

The Treasury Bill Auction and the When-Issued Market: Some Evidence*

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Abstract

We empirically examine the link between the when-issued market and the auction for Treasury bills. We find that on average it is cheaper to buy Treasury bills in the auction than in the when-issued market just before the auction closes. Surprisingly, primary dealers often submit bids in the auction that are higher in price than the concurrent when-issued ask price. We present evidence to show that this is due to the cost of revealing positive information too early by trading in when-issued markets before the auction. In addition, we examine what determines the dispersion of bids in the auction as well as test for collusive behavior in the bidding process.

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1 Introduction and Summary

Based on the huge volume of U.S. Treasury securities traded daily, one may be tempted to conclude that the U.S. Treasury market is perfectly competitive. However, alleged infractions by Salomon Brothers in 1991 suggest that this inference is inaccurate.¹ Strategic behavior in the U.S. Treasury securities market can significantly increase the cost of government debt financing. Moreover, as these markets serve as a benchmark for the valuation of other risky securities such as common stocks and corporate bonds, its impact may be felt in a wide variety of markets. Consequently, these abuses prompted a review of the Treasury securities market.²

In this paper, we empirically examine the link between the forward market and the auction for Treasury bills. Most of the trading for Treasury securities takes place in over-the-counter markets, for which data are not readily available to researchers. By calling a dealer firm over a three-year period, we have gathered data on mid-day forward-contract prices, information that is usually difficult to obtain. The forward market, which is called the when-issued market, opens before the auction and remains open during and after the auction. We investigate the relationship between the when-issued market and the weekly auction for 13- and 26-week Treasury bills. We present evidence that traders in the when-issued market take into account the fact that when-issued prices might reveal, at least partially, their private information. In particular, we find that the change in when-issued prices on auction days after the auction closes but before the announcement of the auction results is significantly related to the information innovation contained in the auction.

Cammack (1991) and Spindt and Stolz (1992) investigate the relation between auction prices for 13-week Treasury bills and prices of seasoned Treasury bills that have the same time to maturity as the newly auctioned bills. They all find systematic underpricing in the auction. Their results, however, are colored by two factors. First, the seasoned bills are usually traded at a (price) discount relative to their on-the-run counterparts,³ an effect that changes the magnitude of (true) underpricing. Second, seasoned Treasury securities are quoted for a different delivery date than the delivery date of the newly auctioned bills. For proper comparison, the secondary market prices for the seasoned securities have to be adjusted. This adjustment introduces measurement errors into their calculations. In contrast, we compare when-issued prices at the auction time with the winning prices in the auction. Both the auction and the when-issued market on the day of the auction are markets for forward contracts with three days to maturity, so no adjustment is needed to make the comparison.

¹Salomon Brothers allegedly cornered two year notes issued by the Treasury in April and May 1991 in order to start a short squeeze.

²See, for example, the Joint Report on the Government Securities Market (1992).

³One reason for this discount may be a difference in liquidity; see Amihud and Mendelson (1991).

Simon (1993) studies Treasury coupon auctions from January 1990 to September 1991 using intra-day when-issued data. He assesses the impact of prorationing⁴ on profitability for different trading schemes.⁵ He also finds that aggressiveness of bidding at auctions is partially reflected in the when-issued prices before the auction results are released. In contrast to Simon's approach, we emphasize the difference between anticipated and unanticipated rate changes, so rather than using the when-issued quotes *per se*, we use the deviation from the expected auction rate when assessing informational content of the auctions. Further, Simon does not distinguish between different maturities but deals with all of them together.

The rest of this paper is organized as follows. We outline, in Section 2, the institutional structure of the when-issued market and the auction for Treasury bills. In Section 3 we describe the data and some summary statistics. We find that on average it was about 2 basis points cheaper to buy 13-week bills in the auction than in the when-issued market.^{6,7} For 26-week bills the auction was cheaper by about 1 basis point. Surprisingly, we find that about 80% of the time for 13-week bills and 77% of the time for 26-week bills, bids were submitted in the auction that were higher in price than the when-issued ask price at the auction time. Explanations for this behavior include noise in the data or erratic behavior by a few insignificant bidders. Another explanation is sophisticated strategic behavior in that bidders with large demands for the securities may forgo buying at low prices on the when-issued market before the auction in order not to reveal this positive information (of their large demand) before the auction.

Further data analysis in Section 4 supports the hypothesis that strategic bidding behavior is the reason why in a vast majority of auctions the highest bid price exceeded the when-issued ask price at auction time. In particular, we find that the change in when-issued prices on auction days after the auction but *before* the announcement of the auction results is positively correlated to the information innovation contained in the auction. We find this relationship to be stronger in auctions in which the highest bid price exceeds the when-issued ask price at auction time.

In Section 5, we examine whether there is any evidence of collusion in Treasury-bill auctions. We do not reject the null hypothesis that during the sample period, bidders in 13- and 26-week bill auctions did not collude. Section 6 contains concluding remarks.

⁴All bids at the highest accepted ("stop-out") rate are filled on a *pro rata* basis.

⁵Cf., Jegadeesh (1993).

⁶A basis point is one hundredth of 1 percent.

⁷This contrasts with Cammack's finding that underpricing in the 13-week bill auction, compared to the corresponding seasoned bills, was 4 basis points during the period 1973-88. Spindt and Stolz's figure for underpricing in the 13-week bill auction from 1982 to 1988 was 7 basis points.

2 Institutional Details of the Treasury Bill Market

We describe the structure of the U.S. Treasury bills market around 1986-88 (the period of our data).⁸

Every week the Department of Treasury auctions 13- and 26-week bills. The auction is held every Monday and the deadline for competitive bids is 1:00 pm.⁹ There are 38 *primary dealers*, who submit sealed *competitive* bids that are discount rate-quantity pairs.^{10,11} Even though primary dealers may submit as many discount rate-quantity bids as they wish, often each primary dealer submits one or two bids only. The primary dealers buy Treasury bills for their institutional clients and for resale on the secondary market. Although anybody may bid competitively, the competitive bidding is dominated by primary dealers, who have easy access to the information necessary for effective bidding. There is also an economic motive for placing bids through a primary dealer, as non-primary dealers have to pay upfront to guarantee their bids, while this requirement does not apply to primary dealers.

The *noncompetitive bidders*, mainly individual investors, submit sealed bids that specify quantity only (up to a maximum of 1 million dollars). The noncompetitive bids, which usually account for 15–20% of the amount sold, always win at a discount rate equal to the quantity-weighted average of the winning competitive bids. The competitive bidders compete for the remaining bills in a discriminatory auction. That is, the demands of the bidders, starting with the lowest rate bidder up, are met until all the bills are allocated. The winning competitive bidders pay the unit prices implied by the discount rates they submitted. After the auction, the Department of Treasury announces summary statistics about the bids submitted. These include total tender amount received, total tender amount accepted, lowest winning rate (highest winning price), highest winning rate (lowest winning price), proportion of bids accepted at the highest winning rate (lowest winning price),¹² quantity-weighted average of winning rates, and the split between competitive and noncompetitive bids. Treasury bills are reregistered to the winning bidders on Thursday and can be resold in an active secondary market (see Fabozzi 1991).

There is a forward market for Treasury bills. Every Tuesday the Treasury announces the amount of bills to be auctioned the following Monday. The primary dealers begin trading, for themselves and for their institutional clients, forward contracts on the bills to be auctioned.¹³

⁸There have been two notable changes since then. First, all securities are now auctioned using uniform-price auctions. Second, the number of primary dealers has increased.

⁹When Monday is a holiday, the auction is held on the first trading day after Monday.

¹⁰For a 13-week bill with a face value of 1000, a discount rate of 5.98%, say, translates into a price of $1000(1 - 5.98\%(91/360)) = 984.88$. The competitive bidders can only submit discount rates which are whole basis points.

¹¹The Treasury stipulates that the sum of the amount of the bills won in the auction by a primary dealer and her long position in the when-issued market cannot exceed 35% of the total amount auctioned.

¹²That is, amount of bids accepted at the highest winning rate divided by the amount of bids received at this rate.

¹³A standard forward contract is for a principal amount of \$5 million.

The maturity date of these contracts is the Thursday of the auction week, the same day that the newly auctioned Treasury bills are delivered. As the bills are to be delivered “when issued,” this forward market is usually referred to as the “when-issued market.”

The when-issued market is a market with zero net supply and can be thought of as a double auction held continuously over several days.¹⁴ The weekly auction of Treasury bills has a positive supply of bills and is held at a single point in time. The open interest in the when-issued market varies from a small amount to several times the amount auctioned.

After the auction, trading continues in the when-issued market until the when-issued contracts mature, subsequent to which the bills are traded in a secondary market. Thus, a primary dealer can acquire Treasury bills in several ways:

- a. Buy in the when-issued market before the auction bidding is closed.
- b. Submit bids in the auction.
- c. Buy in the when-issued market after the auction bidding is closed but before the auction results are announced.
- d. Buy in the when-issued market (or in the secondary market) after the auction results are announced.

If a primary dealer buys in the when-issued market or in the secondary market, she is sure to acquire the bills, whereas she faces the uncertainty of losing in the auction.¹⁵ However, there is a disadvantage to buying in the when-issued market before the auction closes. A primary dealer who has a large demand (from her clients) for the bills to be auctioned may reveal this information if, before the auction, she buys a large quantity in the when-issued market. This will increase the when-issued ask price and, consequently, encourage aggressive bidding in the auction. In contrast, if she bids for a large quantity in the auction this private information will be revealed only after the auction. Therefore, a primary dealer with a large demand is better off relying mainly on methods b., c., and, if necessary, d. above in order to acquire Treasury bills.

Besides partially aggregating the participants’ information, the when-issued market serves as a forward market. Many primary dealers are short in the when-issued market before the auction as they sell these contracts to those institutional clients who want to be certain of obtaining the bills to be auctioned. Of course, some institutional clients may also be short in the when-issued market.

¹⁴A double auction is an auction where bidders can be buyers or sellers; see Wilson (1985) and Hindy (1990). A single auction, such as a Treasury securities auction, is one in which all the bidders are buyers and the auctioneer is the only seller; see, e.g., Milgrom and Weber (1982) and Wilson (1979). Bikhchandani and Huang (1989) incorporate the existence of a resale market in the auction analysis. For a review of the implications of auction theory for Treasury securities markets, see Bikhchandani and Huang (1993).

¹⁵Of course, if a primary dealer fails to acquire bills in the auction, she still has the option of buying in the when-issued or secondary markets.

A *short squeeze* occurs when many of those who have net short positions in the when-issued market fail to acquire bills in the auction. In this event, they have two alternatives. They can buy back in the when-issued market after the auction or they can “borrow” the newly auctioned bills in the *repurchase and reverse markets*, also known as “repo” and reverse markets. The repo and reverse market is a market for short-term borrowing and lending that is collateralized by securities.¹⁶ If, for instance, an individual who possesses securities needs to borrow funds overnight, he can “sell” the securities to a counterparty and at the same time sign with her an agreement to repurchase these securities the next day at a predetermined price. The interest rate earned by the counterparty is called the “repo rate” for the securities used as collateral. The counterparty in a repo agreement is said to be engaged in a “reverse repo” — borrowing securities while lending funds. When there is a short squeeze, say in the when-issued market for 26-week Treasury bills, the repo rate using the newly auctioned 26-week Treasury bills as collateral might decrease dramatically and can even become negative. This is because these bills become scarce commodities and one can borrow money cheaply using them as collateral. These bills are said to be traded “special.”¹⁷

3 The Data

We have collected data for the period from February 24, 1986 to November 28, 1988. Although 145 auctions were held during this period, for 15 of these auctions we could not collect when-issued price data at auction times. The reason for these missing observations was simply that the person providing the data over the phone was out of the office on the days in question. As he was not directly involved with this market, we have good reason to believe that no bias was introduced. We have:

1. 130 observations of the bid and ask (discount) rates for 13- and for 26-week when-issued contracts at 1:00 pm on auction days.¹⁸ (Included in this sample is the crash on October 19, 1987, which together with the following Monday is excluded in many of our regressions for reasons discussed later.)
2. The average of bid and ask rates for 13- and 26-week when-issued rates at 3:00 pm on auction days as well as the week preceding the auction. During the sample period, the auction results were announced after 3:00 pm, so a Monday 3:00 pm quote *does not* reflect the auction announcement.

¹⁶See Stigum (1989), and also Sundaresan (1992), who provides a wide range of descriptive statistics for Treasury auctions and repo and reverse markets.

¹⁷For an example of an apparent anomaly in the pricing of a 30-year Treasury bond in the secondary market as well as in the repo market, see Cornell and Shapiro (1989). Duffie (1992) provides a theoretical framework for analyzing the phenomenon of “specialness.”

¹⁸The when-issued contract is quoted by its discount rate as described in Footnote 10. The bid rate is the discount rate at which one sells and the ask rate is the discount rate at which one buys.

3. Summary statistics of the 130 auctions that correspond to the when-issued rates at 1:00 pm on auction days in our data set. These statistics include quantity-weighted average winning rate, lowest and highest winning rates, and proportion of bids accepted pro rata at the highest winning rate.
4. The 12:15 pm quote of the on-the-run 13- and 26-week bills, i.e., the bills auctioned the previous week.¹⁹ If there was no 12:15 pm quote available, the 11:00 am or the opening quote was used. Altogether, there were eleven missing 12:15 pm quotes for the 13-week bill and eight missing for the 26-week bill. For one auction day, there was no 26-week bill quote available prior to 1:00 pm, and thus the sample size is 130 for the 13-week bills and 129 for the 26-week bills. These missing observations may result in an understatement of Durbin-Watson statistics.

The daily 3:00 pm when-issued data are from Data Resources Inc., (DRI); they are the quotes of Bank of America.²⁰ The when-issued rates at 1:00 pm on auction days are not publicly available. We collected these data in real time by calling a dealer at Shearson Lehman at 1:00 pm on auction days, who in turn got them from Fundamental Brokers Inc. (FBI), an inter-dealer broker.^{21,22} The summary statistics of the weekly auction are announced by the Department of Treasury and published in *The Wall Street Journal*.²³ Table 1 (all tables are in Section 8) lists definitions of the variables we use. To facilitate comparison between 13- and 26-week bills, we represent the data in (discount) rates rather than prices. Sample statistics are shown in Table 2.

We first focus on 13-week Treasury bills. On average, the highest winning rate was 1 basis point higher than the (quantity-weighted) average winning rate (HR13 – AR13) and 4 basis points higher than the lowest winning rate (HR13 – LR13).²⁴ The average bid-ask spread

¹⁹These quotes are collected by the Federal Reserve Bank of New York. For help with access to these data, we thank Roshelle Antoniewicz, Spence Hilton, and David Simon.

²⁰For 12 observations in our data set, the auctions were not held on a Monday. We do not have the when-issued rates for the newly auctioned bills at 3:00 pm on auction days for these data points. Thus the variables CHG13 and CHG26 (defined in Table 1 below) were not available for these observations. However, we do have the when-issued rates at 1:00 pm on the day of the auction for these bills. In calculations involving the when-issued rates at 1:00 pm, we did not exclude those auctions that did not occur on a Monday.

²¹The quotes hardly ever vary across brokers.

²²We thank Chiang Sung for patiently answering our weekly calls for three years. We are also thankful to Elaine Robbins and Gretchen Schroeder who dutifully called Chiang Sung on our behalf to collect these data.

²³We thank Elaine Lai for collecting these data.

²⁴A difference of 1 basis point amounts to $0.001 \times (90/360) \times \$1,000,000,000 = \$25,000$ per \$1 billion of face value for 13-week bills and \$50,000 per \$1 billion of face value for 26-week bills. T-bills are issued every week and primary dealers resell their holdings to their clients. Thus, annually, a 1 basis point difference results in additional primary dealer profits of \$1.3 million for 13-week bills and \$2.6 million for 26-week bills per \$1 billion of face value. Currently, the Department of Treasury issues \$20-35 billion worth of T-bills every week.

of the quotes of the when-issued at 1:00 pm on auction days was 1 basis point (SPRD13).²⁵ On average, it was 2 basis points cheaper to buy 13-week bills in the auction at the average winning rate than in the when-issued market at 1:00 pm on auction days, i.e., one earns a 0.02% higher interest rate at the average winning auction rate than at the when-issued ask rate (ASK13 – AR13). If one could win the auction at the highest winning rate, then it would be about 3 basis points cheaper to buy 13 week bills in the auction than in the when-issued market ($[ASK13 - AR13] - [HR13 - AR13]$). On average the when-issued ask rate at 1:00 pm on auction days is lower than the average winning rate in the auction to compensate for the risk of not winning at the auction. Noncompetitive bidders pay the average winning rate in the auction and are not subject to the risk of not winning at the auction; however, each noncompetitive bidder may not bid for more than \$1 million.

As one may expect, the change in the when-issued rates between 1pm and 3pm on auction days was not significantly different from zero (CHG13). Somewhat surprisingly, the when-issued ask rate at 1:00 pm on auction days was on average 1.5 basis points higher than the lowest winning rate in the auction, with the maximum difference being 8.5 basis points (ASK13 – LR13). In 104 out of 130 auctions, i.e., 80% of the time, there was at least one bidder who submitted in the auction a rate lower (a price higher) than the concurrent when-issued ask rate (price).

The when-issued bid rate at 1:00 pm was on average 0.8 basis points lower than the average winning rate at the auction (BID13 – AR13) and was lower than the highest winning rate by 1.8 basis points (BID13 – HR13). This suggests the possibility of selling in the when-issued market just before the auction and buying back at the auction to make a profit. However, one faces the risk of losing at the auction and being short-squeezed.

Next we turn to 26-week bills. The rate spreads between the highest, lowest, and average winning rates at the auction are similar to those for 13-week bills. The bid-ask spread in the when-issued market at the auction time was also about 1 basis point on average (SPRD26). The when-issued rate difference²⁶ between 26- and 13-week bills at 1:00 pm on auction days, the “term premium”, was about 19 basis points on average (TERMPREM). Thus, during the sample period the yield curve at the lower end was, on average, upward sloping. The term premium was as high as 85 basis points on October 26, 1987 (one week after the stock market crash on October 19, 1987) and 69 basis points on June 20, 1988.²⁷ The when-issued ask rate at the auction time was 1.6 basis points higher on average than the lowest winning rate in the auction (ASK26 – LR26). In 101 out of 130 auctions or about 77% of the time, there was at least one bidder who submitted in the auction a bid rate lower than the when-

²⁵Occasionally, the bid and ask rates are identical. For 9 observations in our sample, the bid-ask spread was zero. This occurs once in a while and is not due to a data problem. When it happens, the market is said to be “locked” and buyers and sellers are each charged a small transactions fee.

²⁶The rate difference here is calculated using the average of the bid and ask rates.

²⁷On this day the Federal Reserve allowed a key short-term rate, the Federal funds rate, to rise further to restrain inflation. The central banks of West German, Britain, and Japan did likewise. The prices of long-term U.S. Treasury issues slumped initially, but rebounded later in the afternoon. See *The Wall Street Journal* of June 21, 1988.

issued ask rate at the auction time. The maximum difference occurred on June 20, 1988, a staggering 28 basis points. On that day, the when-issued ask rate at auction time was higher by 24 basis point than the average winning auction rate.

The when-issued bid rate was on average 0.1 basis points higher than the average winning auction rate (BID26 – AR26). Thus one cannot sell in the when-issued market right at the auction time and buy at a higher rate in the auction. However, on 68 out of 130 occasions, slightly more than 52% of the time, the when-issued bid rate was lower than the average winning auction rate.

The fact that about 80% of the time for 13-week bills and 77% of the time for 26-week bills, bids were submitted in the auction that were higher in price than the when-issued ask price at the auction time is paradoxical.²⁸ Our tests in Section 4 differentiate among three plausible explanations of this phenomenon. First, there could be noise in the when-issued price, perhaps due to lack of liquidity in the when-issued market just before closing. As there are only two and a half hours between the close of the auction and announcement of the auction results, there will not usually be any significant information revelation during this window.²⁹ Hence, *a priori* there is no reason to expect liquidity to increase during this period. Therefore, under the first hypothesis we expect the noise in the when-issued price to persist until the auction results are announced. A second possible explanation of this apparent anomaly is that this is due to mistakes by a few insignificant bidders.³⁰ A third explanation is the cost to a primary dealer of revealing her private information, when it is favorable, before the auction. If a primary dealer who expects interest rates to fall buys a large amount in the when-issued market prior to the auction, she will bid up the when-issued prices and thereby convey information to competing bidders about her high demand. This will make others bid more aggressively in the auction and reduce this primary dealer's probability of winning in the auction, *ceteris paribus*. In contrast, if she submits a bid at a low rate in the auction she will almost certainly win. Other bidders will learn about her high demand only upon announcement of auction results a few hours after the auction.

Thus, as outlined in the preceding paragraph, possible explanations of this phenomenon include:

- e1. Noise in the when-issued price.
- e2. Erratic behavior by a few insignificant bidders.

²⁸Similar behavior was observed in the auction for sulfur dioxide emission allowances conducted by the Environmental Protection Agency in March 1998. Cantor Fitzgerald Inc. paid \$1.2 million for 10,000 allowances in the auction whereas it could easily have bought the same number of allowances for less than \$1.1 million on the over-the-counter market. See "Bids for Emission Allowances at Auction Surprise Brokers as Premiums are Paid," by C. Harder and M. Golden in the *Wall Street Journal*, March 27, 1998.

²⁹This is especially true if, for the relevant tests, we eliminate from the data obviously unexpected events such as stock market crashes.

³⁰Presumably, the bidders who make these errors are not maximizing and will either correct their behavior or be eliminated from the market. Hence, mistakes are not a widespread phenomenon, i.e., are insignificant, in any given auction.

e3. Strategic behavior by bidders (who realize the cost of revealing positive information too early).

If e3 is behind this anomaly then we expect that in auctions where this behavior is exhibited some bidders (presumably those with large demands) will:

- (i) Bid up the when-issued market price after the auction closes but before auctions results are announced.
- (ii) Bid higher in the auction than expected at the time the auction bidding is closed.

Consequently, e3 implies that:

- (iii) There is positive correlation between the unexpected component of the auction price and the movement of the when-issued price after the auction closes but before the results are announced.

If, instead, a combination of explanations e1 and e2 is driving this behavior then it has no economic significance and we should not expect to see (i), (ii), and (iii). In the next section, we find evidence of (i), (ii), and (iii).

It is important to understand that this phenomenon (that the ask price in the when-issued market at auction time is lower than the highest bid price level) cannot be explained by some diversification scheme to reduce the risk of not being allocated a sufficient amount of bills in the auction. A diversification motive would imply that any bidder would buy in the when-issued market before the auction whatever quantities are available at prices below what she bids in the auction; the quantities that she cannot acquire in the when-issued market she would then bid for in the auction through a (possibly diversified) set of bids *at* and *below* the when-issued ask price.

An attempt to short squeeze the market cannot be an explanation for this phenomenon either. Bidders trying to start a squeeze ought not to forgo opportunities to take long positions in the when-issued market at relatively low prices.

4 The When-Issued Market and the Auction

When buying in the when-issued market before the auction closes, the when-issued rates may reveal a primary dealer's private information. Dealers have an incentive not to reveal all their information immediately in the when-issued market (Kyle (1985)). Moreover, as the information will also have an impact on the bidding in the ensuing auction, there is an asymmetry in the incentive to reveal information prior to the auction. A bidder who expects rates to fall has an incentive to hide her private information until after the auction so that other bidders are less aggressive in the auction (than if she reveals her information in the when-issued market before the auction). By waiting until after deadline for submitting auction bids before taking long positions on the when-issued market, this bidder can buy

more cheaply at the auction. In fact, we would expect bullish dealers to buy actively in the when-issued market after the auction closes and before the auction results are announced. A bearish primary dealer has no strong incentive to hold back (from taking short positions in the when-issued market) before the auction, as she probably will not buy aggressively in the auction.³¹

During our sample period, the deadline for submitting bids in the auction was 1:00 pm and the results were announced around 3:30 pm. Thus the window between 1:00 pm and approximately 3:30 pm on auction days was a time to buy in the when-issued market without increasing the competitiveness in the auction. *A priori*, we expect that the rate changes in the when-issued market between 1:00 pm and 3:00 pm on auction days will reflect the unexpected portion of the auction bids, i.e., the information contained in the bids submitted that is not incorporated in the when-issued rates at 1:00 pm on auction days. In this respect we want to stress the word “unexpected.” It is clear from the persistent “underpricing” in the auction that the when-issued rate at 1:00 pm *per se* is not the best forecast of the rates to be realized in the auction. For this reason we assume that the conditional expectations of the auction rates are a linear function of the average of the when-issued bid and ask rates at 1:00 pm on the auction day, and the bid rate at 12:15 pm of the closest substitutes in the secondary market,³² i.e., the on-the-run 13- and 26-week bills auctioned the previous week.³³ If we believe that the secondary market aggregates information better than the when-issued market, there may be additional information in these quotes. To generate the market’s expectation of the auction rates, we regress the average auction rates on the when-issued rates at 1:00 pm and the on-the-run rates at 12:15 pm.³⁴ We report these regressions in Table 3.

In these regressions, and in all subsequent regressions, the coefficients were estimated using the ordinary-least-squares procedure, which yields consistent estimators. The standard errors of these coefficients were calculated allowing for heteroscedasticity by using White’s (1980) procedure. This was motivated by the possibility that the volatility of interest rates may depend on the level of interest rates.

Two observations can be made from Table 3. First, the adjusted R^2 values for both regressions exceeded 0.997 and the Durbin-Watson statistics were insignificant at 95% level, i.e., the hypothesis of no serial correlation was accepted. Second, the coefficients for the on-the-run bills were insignificant at a 95% level. This is evidence that, conditional on when-

³¹To the extent a bearish primary dealer buys in the auction to fulfill orders from their client, she would prefer that her sentiment is revealed to other bidders.

³²Ideally, we would like to have a 1:00 pm quote, but the 12:15 pm bid quote was the closest available.

³³For 13-week bills, the 26-week bill auctioned 13 weeks ago -- the seasoned bill -- has the same maturity as a newly auctioned 13-week bill. But as the on-the-run bill is more liquid, we believe that it is more likely to reflect new information rapidly. In addition, there are a dozen or so missing observations for the seasoned bills.

³⁴In unreported regressions we also included lagged when-issued rate changes as well as lagged auction rates, neither of which were significant. As past prices do not seem to contain any information not reflected in the when-issued rates at 1:00 pm, we settled for the more parsimonious specification reported.

issued rates, other close substitutes in the secondary market do not convey any information about the auction rates for new bills. The residuals from the above regressions are the unexpected part of the auction bids, and we treat them as the “innovation” contained in the auction. The next question is:

1. Are the when-issued rate changes between 1:00 pm and 3:00 pm on auction days positively related to the innovation contained in the auction?

This question may be difficult to examine empirically as the rate changes in the when-issued market after the auction may be related to the information that arrives in the market after the auction. For example, during the stock market crash on October 19 1987, a Monday, and a week later on October 26, 1987, the movements in interest rates after the auction may have a lot to do with new information about the stock market. However, given that there are only two and a half hours in this window, by eliminating obvious drastic events such as stock market crashes we should expect, under e_3 , to see a positive relation between the rate changes in the when-issued market after the auction and the innovation contained in the auction bids.³⁵

To answer Question 1, we regressed the residuals from the regression of Table 3 on the when-issued rate changes after the auction. The residuals are an imperfect measure of the innovation, but under the standard hypothesis that the measurement errors are uncorrelated with the when-issued rate changes after the auction, we need no special adjustment in calculating the regression coefficients, as we use the residuals as dependent variables rather than independent variables. Table 4 reports the regressions of the residuals from the regressions of Table 3, denoted RES13 and RES26, on the when-issued rate changes for 13- and 26-week bills between 1:00 pm and 3:00 pm on auction days.

We have eliminated the two observations on October 19 and 26, 1987, to be consistent with the underlying assumption that there were no major public information surprises after the auction and before 3:30 pm on auction days. For both 13- and 26-week bills, the coefficients of own when-issued rate changes were positive and significant at a 99% level. For 13-week bills, on average 1 basis point of when-issued rate change after the auction indicated 0.28 basis points of information surprise in the auction bids, other things being equal. For 26-week bills, on average 1 basis point of when-issued rate change predicted a 0.59 basis points of information innovation in the auction bids. The when-issued rate changes after the auction for 26-week bills were not significantly related to the information surprise in the bids for 13-week bills. Similarly, the 13-week bill when-issued rate changes after the auction were unrelated to the information innovation in the auction for 26 week bills. Figures 1 and 2 plot

³⁵There is no *a priori* reason to believe that the data point of June 20, 1988 violated our null hypothesis here that there is no dramatically new information arrival between the auction and 3:30 pm on auction days. Thus we did not eliminate this data point from our analysis.

the innovation for 13- and 26-week bill auctions against their own when-issued rate changes. In both figures one can see a positive relationship.

The evidence presented in Table 4 and in Figures 1 and 2 supports the hypothesis that bidders behave strategically in the when-issued market. They may choose not to trade in this market before the auction to prevent their private information from being revealed too early. After the auction the information costs of trading in the when-issued market decrease, and we see that the innovation in the auction is reflected in the when-issued rate changes before the auction results are announced.

In the Treasury coupon market, Simon (1993) finds a similar relationship between mark-ups in the auction (defined as the difference between the when-issued bid rate just before the auction and the auction average rate) and changes in the when-issued rates from the time of the auction and 5 minutes before the auction results are announced. His results, however, are not significant if he excludes the most aggressively bid auctions (8 out of a sample of 66). Inspired by Simon's results, we want to test whether our results also are driven by a few aggressively bid auctions. Let us first define a pair of dummy variables, DM13 for 13-week bills and DM26 for 26-week bills, to be one if the when-issued ask rate at 1:00 pm is higher or equal to the average auction rate, and zero otherwise. Using this definition, we have 38 aggressive 13-week auctions (out of 128), and 32 aggressive 26-week auctions (out of 127). We then pose our question:

2. Is there a difference in the link between auction innovations and changes in the when-issued markets, as investigated above, between aggressively bid auctions and other auctions?

To answer this question, we regress the auction innovation (RES13 or RES26) on the rate changes in the when-issued market (CHG13 and CHG26) and DM times CHG. The coefficient on DM·CHG is an estimate of the difference in this informational link between aggressively bid auctions and other auctions, as defined by DM. These two regressions are reported in Table 5.

We first note that our previous results are *not* driven by the most aggressively bid auctions, as the coefficients on the own when-issued rate changes remain positive and significant at the 95% and the 99% level, respectively. The coefficient on DM13·CHG13 is positive but not significant, whereas the coefficient on DM26·CHG26 is positive and significant at the 90% level. We interpret these results as weak evidence in favor of the hypothesis that the link between auction innovations and when-issued changes is stronger for aggressively bid auctions than for auctions in general, at least for 26-week bills.

Having found that the aggressively bid auctions drive his results, Simon argues that this is evidence in favor of attempts to squeeze the market. We claim that even if there are *no* attempts to squeeze the market and all trades are informationally motivated, this is what we would expect. The reason is very simple: primary dealers face an asymmetry in profiting from their private information. If a dealer thinks that rates will *increase*, there is little

incentive to hide this information until after the auction closes, as the dealer cannot short sell in a Treasury auction (beyond not submitting any bid in the auction). On the other hand, if a dealer is bullish and believes that the rates will go down, she simply holds back in the when-issued trading so as not to reveal the information prematurely, and then submits an aggressive bid in the auction that allows her to acquire a larger quantity at a lower price than would have been the case if her information had become public. A bearish dealer, however, has no similar way of benefiting from her private information in the auction. She would instead try to short sell as much as possible in the when-issued market before the auction results are announced. Of course, this line of reasoning does not imply that there are no squeeze attempts, but simply that the documented phenomenon is wholly consistent with a more traditional game-theoretic explanation outlined above.

In approximately 80% of the auctions in our sample, the lowest winning rate was lower than the when-issued ask rate at the auction time. As discussed in Section 3, there are three possible explanations for this. First, there may be errors in the data or that the when-issued market at 1:00pm on auction days is illiquid and therefore these data are insignificant (hypothesis e1 of Section 3). Second, some bidders make mistakes and that these mistakes are economically insignificant (hypothesis e2). Thus, the quantities bought at these prices will be negligible and with little information content. Third, this may be due to strategic behavior (hypothesis e3). In this case there is information content in the fact that the lowest winning rate in the auction is lower than the when-issued ask rate in the auction. In particular, we expect that when the lowest winning auction rate is lower than the concurrent when-issued ask rate, the innovation in the auction is more likely to be negative, i.e., the winning auction rates are likely to be lower than expected. Because the when-issued rate changes tend to reflect the innovation in the auction, we also expect the when-issued rate changes after the auction to be negative when the lowest winning auction rate is lower than the concurrent when-issued ask rate. We ask:

3. Is the innovation in the auction more likely to be negative in auctions in which the lowest winning rate in the auction is lower than the concurrent when-issued ask rate?

To answer Question 3, we created two dummy variables, DUM13 for the 13-week bill auction and DUM26 for the 26-week bill auction. The variable DUM13 takes the value 1 if the lowest winning rate in a 13-week bill auction is lower than the concurrent when-issued ask rate, and the value 0 otherwise. DUM26 is similarly defined. We then regressed the residuals from the regressions in Table 3, RES13 and RES26, on DUM13 and DUM26. If our intuition is correct, we should find the regression coefficient of DUM_{nn} to be statistically significant and negative when RES_{nn} is the dependent variable, for $nn = 13$ or 26 . Table 6 reports the results of these two regressions. For 13-week bills, the adjusted R^2 was 0.32. The coefficient of DUM13 was -0.035 and significant at a 99% level. The coefficient of DUM26 was small, -0.009 and significant at a 90% level. The average contribution of DUM13 to the innovation

in the auction for 13-week bills was -3.5 basis points. For 26-week bills, the adjusted R^2 was 22% and the coefficient of DUM26 was -0.039 and significant at a 99% level. The coefficient of DUM13 was not significantly different from zero. The average contribution of DUM26 to the innovation in the auction for 26 week bills was -3.9 basis points. This affirms our null hypothesis that the dummy variables and the innovation in the auction are negatively related. In short, these results show that auction bids at rates lower than the coincident when-issued ask rate are economically significant and offer further evidence of the strategic interplay between the when-issued market and the auction.

We finally turn to the issue of information dispersion or divergence of beliefs in the Treasury-bill markets. Market microstructure theory suggests that one measure of the divergence of information or beliefs is the bid-ask spread of the market prices; see Copeland and Galai (1983) and Glosten and Milgrom (1985). It is also plausible that for a given level of divergence of information/beliefs, the bid-ask spread increases as the interest rate uncertainty increases. Auction theory suggests that the more diverse the beliefs of the bidders and the more uncertain they are about the demand for the bills, the more dispersed the bids submitted in the auction. Next we ask:

4. Do the bid-ask spread in the when-issued market and the interest-rate uncertainty before the auction have a positive effect on the dispersion of bids submitted in an auction?

To test this hypothesis, we need a measure of interest rate risk and a measure of dispersion of bids submitted in the auction. Casual empiricism suggests that a high term premium is associated with high interest rate volatility. This is because when the term premium is high, short-term interest rates are expected to rise and therefore the short-term securities are in a bear market situation which is usually associated with high volatility.³⁶ Thus, we use the difference between the average of bid and ask when-issued rates for 26- and for 13-week bills at 1:00 pm on auction days, i.e., the term premium, as an instrumental variable for interest rate risk along with the rate itself. The interest-rate level may also carry some information. Two possible instrumental variables for dispersion of bids in the auction are the difference between the highest and the average winning rates, which was used by Cammack (1991), and the difference between the highest and the lowest winning rates. In what follows we used the latter, but the results are very similar if Cammack's measure is used instead. For these regressions, October 19 and 26, 1987 have been included in the sample, as there is nothing in our hypothesis that disqualifies them.

The results are reported in Table 7. For 13-week bills, the spread between the highest and the lowest winning auction rates is significantly positively related to the term premium and

³⁶The theory of the term structure of interest rates offers some support to the hypothesis that the term premium may be an increasing function of interest rate volatility; see, for example, Cox, Ingersoll, and Ross (1985).

the bid-ask spread of the 13-week when-issued rates at 1:00 pm. The average term premium in our sample was about 19 basis points; its average contribution to the spread between the highest and the lowest winning auction rates was about 1.3 basis points, which was about one-third of the average high-low winning rate spread. The average when-issued bid-ask spread in our sample was 1 basis point, and its contribution to the high-low winning rate spread was about 0.83 basis points. The Durbin-Watson statistic indicates serial correlation. The t-statistics reported in the table are calculated using White's procedure but without allowing for serial correlation. To verify that the significance levels were not artificially high because of the serial correlation, we recalculated the standard errors to account for different distributed lags in the residuals; in no such case were the significance levels reduced.

For 26-week bills, the when-issued bid-ask spread does not make a statistically significant contribution to the auction bid spreads. The term premium has significant explanatory power. An average term premium of about 19 basis points contributed about 1.1 basis points to the high-low spread of auction bids, which averaged 3.6 basis points.

To summarize our results, we find that the term premium and the bid-ask spreads in the when-issued market (the latter only for 13-week bills, however) serve as indicators of dispersion in the ensuing auction.

5 Do Bidders Collude?

It has been alleged that collusion and price fixing are widespread in the Treasury securities market.³⁷ If bidders collude and agree to submit similar discount rates, we expect a small dispersion of winning bids — at least at the lower end of the spectrum of submitted discount rates. At the same time we expect high profits for bidders as they collude in the auction and submit artificially high discount rates. Therefore, in the presence of widespread collusion we expect a decrease in the dispersion of winning bids and high bidder expected profits. Auction theory suggests that if bidders do not collude, their expected profits increase as the divergence of information among them increases (see Reece (1978)). As pointed out in Section 4, the dispersion of winning bids in the auction increases with the divergence of information among the bidders. In the absence of collusion we would expect an increase in the dispersion of winning bids to indicate an increase in bidders' expected profits. Therefore, a positive effect of dispersion of bids on bidders' expected profits would imply that there is no or little collusion, whereas a negative effect would be a reason to suspect widespread collusion.

Bidders' expected profits are very difficult to measure. There are numerous ways for dealers to realize profits through their positions in related markets, such as other fixed-income securities and derivatives. The total profit made by primary dealers is therefore

³⁷See, for example, "Hidden bonds: Collusion, price-fixing have long been rife in Treasury market" in *The Wall Street Journal* on August 19, 1991. Back and Zender (1993) analyzes the susceptibility of different auction formats to collusive strategies.

impossible to estimate from publicly available data. Hence, our attempts to measure profits should only be seen as proxies for different activities in which primary dealers are engaged. These proxies are similar in spirit to those used in the existing literature, e.g., Jegadeesh (1993) and Simon (1993).

First, we use the difference between the when-issued rate at 3:00 pm on auction days and the weighted average winning rate in the auctions as an instrumental variable for bidders' expected profit from post-auction market making, i.e., buying in the auction for resale in the when-issued market. In doing so we assume that the when-issued rate at 3:00 is highly correlated with the when-issued rate after the auction results are announced. As we have not been able to get a when-issued quote right after the auction announcement, our choice of proxy is as close as possible to what we want. For this proxy, the lower the when-issued rate at 3:00 pm on auction days compared to the average winning rate in the auction, the greater the bidders' profits. For our second proxy, we define two new variables, BFR13 and BFR26, as the averages of the when-issued 3:00 pm quotes during the four trading days preceding the auction. If one of these quotes was missing (because of a holiday, for instance), the average is based on three quotes. These quotes are the averages of the bid and ask quotes. Our second proxy is then defined as BFRnn-ARnn, for nn=13 and 26. By using this proxy, we hope to capture the profits from pre-auction market making, i.e., selling short in the when-issued market before the auction and then cover the position through purchases in the auction. We use BFRnn instead of, say, BIDnn, to capture that establishing a substantial short position in the when-issued market requires time if one does not want to move prices too much. Our next problem is to capture the idea of dispersion of winning bids in the auction. Two possible instrumental variables for this dispersion are the difference between highest and average winning rates and the difference between highest and lowest winning rates. We used the difference between the highest and average winning rates to reduce the impact of the strategic interplay between the auction and the when-issued market.

If there is no collusion, we expect that the link between dispersion of bids and profits is positive, i.e., the coefficient on HRnn-ARnn should be negative, since our proxies decrease as profits go up. Our null hypothesis is that there is no collusion, and we ask:

5. Are our two proxies for pre- and post-auction market making profits negatively related to the difference between highest and average winning rates?

We know from Section 4 that the when-issued rate can change between 1:00 pm and 3:00 pm because of the strategic interplay between the when-issued market and the auction. Given that the weighted average of the winning rates in the auction is highly correlated with the when-issued rate at 1:00 pm on auction days, it is plausible that a significant part of the variation in the difference between the when-issued rate at 3:00 pm and the average winning rate in the auction is due to this strategic interplay and not because of any collusive behavior. To take this into account, we regressed our proxy for post-auction market-making profits on

the difference between highest and average winning rates as well as on DUM13 and DUM26. In both sets of regressions, we included the appropriate on-the-run bill rate, BILL13 or BILL26, to control for the overall level of interest rates. The results are reported in Table 8. For our post-auction market-making proxy, the coefficients of the dispersions in bids are all insignificant. In the pre-auction market-making case, the coefficients on dispersion of bids in the 13-week-bill auction are negative and significant for both the 13- and 26-week regressions. The corresponding coefficient for 26-week bills are insignificant in both regressions. For both proxies we, therefore, fail to reject the hypothesis that there was no collusion in the auctions.

6 Concluding Remarks

We have investigated the relation between the auction of 13- and 26-week Treasury bills and the when-issued market for these bills. We have confirmed several hypotheses suggested by economic theory. Perhaps the most interesting among our findings is the evidence of strategic interaction between bidders' actions in the when-issued market and in the auction.

7 References

1. Y. Amihud and H. Mendelson, Liquidity, maturity, and the yields on U.S. Treasury securities, *Journal of Finance* **46**, 1411-1425, 1991.
2. K. Back and J. Zender, Auctions of divisible goods: On the rationale for the Treasury experiment, *Review of Financial Studies* **6**, 733-64, 1993.
3. S. Bikhchandani and C. Huang, Auctions with resale markets: A model of Treasury bill markets, *Review of Financial Studies* **2**, 311-339, 1989.
4. S. Bikhchandani and C. Huang, The economics of Treasury securities markets, *Journal of Economic Perspectives* **7:3**, 117-134, 1993.
5. E. Cammack, Evidence on bidding strategies and the information contained in Treasury bill auctions, *Journal of Political Economy* **9**, 100-130, 1991.
6. T. Copeland and D. Galai, Information effects on the bid-ask spread, *Journal of Finance* **38**, 1457-1469, 1983.
7. B. Cornell and A. Shapiro, The mispricing of U.S. Treasury bonds: A case study, *Review of Financial Studies* **2**, 297-310, 1989.
8. J. Cox, J. Ingersoll, and S. Ross, A theory of the term structure of interest rates, *Econometrica* **53**, 385-407, 1985.
9. D. Duffie, Special repo rates, *Journal of Finance* **51**, 493-526, 1996.
10. F. Fabozzi, *The Handbook of Fixed Income Securities*, Edited, Dow Jones-Irwin, Homewood, Illinois, 1991.
11. W. Fuller, *Statistical Time Series*, John Wiley & Sons, New York, 1976.
12. L. Glosten and P. Milgrom, Bid, ask, and transaction prices in a specialist market with heterogenously informed traders, *Journal of Financial Economics* **14**, 71-100, 1985.
13. A. Hindy, Dynamic price formation in a futures markets via double auctions, *Economic Theory* **4**, 539-560, 1994.
14. N. Jegadeesh, Treasury auction bids and the Salomon squeeze, *Journal of Finance* **48**, 1403-1419, 1993.
15. A. Kyle, Continuous auctions and insider trading, *Econometrica* **53**, 1315-1335, 1985.
16. Joint report on the government securities market (1992), published by the Department of Treasury, the Securities and Exchange Commission, and the Board of Governors of the Federal Reserve System.

17. P. Milgrom and R. Weber, A theory of auctions and competitive bidding, *Econometrica* **50**, 1089-1122, 1982.
18. D.K. Reece, Competitive bidding for offshore petroleum leases, *Bell Journal of Economics* **9**, 369-384, 1978.
19. D. Simon, Markups, quantity risk and bidding strategies at Treasury coupon auctions, *Journal of Financial Economics* **35**, 43-62, 1994.
20. P. Spindt and R. Stolz, Are U.S. Treasury bills underpriced in the primary market?, *Journal of Banking and Finance* **16**, 891- 908, 1992.
21. M. Stigum, *The Repo and Reverse Markets*, Dow Jones- Irwin, Homewood, Illinois, 1989.
22. S. Sundaresan, An empirical analysis of U.S. Treasury auctions: implications for auction and term structure theories, unpublished paper, Columbia University, 1992.
23. H. White, A heteroscedasticity-consistent covariance matrix estimator and direct test for heteroscedasticity, *Econometrica* **48**, 817-838, 1980.
24. R. Wilson, Auctions of Shares, *Quarterly Journal of Economics* **93**, 675-689, 1979.
25. R. Wilson, Incentive Efficiency of Double Auctions, *Econometrica* **53**, 1101-1116, 1985.

8 Tables

Table 1: List of Variables

HRnn:	The highest winning rate in the auction for nn week bills, nn=13 or 26.
ARnn:	The quantity weighted average winning rate in the auction for nn week bills, nn=13 or 26.
LRnn:	The lowest winning rate in the auction for nn week bills, nn=13 or 26.
BIDnn	The bid rate of the when-issued at 1:00 pm on auction days for nn week bills, nn=13 or 26.
ASKnn	The ask rate of the when-issued at 1:00 pm on auction days for nn week bills, nn=13 or 26.
BAnn:	The average of the BIDnn and ASKnn, nn=13 or 26.
TERMPREM:	The “term premium” between the 26-week when-issued and the 13-week when-issued, i.e., BA26 minus BA13.
SPRDnn:	The difference between the bid and ask rates for nn week bills, nn=13 or 26, quoted on the when-issued market at 1:00 pm on auction days, i.e., BIDnn minus ASKnn.
BILLnn:	The bid rate for on-the-run nn week bills, nn=13 or 26, auctioned the previous week, quoted in the secondary market at 12:15 pm (or if that quote was not available at 11:00 am or at the opening of the market) on auction days.
RESnn:	The residuals of the regressions in Table 3, i.e., actual ARnn minus ARnn predicted by the independent variables in Table 3.
DMnn:	A dummy variable whose value is 1 if the nn week bill, nn=13 or 26, when-issued ask rate at 1:00 pm, ASKnn, is greater or equal to the average winning rate in the concurrent auction, ARnn, and is 0 otherwise.
DUMnn:	A dummy variable whose value is 1 if the nn week bill, nn=13 or 26, when-issued ask rate at 1:00 pm, ASKnn, is greater than the lowest winning rate in the concurrent auction, LRnn, and is 0 otherwise. Note that if DUMnn=1 then DMnn=1.
Mnn:	The average of the bid and ask rates for nn week bills, nn=13 or 26, quoted on the when-issued market at 3:00 pm on Monday, (usually) the day of the auction.
CHGnn:	The change in the average of the bid and ask when-issued rates for nn week bills, nn=13 or 26, between 1:00 pm and 3:00 pm on auction days, i.e., Mnn-BAnn.
BFRnn:	The average of when-issued bid and ask rates at 3:00 pm for nn week bills for the four (or three, if there is a missing observation) trading days preceding the auction day, nn=13 or 26.

Table 2: Sample Statistics

	BID13	ASK13	SPRD13	AR13	HR13-AR13
Sample Size	130	130	130	130	130
Max	8.04	8.03	0.06	8.05	0.06
Min	5.06	5.00	0.00	5.08	0.00
Mean	5.97	5.96	0.0109	5.98	0.0097
Std. Dev.	0.60	0.60	0.007	0.61	0.011
No. Positive	130	130	121	130	85
	ASK13-LR13	ASK13-AR13	BID13-AR13	BID13-HR13	HR13-LR13
Sample Size	130	130	130	130	130
Max	0.085	0.05	0.06	0.06	0.18
Min	-0.11	-0.14	-0.13	-0.14	0.00
Mean	0.015	-0.019	-0.008	-0.018	0.04
Std. Dev.	0.033	0.033	0.032	0.036	0.031
No. Positive	104	16	49	27	128
	BID26	ASK26	SPRD26	AR26	HR26-AR26
Sample Size	130	130	130	130	130
Max	8.135	8.125	0.08	8.13	0.04
Min	5.14	5.135	0.0	5.13	0.00
Mean	6.16	6.15	0.012	6.16	0.0087
Std. Dev.	0.64	0.064	0.0098	0.064	0.008
No. Positive	130	130	120	130	99
	ASK26-LR26	ASK26-AR26	BID26-AR26	BID26-HR26	HR26-LR26
Sample Size	130	130	130	130	130
Max	0.28	0.24	0.24	0.23	0.15
Min	-0.097	-0.12	-0.107	-0.107	0.00
Mean	0.016	-0.011	0.001	-0.008	0.036
Std. Dev.	0.038	0.037	0.035	0.036	0.025
No. Positive	101	32	62	36	128
	CHG13	BILL13	CHG26	BILL26	TERMPREM
Sample Size	118	130	118	129	130
Max	0.145	8.05	0.125	8.14	0.85
Min	-0.355	5.03	-0.255	5.15	-0.06
Mean	0.001	5.95	-0.001	6.16	0.188
Std. Dev.	0.059	0.61	0.0505	0.63	0.182
No. Positive	53	130	53	129	116

[†] The rates are in percent. For example, 8.50 means 8.5%. The number of positive items counts the number of observations that are strictly positive.

Table 3: Regression of Auction Rates on When-Issued Rates and Rates of Closest Substitute in the Secondary Market

Independent Variables	Dependent Variables	
	AR13	AR26
Constant	-0.0336* (-1.92)	0.0153 (0.84)
BA13	0.9172*** (26.52)	-0.0183 (-0.77)
BA26	0.0901*** (4.87)	0.8511*** (6.50)
BILL13	-0.0023 (-0.11)	— —
BILL26	— —	0.1647 (1.35)
Sample Size	128	127
Adjusted R^2	0.9980	0.9971
Durbin-Watson	1.92	1.99

[†] The numbers in parentheses are the test statistics under the null hypothesis that the correlation coefficient is zero. These statistics follow a standard normal distribution asymptotically (see, for example, Fuller (1976)), and *, **, and *** denote statistical significance at 90%, 95%, and 99% levels according to the asymptotic distribution.

Table 4: Regression of Residuals from the Regressions of Table 3 on CHG13 and CHG26[†]

Independent Variables	Dependent Variables	
	Innovation from the Prediction of AR13, RES13	Innovation from the Prediction of AR26, RES26
Constant	−0.0004 (−0.17)	−0.0006 (−0.28)
CHG13	0.2803*** (2.96)	−0.1078* (−1.66)
CHG26	−0.0355 (−0.53)	0.5850*** (6.96)
Sample Size	116	115
Adjusted R^2	0.22	0.51
Durbin-Watson	1.80	1.99

[†] RES13 and RES26 are the residuals from the regressions of Table 3. They represent the innovation from the prediction of AR13 and AR26, respectively.

Table 5: Regression of Residuals from the Regressions of Table 3 on CHG13, CHG26, and Dummy for Aggressiveness in the Auction Bidding

Independent Variables	Dependent Variables	
	Innovation from the Prediction of AR13, RES13	Innovation from the Prediction of AR26, RES26
Constant	0.0007 (0.32)	0.0019 (0.77)
CHG13	0.2402** (2.41)	-0.0287 (-0.44)
CHG26	-0.0486 (-0.71)	0.3970*** (2.97)
DM13·CHG13	0.2359 (1.44)	—
DM26·CHG26	—	0.3387* (1.86)
Sample Size	116	115
Adjusted R^2	0.24	0.54
Durbin-Watson	1.79	2.06

Table 6: Regression of Residuals from the Regressions of Table 3 on DUM13 and DUM26

Independent Variables	Dependent Variables	
	Innovation from the Prediction of AR13, RES13	Innovation from the Prediction of AR26, RES26
Constant	0.0355*** (5.36)	0.0252*** (2.85)
DUM13	-0.0354*** (-5.72)	0.0060 (0.58)
DUM26	-0.0091* (-1.95)	-0.0389*** (-5.86)
Sample Size	128	127
Adjusted R^2	0.32	0.22
Durbin-Watson	1.92	2.04

Table 7: Regression of Dispersion in Auction Rates on Dispersion in When-Issued Rates

Independent Variables	Dependent Variables	
	HR13-LR13	HR26-LR26
Constant	0.0082 (0.33)	0.0246 (1.39)
TERMPREM	0.0689*** (3.96)	0.0559*** (3.68)
SPRD13	0.8331** (2.45)	0.5544 (1.48)
SPRD26	-0.0773 (-0.23)	0.1495 (0.49)
BILL13	0.0025 (0.59)	— —
BILL26	— —	-0.0011 (-0.37)
Sample Size	130	129
Adjusted R^2	0.22	0.22
Durbin-Watson	1.36	1.77

Table 8: Regressions to Test for Collusion

Independent Variables	Dependent Variables		Dependent Variables	
	M13-AR13	BFR13-AR13	M26-AR26	BFR26- AR26
Constant	-0.0060 (-0.02)	-0.0049 (-0.05)	-0.0203 (-0.72)	0.0656 (0.84)
HR13-AR13	0.4370 (1.03)	-3.7167* (-1.70)	-0.0993 (-0.29)	-2.6872** (-2.28)
HR26-AR26	-0.0656 (-0.13)	0.3923 (0.27)	0.1555 (0.33)	0.2406 (0.18)
DUM13	0.0100 (1.55)	— —	0.0095 (1.61)	— —
DUM26	-0.0049 (-0.80)	— —	0.0102* (1.88)	— —
BILL13	-0.0028 (-0.49)	0.0006 (0.03)	— —	— —
BILL26	— —	— —	0.0002 (0.05)	-0.0111 (-0.85)
Sample Size	116	128	115	127
Adjusted R^2	-0.017	0.071	0.003	0.049
Durbin-Watson	2.29	2.11	2.18	2.08

Figure 1: Innovation for 13-Week Auction Versus the When-Issued Rate Changes for 13-Week Bills after the Auction

Figure 2: Innovation for 26-Week Auction Versus the When-Issued Rate Changes for 26-Week Bills after the Auction[†]

[†] The lowest-left-hand point in Figure 2 is the data point for June 20, 1988 (see Footnote 27).