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Price Discovery in the Treasury-Bill When-Issued Market

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Abstract

When-issued (i.e., forward) trading in T-bills yet to be auctioned provides a unique environment for examining price discovery. Because T-bills are auctioned in a sealed-bid process, when-issued traders cannot observe the spot market price. Yet the forward price must ultimately converge on the auction outcome price. Our results indicate that traders in the when-issued market "discover" the ultimate auction price. Little evidence is found that standard order flow variables contribute to price discovery. Instead, the ability to observe a few trades with relatively small volume in the when-issued market is sufficient to discover the auction price resulting from the sealed-bid process.

Keywords: price discovery, when-issued trading

JEL Classification: G10

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1. Introduction

A standard approach used to examine the price discovery process is to compare the trading of equivalent assets in multiple markets.[1] This type of comparison is informative because it can lead to a clearer understanding of the costs and benefits of the varying market structures and designs. In this paper, we examine the when-issued market and the auction process for U.S. Treasury bills (T-bills). Although the same underlying asset is traded in both markets, these markets implement significantly different trading rules and structures. The U.S. Treasury operates a sealed-bid auction process through which the newly announced bills are issued. The publicly traded when-issued market is structured as an open-outcry auction in which a potentially richer set of information is available to market participants.

The existing literature in this area combines when-issued trading information with auction results to examine either the extent of underpricing in Treasury auctions relative to when-issued trades or whether strategic auction behavior can be detected in Treasury auctions (see e.g., Nyborg and Sundaresan, 1996). The studies that focus on underpricing examine markups in a very short event window (one to two hours) just prior to the auction announcement. Although these studies acknowledge the role of the when-issued market in the price discovery process, none focus on price discovery. Our analysis differs from prior research in this area as we explicitly investigate and measure the price discovery and learning process throughout the entire ($2\frac{1}{2}$ day) when-issued market that precedes the announcement of the auction results. We can assess only the level of learning that takes place in the when-issued market because the T-bill auction process is not transparent. Although traders can and do participate in both the when-issued market and the auction process, they are able to observe market activity only in the when-issued market. The sealed-bid auction process prevents traders from observing auction market activity and limits them to observing their own bids and the end result of the auction process. Nevertheless, the outcome of the T-bill auction is a useful benchmark when examining the when-issued market.

Our results indicate that many of the previously identified determinants of price discovery appear not to be necessary for this market to function well. For example, we find that order flow, volume, and the lack of transparency in the auction process have little impact on the price discovery process, which appears to work quite well in the when-issued market. Specifically, we find that when-issued contracts that begin trading at a significant spread relative to the auction outcome are able to move toward the auction price after a relatively small number of trades on relatively small dollar volume. Additionally, we find that trading pressure tends to come from buyers when

[1] Examples from other markets include Hasbrouck (1995), Henker and Martens (2008), Chakravarty, Gulen and Mayhew (2004), Mercer (1997), Hasbrouck (2003), and Brandt, Kavajecz and Underwood (2007).

the when-issued price is low and from sellers when the when-issued price is high, relative to the auction price.

Our results add to the work of Brandt, Kavajecz and Underwood (2007), who examine price discovery in two-, five-, ten-, and 30-year Treasury futures contracts and related cash market securities. They determine that net order flow (buy volume less sell volume) drives own-market price discovery. Additionally, when net order flow from both markets is considered jointly, both markets' order flow contributes to price discovery in both markets. A key conclusion of their study is that different information is contained in the order flow of the different markets.

We contribute to the price discovery and learning research, in general, and to T-bill research, specifically, with an analysis of when-issued T-bill forward market trading. We examine the when-issued trading period from the announcement of the bill auction to the announcement of the auction results and find that traders in the when-issued forward market are able to efficiently "learn" and discover the auction settlement price in advance of its disclosure. The auction process that arrives at the auction price is a sealed-bid auction. In comparison, the cash market process used in previous studies is similar to an open-outcry auction. Finding that the when-issued market is able to discover sealed-bid auction prices suggests that observing cash market order flow is not necessary for derivative (i.e., forward) market price discovery. Additionally, we find that order flow, a key variable in previous research, does not play a significant role in the price discovery process for when-issued securities either.

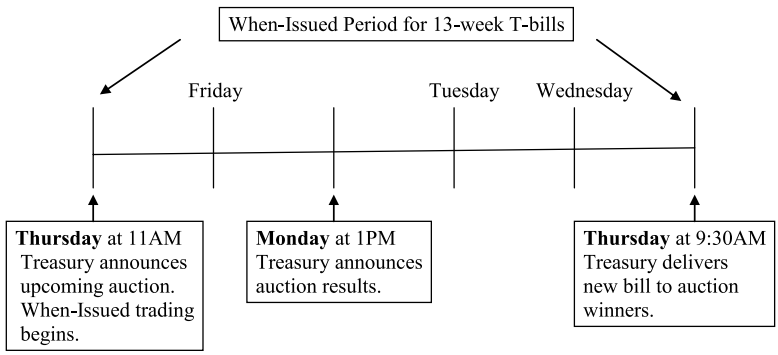
We note that the existing literature finds that order flow moves prices in existing securities with established market prices. We find that a forward market is able to discover the issue price of a new cash market security without significant order flow.[2] The question becomes, if order flow and trading volume do not affect the price discovery process in the when-issued market, then what does? To answer this question we focus on individual T-bills that show a substantial amount of price discovery. Specifically, the difference between the transaction yield and the subsequent auction yield for these particular bills begins outside the bid-ask spread (i.e., three basis points [bps] or more), yet ultimately moves to within the bid-ask spread (i.e., two bps or less) of the auction yield. This "learning" includes trades initiated from the side of the trade expected for an aggressive trade, and comes after traders have some experience in the new when-issued contract. Our results on the side that initiates the trade are consistent with Griffiths, Smith, Turnbull and White (2000) who find that aggressive sell orders (hits in GovPX) occur when depth on the opposite side of the limit book is small; and aggressive buy orders (takes in GovPX) occur when depth on the same side of the limit book is large.

[2] Demand for T-bills, however, is primarily satisfied at the auction as documented in Fleming and Rosenberg (2007), who find evidence suggesting that dealers often hold T-bills from issuance through maturity.

2. The micromechanics of the when-issued market

To provide a frame of reference for our empirical analysis we first describe the market for when-issued trading in T-bills and its relation to the Treasury auction process. Currently, the Treasury auctions and issues three maturities of T-bills: four, 13, and 26 weeks. New bills in each market are issued on every nonholiday Thursday with adjustments made to the process when Thursday is a holiday. When Thursday is a nontrading holiday the Treasury moves the activity to an adjacent day. When-issued trading precedes the issuance of each new T-bill, and begins once the Treasury announces the auction of the particular bill. Accordingly, the when-issued market for each T-bill starts with the announcement of the auction and it ends with the issuance of that new T-bill.

Our analysis focuses on 13-week T-bills. The timeline for 13-week T-bill when-issued trading is as follows:



The when-issued period for 13-week bills begins on a Thursday with a Treasury announcement of a new auction. The announcement of the new auction occurs at 11:00 a.m. Eastern time and includes an estimated dollar amount of maturing bills and an anticipated dollar amount of the new auction. Following this announcement, the market begins when-issued trading in the new bill and the Treasury opens the sealed-bid auction process for the new bill.

The Treasury accepts two types of bids: (1) competitive and (2) noncompetitive. Competitive bidders bid the rate they are willing to accept and the dollar amount of the auction they would accept at their bid rate (or yield). Noncompetitive bidders bid only the dollar amount of the auction they want and then accept the market clearing rate. During our sample period the Treasury conducted only single-price auctions in T-bills. In the single-price auction, the Treasury sorts bids from the lowest rate to the highest rate and then begins accepting bids at the lowest rate and continues up the rates bid until they have filled the auction. The last rate accepted is referred to as the "stop-out" rate and all successful bidders (competitive and noncompetitive) receive the stop-out rate.

The Treasury accepts noncompetitive bids until noon on Monday. It accepts competitive bids until 1 p.m. on Monday, at which time it announces the results from the auction. The announcement of the auction results include: (1) the stop-out rate, (2) amount of bids tendered (3) amount of bids accepted, and (4) any proration of competitive bids at the stop-out rate. Accordingly, at 1 p.m. on Monday all bidders know whether they have received any T-bills in the auction. In addition, all traders know the amount of new bills to be issued on Thursday, the rate at which these new bills will be issued, and the difference between the amount of successful bids and the amount of total bids. At 9:30 a.m. on the Thursday following the auction results the Treasury delivers the new T-bills to the successful bidders and accepts payment in immediately available funds. This process is completed electronically as all T-bills are held in "book-entry" form only. Delivery of the newly issued T-bill ends the period of when-issued trading in the bill and begins secondary market trading in the bill. Then at 11:00 a.m. the Treasury announces the next auction and when-issued trading begins in the next new 13-week T-bills.

2.1. Portion of when-issued timeline analyzed

The when-issued timeline for 13-week T-bills is one week long with a clearly defined beginning and end and with one clearly defined information event during the week. The when-issued market begins with the announcement of the auction, ends with the delivery of the new bills, and is separated into two distinct periods by the announcement of the auction results. This structure provides a unique experimental environment for examining price discovery. In this subsection we discuss the information flows at these two information events and the implications for price discovery.

The first information event is the Treasury announcement of a new auction, in which the Treasury reveals only the dollar amount of new bills it wants to sell in the auction. Following the announcement of the auction, but before the announcement of the auction results, each trader in the when-issued market knows the estimated size of the auction and their demand for bills in the auction. Now, each trader has to determine the demand schedule for how they are willing to participate in the auction. It is reasonable to expect that each trader will have a different demand schedule that is based on the needs and opinions of the trader. Clearly, each trader will attempt to determine the lowest price (highest yield) they can bid in the auction and receive the amount of T-bills they desire.

The second information event is the announcement of the auction results. The announcement signals the culmination of the Treasury's sealed-bid auction process. This announcement provides all market participants the price (stop-out rate) at which the underlying T-bill will be issued. It also provides all participants the dollar size of the auction and the dollar amount of bids. Additionally, this announcement provides all auction bidders the outcome of their bidding.

The period between the two announcements provides an interesting experimental environment for examining price discovery. This period starts with two new financial instruments without any price history. The traders have market history and their demand schedules for the new bill, but no price history for either instrument.[3] During this time the price of the when-issued (forward) contract evolves in parallel with the open bidding process for the T-bill underlying the forward contract. However, the bidding process cannot be observed by the when-issued traders because the Treasury auction uses a sealed-bid process.[4] Then, at 1:00 p.m. on Mondays the Treasury announces the price at which the underlying T-bill will be delivered to the market, which is the price at which the forward contract must trade. During the time between the announcement of the auction and the announcement of the auction results we can observe how traders trade the forward contract and how the trading reveals (or not) the (ultimate) intrinsic price of the underlying T-bill. This analysis is the topic of this study.

2.2. *Auction theory*

The relevance of auction structure to the T-bill auction process has long been recognized and modeled in the literature. Throughout the history of Treasury auctions, beginning with bills in 1929 and coupon-bearing notes and bonds in 1970, the specific auction process has evolved.

The current sealed-bid single-price auction format was introduced by the Treasury in 1992 for two- and five-year notes. This was in part due to rules overhauls resulting from purported auction rule violations occurring in 1991. In 1998, all Treasury auctions switched to the single-price sealed-bid rules. This type of auction

[3] Since new 13-week bills are re-openings of 26-week bills, it might be reasonable to take the price history of the 26-week bills as the price history for the new 13-week bills (see Fleming, 2002). However, the market for a 26-week bill that is about to re-open is very thin. We collect market data during 2001 (our primary sample period) for the Thursday and Friday of when-issued trading and the preceding Tuesday and Wednesday to provide information on market activity on each 26-week bill that is about to re-open. First, we examine bid and ask quotes during regular business hours and find, for all bills on every day, one side of the spread is not quoted at some point during the day. Next, we examine daily trading activity and we find zero trades on 41% of Tuesdays, 45% of Wednesdays, 47% of Thursdays (the day when-issued trading starts), and 73% of Fridays. With very limited market activity in the 26-week bill for the week before it re-opens as a 13-week bill, the 26-week bill cannot be viewed as providing reliable price history for the re-opening. In fact, for the Thursdays with price information, 70% of the off-the-run prices are lower than the auction price. This suggests a pricing bias related to illiquidity. Accordingly, we believe it is appropriate to view the newly auctioned 13-week T-bill as equivalent to a new security without a price history.

[4] When-issued trading and auction bidding are available concurrently. However, one would expect that rational bidders would delay bidding in the auction in an effort to inform their bids by observing prices in the when-issued market. This will delay bidding. Bidders must bid in advance of the 1 p.m. deadline to purchase bills in the auction. Accordingly, bidders will bid when they are sufficiently informed. Thus, bidding and when-issued trading will occur concurrently during some portion of the auction with the expectation that the majority of both will occur in the last few hours of bidding.

structure as it applies to Treasury auctions is analyzed by Milgrom (1989). He demonstrates that a sealed-bid single-price auction transfers more of the surplus to the seller (the Treasury). The sealed-bid element of the auction precludes buyers from incorporating updated estimates of competing buyers' reservation prices. The single-price element leads to a magnification of the winner's curse problem. Milgrom (1989, p. 16) specifically predicts that the single-price sealed-bid auction format adopted by the Treasury will increase the auction receipts as the change to this format will "generate a higher average price than a sealed-bid auction where each bidder pays the amount of his own bid."

Changing to a single-price sealed-bid auction format could potentially affect the demand schedules of Treasury instrument buyers in adverse and unpredictable manners. Garbade and Ingber (2005, p. 1) point out the goal of the Treasury auction process:

> The stated goal of Treasury debt management is to meet the financing needs of the federal government at the lowest cost over time. Since Treasury auctions provide the principal means of financing the federal deficit and refinancing maturing debt, Treasury officials have sought to structure the auction process to minimize the government's costs, both directly by promoting broad competitive bidding and indirectly by promoting liquid post-auction secondary markets for new issues.

Thus, any potential increase in revenues from single-price sealed-bid auctions could be outweighed by the costs of unintended consequences that are at odds with the overall Treasury debt management program.

The existence and operation of a well-functioning when-issued Treasury market may mitigate the potential distortions brought on by the change to a single-price sealed-bid auction format. There is abundant research in the auction literature indicating that open-outcry auctions lead to more efficient and equitable distributions of economic rents than auctions conducted in the sealed-bid format. Maskin and Riley (2000) demonstrate that when buyers are endowed with asymmetric beliefs (not asymmetric information) regarding the auction item, the resulting open-outcry would dominate the sealed-bid auction outcome from the buyer's perspective. Hansen (1985) shows more efficient outcomes obtained in the open-outcry format as participants in a sealed-bid auction do not have the ability to learn (discover) the reservation price of others.

The winner's curse of the single-price sealed-bid auction process can be offset if auction participants have an alternative mechanism for price discovery. Garbade and Ingber (2005) and the *Joint Report on the Government Securities Market* prepared by the U.S. Department of Treasury, Securities Exchange Commission, and Board of Governors of the Federal Reserve System (1992) both argue that the existence of a parallel open-outcry auction facilitates price discovery for the sealed-bid Treasury auction. Specifically, Garbade and Ingber (2005, p. 2) state:

> When-issued trading enables market participants to contract for the purchase and sale of a new security before the security has been auctioned. This type of trading is important

because public dissemination of the yield at which the new note is trading, or the discount rate at which the new bill is trading, provides valuable information about the market's appraisal of the prospective value of the security.

Our empirical examination begins with an analysis of whether the when-issued market does learn the auction price (yield). As theory suggests, the when-issued process is a means of gathering information to inform the auction. Accordingly, bidders should delay their bids until late in the auction period and we expect that when-issued prices and the auction price should converge (clearly they *must* converge *after* the auction results are announced). We begin our analysis with an empirical examination of whether the two processes converge. Assuming that the when-issued market does discover the auction result, we will examine the market mechanisms used for price discovery.

3. Data

GovPX provides Treasury tick data that represent activity in the interdealer broker market. We collect all tick data for 13-week T-bills with maturity dates from April 12, 2001 through January 24, 2008, covering 326 T-bills. For ease of tracking bills we eliminate bills where either Thursday is a holiday. The dates we examine are arbitrary and match the period of GovPX data under a single-price auction process that we have access to.

GovPX provides a variety of information on each T-bill and creates a tick of data each time any piece of information changes. GovPX provides an aggregate volume data field that is designed to accumulate volume across a trading day and thus allow the identification of trades. However, for the majority of our sample period the aggregate volume item is empty for all T-bills. For a few months at the beginning of our sample period GovPX does provide aggregate volume. We use the data with aggregate volume to develop a process to identify trades.[5] The process identifies 24,822 trades in the when-issued market across our sample period. This sample of transactions is the starting point for our analysis.

From the trade tick data we capture the CUSIP of each T-bill in the trade sample. CUSIPs are used to collect auction results from TreasuryDirect. Specifically, we collect the auction stop-out rate, the rate at which the new bill will be issued and thus our target rate for price discovery in the when-issued market. Additionally, we collect the low-yield bid for auctions in 2001, which is the sample for our primary

[5] For each trade GovPX provides: trade side, trade price, trade yield, and trade size. For each new tick, GovPX carries forward from the previous tick all fields that do not change. If the trade price and trade size do not change from the previous tick, the new tick is considered to not be a trade and is removed. All ticks remaining after this screening process are considered to be trades. Our process is back-tested using the data with aggregate volume. We find that the process captures 93% of the actual trades in the data where aggregate volume is available. Our back-testing finds that our process does not over-identify trades. Accordingly, our selection process is biased downward for identifying trades.

analysis. The stop-out yield is the highest yield accepted, so the difference between the stop-out yield and the low yield provides the range of accepted bids and thus a measure of the dispersion of opinions as to an acceptable yield for the T-bill auctioned. In 2001 we find the median difference is five bps with the minimum at two bps and the maximum at 36 bps. These descriptive statistics suggest differences of opinion as to an acceptable price to pay at auction. The maximum is from the first auction after 9/11. The second auction after 9/11 has a difference of ten bps with the third auction difference at three bps.

The typical 13-week T-bill begins with 91 days until maturity. Accordingly, the week of when-issued trading covers a period from 98 days through 92 days until the underlying 13-week T-bill will mature. We use the days to maturity to label our results as follows:

Treasury announces the new auction at 11 a.m. on Thursday	
Thursday	98 days until maturity
Friday	97
Monday before 1 p.m.	94.5
Treasury announces auction results at 1 p.m. on Monday	
Monday after 1 p.m.	94
Tuesday	93
Wednesday	92

Because the focus of the study is price discovery, and the price is revealed at 1 p.m. on Monday, the analysis covers the period before the auction results are announced at 1 p.m. on Monday.

4. Empirical results

4.1. Summary statistics

Table 1 provides summary statistics on spreads, dollar volume, and number of trades by day, for days 98, 97 and 94.5. Panel A provides summary statistics on the absolute value of the spread between the transaction yield and the subsequent auction yield. The statistics show price discovery occurs across the sample. That is, as we move forward through the when-issued period the spread between transaction yields and the auction yield (to be announced) declines, suggesting that market participants are able to learn about the market clearing auction yield.

In prior literature, price discovery has been associated with order flow. Panels B and C show that dollar volume and number of trades increase across the when-issued period. Accordingly, the highest volume occurs when the spread is at its smallest, but it is unclear from these statistics whether volume leads or follows price discovery. Thus, more analysis is required before we can draw any conclusions.

Fleming (2003) states for T-bills that GovPX data cover more than 90% of total interdealer broker activity from 1997 through 2000 with GovPX collecting all

Table 1

Summary statistics for all trades for entire sample

Summary statistics for yield spreads are reported for each day prior to the T-bill auction. Days are labeled relative to bill maturity. Spread is defined as the difference between the yield on a when-issued trade and the subsequent outcome of the sealed-bid auction on the underlying T-bill. Daily dollar volumes and number of trade statistics are also reported.

Day	Mean	Median	10%	90%	Max
Panel A: Spreads relative to auction (absolute value) in basis points					
98	3.64	2.15	0.46	7.21	67.46
97	2.50	1.64	0.35	5.53	40.46
94 (before 1 p.m.)	1.08	0.72	0.13	2.16	18.39
Panel B: Dollar volume ($ millions) per day					
98	189	113	10	420	1,864
97	272	210	32	570	1,490
94 (before 1 p.m.)	750	603	135	1523	2,910
Panel C: Number of trades per day					
98	3.8	3	1	8	21
97	6.4	5	1	13	41
94 (before 1 p.m.)	12.1	9	3	24	80

T-bill activity for six of the seven major interdealer brokers. Akay, Cyree, Griffiths and Winters (2011) show that T-bill trading activity reported in GovPX declines dramatically from 2001 through 2008. Fleming and Mizrach (2009) note that through 2004 GovPX received data from multiple interdealer brokers, but that after the January 2005 purchase of GovPX by ICAP, GovPX received data from only one broker. Thus, given the relation in the literature between price discovery and order flow, a prudent next step is to determine if price discovery occurs across the sample period.

Table 2 presents the mean of absolute spreads for each day of the when-issued period by year across the sample period. The primary insight from Table 2 is that price discovery occurs in every year of the sample, so the basic result is not driven by changes in market coverage of GovPX. However, given the link between order flow and price discovery and the decline in the trading activity captured by GovPX

Table 2

Price discovery by year

Mean of absolute value of spread between auction yield and daily transaction average yield. Spread = daily average yield − auction yield. Results reported in basis points.

Day	2001	2002	2003	2004	2005	2006	2007
98	6.15	2.43	2.11	1.96	3.81	2.38	7.75
97	2.98	2.29	1.21	1.46	2.66	2.02	4.59
94.5	1.81	0.77	0.65	0.80	1.53	0.89	1.30

Table 3

Transaction comparison between 2001 and 1997

Average number of trades per year by day of when-issued period

Day	2001	1997
100	n.a.	106
99	n.a.	770
98	170	774
97	623	776
94.5	1,100	965

Table 4

Price discovery comparison between 2001 and 1997

Mean of absolute value of spread between auction yield and daily transaction average yield. Spread = daily average yield − auction yield.

Day	2001	1997
100	n.a.	5.03
99	n.a.	4.76
98	6.15	3.41
97	2.98	2.80
94.5	1.81	0.97

after 2000, the primary analysis is limited to 2001. The choice of 2001 is also driven by the fact that prior to 1999 the Treasury used a multiple price auction rather than a single-price auction.

We next examine whether GovPX reasonably captures market activity in 2001 by comparing it to daily trading activity in GovPX in 1997 (the only year prior to 2001 for which we have GovPX data). Table 3 provides the average number of trades by day during the when-issued period for both 1997 and 2001. In 1997 the auction announcement occurs on Tuesday instead of Thursday, thereby adding two trading days (99 and 100) to the when-issued period. The announcement occurs mid-day during both years so the first trading day of both when-issued periods is a partial day. Table 3 shows that daily trading activity in 2001 is similar to daily trading activity in 1997. Thus, we conclude that GovPX reasonably captures market activity during 2001.

Table 4 shows dramatic price discovery across the when-issued period under both a single-price auction (2001) and a multiple-price (1997) auction.[6] Additionally,

[6] There is a body of literature on underpricing in multiple (discriminatory) price Treasury auctions. Nyborg and Sundaresan (1996), Malvey and Archibald (1998), and Reinhart and Belzer (1997) do not find underpricing in single (uniform) price auctions, but Goldreich (2007) suggests this is due to limited data. Goldreich (2007) finds underpricing in the uniform price auctions of T notes and T bonds using when-issued GovPX data from 1991 through 2000. Our measure of yield spread would be termed a "markup" in this literature as underpricing was presumed. Since we find both positive and negative "markups," we prefer the term "yield spread" to describe the metric as there is no ex ante supposition of direction. Using

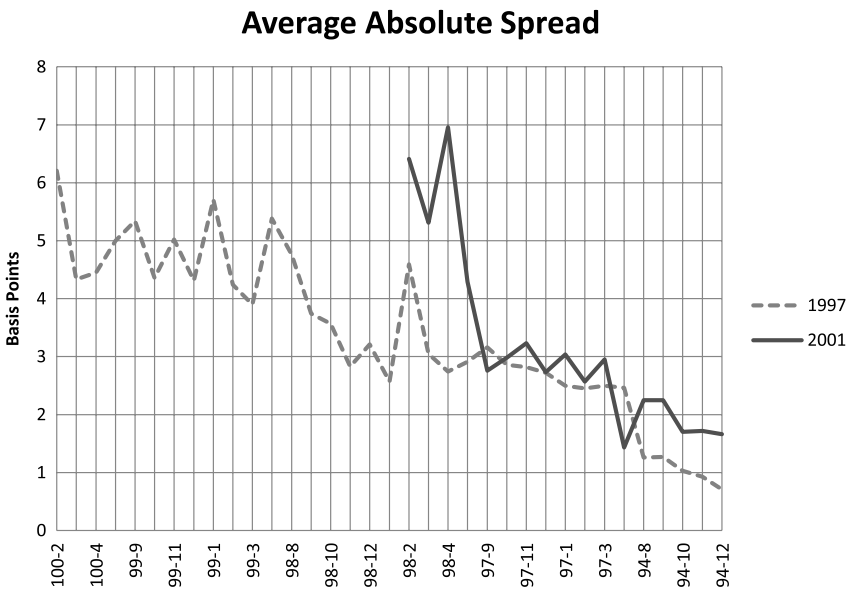


Figure 1

Average absolute spread across when-issued trading period

This figure provides the average absolute spread (spread = daily average yield − auction yield) hourly across the when-issued trading period, which has a different number of days in 1997 and 2001. The *x*-axis is time in day–hour format with day being the number of days until the 13-week T-bill matures. For example, 98–2 is 98 days to maturity during the 2 p.m. hour. Day 98 is Thursday.

Figure 1 suggests that a substantial portion of the price discovery in 2001 occurs at the beginning of day 97 with a substantial portion of price discovery in 1997 occurring at the beginning of day 98. Since the literature suggests that order flow is often associated with price discovery, we next examine the relation between order flow and price discovery.

4.2. Price discovery and order flow

Figure 2 provides insights on trading activity by plotting the average number of trades per hour across the when-issued period for both 1997 and 2001. First, the average number of hourly trades is similar across years, again suggesting that the

the data for Table 4 without taking the absolute value, we examine the average spread across the last hour of trading before the auction results are announced. For both 1997 and 2001 the average spread in the last hour before the auction results are announced is −0.4 bps. The negative sign means that, on average, the when-issued yield is less than the auction yield, which in turn means that the when-issued market in T-bills is overpricing the auction.

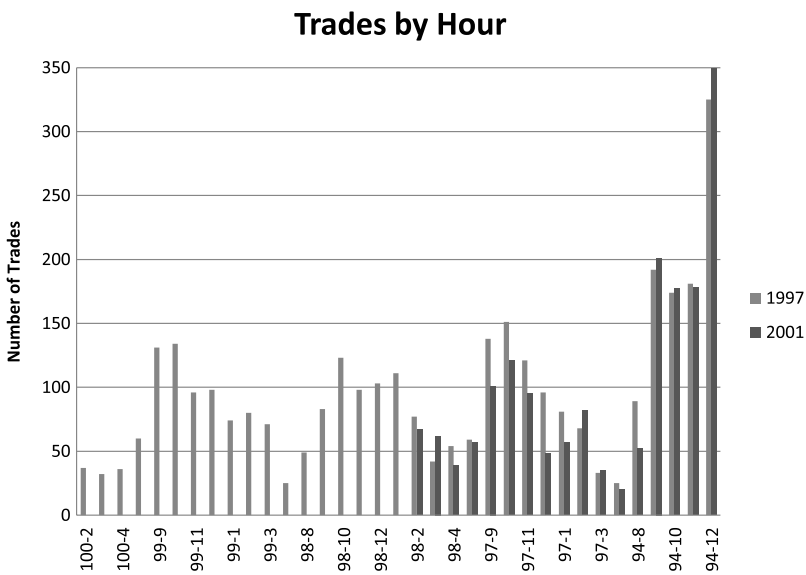


Figure 2

Average number of trades per hour across the when-issued trading period

This figure provides the average number of trades hourly across the when-issued trading period, which has a different number of days in 1997 and 2001. The *x*-axis is time in day–hour format with day being the number of days until the 13-week T-bill matures. For example, 98–2 is 98 days to maturity during the 2 p.m. hour. Day 98 is Thursday.

trading activity during 2001 is not unique. Second, the number of trades during the first two hours on days 97 and 98 is relatively low, while Figure 1 shows that these hours exhibit the largest price discovery. This combination hints at a limited role for order flow in price discovery in when-issued T-bills. Figure 3 provides average dollar volume per hour and also shows limited volume during the early trading hours of days 97 and 98.

4.3. Analyzing individual bills

To this point in our analysis we have presented average results across multiple bills. In this section we focus on individual T-bills from 2001 and examine all bills that start trading at least three bps away from the auction price (trade yield minus auction yield).[7] Three basis points is not an arbitrary choice for the opening spread.

[7] Prior to 1999 the Treasury used a multiple price auction rather than a single-price auction. Thus, in 1997 each accepted bid paid the price that was bid, while in 2001 each accepted bid paid the stop-out price. Since in 1997 there was not a single auction price, it would be difficult to draw conclusions about price discovery on individual bills using the 1997 data.

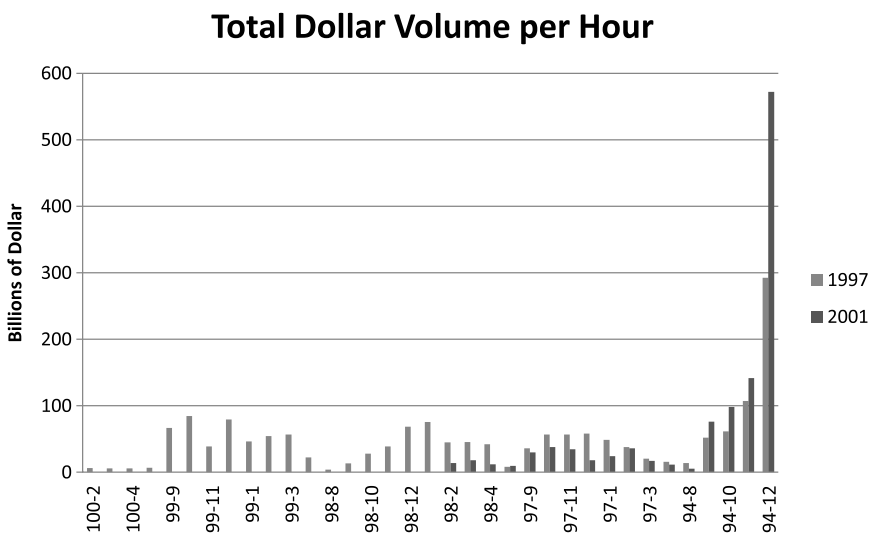


Figure 3

Average dollar volume per hour across when-issued trading period

This figure provides the average dollar volume of trades hourly across the when-issued trading period, which has a different number of days in 1997 and 2001. The *x*-axis is time in day–hour format with day being the number of days until the 13-week T-bill matures. For example, 98–2 is 98 days to maturity during the 2 p.m. hour. Day 98 is Thursday.

Historically, T-bills traded in whole basis points, so a two bp spread was the minimum round trip on T-bill trading. It is difficult to capture mispricing within the bid-ask spread so we started with a two bps spread and then added one bp with the idea that there must be value in looking for mispricing before traders will attempt to learn.[8] Surprisingly, all of these bills move to within three bps of the auction yield before the auction yield is announced, and therefore "learn."

The Treasury conducted 52 regular 13-week T-bill auctions during 2001. Ten bills are excluded from the analysis because of incomplete trading histories, typically because of trading holidays, but the two auctions following 9/11/01 are also among these ten bills. Nineteen bills are excluded because they all have a first when-issued trade spread under three bps and therefore little opportunity to learn (they also have a spread under three bps on the last trade before the auction results). Thus, of the 52 T-bills auctioned in 2001, the three bps screen results in 23 T-bills used in this analysis.

[8] The minimum lot size for T-bills in GovPX is $5 million, so one bp of mispricing represents $125 of opportunity in a 13-week bill.

Table 5 provides information about bill spreads with bills sorted from most negative first spread (column 3, trade yield minus auction yield) to most positive first spread. The second column provides the auction announcement date, and it is apparent that similar first spreads do not cluster in calendar time. The third column provides the signed first spread with 12 first spreads being negative and 11 being positive. This shows that the market is not biased in its mispricing on the opening trade. The fourth column provides the spread on the last trade before the auction yield is announced. For all 23 bills in this sample, traders reduce their spreads from the first trade to the last and, thus, learn. For 21 of the 23 bills, the spread is reduced to less

Table 5

T-bills that start three bps or more away from auction yield: spread data

Auction announce date is the day when the Treasury announces its intention to sell additional securities and begins accepting bids. When-issued trading begins following the auction announcement. The *first spread* is the difference between the yield on the first when-issued trade and the subsequent auction yield. *The last spread before auction* is the difference between the yield on the last trade before the auction results are announced and the subsequent auction yield. *Auction spread* is the difference between low yield bid in an auction and the stop-out yield from the auction. *When spread reaches three bps* is the day (relative to bill maturity) and hour of the trade where the spread goes under three bps (either positive or negative).

CUSIP	Auction announce date (month/day)	First spread (bps)	Last spread before auction (bps)	Auction spread (bps)	When spread reaches three bps	
					Day	Hour
HE4	04/27	−13.98	−2.58	7.5	94.5	12
GF2	02/01	−9.45	−0.15	5	97	9
GN5	03/22	−7.33	−0.63	6.5	98	4
JL6	12/13	−7.04	0.66	5	94.5	9
HN4	05/31	−6.02	0.18	5.5	97	2
HH7	05/17	−4.22	1.98	4	97	10
GK1	03/01	−4.13	2.67	3	97	10
HR5	06/29	−4.10	−2.1	6	97	2
JD4	10/19	−3.21	−0.71	7	97	2
HT1	07/19	−3.20	1.90	3	94.5	9
GS4	07/06	−3.16	−1.56	6.5	97	10
HM6	08/24	−3.13	−0.03	5	97	8
JE2	10/25	3.15	1.65	3	94.5	10
GE5	01/26	4.08	0.48	4	94.5	10
HA2	03/29	4.55	0.45	5.5	97	12
HP9	06/14	4.8	0.06	8.5	97	9
GT2	08/03	5.21	0.51	3	97	10
HQ7	06/21	5.22	1.12	3.5	98	3
HD6	04/19	8.23	−1.57	10.5	97	12
HG9	05/03	9.32	0.62	6	97	8
HC8	04/05	13.26	−0.64	7	97	9
GJ4	02/22	14.34	1.94	6	97	1
GB1	01/04	15.38	−1.22	5	97	9

Table 6

T-bills that start three bps or more away from auction yield: activity data to reach three bps

Number of trades provides a count of the number of transactions until a bill's spread goes under three bps. *Dollar volume* is the total dollar volume of when-issued trading until a bill's spread goes under three bps. *Average trade size* is *dollar volume* divided by *number of trades*. *First trade of the day* is an indicator of whether (yes) or not (no) the trade that moves the spread under three bps is the first trade of a day. GovPX identifies T-bill trades as Hits or Takes. A hit is seller initiated and a take is buyer initiated. *Percent hits* is the percentage of number of trades until a bill's spread goes under three bps that are hits. *Last three trades to three bps* identifies whether the last three trades are H (hits) or T (takes).

CUSIP	First spread (bps)	Number of trades	Dollar volume ($ million)	Average trade size	First trade of day	Percent hits	Last three trades to three bps
HE4	−13.98	19	575	30	No	58	T,T,H
GF2	−9.45	25	803	32	No	52	T,H,T
GN5	−7.33	5	260	52	No	20	H,T,T
JL6	−7.04	16	880	55	Yes	75	H,T,H
HN4	−6.02	13	231	18	No	85	H,H,H
HH7	−4.22	5	236	47	No	80	H,H,H
GK1	−4.13	14	398	28	No	57	H,H,T
HR5	−4.10	8	145	18	No	25	T,H,H
JD4	−3.21	3	80	27	No	100	H,H,H
HT1	−3.20	10	427	43	Yes	100	H,H,H
GS4	−3.16	2	105	53	No	0	T,T
HM6	−3.13	5	130	26	No	20	T,H,T
JE2	3.15	14	865	62	Yes	50	T,T,H
GE5	4.08	7	155	22	Yes	57	T,H,T
HA2	4.55	3	30	10	Yes	33	T,H,T
HP9	4.8	10	720	72	No	70	H,H,T
GT2	5.21	4	170	43	No	50	T,T,H
HQ7	5.22	21	895	43	No	19	H,H,T
HD6	8.23	20	590	30	No	20	T,T,T
HG9	9.32	10	465	47	Yes	20	T,T,T
HC8	13.26	15	604	40	No	60	H,H,T
GJ4	14.34	3	60	20	No	33	T,H,T
GB1	15.38	12	450	38	No	42	T,T,H

than two bps. The fifth column provides the difference between low-yield bid and the stop-out yield. The median difference is 5.5 bps with a minimum of three bps and a maximum of 10.5. These descriptive statistics suggest some difference of opinion in the auction sealed-bids. We also observe that the larger auction differences tend to align with the larger first spread in the when-issued trading. The final two columns of Table 5 provide the day and hour of the trade when the spread moves to less than three bps and remains there. About two-thirds of the time this trade occurs on day 97 (Friday). However, there is no consistent pattern on the time of day.

Table 6 provides information on the trading activity of the 23 bills. We replicate the CUSIP and first trade spread from Table 5 and retain the ordering for reference.

The third column provides the number of trades needed to reduce the spread to less than three bps. It is clear that some trading activity is required for learning, but there is not an apparent pattern, with 13 bills needing ten or more trades and ten bills needing less than ten trades. This result is similar to the analysis by Kandel, Ofer and Sarig (1993). They use implied inflation expectations to explore how markets learn through trading and find that investors learn about the distribution of other investors' information by observing prices. Also, the sign of the first spread does not appear to influence the number of trades.

The fourth column of Table 6 provides the total dollar volume of trades needed to move the spread under three bps with the fifth column providing the average trade size (column 4 divided by column 3). Remembering that $5 million is the minimum trade in this market, it does not appear that high dollar trading is required to learn. Also, there is no size difference between bills that start with negative spreads versus positive spreads. The sixth column identifies whether the trade that moves the spread under three bps is the first trade of the day, but only six of the 23 bills move inside the three bps spread on the first trade of the day.[9]

If when-issued traders knew the auction outcome, then the sign of the spread would predict whether buyers or sellers should initiate price discovering trades. However, recall that the auction is a sealed-bid process and the result is unknown for a few more days, so traders in the when-issued market initiate trades based on their estimate of the sign. A negative spread means the trade price is more than the auction price, so *hits* (seller initiated trades) would tighten the spread. A positive spread means the trade price is less than the auction price, so *takes* (buyer initiated trades) would tighten the spread.

The last two columns of Table 6 provide information on hits and takes. The column labeled *Percent hits* provides the percentage of the number of trades in column 3 that are hits (seller initiated). The percent hits suggest that bills starting with negative spreads tend toward hits while bills starting with positive spreads tend toward takes. This is consistent with learning, in that sellers tend to initiate trades on overpriced bills and buyers tend to initiate trades on underpriced bills. The final column provides the label (hit or take) for the last two trades leading to the trade that moves the spread to less than three bps. Again, when the first spread is negative, this sequence of trading leans toward hits and when the first spread is positive this sequence leans toward takes.

With the underlying auction process being a sealed-bid auction, traders in the when-issued market are unable to observe prices bid, other than through bids they make. However, there is publicly available information that may help the when-issued traders estimate the auction price. Table 7 provides information relative to the 23 bills

[9] We examine the first trade of the day because both the graphical and regression analyses suggest that it is related to the price discovery process in T-bills. Furthermore, the overnight period could give traders the opportunity to reflect on and digest all relevant information.

Table 7

T-bills that start three bps or more away from auction yield: market factors

Auction yield ($t-1$) is the auction result from the bill preceding the bill under analysis while a*uction yield* (t) is the auction result for the bill under analysis. *Difference* is *auction yield* ($t-1$) minus *Auction yield* (t) reported in basis points. *First spread* is carried forward from Table 5, as is *auction announcement date*. Some of the major macroeconomic reports are released at 8:30 a.m. on Friday. *First trade after macroannouncement* is an indicator for whether (yes) or not (no) the trade that moves the spread under three bps is the first trade after the release of the macroeconomic announcement at 8:30 a.m. on Friday.

CUSIP	Auction yield ($t-1$) in %	Auction yield (t) in %	Difference (bps)	First spread (bps)	Auction announcement date (month/day)	First trade after macro-announcement
HE4	3.74	3.98	−24	−13.98	04/27	No
GF2	5.11	5.05	6	−9.45	02/01**	No
GN5	4.48	4.31	17	−7.33	03/22**	No
JL6	1.70	1.76	−6	−7.04	12/13*	No
HN4	3.61	3.59	2	−6.02	05/31	No
HH7	3.63	3.54	9	−4.22	05/17**	No
GK1	4.71	4.70	1	−4.13	03/01	No
HR5	3.38	3.58	−20	−4.10	06/29*	No
JD4	2.20	2.17	3	−3.21	10/19	No
HT1	3.55	3.48	7	−3.20	07/19	No
GS4	3.58	3.56	2	−3.16	07/06	No
HM6	3.33	3.35	−2	−3.13	08/24*	No
JE2	2.17	2.05	12	3.15	10/25	No
GE5	5.09	4.98	11	4.08	01/26	No
HA2	4.20	4.13	7	4.55	03/29	Yes
HP9	3.51	3.44	7	4.8	06/14	Yes
GT2	3.48	3.43	5	5.21	08/03	No
HQ7	3.44	3.38	6	5.22	06/21	No
HD6	4.15	3.74	41	8.23	04/19**	No
HG9	3.98	3.74	24	9.32	05/03	Yes
HC8	4.23	3.91	32	13.26	04/05	No
GJ4	5.04	4.83	21	14.34	02/22	No
GB1	5.86	5.19	67	15.38	01/04**	No

*Federal Reserve target rate decrease of 25 bps two or three days before auction announcement; **Federal Reserve target rate decrease of 50 bps two or three days before auction announcement.

in this sample on previous auction results, Federal Reserve target rate changes, and macroeconomic announcements.

Table 7 begins with the CUSIP and retains the first spread (in column 5) from Table 5 for reference. We also retain the bill ordering from Tables 5 and 6. Absent any dramatic market changes, a potential predictor of the yield from the upcoming auction is the yield from the previous auction. Column 2 provides the auction yield (in percentage) from the auction preceding the bill under analysis. Column 3 provides the auction yield (in percentage) for each bill under analysis, with column 4 providing the difference (yield_{t-1} minus yield_t) in basis points. We compare the difference in column 4 to the first trade spread in column 5. If traders use the previous auction yield

as a predictor of the next auction yield then we would expect that, at a minimum, the results in columns 4 and 5 will have the same sign.

There are four auction yield increases (negative difference) across the 23 bills. Twice the first trade anticipated the auction yield change and twice it did not. Once, the traders anticipated the yield increase in opposition to a Federal Open Market Committee (FOMC) target rate decrease (see column 6). The two times that traders did not anticipate the yield increases were also immediately following FOMC target rate decreases. There are 19 times that the auction yields decreased suggesting positive first trade spreads for trades using the preceding auction yield as a predictor. There are 11 positive first trade spreads and eight negative first trade spreads associated with the 19 auction decreases. These results suggest a limited association between the previous auction yield and the yield on the first when-issued trade.

The Federal Reserve had a very active year for target rate changes in 2001, with 11 target rate decreases (eight of 50 bps and three of 25 bps). Eight of the target rate decreases preceded by two or three days the auction announcements of bills in this analysis. Six of the target rate changes preceded bills that began when-issued trading with a negative spread (trade yield $<$ auction yield), suggesting that traders may have overreacted to the target rate change. This suggests that yields may be influenced by target rate changes. However, as noted above, twice the auction yield moved against the target rate change.

Green (2004) finds an increase in government bond trading following macroeconomic announcements and suggests a greater role for informational trading following announcements. Therefore, in the final column of Table 7 we examine macroeconomic announcements. Specifically, the Friday announcements usually occur at 8:30 a.m. Eastern time and we want to determine if the information from these announcements informs the when-issued market to the point that the first trade after the announcement moves the spread under three bps. We report a "Yes" if the first trade after 8:30 a.m. on Friday (day $= 97$) is the trade that moves the spread under three bps or "No" if it does not. Only three of 23 bills have their spreads move under three bps on the first trade after 8:30 a.m. on Fridays. Clearly, the macroeconomic announcements are not an immediate influence on price discovery in the when-issued market.

While the focus on the details of these 23 bills does not cover all of the possible questions one might wish to examine, the analysis does suggest a lack of a role for order flow in terms of a large number of trades and/or large dollars in price discovery in this market. This analysis also suggests that traders learn by observing some trading activity and that price movement is usually originated from the expected side of a trade before the outcome of the sealed-bid auction is revealed.

4.4. Multivariate analysis of price discovery and order flow

To this point in our analysis we have generated a number of insights from simple univariate statistics. First, we observe price discovery prior to the announcement of

the auction results. Second, there is not a clear link between price discovery and order flow. Third, learning comes after observing some trading and tends to be initiated from the side one would anticipate, ex post, given the sign of the spread. In this section we bring these separate insights together in a multivariate analysis to examine them jointly.

In this analysis we estimate a multivariate regression specified as follows:

$$\Delta spread_i = \alpha + \beta_1 order\ flow + \beta_2 count + \beta_3 hit + \beta_4 first + \beta_5 ln(time) + \varepsilon_i,$$

where

$\Delta spread_i =$ first difference ($\text{spread}_t - \text{spread}_{t-1}$) in spread (trade yield − auction yield), where we use |spread| so a negative first difference is consistent with price discovery,

$order\ flow =$ aggregate signed volume through trade i in the life of a T-bill,

$count =$ aggregate signed trade indicator where a hit = 1 and take = −1 through trade i in the life of a T-bill,[10]

$hit =$ 0/1 variable that equals 1 when the trade is a hit and 0 when it is a take,

$first =$ 0/1 variable that equals 1 on first trade of a day for each trading day between announcement of the auction and the announcement of the auction results, and

$ln(time) =$ natural log of the number of minutes elapsed between two trades.

The results from estimating various specifications of this regression model are reported in Table 8. Panel A reports regression results using only the 23 T-bills that start with a spread in excess of three bps. Panel B provides regression results for the entire 2001 sample. In our presentation of the regression results, we start with a model that contains only the independent variables *order flow* and *count* to isolate our proxies for order flow. We measure order flow as an accumulation of signed volume (*order flow*) and signed hits and takes (*count*) with the idea that informed trading would cluster in either buys or sells and thus move prices.[11] Then we step in the remaining variables to allow the reader to observe the marginal effect of each independent variable and the consistency of parameter estimates. The first variable we step in is an indicator variable (*Hit*) that equals 1 for hits and 0 for takes. This variable follows from our univariate analysis. Next, Figure 1 shows substantial price discovery at the beginning of day 97 in 2001, so we examine the first trade of the day (*first*) to determine if the overnight period is a significant contributor to price

[10] GovPX includes a Last Trade Side data item where it labels a trade as a Hit or a Take.

[11] Evans (2002) and Evans and Lyons (2002) demonstrate the importance of order flow on exchange rates, where order flow is defined as the net of buyer-initiated and seller-initiated orders over a specified time interval. Brandt and Kavajecz (2004) examine price discovery in the U.S. Treasury market and find that order flow explains a large portion of the variation in yields. Easley and O'Hara (1987) demonstrate that both the size of the trade and the sequence of trades are important in the price discovery process.

Table 8

Change in yield spread regressions

Multivariate regression analysis that identifies microstructure variables associated with learning. The dependent variable is the change in the difference between the yield associated with a given trade and the auction yield. Thus a negative change in yield (a smaller spread) implies learning has occurred. Specifically, the change in yield spread is defined as the absolute value of the difference between the yield at time t and the auction yield less the absolute value of the difference between the yield at time $t+1$ and the auction yield. Order flow is the aggregated sum of the signed order volume for each securities when-issued market. The hit/take aggregate count sums the signed trade indicator for each securities when-issued market. Hit indicator is 1 for a hit and 0 for a take. The first trade indicator (before auction) is 1 for the first trade of the day prior to the auction announcement and 0 otherwise. The first trade indicator (after auction) is 1 for the first trade of the day after the auction and 0 otherwise. LN of time between trades is the natural log of the time that has elapsed between trades measured in minutes. Huber–White robust standard errors are used to compute statistical significance. p-Values are reported in parentheses.

	Models			
	1	2	3	4
Panel A: 23 T-bills with first trade spread in excess of three bps				
Constant	0.0117	0.0964	0.1030	0.1257
	(0.818)	(0.016)	(0.136)	(0.120)
Order flow	0.0001	0.0000	0.0000	0.0000
	(0.581)	(0.676)	(0.671)	(0.684)
Hit/take aggregate count	−0.0017	−0.0008	−0.0008	−0.0008
	(0.693)	(0.853)	(0.858)	(0.870)
Hit indicator		−0.1788	−0.1773	−0.1854
		(0.068)	(0.070)	(0.071)
First trade indicator			−0.2604	−0.2092
			(0.383)	(0.522)
LN of time between trades				−0.0124
				(0.642)
Observations	3348	3348	3348	3187
R-squared	0.000	0.001	0.001	0.001
Panel B: Entire 2001 sample				
Constant	0.0241	0.0972	0.1308	0.1366
	(0.114)	(0.014)	(0.088)	(0.159)
Order flow	0.0000	0.0000	0.0000	0.0000
	(0.632)	(0.711)	(0.770)	(0.773)
Hit/take aggregate count	−0.0011	−0.0002	−0.0002	−0.0000
	(0.685)	(0.851)	(0.830)	(0.828)
Hit indicator		−0.2254	−0.2250	−0.2361
		(0.057)	(0.038)	(0.037)
First trade indicator			0.0102	0.0100
			(0.000)	(0.000)
LN of time between trades				0.0021
				(0.761)
Observations	6199	6199	6199	6199
R-squared	0.000	0.001	0.008	0.008

discovery in this market. The final independent variable measures the time between trades (*ln(time)*) and is included to determine if the amount of time to learn between trades contributes to price discovery. The dependent variable is specified so that negative parameter estimates are consistent with learning.

The results reported in Panel A show models with stable parameters and very little explanatory power. The one independent variable that provides some explanatory power (at the 10% level) is the indicator variable for *Hit*.[12] The parameter estimate is consistently negative which suggests that hits are associated with learning. Our order flow variables (*order flow* and hit/take aggregate *count*) that proxy for factors identified in the literature as providing price discovery are statistically insignificant across all model specifications in Panel A.

Panel B replicates the model specifications reported in Panel A and shows results for the entire 2001 sample. Consistent with the results in Panel A, the Panel B results show models with stable parameters and very little explanatory power. The indicator variable *Hit* continues to be negative and significant at the 10% level, suggesting that hits contribute to learning. The order flow variables continued to be statistically insignificant. This suggests that the standard order flow variables of volume and signed trades do not contribute to price discovery in the when-issued T-bill market, which supports our univariate results and plots on the lack of a relation between order flow and price discovery.

Since almost half of the T-bills from the 2001 sample do not go through the learning process, it is not surprising that Panel B provides results with little to no explanatory power. The fact that the results reported in Panel A from the sample that learns, provides little explanatory power suggests that the standard explanations for learning and price discovery do not apply in the when-issued market for T-bills.

5. Conclusion

The goal of this paper is to investigate price discovery in the when-issued U.S. T-bill market. When-issued trading is trading in a forward contract on the next T-bill to be issued from the sealed-bid auction process. This environment provides a unique experimental setting where the price that traders are attempting to discover is revealed later as an outcome of the market clearing auction process.

Univariate analysis suggests that the auction price is discovered in the when-issued market, but that the discovery process is not associated with order flow. Regression analysis supports the lack of association between price discovery and order flow in this market. Analysis of individual bills that begin their trading outside the bid-ask spread but ultimately end within the bid-ask spread finds that trading to within the bid-ask spread occurs after traders have some experience with the bill and

[12] Note that in Table 6 we examine hits and takes for the trades before the spread declines to three bps. In our regression analysis all trades are included in the analysis.

from the expected side of an aggressive trade. Thus, we have price discovery occurring after some experience in the when-issued contract, but without an association with the standard order flow measures presented in the literature.

The lack of association between price discovery and order flow in the when-issued T-bill market remains a puzzle. We offer two possible explanations for this phenomenon that are not necessarily mutually exclusive. First, we posit that the answer lies in the difference between an established market and a "new" market, where the when-issued market begins anew every week on the announcement of the next bill auction. The existing literature focuses on established markets, in which there are equilibrium prices that require significant order flow to move to a different equilibrium (discover new prices). A new market is searching for equilibrium, so it is possible that significant order flow is not required to move prices. The when-issued market is a new market without an equilibrium price. A second possible explanation is that traditional microstructure variables found to be relevant in equity market price discovery research are inappropriate in the context of the T-bill market. The reason for this is the presumed existence and influence of uninformed traders in equity markets may very well not exist in Treasury markets. The continued existence and survival of uninformed traders in an asset market with a minimum lot size of $5 million in trades is doubtful. We leave the examination of these conjectures for future research.

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