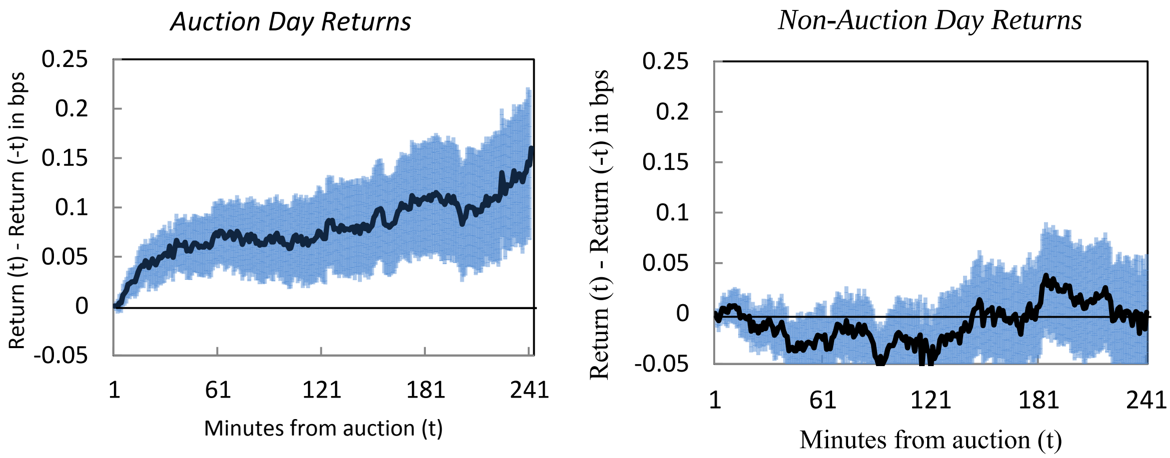
Panel B. 26-Week Bill



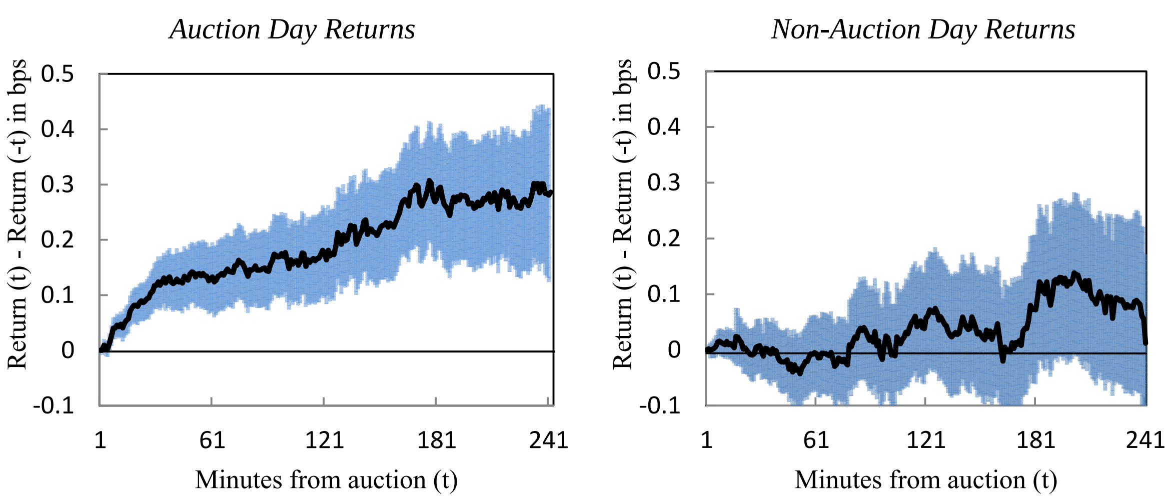
Notes: Panels A and B show average yield change for the 13- and 26-week on-the-run Treasury bills in one-minute intervals for the eight-hour window around auction time from January 1, 1992 to June 30, 2001. Yield change is calculated using the difference of on-the-run 13- or 26-week bill mid-quotes (the average of the best bid and ask quotes) t minutes from auction and at the time of auction, where t ranges from -240, or four hours before auction, to 240, or four hours after auction. All quotes come from GovPX. The dotted blue lines indicate the 95% confidence interval around the sample mean constructed using a t-test.

Figure 10. Cumulative returns around subsequent auction for on-the-run bills

Panel A. 13-Week Bill

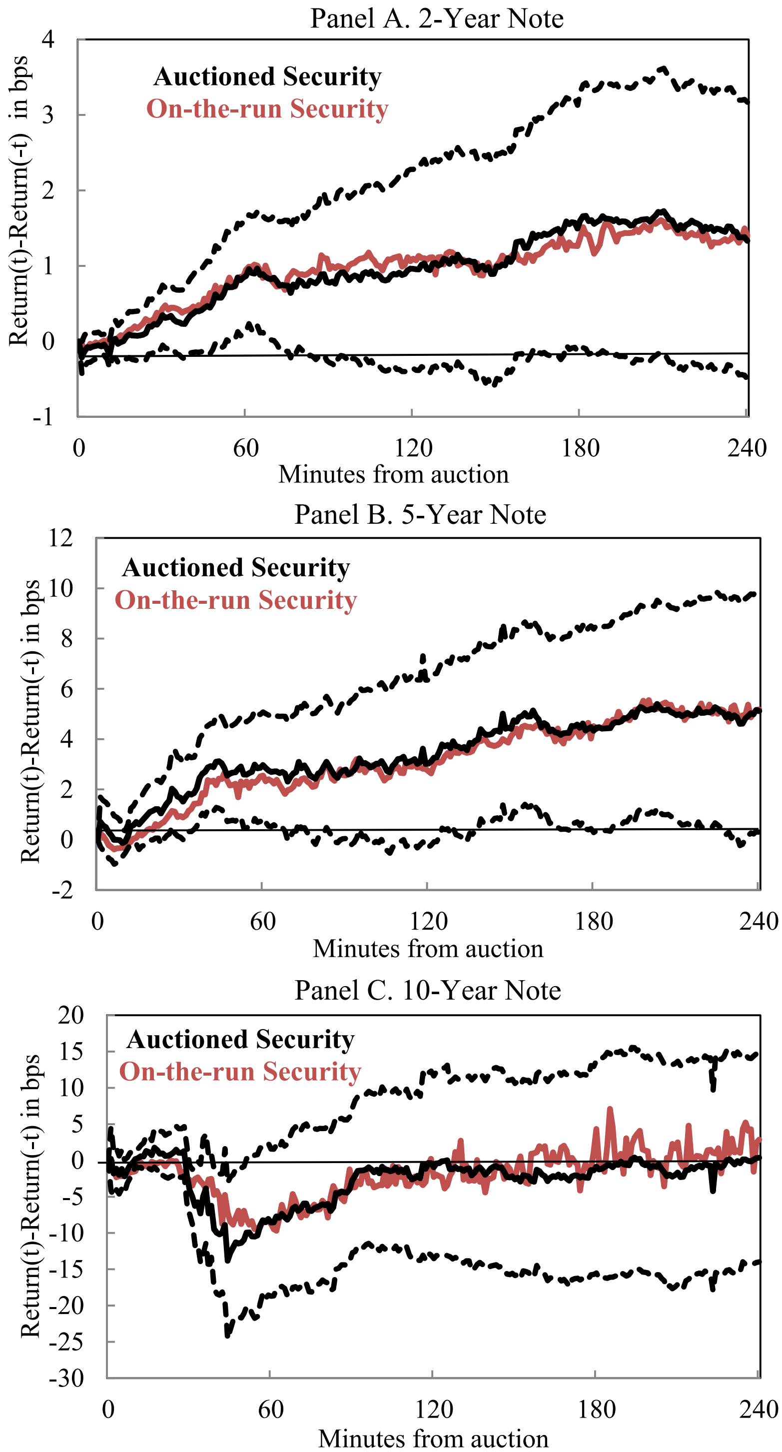


Panel B. 26-Week Bill



Notes: Panels A and B show the average return in the eight-hour window around time of auction for the 13- and 26-week on-the-run Treasury bills between January 1, 1992 and June 30, 2001. In each panel, the left graph shows the average return t minutes from time of auction on days with a Treasury auction of the corresponding security; the right graph shows the average return t minutes from 1:00 p.m., the regular time of auction, on the day following auction. Cumulative return t minutes from time of auction (left graph) or 1:00 p.m. (right graph) is calculated as: ((mid-price(t+10)-mid-price(10))/(mid-price(10))-(mid-price(0)-mid-price(-t))/(mid-price(-t))). Mid-price is calculated as the average of the best bid and ask prices. All quotes come from GovPX. The shaded blue band shows the 95% confidence interval for the sample mean constructed using a t-test.

Figure 11. Cumulative returns around subsequent auction for when-issued notes



Notes: Panels A-C compares average returns in the eight-hour window around auction for the 2-, 5-, and 10-year auctioned (black line) and on-the-run (red line) Treasury notes between January 1, 1992 and June 30, 2001. Cumulative return t minutes from time of auction (left graph) or 1:00 p.m. (right graph) is calculated as: ((mid-price(t+10)-mid-price(10))/(mid-price(10))-(mid-price(0)-mid-price(-t))/(mid-price(-t))). Mid-price is calculated as the average of the best bid and ask prices. All quotes come from GovPX. The dotted lines show the 95% confidence interval for the when-issued mean constructed using a t-test.

Table 1. Summary statistics

Panel A. Treasury note auctions

Variable	2-Year	5-Year	10-Year
Number of issues	252	212	142
Auction size ($ billions)	26.07	20.20	16.43
	(8.70)	(9.90)	(5.47)
Auction yield (%)	3.65	4.21	4.33
	(0.02)	(1.87)	(1.51)

Panel B: Secondary market behavior

Variable	2-Year	5-Year	10-Year
Depth ($ billions)	0.11	0.02	0.02
	(0.15)	(0.02)	(0.02)
Price impact (32nds/billion)	0.32	0.66	1.04
	(0.18)	(0.30)	(0.49)
Bid-ask spread (32nds)	0.33	0.49	0.80
	(0.16)	(0.34)	(0.36)
Price volatility (32nds)	0.25	0.62	1.14
	(0.23)	(0.31)	(0.62)

Panel C. Other variables

Variable	Mean	Std. Dev.
MOVE index	100.21	26.68
VIX index	20.36	8.81
Baa-Aaa spread (bps)	98.82	47.87
TED spread (bps)	52.23	40.27
Yield curve fitting error (bps)	2.83	2.52

Notes: The table shows the averages and standard deviations (in parentheses) of market indicators used to explain supply effects between January 1, 1992 and December 31, 2012. The market indicators are measured as of the day preceding auction day. The Merrill Lynch Option Volatility Estimate (MOVE) and Chicago Board Options Exchange Market Volatility (VIX) indices come from Bloomberg. Moody's Baa-Aaa spread come from the U.S. Economics Database in Haver. The TED-spread is the spread between 3-month LIBOR and the 3-month Treasury bill and comes from the FRED database. Yield curve fitting errors are the average absolute fitting errors from the Nelson-Siegel-Svensson model of Gurkaynak, Sack, and Wright (2007). Depth, price impact, bid-ask spread, and price volatility come from the GovPX platform between January 1, 1992 and June 30, 2001. From July 1, 2001 onwards, they come from the BrokerTec platform. Depth is calculated by taking the average depth at the best bid and ask prices and then averaging across the trading day. Bid-ask spread is calculated by taking the difference of the best bid and ask prices and then averaging across the trading day. Price impact is the weekly coefficient on a regression of 5-minute mid-price changes on 5-minute net order flow (defined as buy-initiated volume minus sell-initiated volume). Price volatility is calculated as the daily standard deviation of 5-minute mid-price changes. Note that depth was not recorded in our GovPX data before July 1994, so its sample is limited to July 1994 to December 2012.

Table 2. Yield changes around subsequent auctions for on-the-run notes

	2-Year Note		5-Year Note		10-Year Note	
t	Mean	t-value	Mean	t-value	Mean	t-value
-180	-0.46***	-2.35	-0.36*	-1.96	-0.75***	-3.33
-150	-0.42***	-2.77	-0.31**	-1.99	-0.60***	-2.96
-120	-0.44***	-3.35	-0.32**	-2.24	-0.46***	-2.53
-90	-0.41***	-3.83	-0.41***	-4.09	-0.28*	-1.85
-60	-0.30***	-3.62	-0.30***	-3.55	-0.18	-1.61
-30	-0.08	-1.20	-0.13*	-1.87	-0.02	-0.25
30	-0.15	-1.11	0.12	0.89	-0.28	-1.29
60	-0.31**	-2.13	-0.07	-0.41	-0.42*	-1.60
90	-0.14	-0.52	-0.05	-0.33	-0.76***	-2.51
120	-0.15	-0.58	-0.16	-0.67	-0.84***	-2.65
150	-0.24	-0.70	-0.25	-1.01	-0.85***	-2.65
180	-0.27	-0.73	-0.30	-1.17	-1.06***	-3.26
No. Obs.	252		211		135	

Notes: The table shows average yield changes from t minutes before auction to time of auction on the secondary market for the on-the-run 2-, 5-, or 10-year Treasury notes between January 1, 1992 and December 31, 2012. We average the best bid and ask prices to get mid-price and then convert into yields. Between January 1, 1992 and June 30, 2001, quotes come from GovPX. Between July 1, 2001 and December 31, 2012, quotes come from BrokerTec. Standard errors are shown in parentheses. For each maturity, the number of observations corresponds to the number of securities for which we observe at least one yield change. *, **, and *** denote significance at the 10, 5, and 1% levels using a t-test of zero means.

Table 3. Cumulative returns around subsequent auctions for on-the-run notes

	2-year Note		5-year Note		10-year Note	
t	Mean	t-value	Mean	t-value	Mean	t-value
30	0.42**	2.09	0.19	0.27	2.61	1.55
60	1.13***	4.17	1.50*	1.76	5.21**	2.77
90	1.07***	2.81	1.92*	1.90	8.32***	4.29
120	1.13**	2.50	1.99*	1.66	10.37***	4.89
150	1.20***	2.43	2.30*	1.87	11.33***	4.65
180	1.37***	2.57	2.64**	2.00	14.11***	5.31
210	1.57***	2.90	2.89**	2.04	12.95***	4.72
240	1.49**	2.58	2.50*	1.66	12.51***	4.73
No. Obs.	249		208		134	

Notes: The table shows average cumulative returns for the on-the-run 2-, 5-, and 10-year Treasury notes in the eight-hour window surrounding auction between January 1, 1992 and December 31, 2012. Cumulative return t minutes from time of auction is calculated as: ((mid-price(t+10)-mid-price(10))/(mid-price(10))-(mid-price(0)-mid-price(-t))/(mid-price(-t))). Between January 1, 1992 and June 30, 2001, quotes come from GovPX. Between July 1, 2001 and December 31, 2012, quotes come from BrokerTec. For each maturity, the number of observations corresponds to the number of securities for which we observe at least one cumulative return. Standard errors shown in parentheses. *, **, and *** denote significance at the 10, 5, and 1% levels using a t-test of zero means.

Table 4. Explaining supply effects using market-wide indicators

	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
DEPENDENT VARIABLE:	2-Year Supply Effect (bps)						5-Year Supply Effect (bps)						10-Year Supply Effect (bps)					
MOVE index/100	1.42						8.42**						24.48***					
	(1.71)						(3.77)						(7.70)					
VIX index		0.05						0.23**						0.68***				
		(0.03)						(0.10)						(0.17)				
Baa-Aaa spread (bps)			0.02**						0.03						0.11***			
			(0.01)						(0.03)						(0.04)			
TED-spread (bps)				0.03***						0.07***						0.09*		
				(0.01)						(0.02)						(0.04)		
Yield curve fitting error (bps)					0.39***						0.81*						1.42***	
					(0.11)						(0.44)						(0.49)	
B-D leverage factor						0.00						0.04***						0.02
						(0.01)						(0.01)						(0.04)
R-squared	0.004	0.006	0.013	0.030	0.024	0.001	0.022	0.018	0.008	0.037	0.008	0.026	0.063	0.047	0.039	0.014	0.025	0.002
Constant	-0.17	0.19	-0.22	-0.11	0.16	1.22***	-5.11	-1.28	0.55	-0.49	1.00	2.89***	-15.79**	-5.97	-2.95	3.95	3.95	8.00***
	(1.61)	(0.77)	(0.74)	(0.54)	(0.44)	(0.39)	(3.74)	(2.16	(2.84)	(1.75)	(1.40)	(1.05)	(6.68)	(5.04)	(4.77)	(3.63)	(3.14)	(2.60)
Observations	247	247	247	247	247	247	205	205	205	205	205	205	140	140	140	140	140	140

Notes: The table shows results from regressing cumulative returns around auction on measures of market conditions for the 2-, 5-, and 10-year on-the-run notes between January 1, 1992 and December 31, 2012. Supply effects are measured using cumulative returns two hours from auction. Cumulative return t minutes from time of auction is calculated as: ((mid-price(t+10)-mid-price(10))/(mid-price(10))-((mid-price(0)-mid-price(-t))/(mid-price(-t))), where mid-price is the average of the best bid and ask prices. Between January 1, 1992 and June 30, 2001, quotes come from GovPX. Between July 1, 2001 and December 31, 2012, quotes come from BrokerTec. Explanatory variables include the Merrill Lynch Option Volatility Estimate (MOVE) Index from Bloomberg, the Chicago Board Options Exchange Market Volatility Index from Bloomberg, the difference between the Aaa and Baa corporate bonds yields as reported by Moody's in the U.S. Economics Database of Haver, the 3 month Treasury bill-LIBOR (TED) spread from FRED, and the yield curve fitting error from the Nelson-Siegel-Svensson model of Gurkaynak, Sack, and Wright (2007). All explanatory variables are measured as of the day preceding auction. Since FOMC announcements are made close to the close of Treasury auctions, we exclude auction days which occur on the same date as FOMC announcements. Newey-West adjusted standard errors are shown in parentheses. *, **, and *** denote significance at the 10, 5, and 1% levels respectively.

Table 5. Explaining supply effects using security-specific indicators

	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
DEPENDENT VARIABLE:	2-Year Supply Effect (bps)					5-Year Supply Effect (bps)					10-Year Supply Effect (bps)				
Depth	-1.72					-41.49					-129.70				
(bil USD)	(1.46)					(40.73)					(145.8)				
Bid-Ask Spread		2.08					2.35					11.52*			
(32nds)		(2.55)					(2.26)					(6.36)			
Price Impact			0.03					46.06					88.26**		
(32nds/bil net flow)			(14.33)					(28.87)					(37.39)		
Price Volatility				-0.40					10.35***					0.40	
(32nds)				(1.78)					(3.29)					(4.98)	
Offer Amount					8.95					139.50*					184.40
(bil USD)					(36.15)					(72.20)					(380.90)
R-squared	0.003	0.004	0.000	0.000	0.001	0.003	0.003	0.013	0.043	0.008	0.005	0.023	0.039	0.000	0.003
Constant	1.56***	0.55	1.24**	1.34***	1.03	4.18**	2.08	-0.55	-3.23	0.69	11.64**	-1.05	-3.33	7.63	5.26
	(0.58)	(0.83)	(0.53)	(0.50)	(0.97)	(1.75)	(1.37)	(2.27)	(2.28)	(1.85)	(5.26)	(5.53)	(5.34)	(5.86)	(6.55)
Observations	217	247	247	247	247	175	205	205	205	205	129	140	140	140	140

Notes: The table shows results from regressing cumulative returns around auction on measures of market conditions for the 2-, 5-, and 10-year on-the-run notes between January 1, 1992 and December 31, 2012. Supply effects are measured by taking the average of cumulative returns in the ten minute interval t=[110,120] minutes from auction. Cumulative return t minutes from time of auction is calculated as: ((mid-price(t+10)-mid-price(10))/(mid-price(10))-((mid-price(0)-mid-price(-t))/(mid-price(-t))), where mid-price is the average of the best bid and ask prices. Depth is calculated by taking the average of the depth at the best bid and ask prices and then averaging across the trading day. Price impact is the coefficient from a weekly regression of 5-minute mid-price changes on 5-minute net order flows (defined as buy-initiated volume minus sell-initiated volume). Bid-ask spread is calculated by taking the difference of the best bid and ask prices and then averaging across the trading day. Price volatility is calculated as the daily standard deviation of 5-minute mid-price changes. All liquidity measures are measured as of the day before auction, except for price impact, which is measured as of the week before auction. Between January 1, 1992 and June 30, 2001, observations come from GovPX. Between July 1, 2001 and December 31, 2012, observations come from BrokerTec. Depth was not recorded in our GovPX data before July 1994, so its sample is limited to July 1994 through December 2012. Since FOMC announcements are made close to the close of Treasury auctions, we exclude auction days which occur on the same date as FOMC announcements. Newey-West adjusted standard errors are shown in parentheses. *, **, and *** denote significance at the 10, 5, and 1% levels respectively.

Table 6. Returns from simple trading strategy exploiting price pressure patterns

Minutes from auction	2-Year Note	5-Year Note	10-Year Note
t = 60	-0.61***	0.15	-1.24
	(0.23)	(0.75)	(1.77)
t = 120	-0.58	0.83	5.25*
	(0.42)	(1.10)	(2.55)
t = 180	-0.360	1.61	9.26***
	(0.51)	(1.28)	(3.03)
t = 240	-0.28	1.50	6.48*
	(0.54)	(1.49)	(3.08)
No. Obs.	250	194	127

Notes: The table shows returns from a simple trading strategy in which an investor shorts the on-the-run 2-, 5-, or 10-year Treasury note t minutes before auction then buys back the note at time of auction. After auction, the investor buys the note 10 minutes after auction, allowing any surprise information from the auction to absorb, and then sells back the note t+10 minutes from auction. The reported returns are the average returns in basis points across all auctions between January 1, 1992 and December 31, 2012. Between January 1, 1992 and June 30, 2001, quotes come from GovPX. Between July 1, 2001 and December 31, 2012, quotes come from BrokerTec. For each maturity, the number of observations corresponds to the number of securities for which we observe at least one return. Standard errors shown in parentheses. *, **, and *** denote significance at the 10, 5, and 1% levels using a t-test of zero means respectively.

Table 7. Yield changes around subsequent auctions for on-the-run bills

	13-Week Bill		26-Week Bill	
t	Mean	t-value	Mean	t-value
-180	-0.26***	-2.98	-0.56***	-5.94
-150	-0.26***	-3.57	-0.48***	-6.43
-120	-0.28***	-4.25	-0.40***	-6.81
-90	-0.26***	-3.84	-0.37***	-6.97
-60	-0.23***	-3.97	-0.29***	-6.79
-30	-0.10**	-2.41	-0.15***	-4.98
30	-0.15***	-4.12	-0.12***	-3.93
60	-0.08	-1.12	-0.01	-0.11
90	-0.02	-0.24	0.04	0.60
120	0.03	0.34	0.04	0.55
150	-0.07	-0.71	0.02	0.21
180	-0.12	-1.25	-0.06	-0.64
No. Obs.	469		465	

Notes: The table shows average yield changes from t minutes from auction to time of auction on the secondary market for the on-the-run 13- and 26-week Treasury bills between January 1, 1992 and June 30, 2001. Yields are measured using the average of the best bid and ask quotes. All yields come from GovPX. Standard errors are shown in parentheses. *, **, and *** denote significance at the 10, 5, and 1% levels using a t-test of zero means.

Table 8. Cumulative returns around subsequent auctions for on-the-run bills

	13-Week Bill		26-Week Bill	
t	Mean	t-value	Mean	t-value
30	0.05***	4.34	0.12***	5.63
60	0.08***	4.54	0.12***	3.87
90	0.06***	3.25	0.16***	4.33
120	0.07***	2.89	0.16***	3.93
150	0.09***	3.57	0.23***	4.64
180	0.11***	3.63	0.29***	5.21
210	0.10***	3.06	0.29***	4.90
240	0.16***	4.12	0.29***	3.56
No. Obs.	469		465	

Notes: The table shows average cumulative returns for the on-the-run 13- and 26-week Treasury bills in the eight-hour window surrounding auction between January 1, 1992 and June 30, 2001. Cumulative return t minutes from time of auction, or return(t), is calculated as: ((mid-price(t+10)-mid-price(10))/(mid-price(10))-((mid-price(0)-mid-price(-t))/(mid-price(-t))). The post-auction price is compared to mid-price 10 minutes after auction, instead of mid-price at time of auction, in order to allow any surprise information revealed by the announcement results to settle in the market. Mid-price is calculated as the average of the best bid and ask prices. Returns are expressed in basis points. Quotes come from GovPX for the entire sample. Standard errors shown in parentheses. *, **, and *** denote significance at 10, 5, and 1% levels using a t-test of zero means.

Table 9. Yield changes around subsequent auctions for when-issued notes

	2-Year Note		5-Year Note		10-Year Note	
t	Mean	t-value	Mean	t-value	Mean	t-value
-180	-0.41	-1.30	-0.58*	-1.76	-0.51	-0.75
-150	-0.30	-1.47	-0.56**	-2.25	-0.35	-0.58
-120	-0.43**	-2.32	-0.50**	-2.39	-0.45	-0.71
-90	-0.34**	-2.36	-0.64***	-3.72	-0.25	-0.50
-60	-0.23**	-2.25	-0.52***	-4.13	-0.12	-0.30
-30	-0.04	-0.55	-0.31***	-3.41	-0.11	-0.45
30	-0.25**	-2.49	0.10	0.67	0.32	0.64
60	-0.35**	-2.04	-0.06	-0.25	0.93	1.12
90	-0.39	-1.45	-0.017*	-0.05	0.27	0.38
120	-0.33	-1.01	-0.19	-0.52	0.23	0.27
150	-0.45	-1.24	-0.40	-1.01	0.36	0.39
180	-0.60	-1.65	-0.39	-0.90	0.26	0.25
No. Obs.	105		83		19	

Notes: The table shows average when-issued yield changes from t minutes from auction and the yield at auction on the secondary market for the auctioned 2-, 5-, or 10-year Treasury notes between January 1, 1992 and June 30, 2001. We take the average of the best bid and ask prices to get a mid-price. When-issued quotes come from GovPX. Standard errors shown in parentheses. *, **, and *** denote significance at the 10, 5, and 1% levels using a t-test of zero means.

Table 10. Cumulative returns around subsequent auctions for when-issued notes

	2-Year Note		5-Year Note		10-Year Note	
t	Mean	t-value	Mean	t-value	Mean	t-value
30	0.35*	1.71	1.67**	1.71	-4.06**	-2.37
60	0.87**	2.31	2.97***	2.31	-8.56	-1.65
90	0.78	1.44	2.79**	1.44	-2.73	-0.54
120	0.96	1.43	3.03*	1.43	-0.94	-0.15
150	1.00	1.31	4.42**	1.31	-2.62	-0.39
180	1.60*	1.83	4.33**	1.83	-0.86	-0.12
210	1.72*	1.79	4.95**	1.79	-1.68	-0.21
240	1.33	1.42	5.12**	1.42	0.37	0.05
No. Obs.	105		83		19	

Notes: The table shows average cumulative returns for the auctioned 2-, 5-, and 10-year Treasury notes in the eight-hour window surrounding auction between January 1, 1992 and June 30, 2001. Cumulative return t minutes from time of auction, or return(t), is calculated as: ((mid-price(t+10)-mid-price(10))/(mid-price(10))-((mid-price(0)-mid-price(-t))/(mid-price(-t))). The post-auction price is compared to mid-price 10 minutes after auction, instead of mid-price at time of auction, in order to allow any surprise information revealed by the announcement results to settle in the market. Mid-price is calculated as the average of the best bid and ask prices. Returns are expressed in basis points. When-issued quotes come from GovPX. Standard errors shown in parentheses. *, **, and *** denote significance at the 10, 5, and 99% levels using a t-test of zero means.

Table A1. Daily returns around subsequent auctions for on-the-run notes

t	2-Year Note		5-Year Note		10-Year Note	
	Mean	t-value	Mean	t-value	Mean	t-value
1	1.52	1.55	5.25*	1.89	-3.44	-0.39
2	4.00***	2.99	14.80***	3.81	3.21	0.16
3	6.70***	4.37	20.68***	4.54	16.78*	1.63
4	9.65***	5.19	27.75***	5.47	25.77**	2.12
5	9.84***	4.96	31.22***	5.26	21.43	1.54
6	11.14***	5.03	26.49***	3.84	26.07*	1.75
7	10.36***	4.29	25.68***	3.56	17.33	1.07
8	10.31***	3.90	27.75***	3.95	17.04	1.07
9	10.63***	3.93	22.76***	3.07	19.86	0.98
10	11.64***	4.07	22.45***	2.84	7.40	0.44
No. Obs.	247		211		141	

Notes: The table shows average cumulative returns for the on-the-run 2-, 5-, and 10-year Treasury notes in the 20-day window surrounding auction between January 1, 1992 and December 31, 2012. Cumulative return t days from time of auction is calculated as: ((price(t)-price(0))/(price(0))-((price(0)-price(-t))/(price(-t))). Daily prices come from CRSP. Standard errors shown in parentheses. *, **, and *** denote significance at the 10, 5, and 1% levels using a t-test of zero means.