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Publication Date
2004-09-29
Revenue Implications of Multi-Item Multi-Unit Auction Designs: Empirical Evidence from the U.S. Treasury Buyback Auctions

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ABSTRACT

We study an important recent series of multi-item multi-unit auctions conducted by the U.S. Treasury in retiring $67.5 billion of its debt. Consistent with auction theory, we find that bidders earn a small volatility-related expected profit as compensation for bearing the risk of the “winner’s curse.” We find that the Treasury is penalized for being “spread too thin” when including multiple bonds in a buyback auction. Thus, the multi-item design of the auction may not have been optimal from the Treasury’s perspective. In contrast, there is no evidence that the multi-unit aspect of the buyback affected the Treasury’s costs. These results have a number of implications for current models of multi-item and multi-unit auctions.
In recent years, there have been many high-profile examples of auctions in which either multiple units of some commodity or security are sold, or multiple complementary or substitutable goods are auctioned simultaneously. Important examples include auctions for Treasury bonds, stocks, and electricity, internet marketplaces such as eBay, electronic financial exchanges, and the simultaneous ascending design used in the FCC Spectrum auctions (see Bikhchandani and Huang (1993), Nyborg, Rydqvist, and Sundaresan (2002), Wolfram (1998), McAfee and McMillan (1996), Cramton (1998), and Milgrom (1998)).

Not surprisingly, these types of multi-item or multi-unit auctions have received a tremendous amount of attention from auction theorists. The literature demonstrates that the properties of these auctions can differ fundamentally those of standard single-item single-unit auctions since the strategy space of auction participants becomes orders of magnitude more complex. Examples of issues that only arise in a multi-unit or multi-item auction setting include strategic demand reduction by bidders (Wilson (1979), Anton and Yao (1992), Back and Zender (1993), Engelbrecht-Wiggans and Kahn (1998), Ausubel and Cramton (2002), Wang and Zender (2002), and many others), interdependencies induced though the budget constraints of bidders (Palfrey (1980), Pitchik and Schotter (1988), Engelbrecht-Wiggans (1987), and Benoit and Krishna (2000)), and the possibility that bundling or package bidding may be optimal (Palfrey (1983), Milgrom (2000), Armstrong (2000), Avery and Hendershott (2000), and Ausubel and Milgrom (2002)). Despite many important theoretical advances in this area, however, relatively little is known about how well multi-item or multi-unit auction designs perform in practice.

To shed light on the empirical properties of these types of auctions, this paper studies an important recent series of Treasury auctions. These auctions represent a unique class since they have both multi-item and multi-unit dimensions. Specifically, during 2000 to 2002, the U.S. Treasury retired $67.5 billion of its debt in 45 separate buyback operations. In these simultaneous discriminatory auctions, the Treasury invited offers for the individual bonds listed in the buyback announcement. The number of different bonds included in these lists ranged from 6 to 26. The Treasury, however, specified only the total par amount (or units) to be bought back, and not amounts for individual bonds (or items). Thus, the Treasury had discretion over the total amount of offers for individual bonds that it could accept, thereby introducing something akin to reserve pricing into the auction. The introduction of this buyback program was in

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1Important examples include Wilson (1979), Demange, Gale, and Sotomayer (1986), Maskin and Riley (1989), Milgrom (2000), and many many others.
response to the budget surpluses of the late 1990s as well as to the Treasury’s goal of having greater control over its debt structure. The buyback program generated a high level of interest among market participants, and individual buybacks were typically oversubscribed by wide margins.

A key aspect of this study is the use of high-frequency intraday data from the Treasury bond market. This has the important advantage of allowing us to measure precisely the Treasury’s buyback revenues (or costs in this procurement context) by comparing winning bids with the nearly-simultaneous secondary market price (common value) of the bonds. Accordingly, we focus primarily on the revenue implications of this series of buyback auctions in this paper.

A number of interesting results emerge from this analysis. First, the evidence is consistent with a framework in which risk averse agents strategically shade their bids and earn a small expected profit to compensate for bearing the risk of the “winner’s curse.” In particular, we find that the average winning offer is 3.80 cents per $100 face value of the bonds higher than the secondary market ask price of the bond, implying that the Treasury suffers a small “market-impact” cost on the order of the bid-ask spread. We also document that the Treasury’s cost is directly related to the volatility of bond prices, supporting the interpretation of this cost as a “risk premium” earned by the bidders.

Second, the variation in the number and notional amount of the bonds included in each buyback allows us to identify how the multi-item and multi-unit aspects of the auction design affect the Treasury’s costs. We find that the Treasury’s expected buyback costs are an increasing function of the number of bonds included in the auction. Thus, the Treasury is penalized for being “spread too thin” over multiple bonds in these buyback auctions. These results raise important questions about the optimal structure of multi-item auction designs. In contrast, we find that there is little relation between the notional amount of bonds bought back (the number of units) and the Treasury’s buyback costs. Thus, these buyback auctions appear to avoid some of the demand-reduction-related problems with multi-unit auctions identified in recent theoretical work, possibly because of their discriminatory design or the Treasury’s implicit reserve capability.

Finally, the sequential nature of the buyback auctions affords a unique opportunity to examine whether there is an upward or downward trend in the Treasury’s expected cost. Milgrom and Weber (1982) show that with affiliation and common values, the expected seller revenue in a repeated auction drifts upward. In contrast, Ashenfelter (1989), Ashenfelter and Genesove (1992), McAfee and Vincent (1993), and others document the declining-price anomaly (or “afternoon effect”) in which repeated

\[2\]To avoid confusion with the literature, we refer to auction participants who offer bonds to the Treasury as bidders and the corresponding offering prices as bids.

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sales of identical items result in declining auction prices. We find no evidence of any trend in the Treasury’s costs over time after controlling for the effects of volatility.


The remainder of the paper is as follows. Section I describes how the Treasury buyback auctions are structured. Section II discusses the data and the empirical approach. Section III presents the empirical results. Section IV summarizes the results and makes concluding remarks.

I. THE TREASURY BUYBACK AUCTIONS

From March 2000 to March 2002, the U.S. Treasury conducted a series of 45 buyback or procurement auctions for its outstanding debt. Like standard Treasury auctions used to issue debt, these buybacks were sealed-offer discriminatory share auctions. Unlike standard Treasury auctions, however, each buyback involved between 6 and 26 different bonds. This feature is important since these bonds were essentially perfect substitutes from the perspective of the Treasury’s stated objective of buying back a specific total notional amount of its debt (across all bonds). Thus, these buyback auctions represent a unique type of auction with both multi-item and multi-unit auction features. These auctions are also interesting from an informational and risk perspective. Because of the active secondary market for Treasury bonds in which bond prices are almost continuously observable, these buybacks can be viewed as almost pure common-value auctions.

At the program’s inception, the Treasury described the four primary benefits that it anticipated would result from the buybacks. First, buybacks would enhance market liquidity by allowing the Treasury to issue benchmark bonds at regular intervals in greater volume. Second, buybacks would allow greater control over the maturity structure of Treasury debt. Third, the buybacks provided an additional cash management tool. Fourth, the buybacks allowed the Treasury to reduce its interest expense by purchasing “off-the-run” debt and replacing it with lower-yielding “on-the-run” debt.

To initiate a buyback, the Treasury issued a buyback auction announcement one to two days prior to the auction. The announcement described which bonds were to be included in the buyback as well as the maximum total notional amount (across all bonds) to be bought back. The Treasury reserved the right to buy back less than the
maximum amount (but never exercised this option). However, the Treasury usually bought back the total desired amount of debt using only a subset of the bonds that it had announced were eligible for buyback.

Any institution approved to conduct open market operation transactions with the Federal Reserve Bank of New York was eligible to submit offers (price and quantity) in the buyback operation. Others who desired to participate could submit offers through the approved institutions. Thus, the number of eligible direct participants in the auction was fixed and finite (although relatively large). In contrast to the debt sales auctions conducted by the Treasury, there was no provision for non-competitive participation.\(^3\)

Offers had to be submitted by the closing time indicated in the buyback auction announcement which was always 11:00 a.m. Offers were binding and the Treasury announced results within two hours after the closing of the auction at 11:00 a.m. Offers were either accepted or rejected at the prices submitted in the offers. For accepted offers, bidders sold their bonds back to the Treasury at their offered price in the quantity offered (discriminatory auction). The public announcement of the results included both the notional amount of offers accepted for each bond as well as the weighted-average price of accepted offers.

The common-value element of these auctions is inherent in the timing of the offers and the acceptance decision. All bidders were required to submit offers by 11:00 a.m. the day of the auction. Furthermore, all participants could observe the secondary market value of the bonds at the time of offer submission. What was unknown to the bidders, however, is what the value of the bond would be at the time that the results of the auction were announced. The uncertainty about the price was substantial. In particular, the standard deviation of price changes in the secondary market between offer submission and announcement of results is 26.09 cents. As we show later, this number is very large relative to the expected benefit to auction participants from an accepted offer. When the auction results are announced, all participants can directly observe the secondary market price of the bonds which is clearly the common value of the bonds to the bidders. Thus, this auction comes close to representing a pure common-value auction. Note that the downside to a bidder of not having an offer accepted is relatively minor. In this situation, the bidder can simply sell the bonds in the secondary market at the current secondary market price.

There may also be a small private-information component to these auctions. Auction participants were dealers in Treasury securities. Thus, they might be expected to have private knowledge of clients who had a need or desire to sell securities that were

included in the buyback operations. This information could influence a dealer’s offer. While the secondary market establishes the common value of the bonds accepted in the auction, the submitted offers vary according to participants’ forecasts of future bond values and whatever private information they may possess. The observed average difference between accepted offer prices and secondary market prices becomes a measure of the cost of the auction to the Treasury.

II. THE DATA

Our study uses a dataset for intraday pricing in the U.S. Treasury market provided by GovPX Inc. This widely-used Treasury bond data source consolidates quote and trade information from the interdealer broker market for U.S. Treasury securities. The dataset contains records of the best indicative bids and offers (in both price and yield) along with information about individual trades (trade size, price, yield, and an indicator for which side initiated the trade). Each quote is time stamped to the second. The information is available either directly from GovPX or through financial service distributors including Bloomberg, Reuters, Bridge, and Telerate. The GovPX dataset is used by industry analysts, dealers, traders, brokers, as well as investors.

Since the buybacks are procurement auctions, our focus is on the expected cost to the Treasury of the auction, where the cost is defined as the difference between the average accepted offer price and the corresponding secondary market ask price for the bonds in each buyback. With this measure of the Treasury’s cost, we can then directly explore how variation in the number of bonds included in the auctions as well as variation in the total par amount of bonds to be auctioned affects the outcome of the buybacks.

As the measure of the secondary market price for each bond, we use the last market quotation in the GovPX dataset available at the time that the auction results are announced (the auction result announcement is time stamped to the nearest minute). The mean (median) time between the last market quotation and the time of the buyback announcement is 57.96 (39.00) seconds. A total of 95.26 percent of

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4 We use the ask price quote for all of the results presented in the paper. The results remain virtually the same when we use the average of the bid and ask quotes.

5 The average accepted offer prices are reported by the Treasury in the announcement of auction results. Buyback and buyback result announcements can be found at http://www.publicdebt.treas.gov/of/ofbuybakpr.htm.

6 We also use the next quotation after the release of the auction results as the measure of the secondary market value of the bonds. This approach gives results almost identical to those we report.
the last market quotes occur within two minutes of the release of the buyback announcement. All of the last market quotations are within 20 minutes of the buyback announcement. Thus, we can compare auction results to virtually simultaneous prices of the bonds in the secondary market.\footnote{Three inflation protected bonds (TIPS) were eligible for buyback in the April 18, 2000 auction. This is the only time that TIPS appeared in any buyback. Since GovPX quotes are not available for these bonds, we exclude them from the analysis. Also, bond quotations for part of the day of the 37th buyback are missing from the dataset. Thus, we exclude the 37th buyback from the analysis.}

Table 1 presents descriptive statistics for the Treasury buybacks. Altogether, there are 45 Treasury buyback operations between March 2000 and April 2002. Of these, 20 occurred during 2000, 22 during 2001, and 3 in 2002. All of the bonds included in these buybacks were originally issued as 30-year bonds during 1980 and 1997. In fact, every 30-year bond issued between 1980 to 1997 was included in at least one buyback operation. In total, the 45 buyback operations involve exactly 45 unique bonds.

There are always multiple eligible bonds in each operation. The number of bonds in a redemption operation ranges from 6 to 26, with a median of 11 and mean of 11.4. The maximum total par amount of bonds that the Treasury proposes to buy back (as stated in the Treasury redemption operation announcement) is between 0.75 to 3 billion dollars, with a mean of 1.5 billion dollars. In the end, the Treasury always redeemed the maximum amount, but did not always spread repurchases evenly among all the eligible bonds. On average, in a given operation, only about 70 percent of the eligible bonds have at least some offers accepted.\footnote{There are also extreme cases. For example, the amount accepted is nonzero for all eligible bonds in two operations, but there are also three redemption operations where only one-fifth of the eligible bonds are bought back. The dispersion seem to be primarily driven by whether the bonds involved in the redemption are callable or not. On average, only 30 percent of the bonds in the nine operations that involve callable securities are bought back, while the ratio is 80 percent for the other operations.} Of course, even when the Treasury accepted some offers for a particular bond, the amount accepted is usually only a fraction of the total amount offered. The amount offered is on average 4.4 times that of the amount accepted.

The maturity dates of the buyback bonds range from February 15, 2010 to April 15, 2032. At the time they were considered for redemption, the time to maturity for these bonds is between 10 to 25 years. The average time to maturity is 18.19 years. The coupon rate for the bonds eligible for buyback ranges from 3.375 to 14.000 percent. Callable bonds and bonds issued in the early 1980’s have the highest coupon. The Treasury always chose a block of bonds (i.e., next to each other in issuance date) for
buyback in the same operation. Thus, bonds eligible for buyback in a given operation are all very similar in coupon and maturity. Finally, the buyback bonds were all selling at premium, and the average bid-ask spread is 0.062 per $100 notional amount (or about 1/16th).

III. EMPIRICAL RESULTS

In this section, we examine how the expected cost to the Treasury is related to the number of bonds (items) and the par or notional amount of the bonds (units) being auctioned. Because both the number and par amount of bonds involved in an auction vary significantly across individual buybacks, we can identify these relations through a simple regression analysis of the time series of realized costs.

To calculate the cost to the Treasury from an individual auction, we first calculate the buyback cost for the individual bonds in that auction. As described, the cost of buying back a bond is the difference between the weighted average accepted price by the Treasury and the corresponding price for the bond in the secondary market (the common value) at the time the auction results are announced. As the measure of the cost for each auction, we take the average of the costs for all bonds bought back in that auction.\(^9\) We repeat this process for each of the 44 auctions for which we have data.

A. The Average Cost.

The average cost over all 44 buybacks is 3.80 cents (all costs are measured per $100 face value of the bonds). Similarly, the median cost is 4.15 cents. Thus, these results are consistent with the hypothesis that bidders strategically shade their bids and earn a small profit on average as compensation for bearing the risk of the “winner’s curse.” It is important to observe, however, that the standard deviation of the average cost is 3.79 cents. Thus, the simple hypothesis that the average cost is zero cannot be rejected. Furthermore, although 26 of the 44 auctions result in positive costs to the Treasury, we cannot reject the hypothesis that positive and negative costs are equally likely.

To put the average cost to the Treasury into perspective, observe from Table 1 that the average bid-ask spread for auctioned bonds is 6.20 cents. Thus, the 3.80 cent point estimate of the average cost to the Treasury is only a fraction of the average bid-ask spread. This result is remarkable in the sense that it implies that Treasury suffers virtually no “market-impact” costs in buying back its debt. For example, recent empirical evidence by Babbel, Merrill, Meyer, and Villiers (2004) estimates\(^9\)

\(^9\)Weighting the average by the amount bought back gives virtually identical results.
that large financial institutions face “market-impact” costs of more than 10 cents for transactions larger than the typical daily trading volume of about $100 million for individual off-the-run Treasury bonds. In contrast, the average notional amount of each bond bought back by the Treasury in an auction is $184.4 million.

B. The Regression Analysis.

To explore how the multi-item and multi-unit aspects of the auctions affect the Treasury’s expected cost, we regress the realized costs from the 44 auctions on a number of explanatory variables. As the measure of the number of items in each auction, we simply use the number of bonds listed in each of the Treasury’s buyback announcements. Recall that this number varies from 6 to 26. Thus, there is considerable time-series variation in this variable which can be used to identify the revenue consequences to the Treasury of increasing the number of items included in an auction. As the measure of the number of units of each bond in the auction, we take the total par or notional amount of bonds to be bought back (in $ billions) as per the Treasury’s buyback announcement, and normalize it by the number of bonds eligible for buyback in that auction. This measure captures the average amount per bond that the Treasury intends to auction and is thus an intuitive measure of the scale (or number of units per item) of each auction.

To shed additional light on the properties of these auctions, we also include the average volatility of the prices of the bonds involved in a buyback as an explanatory variable. Theory suggests that participants in common-value auctions should adjust their Bayesian-Nash equilibrium strategies in response to the degree of uncertainty about the value of the auctioned item. In these procurement auctions, where the uncertainty relates to the future market value of the bonds being auctioned, rational auction participants should increase their offer prices as bond price volatility increases. As a measure of the price volatility of the bonds, we compute the standard deviation of 20-minute price changes during the five days previous to the buyback announcement date (and convert it to a one-day volatility by multiplying it by the square root of 22). As the volatility measure for each auction, we use the average of the volatility measures for the individual bonds bought back in the auction. By using this volatility measure as an explanatory variable, we can test whether the cost to the Treasury, and therefore by inference, the prices offered by auction participants are increasing functions of price volatility.

Finally, we include the number of the auction, ranging from 1 to 45, as an additional explanatory variable. The motivation for this variable stems from the literature on sequential auctions (Milgrom and Weber (1982), Weber (1983), Ashenfelter (1989), and many others). This literature suggests that auction participants may learn over time and resolve underlying informational asymmetries. In this context, the Treasury observes all of the prices and quantities offered, but only releases summary information. Thus, as the buyback program progressed, auction participants may have been
able to learn about other participants’ information sets or supply functions. If so, there could be a trend in the expected cost faced by the Treasury over time. Including this variable allows us to test for time trends in the conditional expected cost to the Treasury. Note that in this analysis, we focus on the Treasury’s cost, not on the auction prices themselves. Since this approach controls for changes in the secondary market price of the bonds, we can then compare the Treasury’s costs over the sample period in a consistent way (without needing all of the auctions to occur within a short time span measured in hours).

In conducting this analysis, it is also important to control for the potential effects of extraneous factors. For example, the Treasury states that one of the motivations for buying back its debt is to replace higher-cost off-the-run bonds with on-the-run bonds. Thus, it is possible that accounting issues could also influence the Treasury’s decisions and, therefore, the average cost of the auctions. To control for the possibility that the Treasury might have exogenous incentives to buy back debt with high coupon rates, longer maturities, or call features, we include the average coupon rate, average maturity, and a dummy variable for callable bonds as additional explanatory variables in the regression. We also control for the possibility of persistence in costs by included the lagged cost as an additional explanatory variable. Finally, as a partial control for variation in the number of auction participants over time, we include the ratio of the total notional amount of bonds offered to the total notional amount of bonds accepted for each auction. This variable controls for the degree to which an auction is oversubscribed.

Table 2 reports the results from the regression. The coefficient for the number of bonds included in each auction is positive and significant. This result is important since it indicates that the multi-item design of the auction was not revenue maximizing for the Treasury. Specifically, the regression coefficient implies that the Treasury’s expected cost increases by about 3.25 cents for every additional bond included in a buyback auction. These results are intriguing since they suggest that the Treasury could have done better by auctioning fewer bonds simultaneously. These results also lend support to recent theoretical work that bundling, package-bidding, or other auction design aspects that reduce the dimensionality of the number of items being auctioned may be revenue maximizing (see Palfrey (1983), Milgrom (2000), Armstrong (2000), Avery and Hendershott (2000), Ausubel and Milgrom (2002), and many others). These results also provide evidence consistent with bidders gaining market power as the number of auctioned bonds increases, perhaps implicitly coordinating through “divide-and-conquer” strategies (Admati and Pfleiderer (1989), Ausubel and Cramton (2002)).

In contrast, the coefficient for the average notional amount of bonds being auctioned is not significant. Thus, the multi-unit aspect of the buyback auctions does not appear to affect the Treasury’s cost directly. This finding has a number of interesting
implications for multi-unit auction theory. For example, Wilson (1979) shows that bidders in multi-unit or share auctions may have incentives to bid aggressively for smaller quantities. One effect of this demand reduction is to reduce the seller’s expected revenue. Back and Zender (1993) and Klemperer and Meyer (1989) show that the demand reduction problem can be mitigated through means such as making the auction discriminatory or introducing nonlinear costs. Ausubel and Cramton (1999) demonstrate that auctions with reserve pricing may allow sellers to avoid low-revenue outcomes in multi-unit settings. Our results indicate that the design of the Treasury buyback auctions may be effective in avoiding some of the revenue problems that may arise in multi-unit auctions.

The coefficient for price volatility is both positive and significant. This supports the hypothesis that auction participants adjust their offer prices in response to forecasted volatility in the value of the bonds being auctioned. These results parallel those reported by Cammack (1991) and Nyborg, Rdyqvist, and Sundaresan (2004) who find a similar relation between expected auction revenue and volatility in Treasury debt issuance auctions.

The regression coefficient for the time trend variable is positive but not significant. Thus, there is no evidence of learning in this series of sequential auctions. This result is interesting in itself given the evidence that there are trends in other types of sequential auctions. For example, Milgrom and Weber (1982) show that in a model with affiliation, the expected revenue from a sequential auction can increase over time. In contrast, Ashenfelter (1989) finds that there is a downward trend over time in sequential auctions of identical lots of wine or art. This is the well-known “declining-price” anomaly (or “afternoon effect”). Other empirical studies that document a similar declining trend include Ashenfelter and Genesove (1992), McAfee and Vincent (1993), and Beggs and Graddy (1997). Furthermore, the experimental literature suggests that learning tends to take place in repeated or sequential auctions for identical items (Kagel and Levin (1986) and Lind and Plott (1991)). Finally, we note that with the exception of the lagged cost variable, none of the control variables are significant.

IV. CONCLUSION

This paper examines the U.S. Treasury’s buyback operations conducted during 2000 to 2002. These buyback operations were simultaneous discriminatory common-value auctions with both multi-item and multi-unit features. The existence of an active secondary market for the securities included in the auctions allows for careful measurement of the cost incurred by the Treasury in these auctions.

The average cost to the Treasury in these auctions is only 3.80 cents per $100 face
value. This value is only a fraction of the bid-ask spread and represents a surprisingly low market impact. Consistent with theory about the winner’s curse, we find that auction participants adjust their strategies in response to the level of uncertainty surrounding the common value. Increases in bond price volatility are accompanied by increases in the average markup the Treasury had to pay above secondary market prices.

We find that the Treasury is penalized for including more bonds in the list of bonds eligible for buyback. Thus, the multi-item design of the auction does not appear to have been optimal from the Treasury’s perspective. In contrast, there is no evidence that variation in the total par amount of bonds auctioned (the number of units per item) affects the Treasury expected cost. In future work, it would be interesting to explore the bidding strategies employed by auction participants in the face of the complex multi-item and multi-unit design of the auctions. Also, it would be useful to understand how the Treasury allocated its demand across the different bonds offered by auction bidders.
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**Summary Statistics for Treasury Buybacks.** This table reports the minimum, average, and maximum values of the indicated characteristics for the 45 Treasury buybacks during 2000 to 2002. The total amount to be bought back is expressed in billions of dollars. The time delay is the time between the announcement of the buyback result by the Treasury and the 11.00 a.m. deadline for submitting offers. The average coupon rate, years to maturity, bid-ask spread, and bond prices are averages over all of the bonds included in each auction (excluding bonds for which we have no price data). The average bid-ask spread and bond price are expressed in dollars per $100 notional amount.

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<th></th>
<th>Minimum</th>
<th>Average</th>
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<td>Number of Bonds on Buyback List</td>
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<td>Average Years to Maturity</td>
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Table 2

Regression Results. This table reports the results from the regression of average cost paid by the Treasury in each auction on the indicated explanatory variables. Number of bonds denotes the number of bonds eligible to be bought back listed in the Treasury buyback announcement. Average par amount is the ratio of the total par amount to be bought back divided by the number of bonds for each buyback, measured in $ billions. Volatility is the average daily volatility of the bonds bought back during the five days previous to the buyback announcement. The time-trend variable is the number of the buyback and ranges from 1 to 45. The coupon and maturity variables are the average values over bonds bought back in each auction. The callable variable is a dummy variable that takes value one if the bonds bought back are callable. The offer-accept ratio is the ratio of the total dollar amount of bonds offered to the total dollar amount bought back in each auction.

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