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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 related to information costs of trading in the when-issued market before the auction. Several hypotheses suggested by economic theory are also tested.

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1 Introduction and Summary

A huge volume of U.S. Treasury bills, notes, and bonds are traded daily by many buyers and sellers. Therefore it may seem reasonable to think of the U.S. Treasury securities market as perfectly competitive. However, recent alleged infractions by Salomon Brothers suggest that such an assumption may be inaccurate. Noncompetitive behavior in the U.S. Treasury securities market can significantly increase the cost of government debt financing. In addition, default-free interest rates determined in these markets serve as a benchmark for the valuation of other risky securities such as common stocks and corporate bonds.

Consequently, these alleged abuses have prompted a review of the Treasury securities market.[1] At the same time these violations reveal how little is known about the market for Treasury securities. This is in part because data are not readily available to researchers as these markets are over-the-counter. Although some auction data is announced by the Department of Treasury, information on forward contracts for Treasury securities is difficult to obtain. We have gathered data on forward contract prices by calling a dealer over a three year period. We use this data to examine the link between the forward market and the auction for Treasury bills.

The U.S. Treasury securities market offers an interesting opportunity to study the price formation process. There are two different markets that exist simultaneously: (i) U.S. Treasury securities are sold at auctions, and (ii) forward contracts on the Treasury securities can be bought and sold for delivery "when-issued." The forward market, which is called the when-issued market, is a double auction.[2] By comparing the prices in these two markets, we can learn how the organization of markets affects prices. The when-issued market opens before the auction and remains open during and after the auction. Before the auction, the when-issued market could aggregate the possibly diverse information of participants in this market, and thus have an impact on the auction. Further, the movement of prices in the when-issued market after the auction and before the announcement of the auction results can be an indication of how efficiently the when-issued market reflects the information innovation contained in the auction. A bidder may trade in the two markets in a manner that best protects her private information. If so, one might be able to detect this behavior by comparing prices across markets.

We empirically examine the relation between the when-issued market and the weekly auction

[1] See, for example, the Joint Report on the Government Securities Market (1992).

[2] A 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.

for 13 week and 26 week Treasury bills. Several hypotheses suggested by economic theory are tested and shown to be broadly consistent with the data. In particular, we present evidence of strategic interplay between the when-issued market and the auction. The data suggest that traders in the when-issued market take into account the possibility that the when-issued prices might reveal, at least partially, their private information. If traders with large demands trade mainly in the auction instead of the when-issued market, their private information is revealed only after the auction is over. Thus auction prices are expected to be more informative than when-issued prices at the auction time.

Cammack (1991) and Spindt and Stolz (1991), 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 find systematic underpricing in the auction, Cammack by 4 basis points and Spindt and Stolz by 7 basis points. 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] This by itself would not change their conclusion of underpricing in the auctions, but would certainly change the magnitude of underpricing. Second, seasoned Treasury securities are quoted for a different delivery date than the delivery date of the newly auctioned bills.[4] For proper comparison, the secondary market prices for the seasoned securities have to be adjusted. This adjustment, done using the Federal funds rate by Cammack and by Spindt and Stolz, 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 (on Treasury bills) with three days to maturity. No adjustment is needed to make the comparison and no measurement errors are introduced.

Other related papers include Cornell and Shapiro (1989), who document an apparent anomaly in the pricing of 30 year Treasury bonds, and Jegadeesh (1992), who estimates the profit primary dealers can make by buying Treasury notes and bonds in the auction and selling in the secondary market.[5] Cornell (1992) examines whether the bid-ask spread on Treasury securities increases during a short squeeze. Related theoretical work includes Wilson (1979), Milgrom and Weber (1982), Bikhchandani and Huang (1989, 1992), Back and Zender (1992), and Duffie (1992).

[3]The newly auctioned Treasury securities are said to be on-the-run.

[4]Starting from the afternoon of the auction day, which is usually a Monday, on-the-run bills are quoted for delivery the coming Thursday when the newly auctioned bills are delivered. Cammack uses a sample of quotes for seasoned bills that are delivered two business days later. Spindt and Stolz use a sample of quotes that are delivered the next business day. Currently, except for on-the-run bills, Treasury bills are quoted for delivery on the next business day.

[5]The total profit made by primary dealers is impossible to estimate using publicly available data. A dealer can take a short position in the when-issue market and buy at the auction. The profit made may not depend on the secondary market price.

The rest of this paper is organized as follows. We describe, 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 in Section 4 we discuss 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] For 26 week bills the auction was cheaper by about 1 basis point. We also 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. This indicates the existence of information costs of trading in the when-issued markets.

In Section 5 we examine the relation between the auction and the when-issued market before the auction. The evidence suggests that the when-issued market aggregates information effectively in that lagged auctions do not convey information about the future auction, given the information contained in the when-issued prices. However, when-issued price changes before the auction can convey some information given the when-issued prices at auction time. We also show that the dispersion of bids in the auction are positively related to the bid-ask spreads and the term premium in the when-issued markets.

We investigate the link between post-auction price changes in the when-issued market and the auction in Section 6. The change in when-issued prices on auction days, after the auction but before the announcement of the auction results, is significantly related to the information innovation contained in the auction. In addition, the information innovation contained in the auction and the price change in the when-issued market after the auction are significantly related to whether there are bids in the auction that are higher in price than the when-issued ask price at the auction time. This is further confirmation of the strategic interaction between the auction and the when-issued markets. We examine, in Section 7, 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 week bill and 26 week bill auctions did not collude. Section 8 contains concluding remarks.

2 Institutional Details of the Treasury Bill Market

Every week the Department of Treasury auctions 13 week and 26 week bills. The auction is held every Monday and the deadline for competitive bids is 1:00 pm.[7] Currently, there are 38 competitive

[6] This contrasts with Cammack's finding that underpricing in the 13 week bills auction, compared to the corresponding seasoned bills, was 4 basis points. Spindt and Stolz's figure for underpricing in the auction was 7 basis points.

[7] When Monday is a holiday, the auction is held on the first trading day after Monday.

bidders, called *primary dealers*, who submit sealed bids that are discount rate-quantity pairs.[8,9] Although 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. 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 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),[10] quantity weighted average of winning rates, and the split between competitive and noncompetitive bids. Treasury bills are delivered to the winning bidders on Thursday and can be resold in an active secondary market.[11]

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.[12] These forward contracts are called when-issued. Their maturity date is the Thursday of the auction week, the same day that the newly auctioned Treasury bills are delivered. 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 there are two different markets for acquiring Treasury bills around auction time — the Treasury auction and 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. The weekly auction of Treasury bills has a positive supply of bills and is held at a single point in time.[13] The open interest in the when-issued market varies from a small amount to

[8]For a 13 week bill with a face value of 1000, a discount rate of 5.98%, say, translates into a price of $1000(1 - 5.98\%(91/360)) = 985.09$. The competitive bidders can only submit discount rates which are whole basis points. A basis point is one hundredth of 1 percent.

[9]The 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. In addition, a primary dealer cannot submit bids in an auction larger in quantity than the total amount auctioned.

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

[11]The Treasury bills are not physically delivered to the winning bidders. Rather, they are registered to the winning bidders in book entry form; see Fabozzi and Pollack (1983).

[12]A standard forward contract is for a principal amount of $5 million.

[13]See Footnote 2.

several times the amount auctioned.

A primary dealer can acquire Treasury bills in three ways — buy in the when-issued market before the auction, submit bids in the auction, or buy in the when-issued market or in the secondary market after the auction. If a primary dealer buys in the when-issued market or the secondary market she is sure to get the bills, whereas she faces the uncertainty of losing in the auction. However, there is an advantage in buying in the auction. A primary dealer who has a large demand for the bills to be auctioned, may reveal this information if she buys before the auction in the when-issued market. This will increase the when-issued ask price and encourage aggressive bidding in the auction. In contrast, if she bids in the auction this private information may be revealed only after the auction.

Besides 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. A *short squeeze* occurs when many of those who are short 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.[14] If, for instance, an individual who possesses securities needs to borrow funds overnight, he can "sell" the securities to a counter party and at the same time sign with her an agreement to repurchase these securities the next day at a predetermined price. This predetermined price may be equal to the selling price paid on the previous day by the counter party. In this case, the counter party is paid an explicit repo rate on the money she invests. Alternatively, the purchase price is set to be different from the selling price so that the counter party earns returns due to her. In either case, the return earned by the counter party is called the "repo rate" for the securities used as collateral. The counter party in a repo agreement is said to be engaged in a "reverse repo" — borrowing securities while loaning out funds. When there is a short squeeze, say in the when-issued for 13 week Treasury bills, the repo rate using the newly auctioned 13 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".

[14]See Stigum (1989).

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. We have:

1. 130 observations of the bid and ask (discount) rates for 13 week and 26 week when-issued at 1:00 pm on auction days.[15]

2. The average of bid and ask rates for 13 week and 26 week when-issued at 3:30 pm on auction days and at 3:30 pm on Tuesday, Wednesday, Thursday, and Friday in the previous week.[16] During the sample period, the auction results were announced after 3:30 pm. Currently, the auction results are announced at around 2:00 pm. The sample size for these observations are as follows:

	Tuesday	Wednesday	Thursday	Friday	Monday
13 Week	144	144	140	137	131
26 Week	144	144	140	137	131

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 prorata at the highest winning rate.

The daily 3:30 pm when-issued data are from Data Resources Inc., (DRI).[17] The when-issued rates at 1:00 pm on auction days are not publicly available. We collected this data in real time by calling a dealer at Shearson Lehman at 1:00 pm on auction days.[18] The summary statistics of the weekly auction are announced by the Department of Treasury, and are published in *The Wall Street Journal*.[19]

[15] The when-issued is quoted by its discount rate as described in Footnote 8. The bid rate is the discount rate at which one sells and the ask rate is the discount rate at which one buys.

[16] The when-issued market begins on Tuesday in the week before bill is auctioned.

[17] For 11 observations in our data set, the auctions were not held on Monday. We do not have the when-issued rates for the newly auctioned bills at 3:30 pm on auction days for these data points. Thus variables CHG13 and CHG26 (defined in Table 1 below) were not available for these observations. However, we 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.

[18] We 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.

[19] We thank Elaine Lai for collecting this data.

4 Data Summary

Table 1 (all tables are in Section 10) lists definitions of the variables we use. To facilitate comparison between 13 week bills 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 and 4 basis points higher than the lowest winning rate.[20] The average bid-ask spread of the quotes of the when-issued at 1:00 pm on auction days was 1 basis point. 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 auctions days, *i.e.*, one earns a 0.02% higher interest rate at the average winning auction rate than at the when-issued ask rate. 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.

Recall that there are three ways to acquire Treasury bills: buy in the when-issued market before the auction, submit bids in the auction, or buy in the when-issued market or the secondary market after the auction.[21] If one buys in the when-issued market before the auction, one can be sure of getting the new bills, while one is uncertain about winning in the auction. We believe that 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.

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. 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).

An explanation of this apparent anomaly may be the cost to a primary dealer of revealing her private information before the auction. If a primary dealer buys a large amount in the when-issued market prior to the auction she may influence the when-issued rates 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, *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 observing a lower bid rate in the auction than the when-issued ask rate may be an indication

[20] Recall from Footnote 8 that 1 basis point is one-hundredth of 1 percent.

[21] The newly auctioned bills are delivered on the Thursday following the auction. Before their delivery, these bills continue to be traded in the when-issued market also for Thursday delivery. After their delivery, these bills are traded in the secondary market for second day delivery.

of the strategic interplay between the when-issued market and the auction. We present a detailed analysis in Section 6.

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 and was lower than the highest winning rate by 1.8 basis points. This suggests the possibility of selling the when-issued 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.

The when-issued rate change between 1:00 pm and 3:30 pm on auction days was 0.1 basis points on average with a standard deviation of 5.9 basis points.[22] The when-issued rate change between Friday 3:30 pm and Monday 1:00 pm was on average 2 basis points with a standard deviation of 9.6 basis points. The rate changes between Thursday and Friday and between Wednesday and Thursday were less than 1 basis point each whereas the rate change between Tuesday and Wednesday was -2.8 basis points. The change in the when-issued rate from Tuesday in the week before the auction to the following Monday at 1:00 pm was -0.3 basis points on average.

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. The when-issued rate difference[23] between 26 week bills and 13 week bills at 1:00 pm on auction days, the "term premium", was about 19 basis points on average. Thus, during the sample period the yield curve at the lower end was upward sloping, on average. 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.[24]

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. In 101 out of 130 auctions or about 77% of the time, there was at least one bidder who submitted a bid rate lower than the when-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. 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

[22] Recall that during the sample period results of the auction were announced after 3:30 pm.

[23] The rate difference here is calculated using the average of the bid and ask rates.

[24] On 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.

time, the when-issued bid rate was lower than the average winning auction rate.

The behavior of when-issued rate changes for 26 week bills are similar to those of 13 week bills except that the rate change between Tuesday and Wednesday was 0.1 basis point for 26 week bills compared to -2.8 basis points for 13 week bills. In addition, the when-issued rate increased from Tuesday before the auction to Monday at 1:00 pm by 1.8 basis points on average.

Table 3 gives sample correlation coefficients between the some of the variables. It is not surprising that the when-issued bid rates are highly correlated with the average auction rates.[25] The bid-ask spread of the when-issued rates at 1:00 pm on auction days, the difference between the highest and the lowest winning auction rates, both for 13 as well as 26 week bills, and the term premium are all significantly correlated with each other. The when-issued rate change between 1:00 pm and 3:30 pm on auction days for 13 week bills was significantly negatively correlated with the difference between the highest and the lowest winning auction rates for 13 week bills, but was significantly positively correlated with the difference between the highest and the lowest winning auction rates for 26 week bills. However, the same when-issued rate change for 26 week bills was not significantly correlated with the difference between the highest and the lowest winning auction rates for 13 week and 26 week bills. The when-issued rate change between 1:00 pm and 3:30 pm on auction days for 13 week bills and 26 week bills were significantly positively correlated.

5 The When-Issued Market before the Auction and the Auction

As discussed in Section 2, the when-issued market aggregates the possibly diverse information held by the primary dealers and their institutional clients. Therefore, first we ask:

1. How well does the when-issued market aggregate information?

Obviously, the when-issued market does not aggregate information perfectly; otherwise, all primary dealers would submit the same bid at the auction.[26] Theory suggests that if the when-issued market aggregates information partially then the when-issued rate changes over time may exhibit serial correlation (see, for example, Brown and Jennings (1989) and Wang (1991, 1992)).[27]

We calculated the daily when-issued rate changes at 3:30 pm from Tuesday to Friday in the

[25] In all tables, we use *, **, and *** to denote significance levels of 90%, 95%, and 99% according to the asymptotic distribution.

[26] There is a possibility that when all bidders have the same information they may randomize. Such Nash equilibria do not exist when the minimum reserve price is greater than $-\infty$.

[27] It is well-known that interest rate levels are highly serially correlated. The when-issued rates in our sample have serial correlations above 0.9. However, our interest lies in serial correlation of changes in when-issued rates.

week before the auction, from Friday at 3:30 pm to Monday at 1:00 pm, and from Monday 1:00 pm to 3:30 pm, for both 13 week and 26 week bills.[28] In Table 4, we report the own correlation coefficients of daily when-issued rate changes for 13 week bills and for 26 week bills, and the cross correlation coefficients between the daily when-issued rate changes for 13 week bills and 26 week bills.

There is some similarity between the own correlation coefficients of 13 week bills and of 26 week bills. The when-issued rate changes from Tuesday to Wednesday and from Wednesday to Thursday were not significantly correlated for both kinds of bills. The rate changes from Wednesday to Thursday and from Thursday to Friday were significantly correlated, positive for 13 week bills and negative for 26 week bills. The rate changes between Thursday and Friday and between Friday and Monday were also insignificant. If one believes that significant correlation between rate changes is an indication of information trades, then the numbers suggest that during the sample period information trades typically occurred in the middle of the when-issued trading cycle. The information appears to be related the slope of the low end of the yield curve as the estimated correlation coefficients for 13 week and for 26 week bills have different signs. There were many significant cross correlation coefficients between the rate changes for 13 week bills and for 26 week bills, but there is no apparent systematic lead-lag relation among the rate changes. We do not see, for example, the rate changes for the 13 week bills leading those for the 26 week bills.[29]

Another way of determining how efficiently the when-issued market aggregates information is to examine whether last week's auction rates carry any information regarding this week's auction rates, given the information contained in current when-issued rates. Our null hypothesis is:

> The conditional expectations of the auction rates are a linear function of the average of when-issued bid and ask rates at 1:00 pm on the auction day, and the daily rate changes up to the auction time of the when-issued contracts for both 13 week and 26 week bills.

Under the null hypothesis, if we regress auction rates on when-issued rates at 1:00 pm on auction days, on when-issued rate changes, and on previous week's auction rates, then the coefficients of previous week's auction rates should not be significantly different from zero. Given that average, highest, and lowest winning auction rates are highly correlated with each other, including all their lagged values as independent variables would create a severe case of multicollinearity. Therefore, when using the average auction rate for 13 week bills as the dependent variable, for example, the

[28] The changes are in the average of the bid and ask when-issued rates.

[29] In equity markets, Lo and MacKinley (1988) documented a lead-lag relation between weekly returns on large stocks and on smaller stocks.

only lagged variable we included was the previous week's 13 week bill average auction rate and the difference between it and the previous week's 26 week bill average auction rate.[30] Other cases were handled similarly. We report these regressions in Table 5.

In these regressions, and in all subsequent regressions, the coefficients were estimated using the ordinary least squares procedure. This 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. When the Durbin-Watson statistic indicated nontrivial serial correlation for the residuals, we recalculated the standard errors of the regression coefficients to account for different distributed lags in the residuals until the standard errors stabilized. The test statistics, calculated using these standard errors, are distributed asymptotically according to the standard normal distribution; see, for example, Fuller (1976).

Two observations can be made from Table 5. First, the adjusted R^2 values for all six regressions exceeded 0.996 and the Durbin-Watson statistics were either insignificant at 95% level or inconclusive. Second, all lagged variables, except one lagged variable in one of the regressions, were insignificant at a 95% level; the exception was the lagged difference between the lowest winning auction rate for 26 week bills and for 13 week bills with the lowest auction rate for 13 week bills as the dependent variable. We view this as a broad support for our null hypothesis that conditional on when-issued rates, lagged auction rates do not convey much information about the auction rates for new bills.

Table 6 reports the results of the same regressions as in Table 5 except that one week lagged auction rates are eliminated as independent variables. These regressions are estimates of the conditional expectations of the auction rates given the when-issued rates. The adjusted R^2 uniformly increased from those of Table 5. The Durbin-Watson statistics were either insignificant at a 95% level or inconclusive.

For 13 week bills, none of the when-issued rate changes contributed significantly to the conditional expectations given the when-issued rates at auction times. For 26 week bills, its when-issued rate at auction time was the most significant factor in predicting the auction rates. In addition, the when-issued rate changes from Friday to Monday contributed negatively and from Tuesday to Wednesday contributed positively to the expectations of auction rates for new bills.

To summarize, our data analysis suggests that the when-issued market for 13 week bills aggregates information well in that past auction rates and when-issued rate changes in the week preceding

[30] These two lagged variables, one being the level of interest rates and the other being the difference between two interest rates, were not highly correlated. Indeed, one fails to reject the hypothesis that they are uncorrelated.

the auction do not contribute to the expectation of the auction rates at auction times conditional on concurrent when-issued rates. However, for 26 week bills, the conditional expectations of the auction rates depend upon some when-issued rate changes in the preceding week, in addition to the when-issued rates at auction times.

Next we ask:

2. Do the rates in the when-issued market before the auction indicate a divergence of information/beliefs among bidders?

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 more uncertain they are about the demand for the bills, the more dispersed the bids submitted in the auction. This leads us to the hypothesis that:

> The bid-ask spread and the interest rate uncertainty 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. The theory of the term structure of interest rates suggests that the term premium may be an increasing function of interest rate volatility; see, for example, Cox, Ingersoll, and Ross (1985). Thus we use the difference between the average of bid and ask when-issued rates for 26 week bills and for 13 week bills at 1:00 pm on auction days, *i.e.*, the term premium, as the instrumental variable for interest rate risk.

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. Recall from Section 4 that around 80% of the time the lowest winning rate at an auction was lower than the when-issued ask rate at auction time. We have argued that this indicates the strategic interplay between the auction and the when-issued markets. The lowest winning rate might carry some important information. Therefore, we ran two sets of regression — one for each choice of instrumental variable for dispersion of bids.

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 with the term premium and 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 0.79 basis points. The high-average winning rate spread is also positively related to the term premium and to the 13 week when-issued bid-ask spread. The average contributions of the term premium and the when-issued bid-ask spread to the high-average winning rates spread were 0.45 basis points and 0.2 basis points respectively. To put these two numbers in perspective, recall from Table 2 that the average high-average rate spread in the auction was about 1 basis point.

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 basis point to the high-low spread of auction bids, which averaged 3.6 basis points, and about 0.28 basis points to the high-average spread, which averaged 0.9 basis points.

6 The When-Issued Market after the Auction and the Auction

Recall from our discussion in Section 2 that one of the disadvantages of buying in the when-issued market is that the when-issued rates may reveal the buyer's private information, whereas when buying in the auction private information is revealed only after the end of the auction. During the sample period, auction results were announced after 3:30 pm. Thus the window between 1:00 pm and 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 rate changes in the when-issued market between 1:00 pm and 3:30 pm on auction days reflect the "innovation" contained in 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. Consequently, we ask:

3. Are the when-issued rate changes between 1:00 pm and 3:30 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 crashes on October 19 and 26, 1987, both Mondays, 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 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.[31]

Under the hypothesis tested in Section 5, that the conditional expectation of auction rates are linear functions of the when-issued rate changes before the auction and the when-issued rates at the auction time, an estimate of the innovation contained in the auction is the estimated disturbance terms of the linear models, *i.e.,* the residuals from the regressions in Table 6. To answer Question 3, we regressed these residuals on the when-issued rate changes after the auction. The residuals are an imperfect measure of the innovation. Under the standard hypothesis that the errors in measurement 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 8 reports the regressions of the residuals from the first and the fourth regressions of Table 6, denoted RES13 and RES26, on the when-issued rate changes for 13 week and 26 week bills between 1:00 pm and 3:30 pm on the auction days. Average winning auction rates are dependent variables in these two regressions in Table 6. The results using the residuals from other regressions are similar and are not reported. 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 week 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 0.38 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 0.45 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 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 lowest-left-hand point in Figure 2 is the data point for June 20, 1988 (see Footnote 24). In the morning on this day, the longer term interest rates increased in response to an increase in the federal funds rate. The

[31] There 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 in our analysis.

when-issued rates reflected this increase. At 1:00 pm the when-issued ask rates were 6.37% for 13 week bills and 7.07% for 26 week bills. The former was a decrease of 6 basis points and the latter was an increase of 30 basis points, both from 3:30 pm on the previous Friday, an indication of dramatic steepening of the short end of the yield curve.

The average winning rate for 13 week bill auction on June 20, 1988 was 6.51%, which was on average 14 basis point higher than the when-issued ask rate for these bills at 1:00 pm. For 26 week bills, the average winning rate on June 20, 1988 was 6.83%, 24 basis points lower than the when-issued ask rate at 1:00 pm. For 13 week bills, most bidders bid interest rates higher than the concurrent when-issued market ask rate, while for 26 week bills at least some bidders bid interest rates much lower than the concurrent when-issued ask rate. Clearly, some of the bidders believed that the short end of the yield curve would flatten out and acted accordingly at the auction. They did not buy a large quantity of the 26 week when-issued before the auction even though they thought these contracts were underpriced. The when-issued ask rates at 3:30 pm were 6.5% for 13 week bills, an increase of 13 basis points from 1:00 pm, and 6.82% for 26 week bills, a decrease of 25 basis points from 1:00 pm. These changes were consistent with the innovations in the auction.

The evidence presented in Table 8 and in Figures 1 and 2 supports the hypothesis that bidders play 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 approximately 80% of the auctions in our sample the lowest winning rate was lower than the when-issued ask rate at the auction time. This may be further evidence of strategic behavior. If this is true then one expects 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 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 ask:

4. Is the innovation in the auction negatively related to DUM13 and DUM26?

5. Are the when-issued rate changes between 1:00 pm and 3:30 pm on auction days negatively related to DUM13 and DUM26?

To answer Question 4, we regressed the residuals from the first and the fourth regressions in Table 6, RES13 and RES26, on DUM13 and DUM26. If our intuition is correct, we should find the regression coefficient of DUMnn to be statistically significant and negative when RESnn is the dependent variable, for nn = 13 or 26. Table 9 reports the results of these two regressions.

For 13 week bills, the R^2 was 0.33. The coefficient of DUM13 was -0.03 and significant at a 99% level. The coefficient of DUM26 was small, -0.0085, and significant at a 90% level. The average contribution of DUM13 to the innovation in the auction for 13 week bills was -3 basis points. For 26 week bills, the R^2 was 16% and the coefficient of DUM26 was -0.0302 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 basis points. This affirms of our null hypothesis that the dummy variables and the innovation in the auction are negatively related.

To answer Question 5, we regressed the when-issued rate changes for 13 week bills and for 26 week bills on the dummy variables DUM13 and DUM26. The results reported in Table 10 provide further evidence that there is an information cost to trading in the when-issued market. Moreover, it seems that bidders have access to information specific either to 13 week bills or to 26 week bills. To see this, note that for 13 week bills the coefficient of DUM13 was -0.033 and significant at a 99% level whereas the coefficient of DUM26 was not significant at a 95% level. DUM13 contributed -3 basis points on average to the when-issued rate change after the auction. The information in DUM13 appears to be specific to 13 week bills even though the when-issued rate changes after the auction and before 3:30 pm for 13 week bills and 26 week bills are significantly correlated, with a correlation coefficient of 0.433 (see Table 3). The results for 26 week bills are similar.

7 Do Bidders Collude?

It has been alleged that collusion and price-fixing are widespread in the Treasury securities market.[32] If bidders collude and agree to submit similar discount rates, at least at the lower end of the spectrum of submitted discount rates, then we expect a small dispersion of winning bids. 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 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 then their expected profits increase as the

[32] See, for example, "Hidden bonds: Collusion, price-fixing have long been rife in Treasury market" in *The Wall Street Journal* on August 19, 1991.

divergence of information among them increases (see Reece (1978)). As pointed out in Section 5, 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 collusion, whereas a negative effect would be a reason to suspect collusion.

Bidders' expected profits are difficult to measure. We use the difference between the when-issued rate at 3:30 pm on auction days and the weighted average winning rate in the autions as an instrumental variable for bidders' expected profit. That is, the lower the when-issued rate at 3:30 pm on auction days compared to the average winning rate in the auction, the greater the bidders' profits. Two possible instrumental variables for dispersion of winning bids in the auction 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. Our null hypothesis is that there is no collusion. Therefore, we ask:

6. Is the difference between the when-issued rate at 3:30 pm on auction days and the weighted average of winning rates in the auctions negatively related to the difference between highest and average winning rates?

We know from Section 6 that the when-issued rate can change between 1:00 pm and 3:30 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 3:30 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 the difference between the when-issued rates at 3:30 pm and the weighted average of the winning rates in the auctions on the the difference between highest and average winning rates and on DUM13 and DUM26. The results are reported in Table 11.

For 13 week bills, the coefficients of the dispersions in bids are negative and not significant and, as expected from our earlier data analysis, the coefficient of DUM13 was negative and significant. We fail to reject the hypothesis that there was no collusion in the auctions of 13 week bills in the sample period. The results for 26 week bills are similar.

8 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.

It would be interesting to investigate the relation between the auction, the when-issued market, and the repo rates for newly auctioned 13 and 26 week bills. The difference between the repo rates on the newly auctioned bills and the repo rates collateralized by generic seasoned bills should be related to the innovation in the auction. When a short squeeze occurs, the winning auction rates are lower than expected. Bidders who sell short in the when-issued market because they believe that the interest rates will go up are surprised. Thus, we expect the innovation in the auction and the above mentioned repo rate difference to be positively related. In addition, this repo rate difference should also be negatively related to the dummy variables, DUM13 and DUM26, defined in Section 6. Unfortunately, we are unable to test this hypothesis because we have been unsuccessful in obtaining repo rate data using the newly auctioned bills as collateral.

Strategic interplay between the when-issued market and the auction may be even more pronounced in the market for Treasury notes and bond because the longer the maturity of a bond the more sensitive its value to a small change in interest rates. Although a similar study for Treasury notes and bonds may be worthwhile, the when-issued data are much more difficult to gather. As in the case of Treasury bills, the when-issued prices at auction time have to be collected in real time. Unlike for Treasury bills, the when-issued prices at 3:30 pm for notes and bonds are not available from DRI. A possible source of this data may be the four brokers, the so-called brokers' brokers, who maintain the government securities market for primary dealers.

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10 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.
ALnn:	The proportion of bids accepted at the highest winning rate prorata for nn week bills.
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.
ARnn_L	One week lagged ARnn, nn=13 or 26.
LRnn_L	One week lagged LRnn, nn=13 or 26.
HRnn_L	One week lagged HRnn, nn=13 or 26.
TERMPREM:	The "term premium" between the 26 week when-issued and 26 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.
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.

Table 1: List of Variables — Continued

Mnn:	The average of the bid and ask rates for nn week bills, nn=13 or 26, quoted on the when-issued market at 3:30 pm on Monday, (usually) the day of the auction.
Fnn:	The average of the bid and ask rates for nn week bills, nn=13 or 26, quoted on the when-issued market at 3:30 pm on Friday in the week before the auction.
THnn:	The average of the bid and ask rates for nn week bills, nn=13 or 26, quoted on the when-issued market at 3:30 pm on Thursday in the week before the auction.
Wnn:	The average of the bid and ask rates for nn week bills, nn=13 or 26, quoted on the when-issued market at 3:30 pm on Wednesday in the week before the auction.
Tnn:	The average of the bid and ask rates for nn week bills, nn=13 or 26, quoted on the when-issued market at 3:30 pm on Tuesday in the week before 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 3:30 pm on auction days, *i.e.*, Mnn-BAnn.

Table 2: Sample Statistics†

	BID13	ASK13	SPRD13	AR13
Sample Size	130	130	130	130
Max	8.04	8.03	0.06	8.05
Min	5.06	5.00	0.00	5.08
Mean	5.97	5.96	0.0109	5.98
Std. Err.	0.60	0.60	0.007	0.61
No. Positive	130	130	121	130
	HR13–AR13	HR13–LR13	ASK13–LR13	ASK13–AR13
Sample Size	130	130	130	130
Max	0.06	0.18	0.085	0.05
Min	0.00	0.00	−0.11	−0.14
Mean	0.0097	0.04	0.015	−0.019
Std. Err.	0.011	0.031	0.033	0.033
No. Positive	85	128	104	16
	ASK13–HR13	BID13–LR13	BID13–AR13	BID13–HR13
Sample Size	130	130	130	130
Max	0.05	0.09	0.06	0.06
Min	−0.15	−0.1	−0.13	−0.14
Mean	−0.029	0.026	−0.008	−0.018
Std. Err.	0.038	0.033	0.032	0.036
No. Positive	12	114	49	27
	BA13–F13	F13–Th13	Th13–W13	W13–T13
Sample Size	122	132	139	143
Max	0.655	0.42	0.21	0.42
Min	−0.26	−0.23	−0.19	−0.95
Mean	0.02	0.007	−0.002	−0.028
Std. Err.	0.096	0.079	0.063	0.157
No. Positive	72	63	62	67
	AL13	CHG13		
Sample Size	130	118		
Max	0.98	0.145		
Min	0.01	−0.355		
Mean	0.47	0.001		
Std. Err.	27.449	0.059		
No. Positive	130	53		

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

Table 2: Sample Statistics — Continued

	BID26	ASK26	SPRD26	AR26
Sample Size	130	130	130	130
Max	8.135	8.125	0.08	8.13
Min	5.14	5.135	0.00	5.13
Mean	6.16	6.15	0.012	6.16
Std. Err.	0.64	0.64	0.0098	0.64
No. Positive	130	130	120	130
	HR26–AR26	HR26–LR26	ASK26–LR26	ASK26–AR26
Sample Size	130	130	130	130
Max	0.04	0.15	0.28	0.24
Min	0.00	0.00	−0.097	−0.12
Mean	0.0087	0.036	0.016	−0.011
Std. Err.	0.008	0.025	0.038	0.037
No. Positive	99	128	101	32
	ASK26–HR26	BID26–LR26	BID26–AR26	BID26–HR26
Sample Size	130	130	130	130
Max	0.23	0.28	0.24	0.23
Min	−0.14	−0.087	−0.107	−0.107
Mean	−0.02	0.028	0.001	−0.008
Std. Err.	0.038	0.038	0.035	0.036
No. Positive	22	116	62	36
	BA26–F26	F26–Th26	Th26–W26	W26–T26
Sample Size	122	132	139	143
Max	0.31	0.33	0.51	0.28
Min	−0.39	−0.56	−0.40	−0.34
Mean	0.011	0.008	−0.002	0.001
Std. Err.	0.083	0.096	0.088	0.09
No. Positive	69	62	56	77
	AL26	CHG26		TERMPREM
Sample Size	130	118		130
Max	0.99	0.125		0.85
Min	0.02	−0.255		−0.06
Mean	0.497	−0.001		0.188
Std. Err.	0.282	0.0505		0.182
No. Positive	130	53		116

Table 3: Sample Correlation Coefficients[†]

	BID13	AR13	HR13–LR13	AL13	SPRD13	TERMPREM	CHG13
BID13	1.000 NA	0.998*** (11.37)	−0.0512 (−0.58)	−0.061 (−0.70)	−0.033 (−0.376)	0.0014 (0.016)	−0.006 (−0.068)
AR13		1.000 NA	0.069 (0.787)	−0.064 (−0.73)	−0.026 (−0.296)	0.027 (0.308)	0.009 (0.101)
HR13–LR13			1.000 NA	−0.262*** (−2.987)	0.326*** (3.717)	0.445*** (5.07)	−0.219** (−2.478)
AL13				1.000 NA	−0.153 (−1.74)	−0.092 (−1.049)	−0.062 (−0.70)
SPRD13					1.000 NA	0.329*** (3.75)	−0.103 (−1.165)
TERMPREM						1.000 NA	0.087 (0.984)
CHG13							1.000 NA
BID26	0.955*** (10.80)	0.962*** (10.97)	0.180** (2.05)	−0.085 (−0.969)	0.063 (0.718)	0.295*** (3.36)	0.02 (0.226)
AR26	0.953*** (10.87)	0.960*** (10.95)	0.194** (2.21)	−0.09 (−1.03)	0.075 (0.855)	0.296*** (3.375)	0.015 (0.17)
HR26–LR26	−0.022 (−0.25)	−0.006 (−0.0684)	0.662*** (7.55)	−0.182** (−2.075)	0.33*** (3.76)	0.464*** (5.29)	0.206** (2.33)
AL26	−0.03 (−0.342)	−0.023 (−0.26)	0.032 (0.365)	−0.07 (−0.798)	0.16 (1.82)	0.06 (0.68)	0.122 (1.38)
SPRD26	−0.026 (−0.296)	−0.025 (−0.285)	0.188** (2.14)	−0.077 (−0.878)	0.381*** (4.34)	0.304*** (3.47)	−0.093 (−1.052)
CHG26	−0.109 (−1.233)	−0.112 (−1.267)	−0.04 (−0.453)	0.044 (0.498)	0.066 (0.747)	−0.117 (−1.323)	0.433*** (5.01)

[†] The sample size for the calculation of these estimates of correlation coefficients is 130, except for those involving CHG13 and CHG26 which have a sample size of 118 (see Footnote 17). The numbers in the 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 3: Sample Correlation Coefficients — Continued

	BID26	AR26	HR26–LR26	AL26	SPRD26	CHG26
BID26	1 NA	0.998*** (11.38)	0.12 (1.36)	−0.010 (−0.11)	0.071 (0.81)	−0.138 (−1.50)
AR26		1 NA	0.13 (1.48)	−0.012 (−0.14)	0.073 (0.83)	−0.103 (−1.12)
HR26–LR26			1 NA	−0.067 (−0.76)	0.249*** (2.84)	−0.049 (−0.53)
AL26				1 NA	0.12 (1.37)	0.01 (0.11)
SPRD26					1 NA	0.1 (1.09)
CHG26						1 NA

Table 4: Correlation Coefficients on When-Issued Rate Changes†

	CHG13	BA13-F13	F13-Th13	Th13-W13	W13-T13
CHG13	1 NA	−0.39*** (4.09)	0.34*** (3.48)	0.11 (1.16)	0.33*** (3.55)
BA13-F13		1.00 NA	−0.055 (−0.595)	−0.013 (−0.14)	−0.086 (−0.922)
F13-Th13			1.00 NA	0.185** (2.117)	0.268*** (3.055)
Th13-W13				1.00 NA	0.07 (0.822)
W13-T13					1.00 NA
	CHG26	**BA26-F26**	**F26-Th26**	**Th26-W26**	**W26-T26**
CHG26	1 NA	−0.08 (−0.84)	−0.09 (−0.92)	−0.09 (−0.95)	0.03 (0.32)
BA26-F26		1.00 NA	0.049 (0.53)	0.195** (2.10)	−0.074 (−0.811)
F26-Th26			1.00 NA	−0.311*** (−3.56)	−0.018 (−0.205)
Th26-W26				1.00 NA	0.041 (0.482)
W26-T26					1.00 NA

Table 4: Correlation Coefficients on When-Issued Rate Changes — Continued†

	CHG26	BA26-F26	F26-Th26	Th26-W26	W26-T26
CHG13	0.48***	0.46***	0.05	0.07	−0.10
	(5.21)	(4.82)	(0.51)	(0.72)	(−1.12)
BA13-F13	−0.26***	0.123	−0.102	0.178*	0.228**
	(−2.73)	(1.33)	(1.103)	(1.91)	(2.45)
F13-Th13	0.03	0.356***	0.629***	0.191**	−0.262***
	(0.31)	(3.85)	(7.227)	(2.186)	(−2.987)
Th13-W13	0.001	0.09	0.167*	0.525***	0.000
	(0.01)	(0.969)	(1.91)	(6.19)	(0)
W13-T13	0.092	0.364***	0.056	0.096	0.257***
	(0.99)	(3.987)	(0.638)	(1.128)	(3.07)

† The samples size used to calculate these correlation coefficients were:

	CHG13	BA13-F13	F13-Th13	Th13-W13	W13-T13	CHG26	BA26-F26	F26-Th26	Th26-W26	W26-T26
CHG13	118	110	105	112	116	118	110	105	112	116
BA13-F13		122	117	116	115	110	117	117	116	115
F13-Th13			132	131	130	105	117	132	131	130
Th13-W13				139	138	112	116	131	139	138
W13-T13					143	116	120	130	138	143
CHG28						118	110	105	112	116
BA26-F26							122	117	118	120
F26-Th26								132	131	130
Th26-W26									139	138
W26-T26										143

Table 5: Regression of Auction Rates on When-Issued Rate, When-Issued Rate Changes, and Lagged Auction Rates: Sample Size = 107

Independent Variables	Dependent Variables			Independent Variables	Dependent Variables		
	AR13	HR13	LR13		AR26	HR26	LR26
Constant	−0.0325	−0.034	−0.073***	Constant	0.033	0.048*	0.021
	(−1.37)	(−1.28)	(−2.969)		(1.21)	(1.798)	(0.794)
BA13	0.8383***	0.799***	0.879***	BA13	0.0012	−0.026	0.039
	(20.867)	(18.395)	(20.071)		(0.02)	(−0.45)	(0.689)
BA13-F13	0.195	0.084*	−0.0899*	M13-F13	0.043	0.084	−0.045
	(0.41)	(1.769)	(−1.65)		(0.699)	(1.43)	(−0.702)
F13-Th13	0.0235	0.037	0.0072	F13-Th13	0.153*	0.165*	0.125
	(0.367)	(0.535)	(0.104)		(1.69)	(1.85)	(1.37)
Th13-W13	0.0352	0.028	0.041	Th13-W13	0.075	0.102	0.046
	(0.538)	(0.39)	(0.062)		(0.727)	(1.35)	(0.645)
W13-T13	0.044**	0.052**	0.036*	W13-T13	0.015	0.022	0.01
	(2.48)	(2.476)	(1.863)		(0.727)	(1.35)	(0.439)
BA26	0.144***	0.18***	0.173**	BA26	0.948***	0.961***	1.009***
	(2.569)	(2.887)	(2.627)		(12.398)	(12.171)	(13.014)
BA26-F26	−0.0268	−0.052	−0.037	M26-F26	−0.2**	−0.216**	−0.253**
	(−0.494)	(−0.942)	(−0.566)		(−2.057)	(−2.248)	(−2.557)
F26-Th26	−0.025	−0.019	−0.091	F26-Th26	−0.104	−0.102	−0.188**
	(−0.389)	(−0.282)	(−1.32)		(−1.14)	(−1.1)	(−2.15)
Th26-W26	0.042	0.052	−0.072	Th26-W26	−0.019	−0.006	−0.186**
	(0.608)	(0.708)	(−0.91)		(−0.211)	(−0.0676)	(−2.13)
W26-T26	0.0022	0.016	−0.021	W26-T26	0.11**	0.094*	0.098***
	(0.612)	(0.441)	(−0.515)		(2.245)	(1.905)	(2.265)
$AR13_L$	0.023	—	—	$AR26_L$	0.046	—	—
	(0.917)	—	—		(1.047)	—	—
$HR13_L$	—	0.026	—	$HR26_L$	—	0.059	—
	—	(0.927)	—		—	(1.42)	—
$LR13_L$	—	—	−0.044	$LR26_L$	—	—	−0.055
	—	—	(−1.16)		—	—	(−1.470)
$AR26_L$−$AR13_L$	−0.054	—	—	$AR26_L$−$AR13_L$	0.03	—	—
	(−1.063)	—	—		(0.627)	—	—
$HR26_L$−$HR13_L$	—	−0.069	—	$HR26_L$−$HR13_L$	—	0.015	—
	—	(−1.171)	—		—	(0.299)	—
$LR26_L$−$LR13_L$	—	—	−0.135**	$LR26_L$−$LR13_L$	—	—	0.041
	—	—	(−2.152)		—	—	(0.83)
Adjusted R^2	0.9977	0.9974	0.9973		0.9968	0.9969	0.9966
Durbin-Watson	1.83	1.80	1.61		1.92	1.98	1.83

Table 6: Regression of Auction Rates on When-Issued Rate, and When-Issued Rate Changes: Sample Size = 115

Independent Variables	Dependent Variables			Dependent Variables		
	AR13	HR13	LR13	AR26	HR26	LR26
Constant	−0.026 (−1.31)	−0.031 (−1.41)	−0.065*** (−2.82)	0.047* (1.89)	0.065** (2.54)	0.019 (0.85)
BA13	0.899*** (57.797)	0.874*** (46.93)	0.96*** (48.1)	−0.035 (−1.38)	−0.054** (−2.01)	0.012 (0.58)
BA13-F13	−0.033 (-0.78)	0.021 (0.46)	−0.13** (−2.53)	0.046 (0.73)	0.073 (1.2)	0.002 (0.028)
F13-Th13	−0.052 (−0.87)	−0.059 (−0.9)	−0.027 (−0.35)	0.135 (1.22)	0.128 (1.17)	0.176* (1.73)
Th13-W13	−0.04 (−0.66)	−0.055 (−0.88)	−0.034 (−0.535)	0.088 (1.03)	0.105 (1.19)	0.087 (1.05)
W13-T13	0.023 (1.12)	0.026 (1.17)	0.007 (0.33)	0.021 (1.07)	0.025 (1.30)	0.02 (0.78)
BA26	0.105*** (6.81)	0.131*** (7.35)	0.047** (2.39)	1.029*** (41.21)	1.044*** (40.88)	0.983*** (48.54)
BA26-F26	−0.015 (−0.3)	−0.037 (−0.72)	0.048 (0.81)	−0.24** (−2.4)	−0.257*** (−2.65)	−0.214** (−2.19)
F26-Th26	0.025 (0.422)	0.035 (0.585)	0.016 (0.247)	−0.15 (−1.479)	−0.15 (−1.45)	−0.17* (−1.79)
Th26-W26	0.082 (1.41)	0.094 (1.58)	0.05 (0.80)	−0.082 (−0.86)	−0.076 (−0.79)	−0.147* (−1.65)
W26-T26	0.037 (1.34)	0.037 (1.25)	0.033 (1.15)	0.073** (2.04)	0.057 (1.62)	0.107*** (2.74)
Adjusted R^2	0.9980	0.9977	0.9974	0.9971	0.9972	0.9969
Durbin-Watson	1.64	1.54	1.55	1.96	2.00	1.79

Table 7: Regression of dispersion in auction rates on dispersion in when-issued rates

Independent Variables	Dependent Variables		Dependent Variables	
	HR13-LR13	HR13-AR13	HR26-LR26	HR26-AR26
Constant	0.023***	0.0037**	0.018***	0.007***
	(5.28)	(2.61)	(4.06)	(5.29)
TERMPREM	0.069***	0.024**	0.054***	0.015***
	(2.96)	(2.28)	(3.71)	(3.46)
SPRD13	0.79***	0.20**	0.52	−0.021
	(4.27)	(2.28)	(1.38)	(−0.23)
SPRD26	−0.049	−0.047	0.19	−0.047
	(−0.15)	(−0.44)	(0.62)	(−0.59)
Sample Size	130	130	130	130
Adjusted R^2	0.22	0.19	0.23	0.08
Durbin-Watson	1.36**	1.37**	1.76	1.95

Table 8: Regression of Residuals from the First and the Fourth Regressions of Table 6 on CHG13 and CHG26†

Independent Variables	Dependent Variables: Innovation from the Prediction of AR13, RES13	Dependent Variables: Innovation from the Prediction of AR26, RES26
Constant	−0.0018	0.001
	(−0.47)	(0.39)
CHG13	0.378***	−0.123
	(3.01)	(−1.45)
CHG26	−0.026	0.453***
	(−0.59)	(6.315)
Sample Size	101	101
Adjusted R^2	0.35	0.39
Durbin-Watson	1.51**	1.90

† RES13 and RES26 are the residuals from the first and the fourth regressions of Table 6. They represent the innovation from the prediction of AR13 and AR26 respectively.

Table 9: Regression of Residuals from the First and the Fourth Regressions of Table 6 on DUM13 and DUM26

Independent Variables	Dependent Variables: Innovation from the Prediction of AR13, RES13	Dependent Variables: Innovation from the Prediction of AR26, RES26
Constant	0.033***	0.0199**
	(5.56)	(2.21)
DUM13	−0.03***	0.0041
	(−6.084)	(0.41)
DUM26	−0.0085*	−0.0302***
	(−1.80)	(−4.558)
Sample Size	113	113
Adjusted R^2	0.33	0.16
Durbin-Watson	1.71	2.03

Table 10: Regression of When-Issued Rate changes on DUM13 and DUM26

Independent Variables	Dependent Variables: CHG13	Dependent Variables: CHG26
Constant	0.04***	0.01
	(3.33)	(0.95)
DUM13	−0.033***	0.016
	(−3.16)	(1.23)
DUM26	−0.01*	−0.032***
	(−1.60)	(−3.39)
Sample Size	116	116
Adjusted R^2	0.09	0.07
Durbin-Watson	2.31	2.04

Table 11: Collusion

Independent Variables	Dependent Variables	
	M13-AR13	M26-AR26
Constant	0.037	0.022
	(1.86*)	(1.46)
HR13-AR13	−0.368	−0.46
	(−0.35)	(−0.6)
HR26-AR26	−0.764	−0.45
	(−0.898)	(−0.695)
DUM13	−0.027**	0.015
	(−2.05)	(1.56)
DUM26	−0.0095	−0.035**
	(−0.9)	(−2.46)
Sample Size	118	118
Adjusted R^2	0.0396	0.0765
Durbin-Watson	1.88	2.08**

Figure 1: Innovation for 13 Week Auction Versus the WI Rate Changes for 13 Week Bills after the Auction

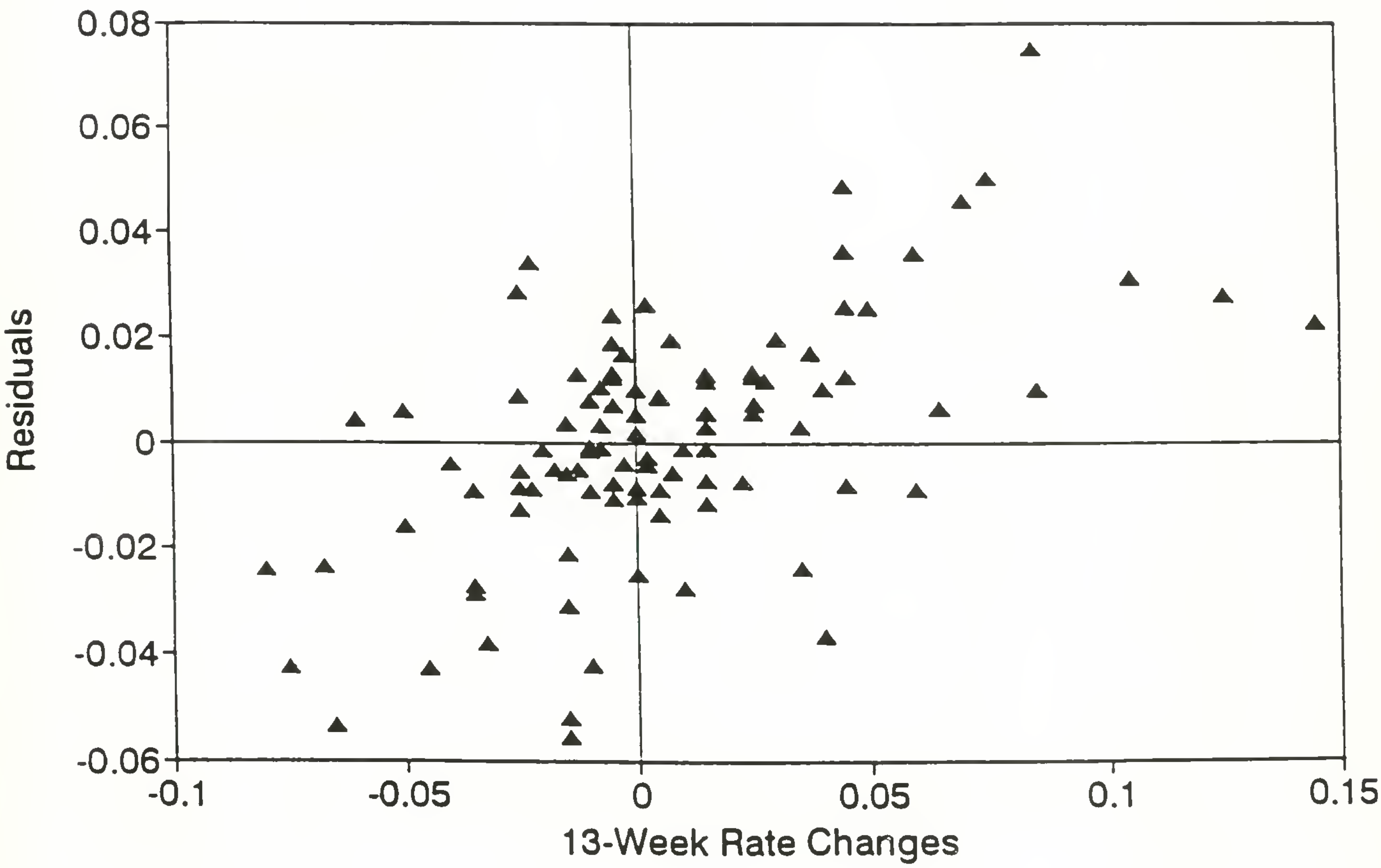
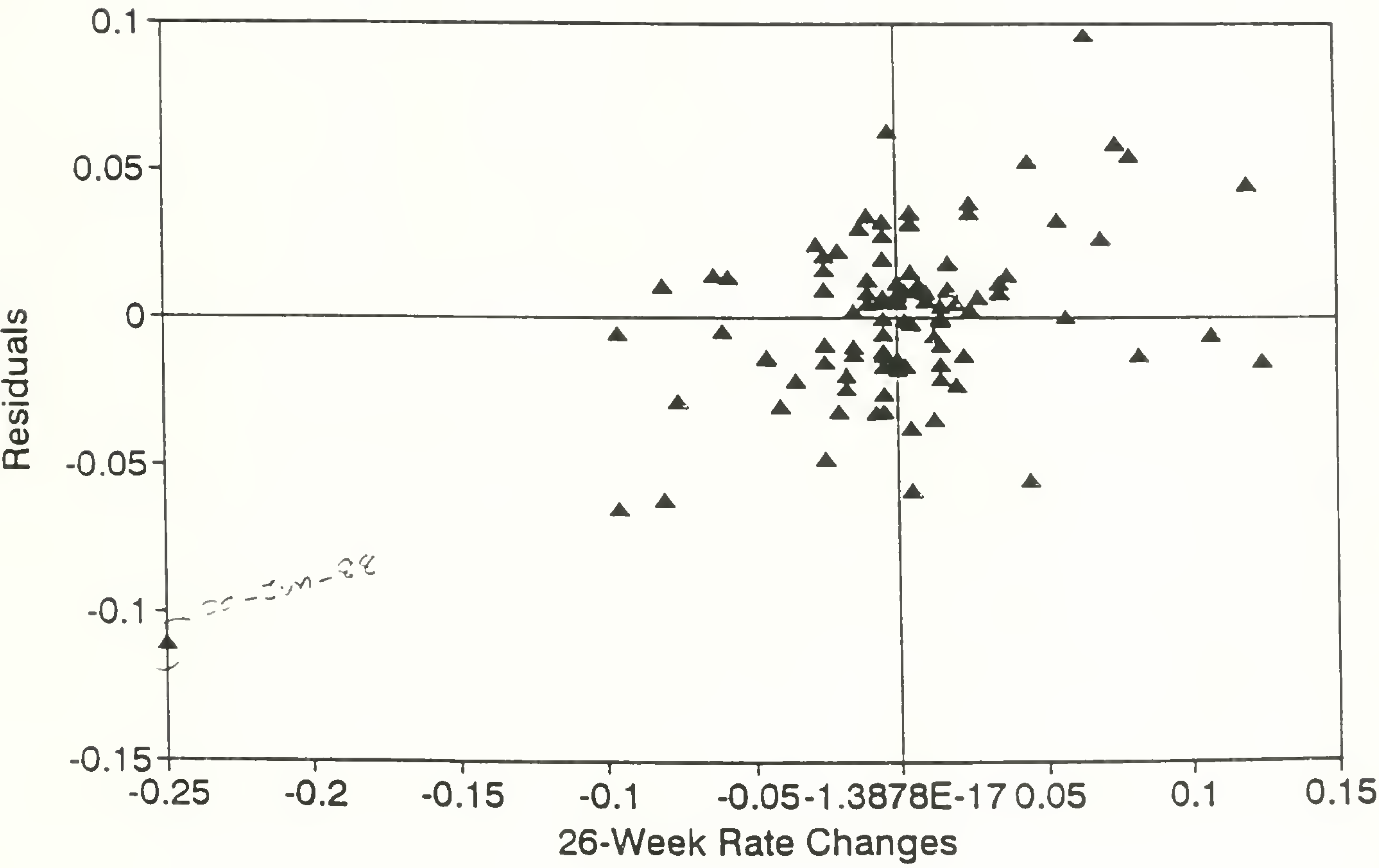


Figure 2: Innovation for 26 Week Auction Versus the WI Rate Changes for 26 Week Bills after the Auction



Date Due
