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The Economics of Treasury Securities Markets

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The market for Treasury securities attracted considerable attention recently, after alleged infringements by Salomon Brothers. Several questions have been raised about the best way of selling U.S. government debt (Joint Report on the Government Securities Market, 1992). One issue is whether altering the auction format would yield greater revenues for the Treasury. Another related question is how susceptible the existing mechanism for selling Treasury securities is to manipulation by buyers. Our objective in this paper is to give an account of what economists' analyses of auctions implies about the market for Treasury securities.[1]

Types of Auctions

Every week the Department of Treasury auctions 13-week and 26-week bills. Less frequently, the Treasury auctions notes, bills, and bonds with longer maturities. For example, one-year bills are auctioned monthly and 30-year bonds are auctioned biannually; see Fabozzi (1991) for an auction schedule. Currently, there are 38 *primary dealers* who can submit sealed bids at the auction. A bid submitted by a primary dealer consists of a price and a quantity

[1]For more complete surveys of the auctions literature, see McAfee and McMillan (1987), Milgrom (1987), Wilson (forthcoming), and the "Symposium on Auctions" in the Summer 1989 issue of this journal, especially Milgrom (1989) and Riley (1989).

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that the dealer is willing to buy at that price.[2] These price-quantity pairs are called competitive bids and primary dealers are often referred to as competitive bidders. Although primary dealers may submit as many price-quantity bids as they like, conversations with some of them suggest that they often submit one or two bids only. The demands of the competitive bidders, starting with the highest price bidder down, are met until the supply is allocated. Winning competitive bidders pay the unit prices they submitted.

There are also noncompetitive bidders, mainly individual investors, who submit sealed bids that specify only the quantity sought, up to a maximum specified by the Treasury. The noncompetitive bids always win at a price equal to the quantity-weighted average of the winning competitive bids. The Federal Reserve Bank also participates in the auction, both on its own account and as an agent for foreign central banks. The Federal Reserve Bank can roll over maturing securities up to a pre-announced amount. Like noncompetitive bidders, the Federal Reserve Bank always wins and buys the securities at the quantity-weighted average of the winning competitive bids. Noncompetitive bids usually account for 15–20 percent of the amount sold in Treasury bill auctions.

After the auction, the Department of Treasury announces summary statistics about the bids submitted. These include total tender amount received, total tender amount accepted, highest winning bid, lowest winning bid, proportion of bids accepted at the lowest price, quantity-weighted average of winning bids, and the split between competitive and noncompetitive bids.

As winning bidders pay the unit price they submitted, this form of auction is known as a *discriminatory auction*. This method is also used by the Department of Interior to auction oil, minerals, and timber leases. Until recently, it was the only auction used by the Department of Treasury.

Although the discriminatory auction is still widely used, the Treasury department recently switched to a *uniform-price auction* for selling two-year and five-year notes.[3] A uniform-price auction also begins by having bidders submit sealed bids to the auctioneer. The demands of the bidders, starting with the highest price bidder down, are met until all the objects are allocated. However, the winning bidders pay only the highest losing bid, even if their bids were actually higher.

Ultimately, the Treasury may switch to an *ascending-price auction* to sell all its securities (Joint Report on the Government Securities Market, 1992, page xiv). In an ascending-price auction, the auctioneer starts with a very low price, and calls out an increasing sequence of prices. Bidders indicate their interest in buying at the current price. The auctioneer stops when the demand at the current price equals the supply. The demands of bidders interested in buying at this price are met. This type of auction is commonly used to sell art.

[2]Actually, bidders submit interest rate-quantity pairs. For expositional convenience, our discussion here is in terms of price-quantity pairs.

[3]See "New Process for Auctions to be Tested," *The New York Times*, September 3, 1992, pp. C11–C12.

A fourth method of auction worth considering here is the *descending-price auction*.[4] Starting with a very high price, the auctioneer calls out a decreasing sequence of prices until a bidder buys some of the objects at the current price. The remaining supply is sold using the same method, again starting with a very high price. This auction is used to sell tulips in the Netherlands.

An Overview of Some Auction Theory

It may seem reasonable to think of the U.S. Treasury securities market as perfectly competitive. After all, 38 primary dealers submit competitive bids in the Treasury securities markets, and thus no single bidder should have a significant impact. In addition, given that Treasury securities are auctioned regularly, there always exist close substitutes for the securities to be auctioned. These close substitutes are traded in secondary markets and their prices quoted openly. For example, when new 13-week bills are auctioned, the 26-week bills auctioned 13 weeks ago have 13 weeks to maturity and should be perfect substitutes for the new bills. Thus, it may be argued that all the primary dealers in the auction for 13-week bills should bid the current secondary market price of the 26-week bills auctioned 13 weeks earlier; there is no information content in the auction and no strategic play by the primary dealers.

Several features of the Treasury securities market, however, render the above argument invalid. First, even though the exact market shares of the primary dealers are not public information, conversations with the market participants indicate that a few of the 38 primary dealers dominate the market, especially in longer term Treasury securities.

Second, a newly auctioned Treasury security and an older Treasury security with the same maturity are not almost perfect substitutes because of differences in liquidity. Treasury securities traded in the secondary market fall into two broad categories—on-the-run and off-the-run—based on their issue dates. For example, a 10-year bond is on-the-run when it is auctioned and issued. It stays on-the-run until new 10-year bonds are auctioned and issued, when it becomes off-the-run. The secondary markets for on-the-run Treasury securities tend to be liquid as the primary dealers have a large inventory, while those for off-the-run Treasury securities tend to be illiquid as they are locked away in investors' portfolios. Two close substitutes of an on-the-run 10-year bond are an off-the-run 30-year bond auctioned 20 years ago and a 10-year bond auctioned three months ago. The market for the off-the-run 30-year bond would be very illiquid. The 10-year bond issued three months ago is near the end of its on-the-run cycle and is not as liquid as when it was freshly auctioned. As a result, the price of an on-the-run Treasury security is usually higher than

[4]Sometimes, academics and practitioners use conflicting names for different auction formats. For instance, academics refer to a descending-price auction as a "Dutch" auction whereas the financial community refers to a uniform-price auction as a "Dutch" auction (Joint Report on the Government Securities Market, 1992, pp. B17–B19). We avoid names that may cause confusion.

that of its off-the-run counterpart. Amihud and Mendelson (1991) find that the average yield of a Treasury note is 43 basis points higher than the yield of a Treasury bill with identical time to maturity, and this amount is significantly different from zero. (One basis point is one-hundredth of 1 percent.) Thus, there is substantial uncertainty about the prices of the Treasury securities to be auctioned.

The uncertainty about the value of the Treasury securities to be auctioned makes it worthwhile for the dominant players in the auction to behave strategically.[5] Consequently, before returning to the particulars of Treasury auctions, and discussing how the process might go wrong or be improved, we describe some of the general background of auction decision-making in more detail.

The Common Values Assumption

An auctioneer can control the rules of the auction, but may not be able to control the information and valuations of the bidders. These are largely determined by the nature of the objects being auctioned, and by other factors. To analyze the outcomes that a particular auction is likely to generate, it is necessary to place some structure on the values of the bidders.

Under the *common values assumption*, each bidder has the same value for the objects. The "same value" doesn't mean that bidders literally know what the object will be worth, of course, but rather that whoever gains the object will receive the same amount for it. Whenever bidders buy an object for resale rather than for personal consumption, the common values assumption is reasonable. In a Treasury securities auction, the common value assumption is appropriate because the value for each bidder is a common and unknown resale price. Therefore, the discussion in this paper will restrict itself to the case where the common values assumption holds.[6]

Although the resale value is unknown at the time of bidding, each bidder is presumed to have some private, imperfect information about the value, on which to base a bid. It is usually assumed that each dealer's estimate is unbiased; that is, on average the bidders' estimates of value are correct.

In the Treasury securities markets, the primary dealers' private information comes from two sources. First, primary dealers have their own forecasts of the movements of the term structure of interest rates. Second and more important, before the auction, institutional buyers such as pension funds and insurance companies place orders for Treasury securities to be auctioned with primary dealers. This conveys information about the demand for these securities.

[5]Later, in our discussion of the when-issued or forward market for Treasury securities, we provide direct empirical evidence of strategic behavior by market participants.

[6]Two other important cases are when the bidders' values are (i) privately known and independently distributed, or (ii) correlated but not common. Most of the results discussed in this paper extend to case (ii). Under case (i) the revenue-equivalence theorem holds—that is, all commonly observed auction formats yield the same average revenue. See the surveys cited in footnote 1.

The Winner's Curse

Bidders with common values are susceptible to the winner's curse. It occurs in this way: assume for simplicity that one indivisible object is for sale and that bidders use similar rules-of-thumb to calculate their bids based on their estimates of true underlying value. (For example, perhaps everyone bids 90 percent of what they believe the true value to be.) Remember that in a common value auction with many bidders, even though each bidder's estimate is unbiased, some estimates will be high and others low. As a result, the highest bidder (the winner) is usually the one who is most optimistic about the true value. Or to put it another way, upon winning, the successful bidder then learns something striking: all other bidders had lower estimates of true value! A bidder who fails to take this factor into account may easily bid too high, thus winning the auction but losing money. This phenomenon is called the winner's curse.[7]

The winner's curse has several implications for optimal bidding strategies. First, as the number of bidders increases (and other factors are held constant), it is usually optimal to bid more conservatively. This is because the highest of, say, ten estimates is likely to be much greater than the highest of two estimates. Thus, the winner's curse is reinforced as the number of bidders increases and, despite the increased competitive pressure, it often causes bidders to shade their bids below their estimates of true underlying value by a greater amount. Nevertheless, the effect of having more bidders tends to outweigh the incentives for bidding conservatively, in that the highest bids and the selling price increase as the number of bidders increases.

Second, as the uncertainty about the value of the object decreases, the winner's curse is weaker. For example, if bidders can assess the true value to within, say, plus or minus 10 percent, then the highest estimate will tend to be much lower than if the bidders can assess the true value only to within plus or minus 50 percent. As uncertainty decreases, bidders recognize that they have less to worry about from the winner's curse. They bid less conservatively, and the selling price typically increases.

An example may help in seeing the impact of this rule. Consider an auction where the object being sold is a jar of pennies and everyone knows the number of pennies in the jar (because the seller counts the pennies in front of everyone). No matter which auction format is used, it is optimal for each buyer to bid either the true value or a penny less than the true value. The profit that buyers can make is (close to) zero. On the other hand, if bidders do not know the number of pennies with certainty but their guesses are unbiased and they are sophisticated enough to avoid the worst ravages of the winner's curse, then the selling price will be less than the true value on average, and the bidders' expected profits will be strictly positive.

[7]The winner's curse was first observed by Capen, Clapp, and Campbell (1971) in oil lease auctions.

It may seem paradoxical that bidders make more money when they have less information. But the rewards to bidding in a common value auction must be based on the value of private information. If the true value is known to everyone, then no one has private information and the expected profit is zero. If the true value is uncertain, then bidders who possess useful private information earn positive expected profit, and the more uncertain the true value the greater the expected profits for these bidders. In turn, the greater the uncertainty about the true value, the lower the seller's revenues.

Expected Revenue Rankings for Static Auctions

This last point implies that the key to understanding which auction format is most favorable to the seller is to compare the amount of information about the true value revealed during the auction.[8]

In a discriminatory auction the winners pay their bids, whereas in a uniform-price auction the winners pay the highest losing bid. Therefore, one might think that a uniform-price auction leads to lower expected revenues for a seller. Surprisingly, the theory does not lead to this prediction, because bidders in a uniform-price auction are likely to bid more aggressively. After all, bidders are aware of the auction procedure, and know whether they will pay the price they bid or the highest losing bid. (This factor alone would lead to equal expected revenues in the two types of auctions.) In addition, the private information of the highest losing bidder is revealed during a uniform-price auction as the winner pays the highest losing bid. Consequently, the fear of the winner's curse in a uniform-price auction is lower than in a discriminatory auction. As a result of these two factors, the average selling price in a uniform-price auction is greater than in a discriminatory auction.

Next, observe that an ascending-price auction reveals at least as much as a uniform-price auction about bidders' private information. In both these auctions, the price paid by the winners is the highest losing bid. However, in an ascending-price auction, bidders may also learn something about the private estimates of other bidders by observing their interest (or lack of it) in buying the objects for sale. This decreases the winners' curse in an ascending-price auction, which causes bidders to be more aggressive than they would be in a uniform-price auction. Consequently, the average selling price in an ascending-price auction is greater than in a uniform-price auction.

When only one unit is being auctioned, a discriminatory auction is equivalent to a descending-price auction in the sense that the optimal strategies for bidders and therefore also the selling prices turn out to be the same in the two auctions (Milgrom and Weber, 1982a, pp. 1090–91). When many identical units are sold, as in Treasury auctions, these two types of auctions are not equivalent, as a descending-price auction reveals more information than a

[8]Most of this section is based on Milgrom and Weber (1982a).

discriminatory auction. During a descending-price auction, bidders learn something about the private information of previous buyers. This decreases the winners' curse, causing bidders to bid more aggressively for the remaining units. Thus, the average selling price in a descending-price auction is greater than in a discriminatory auction.

To summarize, the theory of auctions predicts that in static one-shot situations, an ascending-price auction yields greater expected revenues to the seller than a uniform-price auction which in turn yields greater revenues than a discriminatory auction. In addition, a descending-price auction is also better from the seller's viewpoint than a discriminatory auction. In general, nothing can be said about the revenue comparison between ascending-price and descending-price auctions; it depends on variables like number of objects being sold, number of bidders, and probability distributions of the common value and the bidders' estimates.

The discussion of the winner's curse points out that a seller becomes better off by honestly revealing any private information he has about the objects for sale, as this decreases uncertainty and the winners' curse. In fact, in the long run it is to the seller's advantage to precommit to telling the truth, even though in specific instances, when the information is unfavorable, the seller may derive a short-term benefit by reneging on this commitment.

There are two limitations to the preceding arguments. First, the assumption that bidders are sophisticated and take the winners' curse into account may be incorrect. Several experimental studies find that inexperienced bidders are susceptible to the winners' curse (Kagel, 1992; Thaler, 1988, and the references cited there). If bidders are inexperienced, some of the revenue comparisons described above may be reversed. In this case, the release of public information, or a switch from a discriminatory auction to an ascending-price auction, may decrease revenue because more information curtails the enthusiasm of naive optimistic bidders. However, presumably bidders in Treasury auctions are sophisticated and aware of the winners' curse; if they were not, they would make less than normal or even negative profit and ultimately would be eliminated.

The second limitation may be more serious. In most auction models it is assumed that each bidder wants only one indivisible unit of the objects being sold. (We shall refer to this as the unit demand assumption.) If the unit being auctioned is divisible and bidders are allowed to submit demand functions, then Wilson (1979) has shown that the average selling price can be lower than that under the unit demand assumption. It is not known whether the revenue rankings described above can be reversed if the unit demand assumption is relaxed.[9]

[9]More recently, Back and Zender (forthcoming) show that if the unit demand assumption is relaxed and the seller sets a low enough minimum acceptable bid, then discriminatory auctions yield higher revenues than uniform-price auctions. Maskin and Riley (1989) show that in the private and independent values model, the unit demand assumption is crucial for revenue-equivalence results.

Markets for Treasury Securities

Actual markets for Treasury securities differ in two important ways from the simple auction procedures that have been described. This section discusses the first important difference: the existence of various markets for Treasury securities other than the auction. These are the forward or "when-issued" market, the secondary or resale market, and the repurchase and reverse market. The second important difference, discussed in the following section, is the possibility of manipulating the bidding, which may affect the different auction formats in distinct ways, and have different effects on the forward market.

Treasury securities are issued and delivered to the winning bidders a few days after the auction. These securities can then be resold in a secondary market.

The forward or when-issued market for Treasury securities works this way: after an announcement of the amount of securities to be auctioned by the Treasury, primary dealers begin trading (among themselves and for their institutional clients) forward contracts on the Treasury securities to be auctioned. The seller of a forward contract guarantees to deliver and the buyer of a forward contract guarantees to take delivery of a certain quantity of Treasury securities.[10] On delivery, the buyer pays the forward price which prevailed at the time the forward contract was sold. The delivery date for the forward contract is the issue date of the underlying security, which is why these forward contracts are called "when-issued" contracts. Trading in the when-issued market continues after the auction and up until the issue date of the underlying security. Note that when-issued contracts are forward contracts on Treasury securities that do not yet exist, and that these contracts are in zero net supply. For any Treasury security, the total amount of forward contracts bought (or sold) varies from a small quantity to several times the amount auctioned.

Many institutional buyers use the when-issued market to ensure that they get the Treasury securities to be auctioned. Primary dealers often sell when-issued contracts before the auction, usually to their institutional clients. A seller in the when-issued market can settle his position in two ways: either buy when-issued contracts before they mature, or deliver the underlying Treasury securities when the contracts mature. One important difference between the when-issued market and the Treasury securities futures market in the Chicago Board of Trade is that in addition to the above two methods, a seller of futures contracts on Treasury securities can also settle his position by delivering close substitutes of the underlying securities when the contracts mature.

A "short squeeze" can occur when many of those who sold when-issued contracts fail to acquire the Treasury securities in the auction. They are then

[10]A standard forward contract for Treasury bills is for a principal amount of $5 million. The principal amounts for Treasury notes and bonds are higher.

forced to pay dearly either to buy the when-issued contracts back or to borrow the Treasury securities in the repurchase and reverse market, commonly known as repo and reverse market, to deliver.

The repo and reverse market is a market for short-term borrowing and lending that is collateralized by securities (Stigum, 1989). If one needs to borrow funds overnight, one can sell some securities to a counter party and at the same time sign with that party an agreement to repurchase these securities the next day at a predetermined price. This predetermined price may be equal to the selling price paid on the previous day by the counter party. In this case, the counter party is paid an explicit interest rate on the money invested overnight. Alternatively, the repurchase price is set to be different from the selling price so that the counter party earns a return in that manner. In either case, the return earned by the counter party is the so-called "repo rate" for the securities used as collateral. The counter party in a repo agreement is said to be engaged in a reverse repo—borrowing securities while loaning out funds.

Repo agreements fall into two broad categories, those with general collateral and those with specific collateral. In a general collateral repo agreement, the party who receives funds has the right to change, during the term of the repo, the Treasury security used as collateral; in a specific repo agreement, the receiver of funds cannot make such a change. When a security in high demand is used as collateral in a specific repo agreement, the repo rates tend to be much lower than for a general repo agreement. During a short squeeze, say in the when-issued contract on two-year Treasury notes, the specific repo rate, using the newly auctioned two-year notes as collateral, decreases dramatically as these notes become scarce. In this event, these two-year notes are said to be traded "special" in the secondary market.

It may seem that by borrowing securities in the repo and reverse market sellers of when-issued contracts who are caught in a short squeeze are merely postponing the inevitable—ultimately they have to buy the Treasury securities to settle their reverse repo contracts. However, with time the squeeze eases and the ownership of the Treasury security becomes less concentrated. Indeed, in equilibrium, it should make no difference whether those caught in a squeeze buy the securities now or buy the securities later at somewhat lower prices and meanwhile borrow the securities by loaning out funds at very low interest rates.

There is little empirical evidence on the frequency of short squeezes. According to Corrigan (1993), short squeezes occurred a few times in 1992 and were expected to occur in the early parts of 1993 mainly due to natural economic forces. Several authors have noted that when squeezes occur it is difficult to detect whether their cause is deliberate manipulation or merely chance events (Duffie, 1992; Cornell, 1992; Pirrong, 1992).

One might argue that if sellers are allowed to settle their positions in the when-issued market by delivering close substitutes of the underlying securities, then short squeezes can be eliminated to a large extent (Sundaresan, 1992). This is certainly true and is indeed the practice in the Treasury futures markets

in Chicago. However, many institutional buyers, such as pension funds and insurance companies, are in the when-issued market not for hedging purposes, but to buy the specific Treasury securities for their investments to create cash flows that match their future liabilities. Allowing a broader range of securities to satisfy delivery takes away this important function of the when-issued markets.

The Secondary Market

The auctions discussed earlier in this paper are static. However, the Treasury securities which are delivered to the winning bidders a few days after the auction can readily be resold in an active secondary market. How does this affect the choice between various auction formats?[11]

Competitive bidders in Treasury auctions are large financial institutions, who generally have better information about the term structure of interest rates and the demand for Treasury securities than the information possessed by the smaller institutions and individual investors who buy in the secondary market. By contrast, those who buy in the secondary market may only have publicly known information, like the auction statistics announced by the Department of Treasury. As bids submitted in the auction reveal the private information of competitive bidders, the secondary market prices will be responsive to these bids, a connection empirically verified by Cammack (1991).

How might this connection alter the results of the auction? Competitive bidders typically hold an inventory of fixed income securities and would benefit from an expectation of falling interest rates that would increase the value of these securities. Recall that although 38 primary dealers submit competitive bids, the auction is dominated by a few of them. These large competitive bidders have an incentive to bid higher than they would have if the secondary market buyers did not learn from the auction, to signal to the buyers in the secondary market that the bidders' private information is very favorable. Of course, in equilibrium no one is fooled, but if bidders did not bid higher, secondary market buyers may think that the bidders' information is less favorable than it actually is.

Bidders must face some loss of expected revenue when they increase their bids to send a signal to the secondary market. The costs of sending this signal will differ in various auction formats. For example, the winning bidder must pay the actual price bid in a discriminatory auction. But in a uniform-price auction, the price paid by a winning bidder does not increase with the bid. Therefore, it is cheaper for bidders in a uniform-price auction to bid high to signal their expectation that interest rates are going to fall. In addition, as noted earlier, the pattern of bids in a uniform-price auction would normally be expected to be more aggressive than in a discriminatory auction. These two factors cause the bids and the average winning price to be higher in a uniform-price auction than in a discriminatory auction.

[11]This discussion is based on Bikhchandani and Huang (1989).

The cost to bidders of signaling to the resale market is the same in a descending-price auction and in a discriminatory auction, because winning bidders pay their bids in both of these auctions. However, in a descending-price auction, the information revealed about previous sales induces the bidders to be more aggressive. Thus, the prediction is that descending-price auctions yield greater expected revenue than discriminatory auctions.

In an ascending-price auction, the seller keeps raising the asking price until the total number of units that (the winning) bidders are willing to buy equals the number of units for sale. In this sort of auction, winning bidders would like to signal to secondary market buyers and raise the resale price, but they cannot credibly reveal the auction price up to which they would have been willing to bid. This tends to decrease their bids when compared to the other three auction formats. However, as noted earlier, more information is revealed during an ascending-price auction than in either a uniform-price auction or a discriminatory auction, which tends to increase the bids in an ascending-price auction. The net effect of these two conflicting factors is ambiguous. In general, it is not clear whether ascending-price auctions generate greater expected revenues than discriminatory auctions or uniform-price auctions.

In summary, under these conditions, descending-price auctions and uniform-price auctions yield greater expected revenues than discriminatory auctions. Unlike in static auctions, it is difficult to predict whether ascending-price auctions are better than any of the other auction formats.

The existence of secondary markets also raises questions about whether it still makes sense for the seller to reveal information, and whether it makes sense for noncompetitive bidders to enter the auction, or instead to rely on the secondary market.

Even with a secondary market, honesty remains the best policy for the seller. The essential reason is that by revealing private information, the seller continues to encourage higher bids by decreasing the winners' curse, and (under mild conditions) does not reduce the bidders' incentive to signal to the secondary market. One type of uncertainty is the amount available to competitive bidders, after deducting the noncompetitive bids including the amount bought by the Federal Reserve for itself and for foreign central banks. If the Federal Reserve discloses its intentions before the auction, the Treasury's revenues should increase.[12]

It has been empirically documented by Cammack (1991) and Spindt and Stolz (1991) that the average winning price in the Treasury bills auction is 4 to 7 basis points less than the secondary market price of comparable securities, on average. (Recall that one basis point is one-hundredth of 1 percent.) Presumably, even for Treasury notes and bonds, the auction prices are lower than the corresponding secondary market prices. This underpricing in the auction is the return that competitive bidders earn on their private information. Since

[12]We are grateful to Joseph Stiglitz for pointing this out to us.

noncompetitive bidders in the auction pay the average winning price, small buyers are better off if they submit noncompetitive bids instead of buying on the secondary market. By doing so, they free-ride on the information collected by competitive bidders. As there is an upper limit on the amount of each noncompetitive bid—currently $1 million for bills and $5 million for notes and bonds—buyers with large orders cannot satisfy their demand through noncompetitive bids.

The When-Issued Market

The when-issued market performs two key functions. First, it is a forward market for Treasury securities. Second, it aggregates the diverse information and beliefs of the participants in this market. Those who believe that interest rates will fall are long (that is, are net buyers of when-issued contracts), and those who believe otherwise are short (that is, are net sellers of when-issued contracts). The prices of these when-issued contracts are known to primary dealers and their institutional clients. In this way, the winners' curse is weakened and, presumably, the when-issued market raises the average auction price.

In another paper, we present empirical evidence on the when-issued market and the auction for 13- and 26-week bills (Bikhchandani and Huang, 1992). We document the presence of strategic interplay between the when-issued market and the auction. The data suggest that the traders in the when-issued market take into account the possibility that the when-issued prices might reveal some of their private information. This may raise the price they eventually pay. If traders with large demands buy mainly in the auction, instead of buying in the when-issued market, their private information will get revealed only after the auction. We find that auction prices are more informative than when-issued prices at the time of the auction. However, during a short window after the auction and before the announcement of the auction results, the when-issued prices are informative about the information innovation contained in the auction bids. This is consistent with the idea that post-auction trading in the when-issued market has no information costs in relation to the auction and thus participants in the when-issued market trade according to their information at this time.

The fact that (at least some) bidders recognize the impact of their actions in the when-issued market on the auction provides further support for our claim that although there are 38 primary dealers in the auction, a few of them are large enough to profit from strategic play.

Although the when-issued market performs the two important functions mentioned above, it also provides new avenues for manipulation of the Treasury securities market. For instance, a bidder with very favorable information may refrain from taking a long position in the when-issued market, and instead take a short position to falsely signal unfavorable information. He can then win in the auction at a price lower than he otherwise would. If he wins a large enough quantity in the auction, this could even result in a short squeeze.

Manipulation

The analysis to this point has assumed that there is no manipulation of the auction by bidders, but any auction is at least somewhat susceptible to such behavior. In fact, it has been alleged that bidders in Treasury securities auctions often collude.[13] It's worth noting that not all collusion is necessarily bad for the seller. If bidders talk to each other before the auction merely to share their private information, but not to fix prices, then the winners' curse is diminished and auction revenues increase. One could take the view that the possibility of manipulation should not make a difference to the choice of auction formats, because rules can be passed to make such behavior illegal, and to punish violators severely. And in fact, certain behaviors in Treasury auctions, such as explicit collusion in the auction or cornering more than 35 percent of any particular security, are illegal.

However, not all collusion is benign and not all such violations of laws are detected, which means that violators have at least some chance of making money from their behavior. Thus, we believe that an important criterion in selecting an auction format is to reduce the vulnerability to abuse. Manipulation of the market can come in two forms: collective manipulation involving all or most bidders, and manipulation by an individual bidder.

Collective Manipulation

In the 1960s, Milton Friedman (1960) started a debate on the appropriate Treasury auction by arguing that a uniform-price auction would be better from the Treasury's viewpoint than a discriminatory auction.[14] He claimed that the discriminatory auction discourages nonspecialists from participating in the auction, and encourages collusion among the specialists (primary dealers) who bid in the auction.

While we agree that nonspecialists are at a disadvantage in a discriminatory auction, we believe that they will not be better off in a uniform-price auction. Recall the heuristic that rewards to bidders are based on the value of their private information. Primary dealers tend to have much better information about the value of the auctioned securities than nonspecialists do.[15] Therefore, whether a discriminatory auction or a uniform-price auction is adopted, bidders who have access only to public information cannot make positive expected profits in the auction (Milgrom and Weber, 1982a, 1982b). Under either

[13]See, for example, "Hidden Bonds: Collusion, Price-Fixing have long been Rife in Treasury Market," *The Wall Street Journal*, August 19, 1991, p. A1.

[14]For more information on the participants in the debate in the 1960s, see the references cited in Bikhchandani and Huang (1989). Friedman reiterated his position in "How to Sell Government Securities" in *The Wall Street Journal*, August 28, 1991, p. A8. See Reinhart (1992) for a critique of Friedman's proposal in light of recent events.

[15]As we mentioned before, one of the pieces of private information that primary dealers have is the demand from their customers. Competitive bidders who buy only for themselves would not have such information.

auction format, nonspecialists are better off if they submit noncompetitive bids, which at least ensures positive expected profits, rather than competitive bids.

One way of preventing collusion in the auction is by ensuring that many small bidders participate. But as neither auction format is likely to widen participation, uniform-price auctions are not more likely to discourage collusion on this account.

We are not aware of any formal analysis under the common values assumption which compares the incentives for collusion in different auction formats for a fixed level of bidder participation.[16] However, the following form of collusion seems plausible in uniform-price auctions. In a Treasury auction, each bidder is allowed to submit many price-quantity bids. Suppose that every bidder submits two bids, one at a high price P_H and another at a very low price P_L. If the total quantity demanded at P_H is less than the total supply and the total quantity demanded at P_L is greater than the total supply, then P_L is the highest losing bid and, therefore, the price paid by the bidders. Each bidder wins and gets his demand at P_H and an amount less than and proportional to his demand at P_L. Thus bidders collude on price and compete with each other only through the quantity submitted at P_L. A bidder can profit in a single auction by raising his low bid price a little above P_L as this ensures that his entire demand at this price is met. Such a deviation can be deterred by a breakdown of the collusive arrangement for a long enough period. This scheme can also sustain collusion in an ascending-price auction.

It seems to us that it is more difficult to sustain collusion in discriminatory auctions and in descending-price auctions. Because winning bidders pay their bids in these auctions, in any profitable collusive arrangement every bidder must agree to bid only at low prices. But then the short-term gain from deviating by bidding a little higher than others is greater than in uniform-price auctions. Thus, although in the absence of collusion uniform-price auctions should yield greater expected revenue than discriminatory auctions, the latter appear to be less susceptible to collusion.

In any cartel, the smaller the number of members, the greater the likelihood of collusion. One may think that because there are 38 competitive bidders in Treasury auctions it will be difficult for them to collude. However, several of the 38 bidders are much larger than the rest. Whether collusion and price-fixing are widespread among competitive bidders is an empirical question. One test for detecting collusion using auction and when-issued data can be found in Bikhchandani and Huang (1992), where we failed to reject the null hypothesis that bidders do not collude in the discriminatory auction used for selling 13-week and 26-week Treasury bills.

[16] When the bidders' values are identical and common knowledge, it is easier to sustain collusion in a uniform-price auction than in a discriminatory auction (Milgrom, 1987). Most of the other auction models of collusion assume private and independent values, an unsuitable assumption for Treasury auctions.

Individual Manipulation

An individual bidder can manipulate the Treasury securities market by cornering the market—that is, through a short squeeze. If many bidders hold short positions on the when-issued market and one bidder successfully bids for a large amount at an unusually high price in the auction, then this bidder can obtain a high price in the secondary market, the when-issued market, or in the repo and reverse market. All those who took short positions on the when-issued market are forced to buy or borrow from the bidder who owns most of the units sold at the auction. This is what Salomon Brothers was accused of doing in an auction for two-year notes in 1991.

Is this scenario necessarily bad for the Treasury? After all, the bidder who corners the market buys most of the units auctioned and pays a high price, which would seem to imply higher-than-usual auction revenues.[17] It is true that when there is a short squeeze, the auction prices are higher and the Treasury benefits in that specific auction. However, if short squeezes are commonplace, they will tend to drive competitive bidders out of the market, which will eventually result in lower revenues for the Treasury.

It is illegal to corner the market—no bidder may buy more than 35 percent of the supply in any Treasury auction. Thus, to corner the market, a bidder would have to submit bids through several agents who give the appearance of acting independently. The ease with which a bidder can do this depends more on the reporting requirements and the extent of law enforcement than on the specific auction format. However, assuming that a bidder can bid through several agents without detection, it seems to us that a uniform-price auction is more vulnerable to a short squeeze than a discriminatory auction. After all, if a bidder in a discriminatory auction attempts to corner the market by bidding at very high prices, the bidder must actually pay the high prices bid. However, in a uniform-price auction, if one bidder submits bids for a large total amount at very high prices, then that bidder can be sure of cornering the market, and the price paid is the highest among the others' bids (or slightly less). Similar arguments imply that a descending-price auction is less susceptible to being cornered than an ascending-price auction.

There is another way in which a bidder could manipulate Treasury auctions. Because the same set of bidders participate in the auction every week, it may be worthwhile for a bidder to pay more today in exchange for higher future profits by building a reputation for bidding aggressively (Bikhchandani, 1988). A bidder with such a reputation intensifies the winners' curse for his opponents; they realize that if they beat the aggressive bidder, he must have very unfavorable information. This causes the aggressive bidder's opponents to bid more conservatively, which weakens the winner's curse for the aggressive bidder. In a uniform-price or an ascending-price auction it is very profitable to be the only bidder with this kind of reputation because, upon winning, the

[17]For two arguments taking this position, see an editorial titled "Salomon and the Treasury Cartel" in *The Wall Street Journal*, August 20, 1991, p. A14, and an article titled "Don't Let Salomon Doom T-Bonds" by William E. Simon in the March 30, 1992 issue of the same journal, p. A10.

aggressive bidder does not pay his bid; he pays the highest losing bid which would tend to be lower as others are scared into bidding conservatively.

Since an important aspect of each bidder's private estimate of the true value is the demand for Treasury securities from his clients, a bidder who usually buys large amounts at the auction tends to have more accurate information. This strengthens the winner's curse for the others. Thus, it may be relatively easy and even more advantageous for a dominant primary dealer to build a reputation for aggressive bidding.

Discriminatory auctions and descending-price auctions are less vulnerable to such reputation formation. Although even in these auctions an aggressive bidder would scare off other bidders, it is costly for a bidder to build and maintain this reputation as, each time he wins, the aggressive bidder pays his bid.

Policy Implications

In the absence of manipulation by bidders, uniform-price auctions and descending-price auctions should yield greater expected revenues to the Department of Treasury than discriminatory auctions. We are unable to estimate the predicted increase in the Treasury's revenues if it were to change its auction format. However, assuming that the auction mechanism or the Treasury's information revelation policy does not change the expected secondary market prices of the securities, a weak upper-bound on the increase in revenue may be obtained by estimating bidders' expected profits. The Treasury's revenues cannot increase by more than the bidders' current profits, because bidders will not participate unless they make money. Thus, the key question becomes the profits that primary dealers earn from participating in the Treasury auction.

This is very difficult to estimate, as data regarding their costs are not publicly available. In addition, primary dealers have several sources of Treasury auction-related income; for example, they can sell short on the when-issued market and cover their positions in the auction. The contribution of this trading to their profit is impossible to estimate because data on the volume of when-issued market trades by the primary dealers are not available. Primary dealers can also buy in the auction and sell in the secondary market. Cammack (1991) estimates that during the period 1973–84, the total return to all primary dealers who bought 13-week bills in the auction and sold in the secondary market was approximately $110,000 per $1 billion face value. Using data from the period January 1986 to June 1991, Jegadeesh (forthcoming 1993) estimates the analogous return at $432,000 per $1 billion face value for 2-, 5-, and 7-year notes, and 10-year bonds. Any savings the Treasury may achieve by changing the mechanism for selling securities must be less than this. However, since a huge amount of securities are sold, potential savings could still be substantial.

Earlier events involving Salomon Brothers emphasize the importance of discouraging bidders from cornering an issue or otherwise manipulating the market. Although our earlier discussion of manipulation is somewhat

conjectural, we think that both uniform-price and ascending-price auctions are more susceptible to manipulation than either discriminatory or descending-price auctions. Uniform-price auctions (and perhaps ascending-price auctions) yield greater revenue than discriminatory auctions if there is no manipulation. However, if the Treasury switches to a uniform-price auction or an ascending-price auction, its revenues may fall as bidders may find it easier to collude or game the auction in one of the other ways mentioned earlier.

Several of the reforms outlined in the Joint Report on the Government Securities Market (pp. xiii–xvi) relate to discouraging manipulation by bidders. One proposed reform is to reopen the market and supply additional securities if a "protracted short squeeze develops, regardless of the reason for the shortage." This policy may have substantial costs. First, it is difficult to detect when a short squeeze occurs and whether its cause is bidder manipulation. Second, reopening the market would increase the uncertainty associated with the auction and cause primary dealers to be more conservative in their bidding, as there is always a chance that after the auction the Treasury will increase supply and decrease prices.

The Joint Report (p. xiii) has also suggested that Treasury auctions be opened up so that buyers with smaller demands (those who normally buy on the secondary market) are encouraged to participate in the competitive bidding. As pointed out earlier, we believe that a change in the auction rules will not increase participation substantially, because smaller bidders tend to be less well-informed about the value of the security than primary dealers. Regardless of the auction mechanism, such bidders are better off submitting noncompetitive bids, which enable them to buy at the average price paid by primary dealers without incurring any information collection costs.

Most of the results reported in this paper are based on theoretical models. There has been little by way of empirical testing of revenue ranking predictions of the theory, mainly because of a lack of data sets where different auction formats were used. Some international comparisons are available. Umlauf (1991) suggests that the government of Mexico increased the average selling price for its T-bills by switching from a discriminatory auction to a uniform-price auction. The government of Italy switched in the opposite direction—from a uniform-price to a discriminatory auction—but we are not aware of any studies comparing revenues before and after the change. Although the Treasury did experiment with a uniform-price auction for a brief period in the 1970s, the recent switch to using such an auction for two-year and five-year notes will offer perhaps the best opportunity yet for an empirical test of some of these auction models.

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