Uniform-Price Auctions:
Evaluation of the Treasury Experience

by

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Executive Summary

The Treasury's purpose in conducting uniform-price auctions is to determine whether the uniform-price auction technique reduces the Treasury's financing costs compared with multiple-price auctions, by encouraging more aggressive bidding by participants, and whether it broadens participation and reduces concentration of securities on original issue. Thus, the evaluation has focused on the impact on revenues and the breadth of initial distribution of awards.

In addition to auction technique, a constellation of other factors also affects auction results, such as the economic outlook, expectations for movements in absolute or relative interest rates, and any other factors affecting the portfolio decisions of dealers and investors. For example, the Treasury auction process has undergone regulatory and other changes that may also have had an impact on bidding strategies and trading practices of market participants. The confluence of these and other factors produces significant auction-to-auction volatility in the data, making it difficult to isolate the impact of auction technique itself.

Our methodology was to compare auction results and WI market trading patterns for the 2-year and 5-year notes under the uniform-price and multiple-price techniques. We then examined whether any differences in performance are consistent with the purpose of conducting uniform-price auctions and whether the differences are consistent with the predictions of auction theory.

Impacts on the Distribution of Awards

Some economists contend that uniform-price auctions will encourage more bidders to participate in competitive bidding than do multiple-price auctions by reducing the importance of specialized knowledge regarding market demand and the information costs associated with its collection. A corollary to increased participation is a reduction in the concentration of awards.

We found no significant change in awards to the primary dealer community as a whole, but we found statistically significant evidence that the concentration of awards to the top primary dealers for their own accounts has been reduced. The average share of awards of 2-year notes to the top five and top ten dealers declined, with the reductions ranging from about 5 percent to 15 percent. By contrast, the shares to the top dealers in 3-year and 10-year note multiple-price auctions either remained essentially the same or increased significantly.

The shares of awards to dealers plus their large customers displayed essentially the same pattern as awards for dealers' own accounts. Also, awards for large customers alone increased, from about 17 percent to 25 percent for both the 2-year and 5-year notes, suggesting greater participation by large customers in auctions under the uniform-price technique. Meanwhile, the shares of awards to customers for 3-year and 10-year notes did not change significantly.

The reduced concentrations of awards to the top dealers may be attributed to two interrelated factors. The first is a widening in the overall distribution of auction bids, as one might expect from auction theory. Under multiple-price auctions, there is a relatively tight distribution of large bids around the auction average because successful bidders pay the price actually bid. Under uniform-price auctions, however, the distribution of bids is much broader because there is no penalty for submitting bids well ahead of the market to

ensure supply, unless such aggressive bids in the aggregate match or exceed the auctioned amount.

The second factor is that the evidence suggests large dealers have changed bidding strategies, in response to expected wider bid distributions, by splitting bids into more numerous smaller bids -- some ahead of the market, some at the market, and some trailing off the market.

The combined effect of the broader distribution of bids and the greater incidence of bid splitting is that the bids of the larger, usually more aggressive dealers are increasingly interspersed with the more aggressive bids of other market participants (particularly large customers) who are trying to ensure supply in an auction. The net result is that at the margin the share of awards to the top groups of primary dealers has decreased.

Impact on revenues

The impact of the uniform-price auction technique on revenues is more difficult to analyze because there is a vast array of factors that affect bidding at Treasury auctions. Nevertheless, we have directly tested for any differences in expected revenue from the two techniques, and have examined the empirical results of other researchers with respect to our own findings.

The most direct way to determine the impact on expected revenue of auction technique would be to compare average auction yields under the two techniques, and determine if there is a statistically significant difference.

Our results show that the average spreads of auction yields to WI yields for uniform-price auctions are smaller than those for multiple-price auctions, but the difference is not statistically significant. On this basis, we are unable to conclude that there is a difference in expected revenue.

However, by examining the average auction spreads separately and testing whether each spread is statistically distinguishable from zero, we did obtain statistically significant results. The data show that the average yield spread is different from zero in multiple-price auctions, whereas there is no similar evidence for the uniform-price technique. On this basis, expected revenue under the uniform-price technique is marginally greater than under the multiple-price technique.

The primary reason for the lack of a statistically significant difference between auction yields and WI yields under the uniform-price auction technique is greater auction-to-auction volatility of the results with respect to the WI market. The greater volatility is partly a result of the broader and more volatile distributions of bids, and partly a result of the difference in the yield measure used to report auction results under the two techniques. In multiple-price auctions, an average yield concept is used, while in uniform-price auctions, the reported yield is not an average, but a marginal or stop-out yield. An average of a relatively stable set of numbers is inherently less volatile than the endpoint of another set of numbers that exhibits more variability. Thus, uniform-price auctions may produce greater revenue on average, but present greater uncertainty regarding revenue at any given auction.

Uniform-price Auctions:
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Introduction

One of the recommendations of the Joint Report on the Government Securities Market[1] was that the Treasury consider alternatives to the sealed-bid auction technique for auctioning Treasury securities. After an extensive review of the issues, the Treasury announced on September 3, 1992, that it would conduct a uniform-price auction experiment for all auctions of 2-year and 5-year notes.

The uniform-price technique differs in only one important way from the multiple-price auction technique that the Treasury has been using to issue notes and bonds since the 1970s. In the traditional format, competitive bids state the amount and yield desired and are ranked from the lowest to the highest yield. Awards are made at successively higher yields until the amount allotted for competitive tenders is fulfilled, with awards at the highest yield prorated. The process for the uniform-price auctions is identical except that, instead of awards being made at the individual yields stipulated by the bidders, all accepted bids are filled at the highest yield of accepted competitive tenders.

The purpose of using uniform-price auctions for the 2-year and 5-year notes is to determine whether the alternative auction technique results in reducing the Government's financing costs by encouraging more aggressive bidding by participants, and whether it results in broader participation and reduced concentration of securities on original issue.

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[1] Joint Report on the Government Securities Market. Washington, D.C., Government Printing Office, 1992.

The remainder of this paper is divided into five parts: an overview of the Treasury auction process; a summary of the results of auction theory, particularly as they apply to the Treasury market; a review of the empirical work related to the auctioning of Treasury securities; an analysis of the results of the uniform-price auctions thus far; and a summary and conclusions.

I. Treasury Auction Process

Total Treasury debt amounted to $4.9 trillion on October 1, 1995, including $3.3 trillion of marketable securities held by private investors.[2] The Treasury has auctioned large amounts of marketable Treasury securities in the past ten years. In fiscal year 1985, the Treasury sold less than $1.2 trillion of marketable Treasury securities. By fiscal year 1995, this figure had increased to over $2.2 trillion.

Marketable Treasury securities

The Treasury issues three types of marketable securities -- bills, notes, and bonds. They are commonly known as marketable securities because they can be bought and sold in the secondary market at prevailing prices through financial institutions, brokers, and dealers in government securities.

Treasury bills are short-term securities, with original-issue maturities of 13, 26, or 52 weeks. The 13- and 26-week bills are auctioned weekly, while 52-week bills are

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[2] The rest of the public debt is comprised of nonmarketable Treasury securities (including those issued directly to federal trust funds), United States savings bonds, state and local government series securities, and marketable securities held by federal government accounts and the Federal Reserve System.

auctioned every four weeks. Bills are issued at a discount from face value (par amount) and are redeemed at their face value at maturity.

Treasury notes have fixed maturities of more than 1 year and not more than 10 years. They are issued with a stated rate of interest, earn interest semiannually, and are redeemed at par at maturity. The Treasury currently offers notes with original-issue maturities of 2, 3, 5, and 10 years. The 2- and 5-year notes are issued once a month, and 3- and 10-year notes are issued once a quarter.

Treasury bonds are long-term securities with fixed maturities of more than 10 years. As with notes, bonds are issued with a stated rate of interest, earn interest semiannually, and are redeemed at par at maturity. Until May 1993, 30-year bonds were offered once a quarter along with the 3-year and 10-year notes. Since then, the Treasury has sold bonds in two offerings each year, in mid February and mid August.

Evolution of Treasury financing techniques

The Treasury has employed multiple-price auctions for Treasury bills since they were introduced in 1929. Since then, the only major modifications to bill auctions have been a provision for noncompetitive bids in 1947 and a change in 1983 to receiving bids on the basis of yield (bank discount basis) rather than price.

Prior to the early 1970s, the traditional methods for selling notes and bonds were subscription offerings, exchange offerings, and advance refundings. Subscriptions involved the Treasury setting an interest rate on the securities to be sold and then selling them at a fixed price. In exchange offerings, the Treasury would allow holders of outstanding maturing securities to exchange them for new issues at an announced price and interest rate (coupon rate). In some cases, new securities were issued only to holders of the specific maturing securities; in others, additional amounts of the new security would be issued. Advance refundings differed from exchange offerings in that the outstanding

securities could be exchanged before their maturity date. A fundamental difficulty with subscription offerings was that market yields could change between the announcement of the offering and the deadline for subscriptions. Increased market volatility in the 1970s made fixed-price subscription offerings very risky for the Treasury.

A multiple-price auction technique for notes and bonds had been introduced in 1970, in which the interest rate was still preset by the Treasury, and bids were made on the basis of price. Setting the coupon rate in advance, however, still involved forecasting interest rates, with the risk that the auction price could vary significantly from the par value of the securities. In 1974, the Treasury started to conduct multiple-price auctions for coupon issues on a yield basis. Bids were accepted on the basis of an annual percentage yield, with the coupon rate based on the weighted average yield of accepted competitive tenders received in the auction. Yield auctions freed Treasury from having to set the coupon rate prior to the auction and ensured that the interest costs of new note and bond issues would accurately reflect actual market demand and supply conditions at the time of the auction.

A uniform-price auction technique was used in six auctions of long-term bonds in Treasury mid-quarter refundings between February 1973 and May 1974. The coupon rate was preset by the Treasury and bids were accepted in terms of price, starting with the highest price and moving through successively lower prices until the offering had been fully placed. All successful bidders were awarded securities at the lowest price of accepted bids. The results of this experiment were inconclusive and will be addressed later.

Current auction techniques

Today, all Treasury marketable securities are sold in auctions and all Treasury auctions are conducted on a yield basis. The Treasury has a regular, predictable schedule for offering marketable securities, which is well known to market participants. The details are usually announced about one week prior to an auction, and the settlement date occurs from a few days to about one week after an auction, depending upon holidays and other vagaries of the calendar.

The Treasury sells the entire announced amount of each security offered at the yield or yields determined in the auction. It does not set a maximum acceptable yield (minimum price), nor does the Treasury add to or reduce the announced size of an offering after the offering is announced.[3]

The Treasury accepts competitive and noncompetitive bids at auctions. Noncompetitive bids are accepted from the public for up to $1 million of Treasury bills and up to $5 million of notes and bonds. All noncompetitive bids are awarded in full at the auction yield determined by the competitive bidders. The ability to bid on a noncompetitive basis ensures that small investors, who may not have current market information, can purchase securities at a current market yield. Noncompetitive bidding eliminates the risk that a prospective investor might bid a yield that is too high and not obtain the securities desired or might bid a yield that is too low and potentially pay too much for the securities.

Competitive bidders submit tenders stating the yield (discount rate for bill auctions) at which the bidder wants to purchase the securities. The bids are ranked from the lowest yield to the highest yield required to sell the amount offered to the public. In

[3] The only exception is to add awards to foreign official accounts that are held in custody at the Federal Reserve Bank of New York.

the multiple-price auction technique, awards are made at successively higher yields until the amount allotted for competitive tenders is fulfilled, with awards at the highest yield prorated. Successful competitive bidders pay the price equivalent to the yield that they bid. In an auction of Treasury notes or bonds, the coupon rate is based on the average yield of accepted competitive bids.

The process for a uniform-price auction is identical except that, instead of competitive awards being made at the individual yields specified by the bidders, all accepted bids are filled at the highest yield of accepted competitive tenders.

When-issued market

Market participants can begin trading Treasury securities as soon as the details of an issue have been announced. From the time of the announcement until the securities are issued, usually a period of about a week and a half, the issue is said to trade on a "when, as, and if issued" (WI) basis.[4] Prior to auctions, WI securities are quoted for trading on a yield basis because a coupon is not determined until after an auction is completed. After auctions, they are quoted on a price basis.

The when-issued market serves as an important price discovery mechanism that allows bidders to gauge the demand for an issue. By reducing uncertainty, when-issued trading allows competitive bidders to bid more confidently and aggressively, and it provides noncompetitive bidders with a proxy for the likely auction average yield.

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[4] When-issued trading of bills has always been allowed. However, pre-auction trading of notes and bonds was effectively prohibited from 1941 to 1975 and from 1977 to 1981. In August 1981 the Treasury officially allowed when-issued trading for notes and bonds. The only significant change since that time was the prohibition in October 1983 of when-issued trading of all Treasury securities awarded to noncompetitive bidders.

Auction participants

To participate in a Treasury auction, any potential investor may submit tenders to a participating Federal Reserve bank or branch, which acts as the Treasury's fiscal agent in the auction, to Treasury's Bureau of the Public Debt, or bid indirectly through a dealer.

Typically, between 75 and 85 bidders submit competitive tenders in Treasury auctions for securities to be held in the commercial book-entry system. Additionally, between 850 and 900 bidders submit noncompetitive tenders in Treasury auctions for securities to be held in the commercial book-entry system. Also, on average there are about 19,000 noncompetitive tenders per auction for securities to be held in the TREASURY DIRECT book-entry system.

The 37 primary dealers account for a large proportion of the participation in Treasury auctions. The Federal Reserve expects primary dealers to demonstrate their continued commitment to the market for government securities by participating in Treasury auctions. It should be emphasized, however, that auctions are open and that others besides primary dealers can and do participate, either directly, or through any government securities broker or dealer that is registered with the Securities and Exchange Commission (SEC) or through a depository institution.

All federally regulated financial institutions and SEC-registered government securities brokers and dealers may submit bids in Treasury auctions for their own account and for the accounts of customers. Financial institutions, brokers, and dealers are required to submit customer lists when submitting bids for the accounts of customers. All other entities or individuals may submit either competitive or noncompetitive tenders only for their own accounts.

Treasury auction rules

The uniform offering circular for Treasury securities contains the Treasury auction rules. The rules set out the responsibilities of bidders and of entities that submit bids for other parties in Treasury auctions and provide for certain limitations on auction awards to promote distribution of Treasury securities.

For example, awards to any bidder in a Treasury auction may not exceed 35 percent of the amount that is offered to the public. In order to facilitate enforcement of this "35-percent rule", the offering circular also requires that any bidder report the amount of its net long position when the total of a) its bids in the auction plus b) the bidder's net long position in the security being auctioned equals or exceeds $2 billion. The maximum award that will be made to any bidder is 35 percent of the public offering, less the bidder's reported net long position.

The most significant other auction rules concern limitations on tender amounts recognized at single yields, requirements for bidders to report net long positions, single-bidder guidelines, and when-issued trading.

II. Auction Theory

This section provides an overview of the main issues in auction theory, particularly, as they relate to the revenues of a seller.[5] The current state of auction theory involves many abstractions from the complexities of the real world. For example, auction theory is usually couched in terms of a single, indivisible, homogeneous good being sold at

[5] For recent surveys of auction theory, see McAfee and McMillan (1987) and Milgrom (1989). For surveys related specifically to Treasury auctions, see Mester (1988), Reinhart (1992), and Chari and Weber (1992). The following overview is based on these works.

a one-time event (e.g., auctions for works of art) with some results extended to the sale of multiple units of a good. By contrast, in auctions for Treasury securities, discrete multiple units are sold, bidders may submit numerous bids, and the securities are sold on a repeated, periodic basis. Empirical studies have provided only limited evidence for the relevance of the predictions of auction theory to the auctioning of Treasury securities. Nor does auction theory address the situation in which a good trades actively prior to the auction.

We will first describe the processes for the major types of auction techniques as they apply to a single good and then extend the analysis to multiple goods. We will also examine the impact of auction types on the information that is revealed to bidders. Then we will review the assumptions regarding bidder behavior. Putting it together, we will then examine the impacts of the above on revenues to the seller. Finally, we will also consider some of the issues regarding the nonconformaties between auction theory and auctions for Treasury securities, and look at other ideas that are not strictly based on auction theory.

Auctions are often used as a technique for selling goods when a seller has uncertain information regarding the market value of a good. The alternatives include simply setting a fixed price for the good or conducting a negotiated sale. The primary drawback of a fixed price is its inherent inertia or unresponsiveness to changes in conditions that affect demand and supply. This is particularly important if there are changes in market conditions in the time lag between the setting of a price and the subsequent sale and also if sales are conducted over a period of time.[6] Negotiated transactions, on the other hand, are usually conducted with a limited number of parties and are time consuming, with a number of iterations frequently required before a mutual settlement is reached. By contrast, in

[6] As evidenced when the Treasury set the coupon rate ahead of its subscription offerings, there is a risk that one or more of the factors affecting demand will change before the good is sold.

soliciting prices via an auction from market participants, a seller may obtain timely information regarding the market demand for a good.

Auction types

There are four basic types of auctions in general use. Two auction formats are referred to as open outcry auctions, where an auctioneer calls out a succession of prices and bidders may or may not respond at a particular price. The other two are called sealed-bid auctions, where bidders submit one or more sealed bids in private before a given deadline.

Open and sealed-bid auctions are further distinguished by whether successful bidders pay the actual prices bid, or whether all successful bidders pay the same price -- the price that allocates all of the goods sold. Thus, there are four types of auctions in the basic paradigm, and there is a two-way scheme for classifying them: auctions are open or closed; and awards are made at the particular prices bid or at a uniform price.

While the preceding refers to multiple units of a good, basic auction theory is couched in terms of a single good, with some of the results extending to multiple units under certain limiting assumptions. The following will describe the four types of auction mechanisms, first in terms of a single good and then by how the mechanism is extended to accommodate the sales of multiple units of a good.

Open auctions

In open auctions, the auctioneer may either raise the price successively until the amount auctioned is sold, or he may successively lower the price until it is sold. The former technique is frequently called an "English auction" and the latter is commonly called a "Dutch auction." We will refer to the two forms of open auctions by the operation

of their pricing mechanisms -- that is, as ascending-price auctions and descending-price auctions.

The ascending-price auction format is probably most familiar because of its widespread use in the art world. In the case of a single good, an auctioneer starts the bidding by calling out a low price (sometimes referred to as a reserve price). As the auctioneer successively raises the price, bidders with lower valuations retreat to the sidelines.[7] The auction is over when there is only one bidder remaining, who purchases the good at the highest price bid.

In an ascending-price auction for multiple units, the quantity bid for at each price is compared to the amount offered. If the total value of bids submitted at a given price is greater than the amount offered, the auctioneer raises the price, and continues to raise the price until the amount bid for by the remaining participants no longer exceeds the amount offered. Participants who remain until the last round receive a full award. If the quantity bid by the surviving bidders in the last round falls short of the total offered, prorated awards are made to those who bid at the second highest price. All awards, however, are made at the second highest price because that is the last price at which the auction was fully subscribed.[8]

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[7] The concept of value or valuation in an auction context is the maximum amount a bidder would be willing to pay for a good if the bidder had no uncertainty regarding any relevant aspect of the good. As we will see, there may be a difference between a bidder's valuation of a good and the actual price a bidder is willing to pay for it.

[8] In the case of one good, an open ascending-price auction is sometimes called a first-price auction because the good is sold at the highest, or first, price bid. With multiple units, it is a second-price auction. However, it will be shown later that the equilibrium for a single-good auction is also at the second highest price. That is why this auction technique is also referred to as a second-price auction.

In a descending-price auction, the auctioneer starts off at an excessively high price and successively lowers the price. In the case of one good, the bidder with the highest valuation placed on the good would be the first to bid, the object is sold at that price and the auction is over. In practice, a descending-price auction for multiple goods is actually a series of auctions for single units. After a bidder submits an initial bid, the auction for that unit is over and the next unit is put on the block, with the auctioneer starting again at an excessively high price. In contrast to multiple goods sold under an ascending-price auction technique, however, successful bidders would pay the particular price at which they bid.

Sealed-bid auctions

In sealed-bid auction techniques, prices are not called out by an auctioneer, but are submitted privately by bidders at or before a given deadline. After the bidding has closed the bids are opened and ranked according to price from the highest to the lowest. As with the two open outcry auction techniques, awards are made according to two different pricing criteria.

In the first technique, after bids are ranked, the good is sold to the highest bidder at the actual price bid. (For a single good, this technique is also referred to as a first-price auction.) In auctions of multiple units, awards are made starting with the highest price and continuing down until the amount offered is covered, with successful bidders paying the particular price they bid. Thus, the auctioneer acts like a discriminating monopolist, charging different prices to different bidders.[9] This is the reason this auction format is also called a discriminatory-price or multiple-price auction.

The other pricing criterion for sealed-bid auctions is still based on ranking the bids in descending order. However, the good is awarded to the highest bidder not at the actual

[9] In essence, the seller extracts the consumer surplus under the demand schedule.

price bid, but at that of the second highest bidder. (Because the good is sold at the second highest price, for a single good this auction technique is known as a second-price auction.) For multiple units, the awards are still made in order of descending prices, but a uniform price is paid by all bidders -- the price that just exhausts the amount offered. Thus, we will refer to it as a uniform-price auction.

Auction type and information revealed

A major tenet of auction theory is that the expected revenue from the four auction techniques depends on both the assumptions regarding bidder behavior and the information revealed to bidders by auction technique. The information revealed depends on auction type.

With regard to sealed-bid techniques, bidders obtain the least information in a multiple-price auction. The only information available to a bidder in this format is the knowledge of his own valuation and the price he is willing to bid. Although it may not appear to be an important distinction, in a uniform-price auction a bidder knows not only his own bid, but each bidder also knows that the price paid by the winner depends not on the highest price bid but on the price of the second highest bidder.

There is also a distinction with respect to the information obtained in the two open outcry formats. In an ascending-price auction, as the price rises, a bidder receives information regarding the valuations of other participants, as he not only observes the number of bidders retreating to the sidelines but also at what prices they do so. In a descending-price auction, instead of observing bidders withdraw, information is received in a negative sense in that the observation is made that other bidders remain in the auction process. Thus, no information is provided except that the price has not yet descended to the price of the bidder with the highest valuation. Once it has though, it's too late. The auction is over.

Thus, auction techniques can be ranked according to the informational content they provide bidders regarding other participants' valuations. In both a multiple-price and descending-price auction, a bidder knows only his own valuation. He must make a best guess as to the bidding strategies of other participants. In a uniform-price auction, a bidder has the additional knowledge that the winner pays not the actual price bid but that of the second highest bidder. Finally, in an ascending-price auction, bidders obtain the most information, as they observe both the number of participants withdrawn and at what prices they do so.

Assumptions regarding bidder behavior

Apart from auction technique, bidders behave differently depending on whether they want to purchase a good for its own inherent value, or whether they purchase it for its potential resale value. In the first instance, referred to as the independent private values case, each bidder has independent private information which permits him to know with certainty the value he places on the object being sold, and this value is not affected by information regarding the values of other bidders.

The assumption of private values is exemplified by an auction for art in which a bidder's only interest is to purchase the art for its own sake and not for its resale value. Each bidder knows his own valuation with certainty and what he is willing to bid. Bidders are interested in the valuations of others only to the extent that it affects how high they have to bid.

At the other end of the spectrum is the assumption of common values.[10] This is typically the situation in which a bidder purchases a good for resale. The good is worth

[10] In between is the concept of correlated or affiliated values. Milgrom and Weber (1982a) have shown that most of the results discussed below with respect to common values will hold for correlated values.

the same to each bidder -- the value that can be obtained in the market by selling it. However,

this value is not known to the bidders with certainty at the time of the auction. Each bidder still has private information regarding the value of the good, but now it is only an estimate. Because each bidder has only an estimate of the true value, he is interested in obtaining as much information as is possible regarding the value estimates of other bidders.[11]

Thus, in addition to classifying auctions as open versus sealed-bid and multiple-price versus uniform-price, auction models are also classified according to whether bidders have private independent values or common values regarding the good being sold.

Finally, there are two other assumptions regarding bidder behavior that are incorporated in both the private values and the common values models. The first is that bidders are risk neutral. That is, losses and gains are viewed symmetrically, and a bidder's only interest is in maximizing expected rents from the object on which he bid. Risk averse bidders, on the other hand, would place excessive weight on the fear of loss and would be inclined to submit extravagantly high bids to mitigate the likelihood of such loss.

Second, bidders are symmetric. That is, all bidders appear the same to the seller and to each other in terms of their behavior. The seller does not attempt to segment the market by recognizing and giving preferential treatment to any particular class of bidders. On the demand side, if any two bidders have the same valuation they will submit the same bids. In practice, however, bidders with the same valuation may not necessarily be expected to submit the same bids. Examples of bidders having different mappings

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[11] See Chari and Weber (1992). They use the term "value estimate" to describe a bidder's maximum willingness to pay given that bidder's information.

between their valuations and prices bid might include art dealers and collectors, wholesalers and retailers, or government securities dealers and ultimate investors.

Auction type and revenue

Independent private values case. One of the more surprising results of auction theory is that for a single good in the private values case, all four auction types yield the same expected revenue.[12] Although the following analysis holds for only a single good, we will keep the convention of referring to open auctions as either ascending-price or descending-price, and sealed-bid auctions as multiple-price or uniform-price auctions.

Auction theory predicts that bidders try to maximize their gains at auctions, taking into account the strategies of other bidders and the information revealed by auction technique. That is, bidders face a trade-off between submitting a higher or lower bid, which is directly related to the probability of winning the good, but which at the same time, is inversely related to the expected gain from winning. In facing this trade-off, a bidder in the private values case is interested in information regarding other bidders' valuations only to the extent that it affects how close to his known valuation he will have to bid in order to expect to win.

In both descending-price and multiple-price auctions a bidder's decision is based on the same information -- certainty with regard to his own valuation but no information regarding the strategies of other bidders. Thus, each bidder knows that he must choose how high to bid without knowing the decisions of other bidders, and if he wins, he has to pay the actual price bid. However, to win, a bidder really only has to bid higher than the second highest bidder. Assuming that bidders are rational, risk-neutral and symmetric,

[12] This was first demonstrated by Vickery (1961). Maskin and Riley (1989) have shown that this result holds only for the single-good case.

bidders will shade their bids below their true valuations. In equilibrium, the optimal degree of bid shading is to bid at the expected second highest valuation.[13] By bidding any higher, a bidder is no more assured of winning, but is unnecessarily reducing his potential gain; by bidding any lower, a bidder may enhance his potential gain, but is unnecessarily reducing his chances of winning.

In a strict sense, this does not represent bid shading in the context of the winner's curse because it is not in response to a potential regret for having paid more than a common market value.

Under the assumption of private values, in both the ascending-price and uniform-price auctions, bidders are willing to bid their true private valuation because in equilibrium the award will not be made at the highest bid price but at the second highest bid price. Thus, all four techniques yield the same revenue under the private values assumption.

Common values case. This revenue equivalence breaks down if the basic assumptions are altered. Most relevant to the present study is the impact of relaxing the private independent values assumption. Under the common values assumption, it is still assumed that each bidder has some private information about the value of the good, but in this case, not enough information to be certain about the true market value. Each bidder makes his best estimate of the value of the good based on his private information, but unlike in the private values case, his estimate may change based on information regarding other bidders' estimates that may be revealed during the auction process.

[13] Actually, the result is that the equilibrium price is higher than the second highest bid by an infinitesimally small amount.

Knowing more about other bidders' value estimates, which reflects the other bidders' private information, reveals more about the likely market value of the good being auctioned, which is precisely what the bidders are trying to estimate. By winning, a bidder reveals that he placed a higher value on the good than the value estimates held in common by all other participants.

For this reason, it is in a bidder's interest to obtain as much information as possible regarding the value estimates of other bidders. Auction theory shows, however, that the greater the information provided by the auction format regarding the value estimates of other bidders, the higher the expected winning price, or expected revenue to the seller. In addition, if the behavioral assumptions of risk neutrality and bidder symmetry hold, the auction types can be ranked according to the expected revenue they generate.[14]

The expected revenue from a descending-price auction and a multiple-price auction will be the same as in the private values case because the winning price is related only to the valuation of the winning bidder. No new information is provided in the auction process that would contribute to a change in strategy. Each bidder still follows the same strategy as in the private values case, i.e., they shade their bids and assume that others will also.

Now, however, the bid shading is more appropriately identified as a response to the winner's curse because winning leads to the regret that one has paid more than the common market value, and thus, will be less likely to realize a profit from selling it.

The expected revenue in a uniform-price auction is now higher than that of both the descending-price and multiple-price auction techniques. In this case, revenue is determined not by the winning bidder's price but that of the second best price. Given that bidders have only uncertain estimates of the true value, combined with the fact that the

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[14] Milgrom and Weber (1982a).

winner's curse is lessened because the winning price is not based on their estimate but that of the second best price, participants bid more aggressively, increasing expected revenue. It should be emphasized, however, that because the value estimates are uncertain, bid shading is not eliminated, only lessened.

With common values, an ascending-price auction will yield even higher expected revenues. As noted above, bidders in an ascending-price auction receive important information regarding other participants' estimates of the common value of the good which is absent in the other auction techniques. In an ascending-price auction, the expected price is related to the value estimates of all non-winners. This information can reinforce a bidder's confidence in his own estimate of the true value, particularly if it is high, as the price escalates. This mutual reinforcement among all remaining bidders will lead to more aggressive bidding and a higher expected revenue.

Implications of auction theory for Treasury markets

Auction theory is usually couched in terms of a single good auctioned at a one-time event, with each bidder submitting a single bid at the relevant time in the auction process, and behaving according to certain restrictive assumptions. Auctions for Treasury securities, however, are repeated on a periodic basis and are for multiple goods, for which bidders may submit a whole schedule of bids, some of which may be viewed as underwriting bids; there is an active well-defined WI market in which participants can purchase the identical good (but at a known yield) at the time of an auction or before or after; and there is a well-defined group of bidders, which may or may not act according to the assumptions, that participate in virtually all auctions.

Thus, while auction theory suggests that uniform-price auctions will provide higher expected revenue to the seller than multiple-price auctions, applying the predictions of auction theory to the Treasury securities market is not without ambiguity. Empirical

efforts have confirmed this. The following will address some of the issues to consider in making the transition from theory to the Treasury securities market.

It can be shown that relaxing the assumptions regarding bidder behavior will affect the predictions of auction theory regarding expected revenues, resulting in other rankings, or rankings that are indeterminate.[15] In Treasury auctions, for example, there may be asymmetries of information between dealers and other investors leading to different strategic behaviors based on different value distributions. Most competitive bidders in Treasury auctions are large dealers and financial institutions.[16] Dealers in particular have information regarding the strength of demand that is gleaned from customer bid lists. In addition, it is in the dealers' interest to enhance the perceived strength of demand at an auction. That is, to the extent that secondary market prices react to auction results, it is in the interest of dealers to submit more bids farther off the market to increase the cover ratio (ratio of bids tendered to bids accepted), in order to signal to potential buyers in the secondary market that their private information is very valuable.[17] Thus, dealers with the same valuations as other investor class bidders may behave differently. While it is usually assumed in theory that all bidders are symmetric, the empirical import of potential asymmetries is uncertain.

Auction theory also assumes that bidders are risk neutral. When bidders are risk-averse they place a premium on auction formats that have less uncertainty.[18] Since in descending-price and multiple-price auctions, bidders know with certainty that they will

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[15] See McAfee and McMillan (1987) or Mester (1988).

[16] In this context, the competitiveness of the market may also be brought into question. Of the large dealers and financial institutions there is a much smaller group that accounts for a significant portion of awards from auction to auction.

[17] See Bikhchandani and Huang (1989 and 1993).

[18] Holt(1980) and Harris and Raviv (1981) have extended Vickery's independent private values case to the analysis of risk aversion.

pay the price bid, as opposed to paying the unknown valuation of another bidder under the uniform-price and ascending techniques, they will bid more aggressively in these type of auctions. Allowing for risk aversion skews bidders' preferences and thus the revenue rankings toward descending-price and multiple-price auctions.

It can be argued, however, that risk aversion should not be much of a concern in Treasury securities auctions, largely because the value of bids submitted by each participant at any single auction is not likely to be so large relative to the wealth of a bidder for risk aversion to be a significant factor.[19] Even if a bid were large relative to wealth, it could be argued that, given a deep, liquid secondary market, risk exposure is more accurately captured by the difference between the expected auction price and expected resale price.

In extending the common values auction model to multiple units, such as Treasury auctions, some research has shown that the revenue rankings of the four auction techniques hold. But the results are based on the assumptions that the goods are perfectly indivisible and that each bidder submits a bid for only one unit of the good being sold (referred to as the unit demand assumption). If, however, we change these assumptions, the results have been shown in some cases to be inconsistent with the classical revenue rankings. For example, Back and Zender (1993) assume that bidders submit bids for multiple units of perfectly divisible goods and argue that it is possible for multiple-price auctions to yield higher revenue than uniform-price auctions. They provide an illustration in which bidders collectively, but not necessarily collusively, submit aggressive bids to stifle competition, with the result that revenues under the uniform-price technique may be lower than with multiple-price auctions. There are no formal auction models, however, that capture more

[19] See Chari and Weber (1992).

than a limited number of characteristics of a periodically repeated auction process for multiple units of discrete goods in which a set of sophisticated bidders have both price and nonprice motives for participating.

Auction theory does, however, lead to potentially important implications regarding the winner's curse that have been a focus of empirical work. Auction theory predicts that in a common values setting there is a positive relationship between the expected bid shading (i.e., gain to bidders) in an auction and the expected dispersion of bids, given a fixed number of bidders.[20] First, there is an inverse relationship between the intensity of bidding competition and the dispersion of bids. As the dispersion of bids increases, the probability that another bidder's valuation is just below or just above a given bidder's valuation is lessened. Secondly, a greater dispersion of bids means that there is a reduced probability of another bidder submitting a price just below a given bid which leads to increased bid shading.[21] In addition, there is a direct relationship between uncertainty regarding the common value of a good and the dispersion of bids: the greater the uncertainty, the greater the dispersion of bids; or alternatively, the lower the uncertainty, the tighter the dispersion of bids, and hence, the weaker the winner's curse. This link between uncertainty and the winner's curse has been the focus of empirical work.

An implication of this linkage is that as uncertainty is lessened, or the amount of information revealed about a security's value in the WI market increases, the winner's curse becomes weaker. Thus in one sense, to the extent that greater liquidity of secondary or forward markets increase information on the true value of a security, the more it is of

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[20] Alternatively, for a fixed expected dispersion of bids, there is an inverse relationship between expected gain to bidders and the number of bidders. That is, the fewer the bidders, the less likely it is that another bidder will bid at a higher price. It has been shown that as the number of bidders goes to infinity, bids approach true valuation. See Wilson (1977).

[21] This result does not hold in an independent private values setting, because there is no motive for increased bid shading. See McAfee and McMillan (1986).

interest to the Treasury to promote development of these markets.[22] However, to the extent that participants may use the WI market to send misleading signals for strategic purposes, it detracts from its value.

Friedman's proposal

As seen, many of the results of auction theory are based on very restrictive assumptions that are not satisfied in the Treasury securities market. In light of the nonconformaties between auction theory and practice, Milton Friedman has put forth an informal analysis based on auction theory suggesting that the Treasury's traditional multiple-price auction technique costs the Treasury money and also favors the dealer community.[23]

Friedman contends that switching to a uniform-price auction would reduce the cost of financing the debt. While the Treasury would give up the consumer surplus it receives as a discriminating monopolist, Friedman argues that the uniform-price format would more than offset this decline in revenue by increasing demand on two counts. First, as auction theory suggests, the switch to a uniform-price format would lead to more aggressive bidding, because the fear of the winner's curse is reduced.

Secondly, because uniform-price auctions are strategically simpler, they would reduce bid preparation costs and encourage more bidders to participate.[24] The primary dealers would lose the extra rents they earn by the services they perform in the current

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[22] See Bikhchandani and Huang (1993).

[23] Friedman originally proposed this idea in Friedman (1959). For a recent statement, see Friedman (1991).

[24] Friedman's original argument regarding multiple-price auctions and the need for specialized knowledge also focused on the strong incentive for collusion among bidders. Reinhart (March 1992) and Chari and Weber (1992) also argue that uniform-price auctions will reduce market manipulation and the likelihood of a squeeze.

system. That is, dealers are viewed as having a technical edge in the resources devoted to sophisticated financial analysis of the general factors moving the market, and in particular, the strength of demand for a given issue. A uniform-price format is perceived as leveling the playing field by reducing the importance of this specialized knowledge. According to Friedman, more bidders would be induced to bid directly in auctions because the fear of being awarded securities at too high a price is eliminated.

The net impact of both factors, according to Friedman, would be to increase auction demand by enough to more than compensate for the revenues foregone by giving up discriminatory pricing.

III. Empirical Evidence

The empirical studies of Treasury auctions follow two closely related approaches. One involves attempting to directly compare the revenues from the two auction techniques by relating prices bid or bidder profits to the factors affecting the demand function, and examining whether the impact of auction technique on auction demand is consistent with the predictions of auction theory. The other involves attempting to directly test predictions of auction theory, such as the impact of uncertainty on the winner's curse, and then to discern whether auction technique affects the results.

Both approaches look at the observed relative prices in the auction versus the WI market, or the secondary market, and examine changes in these relative spreads. However, since only the prices and spreads are observable, and not the actual demand and supply schedules, assumptions must be made regarding the factors affecting demand and supply. Most importantly, it is usually assumed that prices in the WI market or the secondary market are independent of auction technique. Thus, any difference in the spread between auction average yields and WI or secondary market yields is attributed to a change in

behavior due to the auction process. The validity of this assumption, particularly with respect to the WI market, is discussed in more detail later.

In addition to the Treasury's current use of the uniform-price auction technique, there have been at least three major experiments with uniform-price auctions of financial commodities: the U.S. Treasury's auctions of long-term bonds in 1973 and 1974; the International Monetary Fund's decision to alternate between multiple-price and uniform-price auctions for part of its gold stock from 1976 to 1980; and the Mexican Government's decision in 1990 to switch from multiple-price to uniform-price auctions to sell its debt. Two studies are available that examine the U.S. Treasury's experiment, and one is available on the Mexican experiment.[25]

Tsao and Vignola (1977) attempted to test the Friedman hypothesis by analyzing the impact of auction technique on the auction demand function for Treasury securities using data from sixteen long-term bond auctions held between February 1973 and August 1976, the first six under a uniform-price auction format and the remaining ten under a multiple-price format. Tsao and Vignola tested whether the auction demand function shifted upward due to auction technique, and whether the shift resulted in an increase or decrease in Treasury revenue.

Their results suggested that non-dealer demand is increased when securities are auctioned under a uniform-price format, and that it is increased by enough to increase

[25] While the IMF conducted a study of the gold auctions around the time of the experiment, it is not publicly available. We have, however, seen other IMF reports that indicate that the results were inconclusive.

revenues to the Treasury. However, it has been acknowledged by the authors that there is a potentially fatal problem with the data in the study.[26]

Simon (1992) re-examined the Treasury's 1970s experiment with uniform-price auctions, focusing on the average markups of auction average yields over a proxy for WI bid yields at the market close.[27] Contrary to the generally accepted prediction of auction theory, Simon's results show that the markups were a statistically significant 7 to 8 basis points higher for uniform-price auctions than for multiple-price auctions, suggesting that uniform-price auctions actually raised the Treasury's borrowing costs. However, he suggests that since pre-auction trading was banned during the period of the experiment, dealers were unable to distribute the supply in advance of the auctions. Thus, they were unable to get a good estimate of demand, and appear to have bid more cautiously.

By contrast, in a study of the Mexican uniform-price experiment with 1-month T-bills, Umlauf (1993) found support for uniform-price auctions. Comparing auction prices with average resale prices on the day auction results were announced,[28] Umlauf found that after the auctions were switched from a multiple-price to a uniform-price format bidder profits decreased.

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[26] The August 1973 auction was greatly undersubscribed, with a large portion being awarded to U.S. Government accounts. The August 1973 results comprised almost 20 percent of the uniform-price data, and Tsao and Vignola did not account for this anomaly.

[27] As noted previously, there was a prohibition on pre-auction WI trading of notes and bonds until March 1975, or for all of the uniform-price auctions but for only three of the ten multiple-price auctions. Ten of the auctions were reopenings, however, which provided a benchmark rate. In the other auctions, the WI rate at the close on the following day, with an adjustment made to account for rate changes in the interim, was used.

[28] The Mexican government accepts bids for T-bills until 1:30 p.m. on the day of an auction and announces the auction results on the following morning.

The relevance of the results to the U.S. Treasury market, however, are questionable because the institutional and market environment in Mexico is quite different. Although potential participants number in the hundreds, in practice, according to Umlauf, there is an active collusive cartel of bidders.[29] Also, the amounts auctioned varied significantly from auction to auction; there were occasional cancellations or changes in the announced sizes of auctions, sometimes after the submission of bids; also, there was heavy, volatile foreign demand during the period under study.

The Mexican Government returned to multiple-price auctions in January 1993, not because uniform-price auctions were more expensive -- according to Umlauf, the evidence suggests they were not -- but to increase domestic participation in the auctions and to reduce sharp swings in bill rates.[30]

Although not an attempt to compare auction techniques, Cammack (1991) directly examined Friedman's contention that the difference between auction and secondary market prices reflected the return to dealers for their services. Using data for the 1973-1984 period, Cammack found that on average the mean auction price for Treasury bills was four basis points below a comparable secondary market price.[31] On the assumption that the secondary market price reflected the "true value" of the bill, this result is consistent with auction theory's prediction regarding bid shading in a multiple-price auction with common

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[29] According to Umlauf, "Auction participants openly acknowledge collusion among the six largest bidders. No legal deterrents to collusion exist...Cartel members agree before each auction on the prices of bids and divide cartel purchases amongst themselves." The six largest bidders on average purchased 73 percent of the auctioned issues over 1986-1991. During 1992, auctioned securities were usually awarded to a group of only three to eight bidders, in approximately equal amounts to each bidder.

[30] In December 1990, the Mexican bill market was opened to foreign investors. Foreign bidding was reported to be very aggressive, crowding out domestic participants, and resulting in auction yields that were well below comparable market yields.

[31] Reinhart (1992) updated Cammack's results through August 1991, getting similar results.

values. Or in Friedman's terms, this gain is the return to dealers' costs of participating in the auction.

The crux of Cammack's contribution is a test of whether this observation actually reflects the predictions of auction theory. Specifically, she tested whether there is a positive relationship between the expected gain in the auction and the expected dispersion of bids, given a fixed number of bidders. To represent the expected dispersion of bids, Cammack derived a measure for the expected auction tail, and to reflect the expected number of bids, Cammack constructed expected coverage ratios and ratios of competitive bids to noncompetitive bids.[32]

Consistent with auction theory, Cammack found the coefficient for the expected tail to be positive and significant, i.e., the greater the uncertainty, the greater the bid shading. However, the coefficients for the measures representing the number of bidders were not only of the wrong sign, but in most instances they were insignificant. Thus, there was no evidence to support the hypothesis that increasing the number of bidders increases competition and reduces bid shading.[33]

In other recent work, Simon (1994) compared the contemporaneous WI market and the auction market. Simon examined 66 note and bond auctions between January 1990 and September 1991. Comparing the auction average yields with the WI bid yields at the times of the auctions, Simon found underwriting premiums that dealers earn through bidding at auctions to be small on average, at 0.37 of a basis point. Simon also tested auction theory by comparing these results against measures of uncertainty. We will review his analysis in greater detail below.

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[32] To derive these expected measures, Cammack used univariate time series modelling on the observed tail and the two ratios, and then made one-period forecasts to derive expected values for the next auction.

[33] Spindt and Stolz (1992), however, show that the degree of underpricing declines with auction participation.

Nyborg and Sundaresan (1995) examined Treasury bill, note, and bond auctions from July 1992 to August 1993, and also compared the spreads between average auction yields and the contemporaneous WI market yields. They found a positive and statistically significant markup for Treasury bill auctions, a positive markup for all other multiple-price auctions, and no significant markup for uniform-price auctions.[34] Like Simon, they also examined the relationship between the markups and volatility in the WI market prior to the auctions, with similar results. Their analysis will also be discussed in more detail below.

IV. Evaluation of Treasury Uniform-Price Auctions

A primary focus of the following analysis will be the Treasury's criteria for implementing the uniform-price auction technique, that is, whether it reduces financing costs, by encouraging more aggressive bidding, and whether it broadens bidder participation and the distribution of awards on original issue. However, we will also examine the work of other researchers to see if our results are consistent with their findings.

We have compared the performance of the 2-year and 5-year notes under the multiple-price and uniform-price techniques to determine whether differences in performance are consistent with the basic tenets of auction theory or with the findings of other researchers.

In a further effort to isolate the impact of auction technique from other factors affecting the Treasury securities market, we have also compared the auction performance of the 3-year and 10-year notes with the performance of 2-year and 5-year notes over the

[34] They do not infer that the markups for multiple-price auctions of 2-year and 5-year notes are significant because of a limited number of observations.

same time periods. In many cases, however, inferences based on such comparisons should be made with caution because of the smaller number of observations for the 3-year and 10-year securities, the auction-to-auction volatility of the data, and the different maturities of the securities.

In addition to auction technique a variety of factors impact auction results, including the economic outlook, movements in absolute or relative interest rates, and any other factors that affect the portfolio decisions of dealers or investors. The confluence of these factors results in significant auction-to-auction volatility in the data, making it difficult to isolate the impact of auction technique itself.

Concentration of awards

One of the stated purposes of conducting uniform-price auctions is to see whether the technique broadens participation and reduces concentration of Treasury securities on original issue. As previously noted, it has been argued that uniform-price auctions will encourage more bidders to participate in competitive bidding by reducing the importance of specialized knowledge of market demand and the information costs associated with its collection. An imperfect corollary to increased participation is a reduction in the concentration of awards.

Charts 1 through 3 contain data on large competitive awards (based on bids of $1 million or greater) to primary dealers, their customers, and direct bidders through the New York, Chicago, and San Francisco Federal Reserve banks and branches.[35] The concentrations of competitive awards are measured as the average percentages of total private awards going to the top five, top ten, and all bidders for four groups: awards to all large competitive bidders, whether dealers, customers, or direct bidders; awards to dealers

[35] Virtually all competitive bids and awards are made through these three banks and branches.

only for their own account; awards to dealers plus their large customers; and awards to large customers of primary dealers.

We divided the auctions into two periods, the multiple-price auction period (January 1990 to August 1992) and the uniform-price period (September 1992 to December 1994) and examined whether there was a statistically significant change in the concentration of auction awards between the two periods.[36] As a control, remembering the caveats noted above, we compared any changes in concentrations for the 2- and 5-year notes to those of the 3- and 10-year notes.

Awards to dealers for their own accounts

In general, we found statistically significant evidence that the concentration of awards to the top primary dealers fell for the uniform-price auctions, although awards to all primary dealers for their own accounts did not change significantly.[37] (See Chart 1.) For example, the average share of awards to the top five dealers fell from an average of 38 percent to 31 percent for 2-year notes and from 46 percent to 32 percent for 5-year notes. Meanwhile, awards to the top ten dealers fell from an average of 51 percent to 45 percent

[36] We also broke each of these two periods into sub-periods. We divided the multiple-price period into the period before the Salomon Brothers improprieties were known (January 1990 to August 1991) and the period afterwards (September 1991 to August 1992). The uniform-price period was divided into the period of steady Federal Reserve policy (September 1992 to January 1994) and the period of more restrictive policy (February 1994 to December 1994). However, with only a couple of minor exceptions, there were no differences in award concentrations between these sub-periods.

[37] The statistical analysis which follows involves testing the differences between the average shares of awards during the multiple-price and uniform-price periods and assumes that the populations under consideration are normally distributed. However, because the concentrations are measured as percentages, the populations may not be normally distributed. Consequently, we also tested the differences in shares using the nonparametric Mann-Whitney U test and found that the results were virtually identical.

and from 57 percent to 47 percent for 2- and 5-year notes, respectively.[38] Although competitive awards to the primary dealer community as a whole fell somewhat, the decline was not statistically significant.

By contrast, the concentration of competitive awards for 3- and 10-year notes to not only the top dealers but to all dealers over the same periods either remained essentially the same or increased significantly. (See Chart 1.)

The reduced concentrations of awards to the top dealers may be attributed to two interrelated factors: changes in the overall distribution of bids, as one might expect from auction theory; and changes in the bidding strategies of the largest dealers.

As auction theory predicts, under multiple-price auctions, there is a relatively tight distribution of large bids around the auction average. (See Charts 9 and 10.) In virtually all cases, there is either no tail or only a one basis point tail.[39] Similarly, there are very few bids more than one basis point ahead of the market, because bidders in multiple-price auctions are awarded the securities at the actual price bid.

Under uniform-price auctions, however, the distribution of bids is much broader and the amounts bid at each yield tend to be smaller. The broader distribution follows from auction theory in that there is no penalty for bidding ahead of the market, unless such aggressive bids in aggregate match or exceed the auctioned amount. Similarly, bids two or more basis points behind the market are also meaningful because if awarded, the price of all awards will be at that of the lowest accepted bid.

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[38] The differences are consistent with regression results (not shown) that show that the change to uniform-price auctions decreased the shares to the top five dealers by about 8 percent and decreased the shares to the top ten dealers by about 6 percent.

[39] The auction tail is the difference between the highest accepted yield and the auction average yield.

Anecdotal evidence also suggests that large dealers have changed bidding strategies by splitting bids into more numerous smaller bids, some ahead of the market, some at the market, and some trailing off the market. Also, the incidence of bid splitting by dealers and the range over which bids are split varies from auction to auction. One effect of the bid splitting is that the bids of the larger, usually more aggressive dealers are more interspersed with the more aggressive bids of other market participants (including other dealers, customers, and direct bidders) trying to ensure supply in an auction. The net result is that at the margin this greater density of aggressive bids by other participants has reduced, on average, the share of awards to the top groups of primary dealers.

Awards to dealers plus their large customers

Although not as consistent, the trend is similar for competitive awards to the top dealers plus their large customers.[40] The percentage of private awards to both the top five and top ten dealers plus their large customers declined significantly for the 5-year note auctions, falling from about 59 percent to 44 percent and from 72 percent to 64 percent, respectively. For 2-year notes, the changes in shares to the top five and top ten dealers plus their large customers were insignificant. However, the percentage of private awards going to all dealers plus their large customers increased significantly, from 81 percent to 88 percent.

[40] Includes awards to dealers plus the large customers of those same dealers. The shares representing awards to large customers is not derived by netting out the customer awards from the total of dealer plus customer awards.

By contrast, for 3-year and 10-year notes, the shares of competitive awards for these groups increased across the board, but by significant amounts only in the cases of the broader groupings for 3-year notes.

Large customer awards

Awards to large customers of primary dealers have risen under the uniform-price auction technique. (See Chart 2.) In general, however, the changes are significant only for large customers as a whole. For example, the shares of awards to all large customers rose from about 16 percent to 26 percent for 2-year notes, and from 19 percent to 25 percent for the 5-year notes.

Taken together with the data on all dealers plus their large customers, this evidence suggests that under the uniform-price technique there has been some substitution of customer awards for dealer awards for 2-year and 5-year notes. This finding is consistent with that presented above on awards to dealers for their own account. That is, the decrease in total dealer competitive awards is partially offset by an increase in competitive awards to all large customers. (See Chart 1.)

Top competitive awards

The last category of awards that was examined was top competitive awards to bidders regardless of whether they were dealers, dealers' customers, or direct bidders. (See chart 3.) Once again, this category lends support to the notion that the uniform-price technique has reduced award concentrations, but the evidence suggests that it has had a much smaller impact on increasing overall participation.

Impacts on Revenue

The primary purpose of conducting uniform-price auctions is to evaluate whether a uniform-price auction format will reduce financing costs, or equivalently, increase revenue. The most direct way to determine the impact on revenue of auction technique is to compare auction prices under the multiple-price format with auction prices under the uniform-price format and determine if there is a statistically significant difference between the two.

Treasury auctions are conducted in terms of yield, not prices. A direct comparison of auction yields, however, is difficult because yields vary from auction to auction, giving rise to the need for a common reference point. Yields in the contemporaneous WI market provide such a common point of reference.[41] The difference between auction yields and contemporaneous WI yields, or $(Y_A - Y_{WI})$, is commonly referred to as the auction spread. A positive spread (or markup) means that the yield in an auction is greater than the yield in the WI market at the time of an auction. Or, in terms of price, the price in an auction is lower than that in the WI market.

The contemporaneous WI yield is used as a benchmark against which to measure auction yields under the two formats because potential bidders for auctioned securities have a choice between purchasing securities at auctions or purchasing securities in the WI market anytime after the announcement of the securities to be auctioned. In particular, potential bidders face the choice between bidding in an auction or in the WI market in the time period from shortly before an auction up to the time of the auction.

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[41] Treasury auctions are usually held at 1:00 p.m. In some cases, such as when more than one security is auctioned on the same day, auctions have been held at other times. All data have been appropriately adjusted.

It should be noted that, although it is standard practice for researchers to compare WI yields with auction results, there are some issues that should be addressed regarding the use of contemporaneous WI yields. For example, the transaction sizes in the WI market are usually smaller than the range of sizes of bids of large participants in auctions. Typical transaction sizes in the WI market range from millions of dollars to tens of millions of dollars, while typical accepted competitive dealer bids in auctions range from millions and tens of millions to hundreds of millions of dollars.

The difference in relative transactions sizes has led some to question the usefulness of comparing auction yields with WI yields.[42] However, it is reasonable to assume that if WI yields were not reflective of value, arbitrage would eliminate any differences in relative values between WI yields and auction average yields. That is, if WI yields shortly before an auction were lower than the expected auction yield, dealers would sell short the WI security until the WI yield reached the expected auction yield in order to take advantage of the difference between the two.

Additionally, some have questioned the relative liquidity of the WI market at 1:00 p.m.[43] However, the data on transactions activity, suggest that there is ample liquidity in the time periods up to and including 1:00 p.m. Given sufficient liquidity, the 1:00 p.m. quote has the advantage that it provides an alternate, contemporaneous price for the auctioned security. Thus, it is assumed that the markup at 1:00 p.m. should approach zero, with any discrepancy reflecting compensation for the resources used and risks associated with participating in the auction.

It could also be argued that auction technique may have a discernable effect on WI market yields by affecting supply and demand in the WI market. On the demand side, if bidders are confident that a uniform-price format reduces the importance of specialized

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[42] See Nyborg and Sundaresan (1995).

[43] Ibid.

market knowledge, then more bidders may be willing to forego buying in the WI market and bid directly in the auction. The impact would be to shift the WI demand curve to the left, ceteris paribus, reducing the equilibrium price.

On the supply side, it can be argued that dealers may be more willing to put on shorts in the WI market because they are more assured of acquiring supply (with an aggressive bid) in a uniform-price auction, while mitigating the attendant price penalty inherent in a multiple-price format. Thus, dealers may be more willing to short the security in the WI market, shifting the supply curve to the right. The net impact of the hypothesized shifts in supply and demand would be to lower the WI equilibrium price (increase yield).

However, the demand and supply schedules are not observable, and it is usually assumed that the WI market is not affected by auction technique. The essence of the argument is that if there is an impact on yields in the WI market, relative to either yields in the auction or to yields on other securities, it is likely to be very minor or else the differential would be arbitraged away. We also view this as a reasonable assumption. That is, we assume that auction technique does not affect WI bid yields and that a comparison of auction results relative to the WI bid yields under both the multiple-price and uniform-price auction formats provides a useful comparison of expected revenue under the two formats.

Direct comparison of auction results

The most straightforward way to test whether the uniform-price auction technique reduces financing costs relative to the multiple-price technique is to directly compare auction spreads under the two techniques. If the auction spread is significantly smaller under the uniform-price technique, then the premium to bidders is smaller, or alternatively, expected revenue to the Treasury is greater.

We measure auction spreads by comparing the auction results to the bid side of contemporaneous WI yields because dealers who need to cover short positions are far and away the primary participants in Treasury auctions, and short positions are established at the bid side of the WI market.[44]

Chart 4 shows the average spreads between auction results and the contemporaneous WI bid yields for 2- and 5-year note auctions held under the multiple-price auction format (June 1991 through August 1992) and the uniform-price auction format (September 1992 through September 1995). In addition, for purposes of comparison the spreads for the 3-year and 10-year note auctions, which are all held under the multiple-price format, are shown divided into the same two time frames and for the entire period (June 1991 through September 1995).

The average auction spread for 2-year notes during the multiple-price period, 0.41 of a basis point, was cut by about half, to 0.22 of a basis point, during the uniform-price period, and that for 5-year auctions was reduced by about a third, from 0.33 to 0.23 of a basis point. In spite of the proportionately large changes in the average auction spreads, we cannot say that there is a statistically significant difference between them for either the 2-year or 5-year note auctions. The reason for the lack of statistical significance in the differences is that the average spreads for uniform-price auctions are not particularly reliable because of the auction-to-auction volatility in the spreads, as revealed by the large standard errors shown in Chart 4.

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[44] In the past, attempts to measure markups have used various gauges against the auction average. Cammack (1991) used the average of the current on-the-run issue at the market close on auction day. Spindt and Stolz (1992) used the WI bid yield 30 minutes before the auction. Simon (1994) and Bikhchandani and Huang (1989) used the WI bid yield at auction time. And Nyborg and Sundaresan (1995) use WI bid yields during various intervals around auction time.

Thus, a direct comparison of the average spreads under the two auction formats does not provide sufficient evidence to conclude that uniform-price auctions increase expected revenue to the Treasury relative to multiple-price auctions.

Indirect comparison of auction results: auction results under the two techniques versus 1:00 p.m. WI bid yields

Although a direct comparison of auction spreads does not reveal a statistically significant distinction between the two techniques in terms of expected revenue, additional information regarding relative revenue impacts may be obtained from an indirect comparison of the two techniques. That is, instead of comparing the spreads to each other, we can examine whether auction results under the two techniques are significantly different from the yields in the contemporaneous WI market, or whether the auction spreads as we have defined them are significantly different from zero.
The presence of statistically significant positive spreads between the auction results and the 1:00 p.m. bid yields would represent expected premiums to successful competitive bidders, and expected revenue foregone by the Treasury.

As shown in Chart 4, the average spreads between the auction average yields and the contemporaneous WI bid yields are positive and statistically different from zero at the 99% level of significance for the 2- and 5-year notes under the multiple-price format . For the 3- and 10-year notes the average spreads for the whole study period are also positive and statistically different from zero at the 99% level of confidence.[45]

[45] For the 3- and 10-year note auctions, the whole study period is the relevant time frame for purposes of comparison because, due to their quarterly auction schedules, there are only five observations of each maturity in the June 1991 through August 1992 time period and twelve observations in the September 1992 through September 1995 period.

This result is consistent with other evidence that there is a statistically significant premium to dealers for bidding in auctions.[46]

By contrast, under the uniform-price format the average spreads for the 2- and 5-year notes are not significantly different from zero. That is, there is no statistically significant markup thus far in the uniform price-auctions. This result held true for uniform-price auctions held during the period from September 1992 through January 1994 when interest rates were generally flat or falling, and for the auctions since then, which have been held under a variety of interest rate conditions (although the range of fluctuations has been moderate by historical standards).

Thus, although upon direct comparison of the two auction techniques there is no statistically significant evidence of a difference in expected revenue to the Treasury, when results under the two techniques are compared to yields in the contemporaneous WI market, there is evidence of a difference. The data show there is a statistically significant premium to successful bidders in multiple-price auctions, which implies that expected revenue to the Treasury is reduced, whereas there is no similar evidence of a significant premium to successful bidders under the uniform-price technique. These results suggest, albeit not strongly, that expected revenue under the uniform-price technique is at least as great and probably greater than under the multiple-price technique.

Volatility of auction-to-auction results

Once again, the primary reason for the lack of statistical significance in the comparison of the results under the uniform-price technique when compared to the contemporaneous WI yields is the auction-to-auction volatility.

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[46] Most recently, Simon (1994) and Nyborg and Sundaresan (1995).

Charts 5 through 7 show the behavior of the spreads of auction results to 1:00 p.m. bid yields on an auction-to-auction basis for the 2-,5-, and 3- and 10-year notes. As charts 5 and 6 show, the behavior of the 2- and 5-year spreads on an auction-to-auction basis under the two techniques is notably dissimilar. For the thirty multiple-price 2- and 5-year note auctions from June 1991 to August 1992 the spreads between individual auction results and the 1:00 p.m. WI bid yields are almost uniformly non-negative (with the September 1991 2-year note auction being the only exception). For the thirty-four multiple-price 3- and 10-year note auctions shown in chart 7, in only three of the auctions have the average yields been below the 1:00 p.m. WI bid yields.

Thus, the data show that under the multiple-price format there has been a relatively stable and statistically significant average premium to successful competitive bidders.

By contrast, under the uniform-price auction format, in more than half (42 out of 74) of the individual auctions from September 1992 to September 1995 the auction yields have been below the 1:00 p.m. WI bid yields, producing negative auction spreads, and no statistically significant premium can be said to exist.

The greater auction-to-auction volatility of uniform-price auction results relative to the 1:00 p.m. WI bid yields is partially attributable to the different concepts employed in the reporting of auction results under the two formats. In multiple-price auctions, an average yield is used, whereas in uniform-price auctions a single number, the stop-out yield, is employed. In and of itself, a single number that represents the end point of a varying set of numbers can be expected to possess more variability than the average of a relatively stable set of numbers. In addition, the volatility of auction results under the uniform-price technique is a result of considerably more variability in the distributions of bids. The bid distributions for uniform-price auctions are much more volatile than those for multiple-price auctions in terms of variability of the modes, means, and standard deviations than the bid distributions in multiple-price auctions.

The practical import of this volatility for the purposes of this study is that, while on average uniform-price auctions may reduce financing costs, it is much less certain what the impact on revenue will be in any individual auction.

Liquidity of the WI market around 1:00 p.m.

We also examined the data to determine whether there is any basis for questioning the liquidity of the WI market at 1:00 p.m., and, therefore, for questioning the validity of the use of the 1:00 p.m. WI bid yields and conclusions drawn from their use. Inspection of transactions volume and WI yield data at 5-minute intervals throughout the trading day suggests that the market is as liquid or more liquid shortly before auction time than at other times of the day. In fact, the three 5-minute periods that comprise the 15 minutes up to and including 1:00 p.m. under both auction formats are among the most active periods of the day, as measured by average transactions volume, average number of transactions, and average transaction size.

Additionally, it has been argued that the bidding decisions of auction participants are not made at 1:00 p.m., but instead they are made at some point shortly before 1:00 p.m. A comparison of auction yield results to WI bid yields at other points in time prior to auctions reveals that the behavior of the spreads is not significantly altered. As shown in Chart 8, the average spreads between auction results and WI bid yields at 12:45 p.m., 12:50 p.m., and 12:55 p.m. are positive and statistically significant at the 99% level of confidence for the 2- and 5-year multiple-price auctions combined, and are statistically significant at the 99% and 95% levels of confidence for the 3- and 10-year multiple-price auctions. Meanwhile, uniform-price auction spreads at the same times continue to be statistically indistinguishable from zero.

The relative consistency in the behavior of yield spreads at the different points in time prior to 1:00 p.m. with those observed at 1:00 p.m. provides additional support for the assumption that the contemporaneous WI bid yields are an accurate reflection of the market value of the securities at the times of auctions.

Other Issues

In the following sections we look at issues raised by other researchers that, according to auction theory, may influence expected revenue under the two auction techniques. First, we look at how uncertainty may affect the markups at auctions. As part of this examination, we look at both bid dispersion and volatility of WI yields as proxies for uncertainty. Next, we look at movements in WI yields throughout auction days in an attempt to compare volatility in the WI market under the two techniques, and also to examine the concept that has been put forward that volatility in the WI market prior to auctions is associated with the release of private bidder information. Finally, we look at intraday movements in yields in the WI market in an attempt to find evidence of differences in either information sharing or strategic bidding behavior under the two auction formats.

Auction markups and the dispersion of bids

As discussed earlier, auction theory suggests that uncertainty will have an impact on auction results. Specifically, auction theory predicts that uncertainty will increase bid dispersion. As bid dispersion increases, for a given number of bidders, the likelihood that rival bidders will submit bids slightly stronger than one's own bids decreases. Consequently, each bidder can shade his bid lower without reducing the likelihood of receiving the auctioned goods, and revenue to the seller declines.

To test the relationship between uncertainty and the dispersion of bids, we used volatility of WI bid yields as a proxy for uncertainty. We regressed the dispersion of

auction bid yields in 2- and 5-year note auctions against volatility, as measured by the standard deviation of WI market bid yields , during several time periods before auctions. The results (not shown) indicate that there is a positive relationship between the volatility of WI bid yields in the half hour before auctions and the dispersion of bids under both auction formats. Moreover, the impact is of a comparable magnitude under both the multiple- and the uniform-price techniques.

However, volatility exhibited differing impacts on dispersions of bids over longer time periods according to the auction technique used. For multiple-price auctions, volatility over longer time periods, such as at 1-, 2-, and 3-hour periods before the auction, had a very small and statistically insignificant impact on the dispersion of bids. For uniform-price auctions, however, there was a much stronger positive relationship between volatility and bid dispersion in the 1-, 2-, and 3-hour periods prior to auctions.[47]

Next, given evidence that uncertainty (as measured by volatility) is positively related to the dispersion of bids, we directly examine the impact of the dispersion of bids on auction markups. To look at this, we regressed the auction markup against the dispersion of bids and against the modified duration of the auctioned securities. Duration is included because, as a measure of price sensitivity, it may be considered a risk factor in auctions.[48] The results are shown in Table 1 and indicate that bid dispersion has a positive and statistically significant impact on markups in both multiple- and uniform-price auctions. The results, however, suggest that the markup is nearly twice as sensitive to bid dispersion under the uniform-price format than under the multiple-price.

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[47] This relationship was statistically significant at the 99% level for the 2- and 3-hour periods but not quite significant at the 95% level for the 1-hour period.

[48] Simon (1994) included duration in his regression analysis, which compared WI yield volatility and the markup. We discuss his results in greater detail in the next section.

Table 1

Markups versus Dispersion of Bids

Multiple- and Uniform-price Auctions

2- and 5-year Notes

(June 1991 - November 1994)

Markup regressed on:	Multiple-price	Uniform-price
Intercept	-0.615**	-5.926**
	(0.266)	(1.663)
Dispersion of Bids	0.776**	1.540**
	(0.222)	(0.363)
Duration of auctioned securities	-0.030	-0.273
	(0.052)	(0.152)
R^2	0.30	0.33
D.W.	1.69	2.09

Standard errors are shown in parentheses. Two asterisks indicate statistical significance at the 99% level. The regressions are estimated with ordinary least squares and White's (1980) correction for heteroskedasticity.

Given this result, it should be noted that bid dispersion is also much more volatile from auction to auction under the uniform-price format. Charts 9 and 10 show the average distribution of bids under each auction technique for both the 2- and the 5-year note auctions. It is evident from these graphs that bids are submitted over a much broader range in uniform-price auctions. However, although the average bid dispersion looks like a relatively smooth, uniform-distribution, an auction by auction analysis of the same data reveals a great deal of variability in the distribution of bids for uniform-price auctions. The mean and standard deviation of bids vary widely, and in many cases, the distribution displays several modes. Consequently, this analysis suggests that the increased volatility

of auction-to-auction results under the uniform-price technique is due to a large extent to more volatile dispersion of bids from auction to auction.[49]

Auction markups and volatility of WI yields

Other researchers have examined the relationship between auction markups and uncertainty using the volatility of WI bid yields prior to auctions because they do not have data on the actual distributions of bids. As a check on the results obtained above using the bid dispersions, and to verify the results of others using our data, we will also examine the relationship between auction markups and uncertainty as measured by the volatility of WI yields. To find the appropriate time frame over which uncertainty is a factor affecting the behavior of bidders, we examined volatility of WI bid yields at various time intervals prior to auctions. We also looked at this relationship for both multiple- and uniform-price auctions in order to determine whether volatility has a different impact on auctions according to the technique used.

Before presenting our results, however, we briefly examine the findings of Simon (1994). Simon examined the impact of uncertainty on the markups in multiple-price Treasury coupon auctions from January 1990 through September 1991. He found that uncertainty in the half hour before auctions has a positive and statistically significant impact on markups.[50] That is, an increase in uncertainty prior to auctions leads to increases in the markups that successful bidders receive at auctions. Moreover, he found that markups are not impacted by the volatility of WI yields for longer time periods on the mornings of auctions.

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[49] As previously noted, the reporting of uniform-price auction results in terms of a stop-out yield as opposed to an average yield also plays a role in volatility of auction results.

[50] Simon used the standard deviation of WI bid yields in the half hour before Treasury auctions in 10-minute intervals as a proxy for uncertainty. He also included duration in his analysis because, as a measure of the price sensitivity of the auctioned security, it represents a risk factor in auctions.

We regressed the markups at auctions against uncertainty and duration for the 2- and 5-year multiple-price Treasury note auctions from June 1991 to August 1992 and on uniform-price auctions from September 1992 to November 1994. The results are listed in Tables 2 and 3.

Table 2
Markups versus Volatility
Multiple-price Auctions
2- and 5-year Notes
(June 1991 - August 1992)

Auction Markups regressed on:	
Intercept	0.232 (0.198)
Standard deviation of WI yields (in ½ hour before auctions)	1.177 (0.614)
Duration of auctioned securities	-0.058 (0.063)
R^2	0.13
D.W.	1.82

Standard errors are shown in parentheses. The regressions are estimated with ordinary least squares and White's (1980) correction for heteroskedasticity.

Like Simon, we found evidence that in multiple-price auctions, increases in the volatility of WI yields prior to auctions lead to increased markups (the results are just below the 95 percent significance level). The results in Table 2 show that a 1 basis point increase in the standard deviation of WI bid yields in the half hour prior to an auction will lead to a 1.18 basis point increase in the markup, a comparable but somewhat stronger impact than the 0.83 basis point increase reported by Simon. Other regression results that are not shown, indicate that the volatility of WI bid yields over 1-, 2-, and 3-hour periods prior to auctions does not affect markups in multiple-price auctions. This is also consistent

with Simon's findings. Additionally, we found that duration is not a statistically significant explanatory variable, but its inclusion in the regression equation improves the results.

Table 3
Markups versus Volatility
Uniform-price Auctions
2- and 5-year Notes
(September 1992 - November 1994)

Markup regressed on:	½ hour before auctions	1 hour before auctions	2 hours before auctions	3 hours before auctions
Intercept	-0.856 (0.707)	-0.707 (0.749)	-0.599 (0.706)	-0.390 (0.643)
Standard deviation of WI yields before auctions	4.391** (1.115)	2.858** (0.939)	2.079** (0.684)	1.544** (0.496)
Duration of auctioned securities	-0.103 (0.180)	-0.081 (0.190)	-0.164 (0.187)	-0.224 (0.198)
R^2	0.21	0.13	0.14	0.12
D.W.	1.93	2.04	2.08	2.12

Standard errors are shown in parentheses. Two asterisks indicate statistical significance at the 99% level. The regressions are estimated with ordinary least squares and White's (1980) correction for heteroskedasticity.

For uniform-price auctions, we found that the volatility of WI yields in the half hour prior to auctions has a stronger impact on markups. The results shown in Table 3 indicate that a 1 basis point increase in volatility will lead to a 4.39 basis point increase in the auction markup. Once again, duration is a statistically insignificant variable, but its inclusion improves the overall regression results.

More significantly, the data suggest that markups at uniform-price auctions are related to the tone of the market over longer periods on the mornings of auctions. Volatility in the WI market at 1-, 2-, and 3-hour periods prior to uniform-price auctions has a positive and statistically significant impact on markups.

In fact, the volatility of yields has an increasingly strong impact on markups as the auction time draws closer. Table 3 shows the regression results for various time periods leading up to auctions. These results indicate that a 1 basis point increase in volatility in the 3-hour period before an auction will increase the auction markup by 1.54 basis points. In the 2-hour period before an auction, the same rise in volatility will raise the markup by 2.08 basis points, and in the hour before an auction, the increase will be 2.86 basis points.

Nyborg and Sundaresan (1995) also examined the volatility of WI bid yields prior to Treasury auctions. In their analysis, however, the volatility of WI bid yields represents the release of information. Thus, WI bid yield volatility is related to a reduction in uncertainty rather than an augmentation of it. Our analysis appears to support the notion that WI volatility is a sign of uncertainty rather than an indicator of the revelation of information since increases in volatility lead to increases in the size of auction markups. If volatility indicated an increase in the release of information, one would expect the regression coefficient to show a negative sign. That is, increases in volatility would reduce markups because bidders would be more certain of the demand for the securities to be auctioned and/or of opposing bidders' strategies.

One final observation concerning uncertainty and the markup might also be made. Given the volatility of auction-to-auction results and the greater sensitivity to the tone of the market prior to auctions, it appears that uniform-price auction markups may be impacted to a greater degree by events that occur on the mornings of auctions. That is,

events that unsettle the markets may have a stronger impact on uniform- than on multiple-price auctions. In the case of uniform-price auctions, uncertainty may augment an already-broad distribution of bids, thereby further contributing to volatile auction-to-auction results. This notion is supported by additional empirical evidence: in our sample only one of the 2-year and 5-year note multiple-price auction averages has come in 2 basis points above the contemporaneous WI bid yield (the rest were one basis point or less), while uniform-price results have been as much as 7 basis points higher than the relevant WI bid yield.

Intraday movements in WI yields

Intraday movements in WI yields are considered relevant because they provide publicly available information on the "common value" of a WI security as an auction approaches. As noted earlier, it has been argued that dealers are more likely to reveal more private information in the pre-auction WI market under a uniform-price format than under a multiple-price format because it is of less value in the auctions. Also, changes in WI bid yields after auctions may provide information regarding bidding strategies and the aggressiveness of auction bidding relative to subsequent market values. First, we take up the issue of information release in the WI market under the two formats.

The argument goes that if more private information is released on the mornings of auctions, there should be more volatility in the pre-auction period of uniform-price auctions as WI market participants react to the new information. It then follows that, if there is more information available going into auctions, there should be less reaction to auction results and, thus, less volatility in WI market yields after auctions.

One way of looking at volatility is to examine how spreads of auction results relative to intraday WI bid yields vary across auctions for the two techniques.[51] Charts 11 and 12 show markedly higher volatility of spreads for uniform-price auctions than for multiple-price auctions on the mornings of auctions for both the 2- and 5-year notes. This result could be interpreted as being consistent with the notion that the release of information is associated with higher volatility.

Given the presence of increased volatility on the mornings of auctions under the uniform-price technique, one would expect volatility to fall following the release of results. This is, in fact, what happens. After results are released the level of volatility for the uniform-price auctions drops and becomes lower for both the 2-year and 5-year notes.[52] Later in the afternoon, on average, volatility drifts upward in a comparable fashion for both techniques.

The greater volatility of spreads of auction results to WI bid yields early on auction days and the reduced volatility after results are announced has been attributed by others to the release of information in the pre-auction WI market.[53] It can be interpreted alternately that these results are simply due to the greater volatility of auction-to-auction results with respect to the WI market under the uniform-price format, and are not necessarily related to any significant difference in WI market volatility between the two auction formats.

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[51] Volatility of spreads across auctions at various times on auction day is calculated by taking the sample standard deviation of spreads (auction result minus WI bid yield) across auctions at 5-minute intervals and then taking a 15 minute rolling average.

[52] The average amount of time between auctions and announcements of results was 61.5 minutes and 59.0 minutes for the 2- and 5-year multiple-price auctions, and 54.5 minutes and 49.0 minutes for the 2- and 5-year uniform-price auctions, respectively.

[53] See Bikhchandani and Huang (1989) and Nyborg and Sundaresan (1995).

To examine this, we compared WI bid yields at various points in the day to the WI bid yield at a specific time (1:00 p.m.) rather than to auction results. Charts 13 and 14 demonstrate how spreads of 1:00 p.m. WI bid yields to intraday WI bid yields vary across auctions for the 2- and 5-year note auctions under both auction formats. (Using this measure, it is quite natural to expect volatility to be higher farther away from 1:00 p.m. and to converge toward zero at 1:00 p.m.) As shown, the variability of spreads of WI bid yields at various times during a day to the 1:00 p.m. WI bid yields is highly comparable under the two formats. In the mornings, standard deviations are higher and drift downward as auction time approaches. After auction time, the pattern of volatility is similar and drifts upward. Thus, when the spreads of WI bid yields are examined relative to another WI bid yield, rather than to auction results, the data indicates that there is little distinction in intraday yield volatility between the two auction techniques.[54]

These results are contrary to what one would expect if more private information is revealed in the pre-auction WI market under a uniform-price auction format, and such information release is associated with an increase in volatility.

Strategic behavior

Some analysts have suggested that the multiple-price auction technique is more susceptible to information sharing and/or the implementation of strategic bidding strategies following aggressively bid auctions. To examine this hypothesis with our data, we looked the relationship between the aggressiveness of bidding at auctions and subsequent movements in WI bid yields.

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[54] Another way to measure volatility is to examine intraday movements in spreads, or to observe how spreads vary throughout each auction day, and then take an average of this measure for each technique. However, examination of intraday WI market volatility using this measure does not show a definitive pattern of greater volatility on the mornings of uniform-price auctions, nor does it show less of a reaction to auction results.

If bidders share information regarding the aggressiveness of bidding before results are announced, it has been argued that WI yields would react accordingly. More specifically, WI yields would be expected to fall after an aggressively bid auction as prices are bid up, and to rise (prices fall) following a poorly bid auction.

Alternately, it has been suggested that the movement in WI yields before auction results are announced might be explained by the implementation of strategic bidding strategies by aggressive bidders in the auction. It has been suggested that such bidders might purchase additional securities in the WI market following the auction, thereby further bidding up prices. This allows those same bidders to control a larger share of the securities, which they can sell at a premium in the WI market following the announcement of auction results. Presumably, this strategy is only effective following aggressively bid auctions.

By contrast, bearish market participants do not have the same opportunity to bid strategically since bearish participants cannot sell securities in the auction. Although they have the option of shorting securities following the auction, participants pursuing such a strategy face the risk of having to cover their positions at unexpectedly high prices following a surprisingly strong auction. As a result, one would expect yields to fall after an aggressively bid auction when strategic trading takes place, but one would not expect a correspondingly strong rise in yields after a poorly bid auction.

Simon (1994) and Nyborg and Sundaresan (1995) each examined the behavior of WI bid yields at various times following Treasury auctions in order to determine whether information sharing or strategic trading took place. For Treasury coupon auctions from January 1990 through September 1991, Simon found that there was a statistically significant positive relationship between the markups at Treasury auctions and the movement of WI bid yields from the time of an auction to five minutes before the release of results. Additionally, Simon tested this relationship when Treasury auctions with negative markups (i.e. aggressively bid auctions) were excluded and found that the results

were no longer statistically significant. Consequently, he concluded that this asymmetry of results supported the notion that the movement of WI yields before auction results are announced is not due to information sharing. Rather, strategic trading may be taking place whereby aggressive bidders in an auction augment their positions in the WI market and simultaneously bid up prices.

Nyborg and Sundaresan came to the same conclusion as Simon regarding strategic trading for multiple-price auctions from July 1992 to August 1993. However, their regression coefficients suggest a weaker association between markups and WI yield movements and are not statistically significant. Nyborg and Sundaresan also examined uniform-price auctions and found that there was no association between markups and WI yield movements before results are announced, suggesting that neither strategic trading nor informational advantages are present in this auction format.

We examined the relationship between markups and WI bid yield movements during various time periods following 2-year and 5-year note auctions. First we regressed the change in WI bid yields from the time of an auction to five minutes before auction results were announced against the auction markup and against duration. In the case of multiple-price auctions there was no statistically significant evidence that markups had an impact on the movements of WI bid yields before auction results were announced (results are not shown). Furthermore, there was no evidence that markups had an impact on movements in WI yields when auctions with negative markups were excluded. This appears to indicate that neither information sharing nor strategic trading was a factor following the multiple-price auctions that we examined.

In the case of uniform-price auctions we found a statistically significant positive relationship between auction markups and the movements in WI yields between an auction and five minutes before results were announced. In addition, when we excluded auctions with negative markups (i.e., aggressively bid auctions) the coefficient on markups became greater and remained statistically significant. Moreover, when we ran the same regression

for only auctions with negative markups, the results were no longer significant. These results indicate that in the case of uniform-price auctions, there was an asymmetric movement in yields. That is, yields rose before results were announced following poorly bid auctions, but they did not fall after aggressively bid auctions. However, it would be difficult for participants with bearish sentiments entering auctions to impact after-auction markups to the same extent as bullish bidders. Thus, these results are open to question.

In order to determine the extent to which information regarding the aggressiveness of bidding is revealed before and after auction results are announced, we regressed the movements of WI bid yields from five minutes before to five minutes after the announcement of auction results and from auction time to five minutes after the results are announced against markups and duration. For multiple-price auctions, the results showed a positive and statistically significant relationship between the movements in yields and markups for both periods. Moreover, the yield movements showed a virtually one-to-one mapping. This suggests that there is very little sharing of information before multiple-price auction results are announced. Rather, the aggressiveness of bidding is reflected in WI yield movements only after results have been announced.

The results of our analysis for uniform-price auctions differed somewhat. They indicate that the movement in WI bid yields from five minutes before to five minutes after the result announcement is about twice as strong as the yield movement prior to the announcement. Thus, for uniform-price auctions, about one-third of the reaction to the aggressiveness of bidding occurs before the results are announced, and two-thirds occurs afterwards.

In summary, there is little if any evidence that information sharing and/or strategic trading takes place under either auction technique. In the case of uniform-price auctions, it appears that there is some reaction to the aggressiveness of bidding before auction results are announced, but only after poorly bid auctions. This suggests that some information

may enter the pre-announcement market following a weak auction, but it is unlikely that strategic bidders could act effectively.

V. Summary and Conclusions

The Treasury's purpose in conducting uniform-price auctions is to determine whether the uniform-price auction technique reduces the Treasury's financing costs compared with multiple-price auctions, by encouraging more aggressive bidding by participants, and whether it broadens participation and reduces concentration of securities on original issue. Thus, the evaluation has focused on the impact on revenues and the breadth of initial distribution of awards.

In addition to auction technique, a constellation of other factors also affects auction results, such as the economic outlook, expectations for movements in absolute or relative interest rates, and any other factors affecting the portfolio decisions of dealers and investors. For example, since the Salomon Brothers revelations in 1991 the Treasury auction process and secondary market trading practices have undergone regulatory and other changes that may also have had an impact on bidding strategies and trading practices of market participants.

The confluence of these and other factors produces significant auction-to-auction volatility in the data, making it difficult to isolate the impact of auction technique itself. Despite our inability to examine auction technique as in a laboratory setting, we can make inferences based on our analysis regarding the impacts of auction technique on the distribution of securities and on revenues.

Our methodology was to compare auction results and WI market trading patterns for the 2-year and 5-year notes under the two techniques. We then examined whether any

differences in performance are consistent with the purpose of conducting uniform-price auctions and whether the differences are consistent with the predictions of auction theory.

In attempting to isolate changes due only to auction technique, we compared the performance of the 2-year and the 5-year notes under the two auction techniques to the 3-year and 10-year note multiple-price auctions over the whole time period. In many cases, however, inferences based on such comparisons are tenuous because of the small number of observations on the 3-year and 10-year notes and because of auction-to-auction volatility. Also, market participants do not view the 3-year and 10-year notes, which are auctioned quarterly and are traded less actively in the secondary market, as close substitutes for 2- and 5-year notes, which are auctioned monthly and are the most actively traded of all Treasury securities.

Impacts on the Distribution of Awards

Some researchers contend that uniform-price auctions will encourage more bidders to participate in competitive bidding by reducing the importance of specialized knowledge regarding market demand and the information costs associated with its collection. A corollary to increased participation is a reduction in the concentration of awards.

We found statistically significant evidence that the concentration of awards to the top primary dealers for their own accounts has been reduced. The data show a distinct, parametric reduction in award concentrations to the top dealers under the uniform-price technique. The average shares of awards of both 2-year and 5-year notes to the top five and top ten dealers declined, with the reductions ranging from about 5 to 15 percent. For the primary dealer community as a whole, the shares of awards in the 2-year and 5-year notes edged downward, but not by a statistically significant amount.

By contrast, the shares of awards to the top dealers in 3-year and 10-year note multiple-price auctions either remained essentially the same or increased significantly.

The shares of awards to dealers plus their large customers displayed essentially the same pattern as awards for dealers' own accounts. Also, awards for large customers alone increased, from around 17 percent to 25 percent for both the 2-year and 5-year notes, suggesting greater participation by large customers of dealers in auctions, rather than in the secondary market. Meanwhile, for 3-year and 10-year notes, the shares of awards to customers did not change significantly.

The reduced concentrations of awards to the top dealers may be attributed to two interrelated factors: a widening in the overall distribution of auction bids, as one might expect from auction theory; and resultant changes in the bidding strategies of the largest dealers. Under multiple-price auctions, there is a relatively tight distribution of large bids around the auction average because successful bidders pay the price actually bid. Under uniform-price auctions, however, the distribution of bids is much broader and the amounts bid at each yield tend to be smaller. The broader bid distribution follows from auction theory in that there is no penalty for submitting bids ahead of the market, unless such aggressive bids in the aggregate match or exceed the auctioned amount.

The evidence suggests that large dealers have changed bidding strategies, in response to expected wider bid distributions, by splitting bids into more numerous smaller bids -- some ahead of the market, some at the market, and some trailing off the market. The combined effect of the broader distribution of bids and the greater incidence of bid splitting is that the bids of the larger, usually more aggressive dealers are increasingly interspersed with the more aggressive bids of other market participants (particularly large customers) who are trying to ensure supply in an auction. The net result is that at the margin the share of awards to the top groups of primary dealers has decreased.

Impact on revenues

The impact of the uniform-price auction technique on revenues is more difficult to analyze because there is a vast array of factors that affect bidding at Treasury auctions. Nevertheless, we have directly tested for any differences in expected revenue from the two techniques; tested several hypotheses of auction theory; and examined the empirical results of other researchers with respect to our own findings.

The most direct way to determine the impact on expected revenue of auction technique would be to compare average auction yields under the two techniques and determine if there is a statistically significant difference. A direct comparison of auction yields, however, is difficult because yields vary from auction to auction, giving rise to the need for a common reference point. Yields in the contemporaneous WI market provide such a reference.

Thus, we examined the average spreads between auction yields and the appropriate WI yields for each technique. Our results show that the average spreads for uniform-price auctions are smaller than those for multiple-price auctions, but the difference is not statistically significant. On this basis, we are unable to conclude that there is a difference in expected revenue.

However, by examining the average auction spreads separately and testing whether each spread is statistically distinguishable from zero, we did obtain statistically significant results. The data show that the average spread is different from zero in multiple-price auctions, whereas there is no similar evidence for the uniform-price technique. On this basis, expected revenue under the uniform-price technique is marginally greater than under the multiple-price technique.

The primary reason for the lack of a statistically significant difference between auction yields and WI yields under the uniform-price auction technique is greater auction-

to-auction volatility of the results with respect to the WI market. The greater volatility is partly a result of the broader and more volatile distributions of bids, and partly a result of the difference in the yield measure used to report auction results under the two techniques. In multiple-price auctions, an average yield concept is used, while in uniform-price auctions, the reported yield is not an average, but a marginal or stop-out yield. An average of a relatively stable set of numbers is inherently less volatile than the endpoint of another set of numbers that exhibits more variability. Thus, uniform-price auctions may produce greater revenue on average, but present greater uncertainty regarding revenue at any given auction.

Since there is increased volatility of auction results relative to WI yields under the uniform-price technique, the outcome of any given auction is less certain, and therefore, participants may be more cautious in bidding under this regime when uncertainty increases. Our analysis suggests that auction results with respect to the contemporaneous WI market are affected by the tone of the market on the mornings of auctions. The volatility in the WI market on the mornings of auctions has a stronger impact on markups for uniform-price auctions than for multiple-price auctions. This may lead to a potential loss of revenue to the Treasury in times when the markets are unsettled.

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APPENDIX OF CHARTS

Large Competitive Awards to Primary Dealers
And Awards to Primary Dealers Plus Their Large Customers
as a Percentage of Total Private Awards#

		Dealer Own Accounts		Dealers Plus Their Large Customers	
	Top	Jan '90-Aug '92	Sept '92-Dec '94	Jan '90-Aug '92	Sept '92-Dec '94
Two-Year	5	38.3	31.1 *	48.4	44.5
	10	50.8	45.4 *	63.5	64.1
	All Dealers	66.2	63.4	81.4	87.9 *
Five-Year	5	46.3	32.0 *	59.1	44.0 *
	10	57.1	46.6 *	72.4	63.7 *
	All Dealers	69.2	63.9	87.2	88.2
Three-Year	5	41.8	43.5	51.8	57.2
	10	53.5	55.3	65.2	72.6 *
	All Dealers	67.6	68.2	82.0	88.1 *
Ten-Year	5	40.7	54.8 *	60.3	61.8
	10	54.5	67.2 *	75.5	76.9
	All Dealers	71.5	78.7	91.5	92.0

* Indicates that percentage is significantly different from the previous period at the 95% level.

#Large competitive awards (based on bids greater than or equal to $1 million) to primary dealers for their own accounts and awards to their customers through the New York, Chicago, and San Francisco Federal Reserve Banks and branches.

Department of the Treasury
Office of Market Finance

Top Competitive Awards
to Primary Dealers' Large Customers#

Two-Year

	As Percent of Total Private Awards	
Top	Jan '90-Aug '92	Sept '92-Dec '94
5	12.9	16.1
10	14.8	20.0 *
All	16.3	25.5 *

Five-Year

	As Percent of Total Private Awards	
Top	Jan '90-Aug '92	Sept '92-Dec '94
5	14.5	15.6
10	16.8	19.7
All	18.6	25.3 *

Three-Year

	As Percent of Total Private Awards	
Top	Jan '90-Aug '92	Sept '92-Dec '94
5	12.1	13.1
10	13.8	15.7
All	15.5	18.9

Ten-Year

	As Percent of Total Private Awards	
Top	Jan '90-Aug '92	Sept '92-Dec '94
5	15.1	9.4
10	17.6	11.5
All	20.0	13.7

* Indicates that percentage is significantly different from the previous period at the 95% level.

#Large competitive awards (based on bids greater than or equal to $1 million) to the customers of primary dealers through the New York, Chicago, and San Francisco Federal Reserve Banks and branches.

Department of the Treasury
Office of Market Finance

Top Large Competitive Awards
to Primary Dealers, Large Customers, or Direct Bidders#

Two-Year

	As Percent of Total Private Awards	
Top	Jan '90-Aug '92	Sept '92-Dec '94
5	45.5	35.8 *
10	61.3	53.6 *
All	87.9	91.9 *

Five-Year

	As Percent of Total Private Awards	
Top	Jan '90-Aug '92	Sept '92-Dec '94
5	53.1	35.8 *
10	67.5	54.6 *
All	91.1	92.7

Three-Year

	As Percent of Total Private Awards	
Top	Jan '90-Aug '92	Sept '92-Dec '94
5	50.7	49.6
10	64.4	65.4
All	89.4	93.4

Ten-Year

	As Percent of Total Private Awards	
Top	Jan '90-Aug '92	Sept '92-Dec '94
5	49.9	57.0
10	67.1	72.0
All	93.6	95.0

* Indicates that percentage is significantly different from the previous period at the 95% level.

#Large competitive awards (based on bids greater than or equal to $1 million) to primary dealers for own accounts, to customers of primary dealers, or to direct bidders through the New York, Chicago, and San Francisco Federal Reserve Banks and branches.

Department of the Treasury
Office of Market Finance

Average Spreads Between Auction Results and 1:00 pm WI Bid Yields

(Basis Points, Standard Error in Parentheses)

Securities	Multiple-price Period 6/91-8/92	Uniform-price Period 9/92-9/95	Whole Period 6/91-9/95
2-YR			
	0.41 **	0.22	
	(0.13)	(0.26)	
5-YR			
	0.33 **	0.23	
	(0.06)	(0.32)	
2-YR & 5-YR			
	0.37 **	0.22	
	(0.07)	(0.20)	
3-YR			
	0.50	0.57 **	0.55 **
	(0.22)	(0.17)	(0.13)
10-YR			
	0.56	0.81 **	0.74 **
	(0.40)	(0.22)	(0.19)
3-YR & 10-YR			
	0.53 *	0.69 **	0.64 **
	(0.22)	(0.14)	(0.11)

* Significantly different from zero at the 95% level.

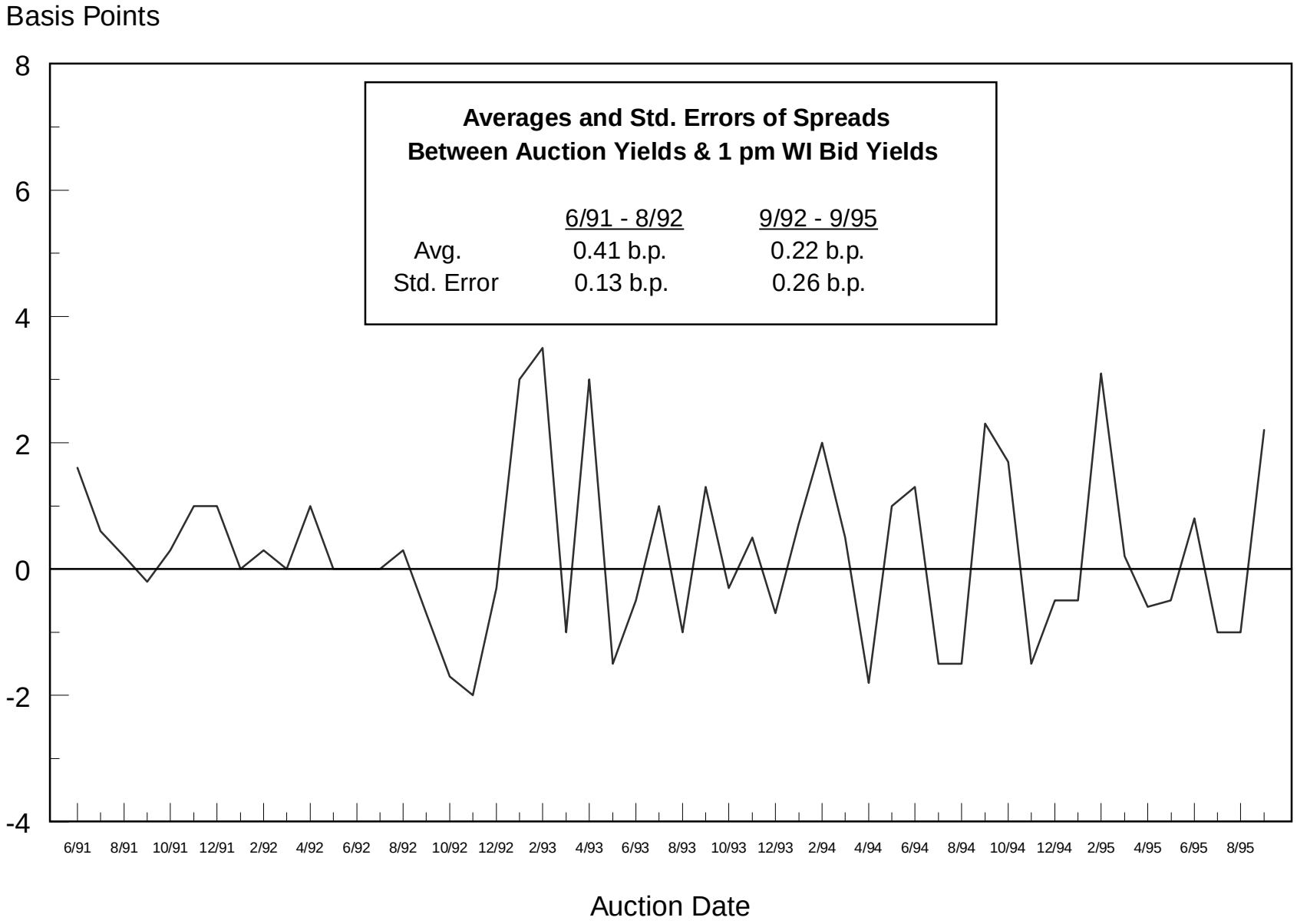
** Significantly different from zero at the 99% level.

Source: GOVPX, Inc.

Department of the Treasury
Office of Market Finance

Data for this chart is found in c:\data\123\dutchauc\spreads\avspda.wk4
in a spreadsheet with Chart 4_dat on the tab.
Data can also be duplicated using the sas programs in the debtfin
account on the vax. The program names are Newset2.sas, newset5.sas,
newset2_5.sas, newset3.sas, newset10.sas and newset3_10.sas

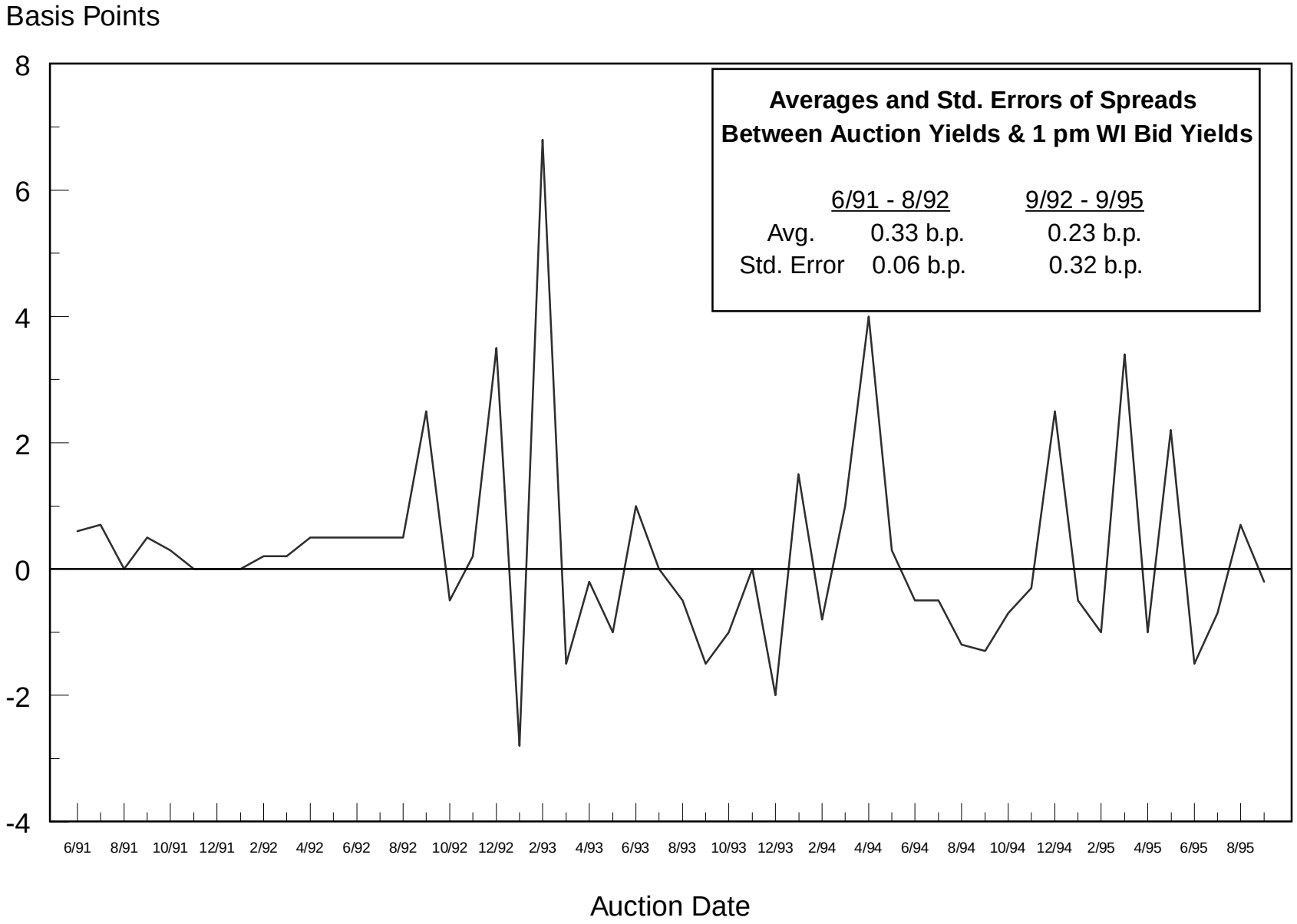
AUCTION SPREADS
AUCTION RESULTS - 1 PM WI BID YIELDS
2-YEAR NOTES
(June '91 through September '95)



Source: GOVPX, Inc.

Department of the Treasury
Office of Market Finance

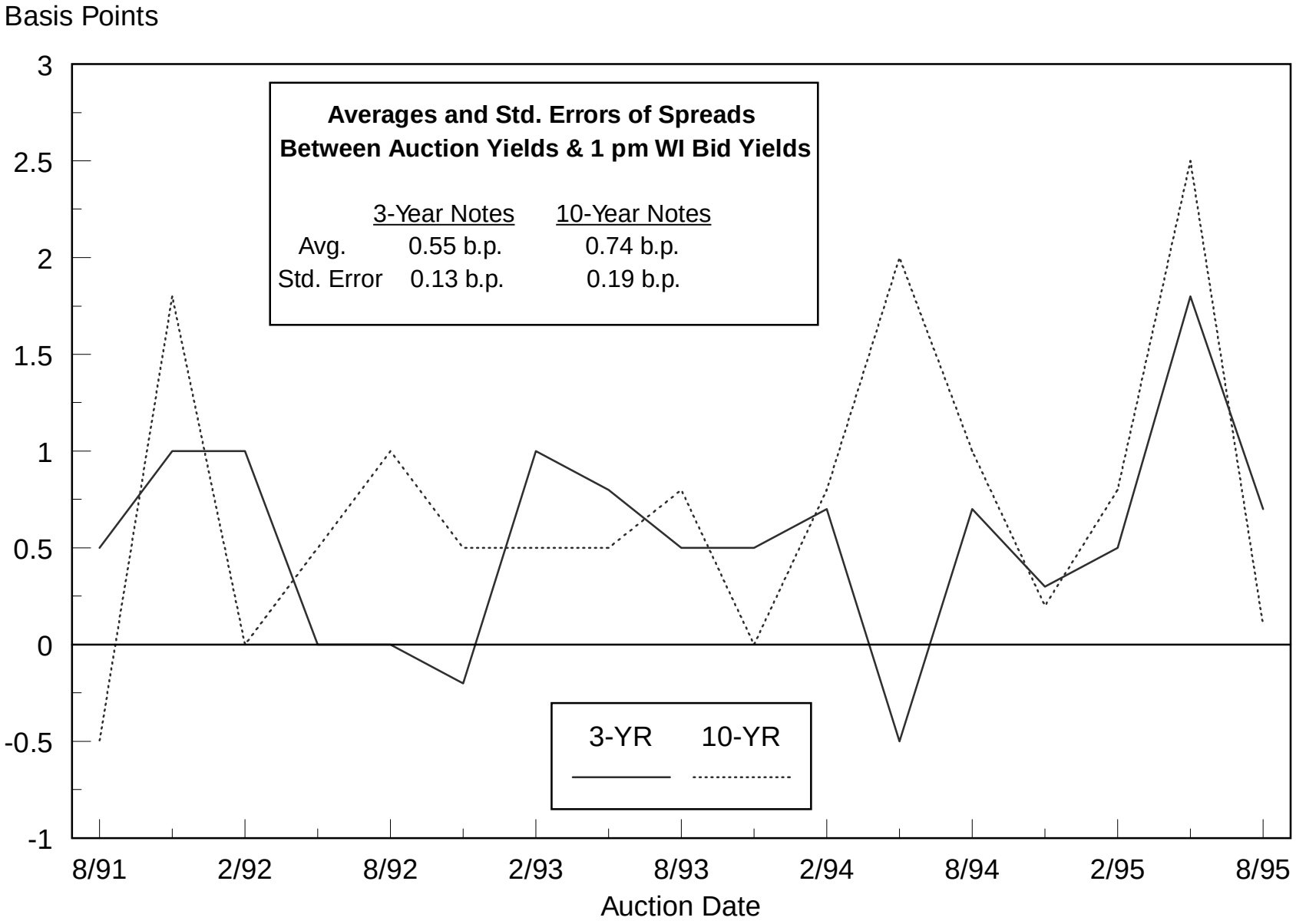
AUCTION SPREADS
AUCTION RESULTS - 1 PM WI BID YIELDS
5-YEAR NOTES
(June '91 through September '95)



Source: GOVPX, Inc.

Department of the Treasury
Office of Market Finance

AUCTION SPREADS
AUCTION RESULTS - 1 PM WI BID YIELDS
3-YEAR & 10-YEAR NOTES
(August '91 through August '95)



Source: GOVPX, Inc.

Department of the Treasury
Office of Market Finance

Average Spreads Between Auction Results and WI Bid Yields

(Basis Points, Standard Error in Parentheses)

Securities	6/91-8/92	9/92-11/94	Whole Period 6/91-11/94
2-YR & 5-YR			
1:00 pm	0.37 **	0.19	
	(0.07)	(0.25)	
12:55 pm	0.31 **	0.20	
	(0.08)	(0.27)	
12:50 pm	0.26 **	0.27	
	(0.08)	(0.28)	
12:45 pm	0.36 **	0.34	
	(0.09)	(0.30)	
3-YR & 10-YR			
1:00 pm	0.53 *	0.56 **	0.55 **
	(0.22)	(0.13)	(0.11)
12:55 pm	0.55 *	0.54 **	0.54 **
	(0.24)	(0.13)	(0.12)
12:50 pm	0.50	0.47 *	0.48 *
	(0.29)	(0.20)	(0.16)
12:45 pm	0.52	0.38	0.43 *
	(0.34)	(0.21)	(0.18)

* Significantly different from zero at the 95% level.

** Significantly different from zero at the 99% level.

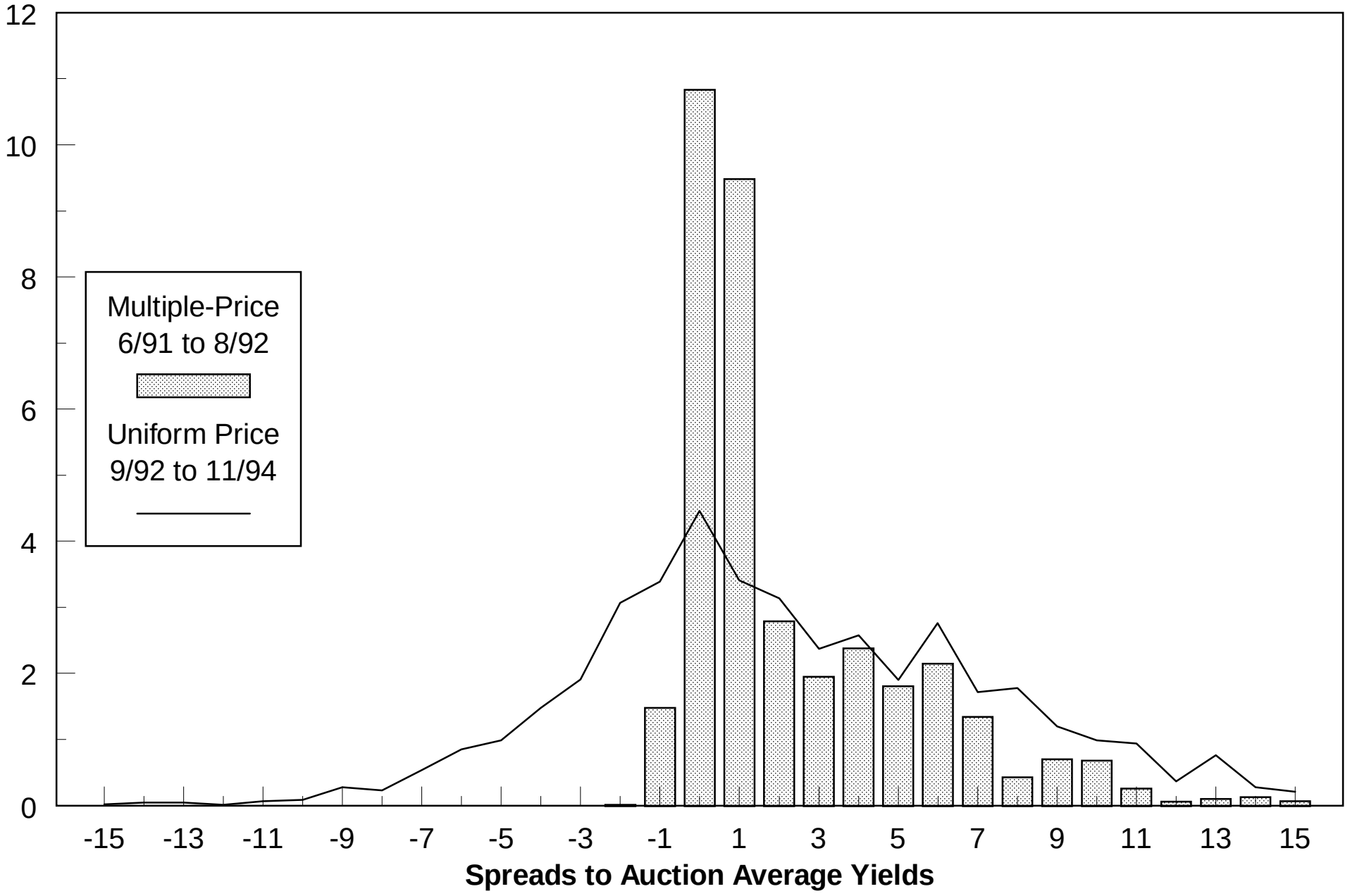
Department of the Treasury
Office of Market Finance

Data for this chart can be duplicated using the sas programs in the debtfin account on the vax. The program names are Newset2.sas, newset5.sas, newset2_5.sas, newset3.sas, newset10.sas and newset3_10.sas
Some (but not all) data for this chart is also found in c:\data\123\dutchauc\spreads\avspda.wk4 in a number of the spreadsheets.

Average Bids at Various Yields Relative to Auction Yield Results

Two-Year Notes

(June '91 through November '94)



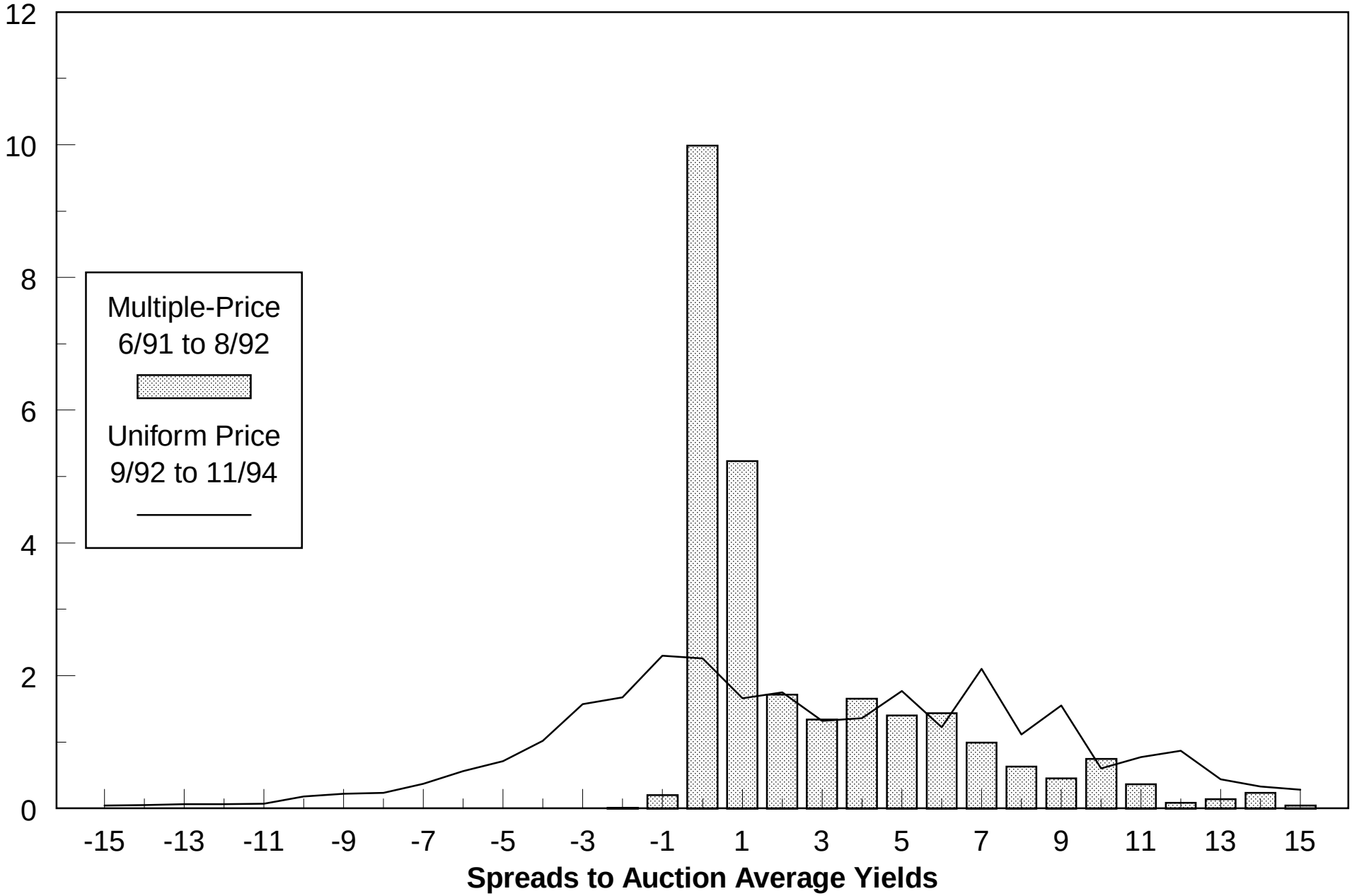
Note: Bid yields truncated at + or - 15 basis points with respect to auction yield results

Department of the Treasury
Office of Market Finance

Average Bids at Various Yields Relative to Auction Yield Results

Five-Year Notes

(June '91 through November '94)



Note: Bid yields are truncated at + or - 15 basis points with respect to auction yield results

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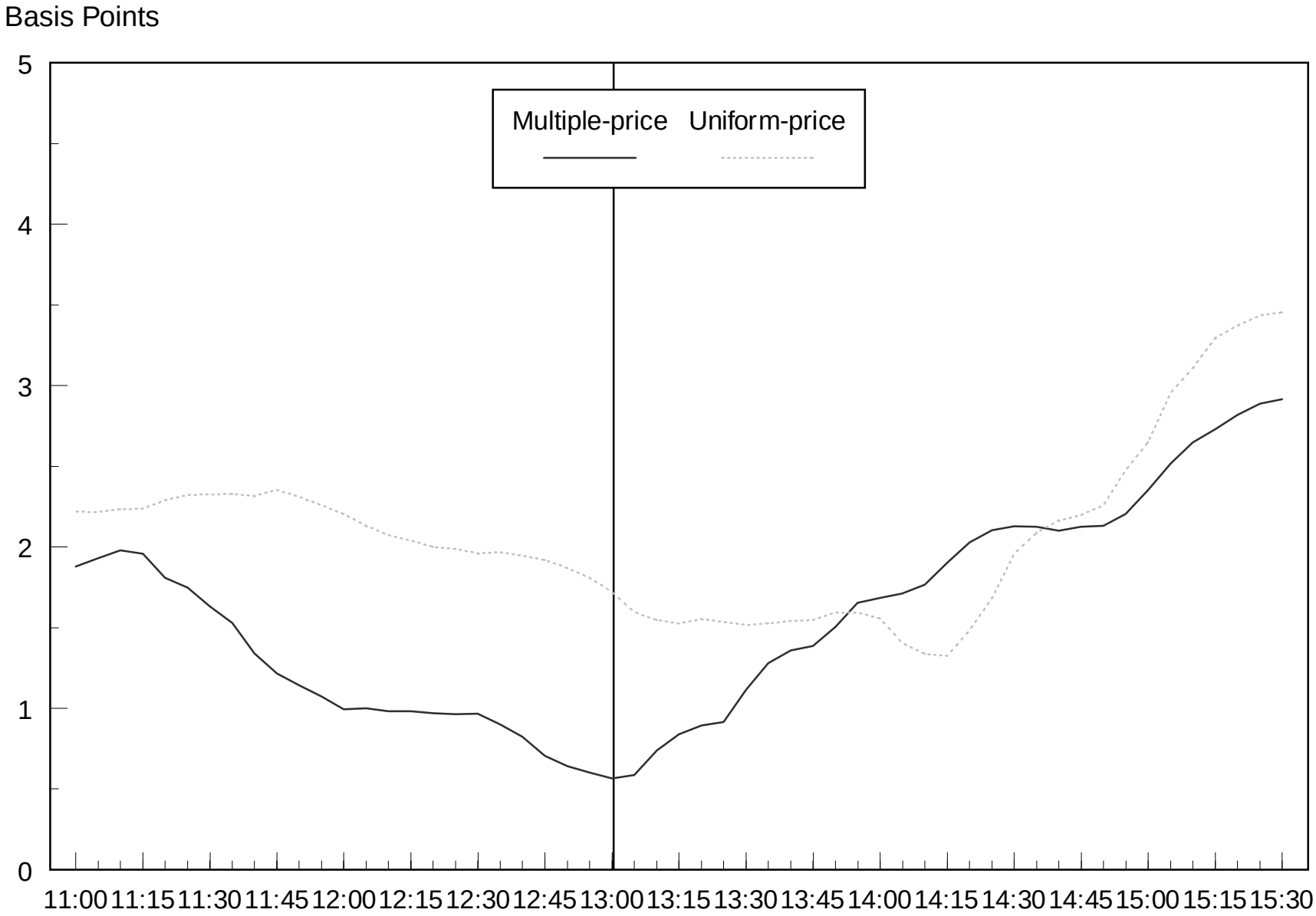
Office of Market Finance

VOLATILITY OF SPREADS BETWEEN AUCTION RESULTS AND INTRADAY WI BID YIELDS 2-YEAR NOTES



Source: GOVPX, Inc.
Data 6/91 through 11/94.

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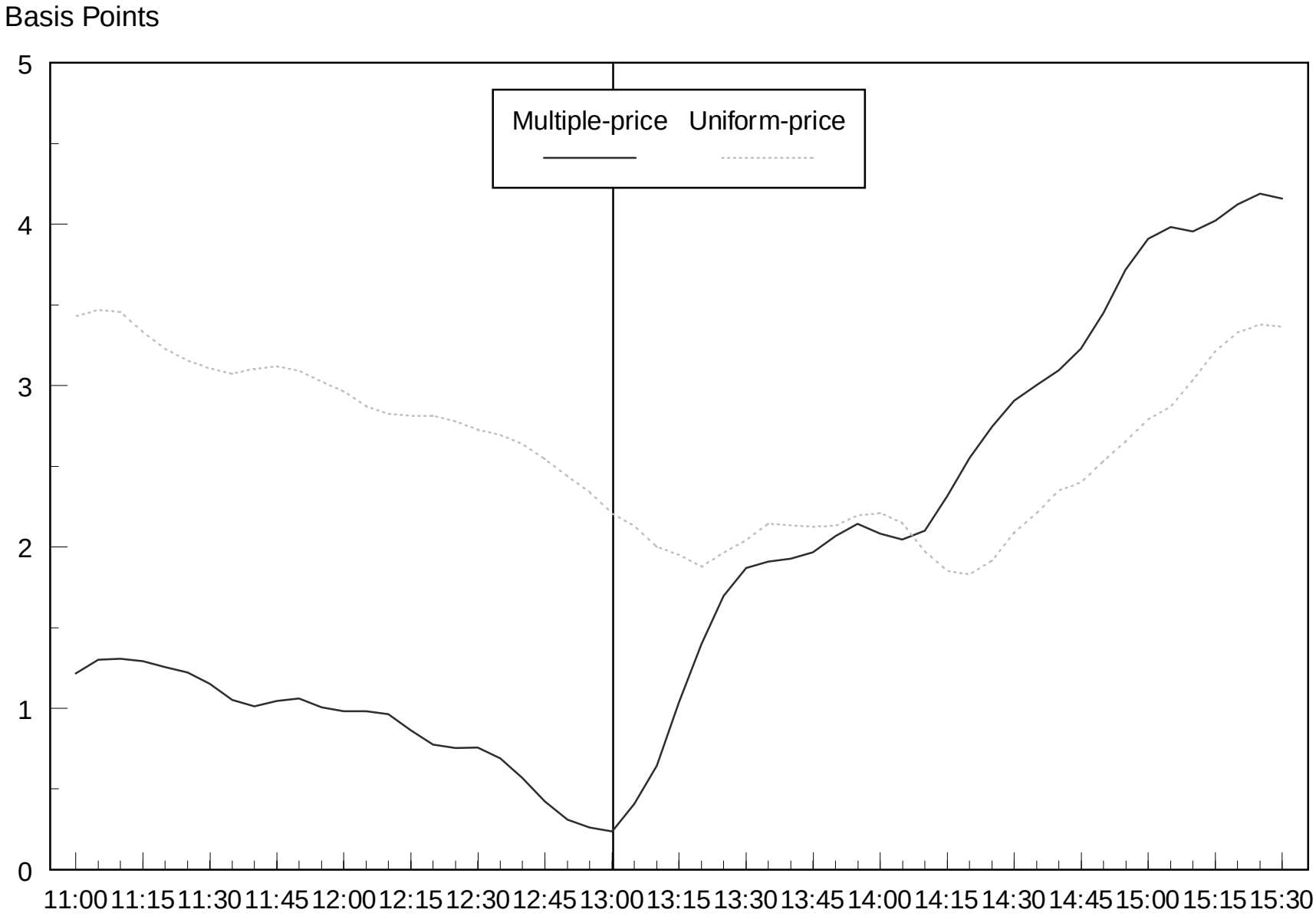
Office of Market Finance

VOLATILITY OF SPREADS BETWEEN AUCTION RESULTS AND INTRADAY WI BIDYIELDS 5-YEAR NOTES



Source: GOVPX, Inc.
Data 6/91 through 11/94.

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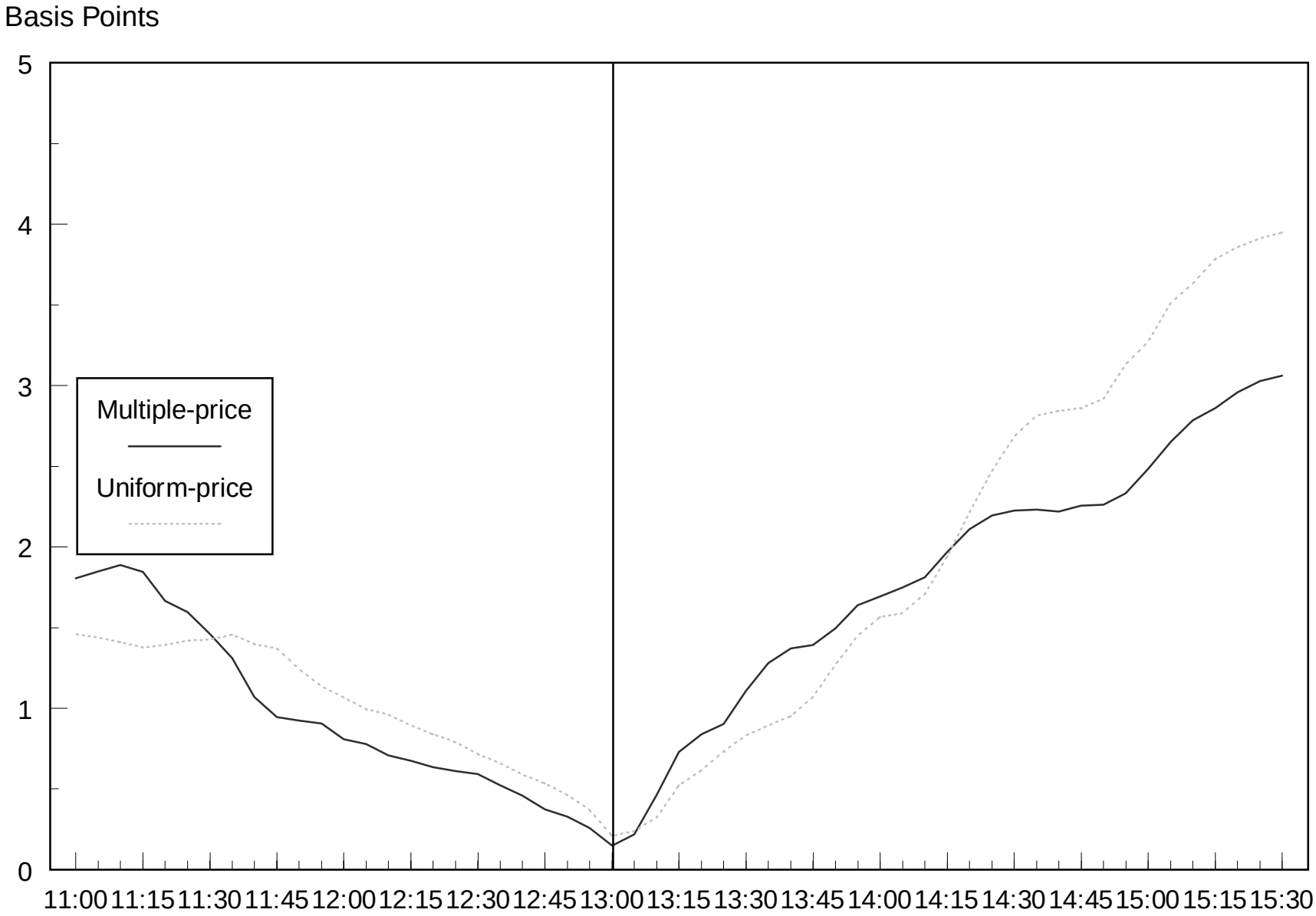
VOLATILITY OF SPREADS BETWEEN
1 PM WI BID YIELDS AND WI BID YIELDS AT OTHER TIMES
2-YEAR NOTES



Source: GOVPX, Inc.
Data 6/91 through 11/94.

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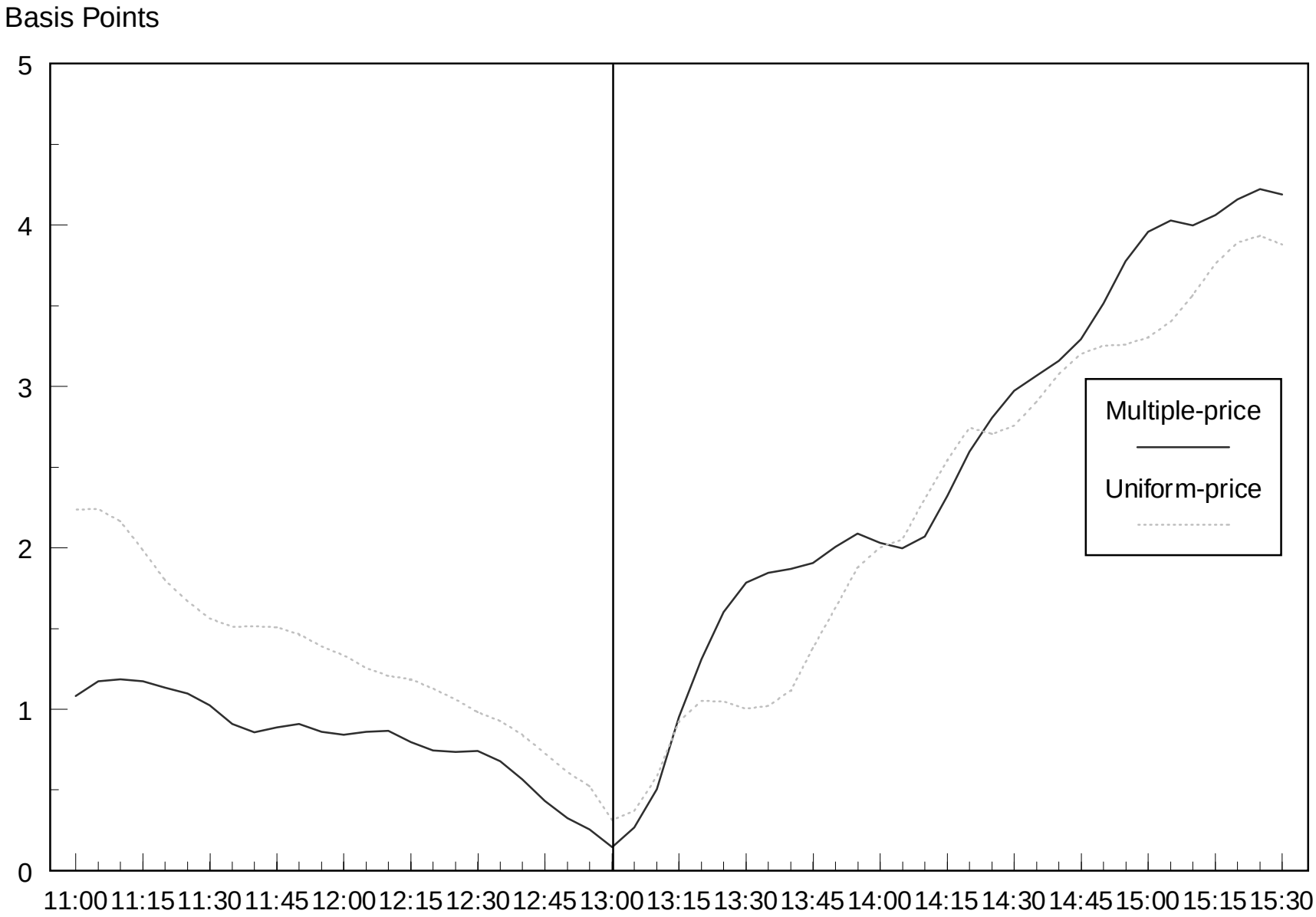
VOLATILITY OF SPREADS BETWEEN
1 PM WI BID YIELDS AND WI BID YIELDS AT OTHER TIMES
5-YEAR NOTES



Source: GOVPX, Inc.
Data 6/91 through 11/94.

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