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The U.S. Treasury Buyback Auctions: The Cost of Retiring Illiquid Bonds

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ABSTRACT

We study an important recent series of buyback auctions conducted by the U.S. Treasury in retiring $67.5 billion of its illiquid off-the-run debt. The Treasury was successful in buying back large amounts of illiquid debt while suffering only a small market-impact cost. The Treasury included the most-illiquid bonds more frequently in the auctions, but tended to buy back the least-illiquid of these bonds. Although the Treasury had the option to cherry pick from among the bonds offered, we find that the Treasury was actually penalized for being spread too thinly in the buybacks.

ONE OF THE MOST DRAMATIC RECENT EVENTS in the Treasury bond market was the surprise announcement in January 2000 of the Treasury's first buyback program for its long-term debt in 70 years.[1] Through this program, the Treasury retired $67.5 billion of its debt in 45 separate buyback operations. The introduction of this program was in response to the budget surpluses of the late 1990s as well as to the Treasury's goal of replacing older off-the-run debt with lower-coupon on-the-run debt. Market participants supported the buyback program enthusiastically and individual buybacks were invariably oversubscribed by wide margins.

The buyback auctions differed from the standard Treasury auctions used to issue bills and bonds in several important ways. Foremost among these was that the bonds involved were older and less-liquid issues, contrasting sharply with the usual Treasury issuance auction for highly liquid on-the-run bills and bonds. Thus, the Treasury faced the risk of suffering huge market-impact costs in buying back such massive amounts of its illiquid debt. To address this problem, the Treasury designed a unique structure for the buyback auction that gave the Treasury a number of options that could be used to mitigate the

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[1] On the day after the announcement, long-term Treasury markets had their largest single-day rally since Black Monday, October 19, 1987. The 30-year Treasury bond rallied by five points ($5 per $100 notional amount) and dropped 32 basis points in yield.

market-impact costs. First, the Treasury had the option to choose which of the more than 50 eligible bonds to include in each buyback auction. That is, the Treasury had the ability to set the agenda for each auction in a way that could minimize its buyback costs. Second, the Treasury also had the option to cherry pick among the various bonds offered by auction participants. Specifically, the Treasury buyback announcement specified the *total* amount of debt to be bought back in an auction from a list of as many as 26 bonds, but it did not specify the amount for *individual* bonds. Thus, the Treasury could pick and choose among the different bonds offered since they were perfect substitutes from the perspective of retiring debt.

How well did the buyback auction process work in reducing the Treasury's buyback costs for their illiquid debt? On the one hand, the Treasury clearly used its options since it did not simply follow a $1/N$ policy among eligible bond issues in auctioning and buying back its debt. The Treasury's strategic behavior could therefore have reduced its buyback costs. On the other hand, these options also had the potential to increase the winner's curse problem faced by buyback auction participants and, in turn, affect equilibrium bidding strategies and prices in a way that might actually have increased the Treasury's buyback costs. Whether the Treasury was well served by the buyback auctions is an important open issue not just for the United States, but also for a growing number of countries that are considering or have already implemented buyback programs of their own, such as Australia, Canada, Finland, Germany, Iceland, Italy, the Netherlands, Norway, Poland, South Africa, South Korea, and Sweden.

This paper studies the buyback auctions from the perspective of the key decisions made by auction participants throughout the process, as well as from the perspective of the auction outcomes for Treasury buyback costs, bond prices, and bond market liquidity. 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 precisely measure the Treasury's buyback cost by comparing winning offers with the nearly simultaneous secondary market prices of the bonds.

We begin by examining the decisions made by the Treasury in determining which bonds to include in the buyback auctions. Although almost every eligible 30-year bond was included in the buyback auctions on a rotating basis, the results indicate that the Treasury had a tendency to include the most-illiquid bonds in the auctions more frequently.

Next, we study the decisions by auction participants in offering their bonds to the Treasury. Not surprisingly, the larger the outstanding notional amount of the bond in the market, the larger was the amount of the bond offered to the Treasury. Moreover, auction participants tended to offer a larger amount of the most-illiquid bonds.

Finally, we examine the acceptance decisions by the Treasury. Interestingly, despite the Treasury's tendency to include the most-illiquid bonds in buyback auctions, on average the Treasury bought back more of the least-illiquid bonds included in each auction. Furthermore, the Treasury had a strong propensity to buy back bonds with higher coupons and longer maturities. This suggests

that the Treasury may have been trying to minimize its interest expense rather than its buyback costs. This is analogous to a firm following the internal rate of return (IRR) rule rather than the net present value (NPV) rule in making capital budgeting decisions.

Turning to the auction outcomes, we find that the average offer accepted by the Treasury is only 4.38 cents per $100 notional amount higher than the ask price of the bond in the secondary market. This average buyback cost is remarkably small given the huge notional amount of bonds involved in the buyback auctions. In fact, this average cost is only slightly larger than the cost for auctioning on-the-run bonds in standard Treasury auctions, and is smaller than the usual bid-ask spread observed in the markets for much smaller volumes. These results suggest that the buyback auction structure was generally successful in minimizing the market-impact cost of buying back illiquid debt issues. The results also indicate that the Treasury's costs are directly related to the volatility of bond prices, suggesting that at least some of these costs represented compensation to auction participants for bearing the risk of the winner's curse. Surprisingly, however, we also find that the Treasury's buyback cost is an *increasing* function of the number of bonds included in each auction. Thus, rather than benefiting from the option to pick and choose, the Treasury actually appears to have been penalized for being spread too thinly in these buyback auctions.

We also study how the liquidity of bonds changed during the buyback auction process. Surprisingly, bonds included in a buyback actually became *less* liquid relative to other bonds once a buyback was announced. After the buyback was completed, however, the relative difference in liquidity disappeared. There is no discernable effect in the relative pricing of included and excluded bonds during the buyback auction process. Finally, we examine whether the Treasury used the "timing" option provided to it by the buyback auction structure. Since the auctions closed at 11:00 a.m., but auction results were not announced until up to 2 hours later, the Treasury had the option to condition its decisions on price movements subsequent to the close of the auction. We find no evidence that the Treasury exploited this timing option.

Other recent work on Treasury auctions includes Bikhchandani and Huang (1989, 1993), Cammack (1991), Spindt and Stolz (1992), Umlauf (1993), Simon (1994), Nyborg and Sundaresan (1996), Gordy (1999), Bikhchandani, Edsparr, and Huang (2000), Nyborg, Rydqvist, and Sundaresan (2002), and Keloharju, Nyborg, and Rydqvist (2005). This paper extends and complements this literature by focusing on buyback auctions rather than the usual type of Treasury issuance auctions. Because these buyback auctions differed in a fundamental way from the usual issuance auctions, our results offer a new perspective on the Treasury auction process.

I. The Treasury Buyback Auctions

From March 2000 to April 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 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 multiunit auction features.[2] 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 pure common-value auctions.

At the program's inception, the Treasury anticipated that four primary benefits 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 the Treasury greater control over the maturity structure of its debt. Third, the buybacks would provide an additional cash management tool. Fourth, the buybacks would allow 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 1 to 2 days prior to the auction. The announcement identified which of the eligible bonds were to be included in the buyback as well as the maximum total notional amount (across all bonds) to be bought back. The set of 51 eligible bonds included all bonds originally issued as 30-year bonds, with maturity dates between February 15, 2010 and April 15, 2032, and with coupon rates from 3.375 to 14.000%. The Treasury reserved the right to buy back less than the maximum amount, but never exercised this option. Intuitively, it is clear why the Treasury would be extremely unlikely to exercise this option. To buy back less debt than was planned would likely be viewed by the market as an auction failure in the same way that an undersubscribed issuance auction would be viewed as an extremely negative signal about the Treasury's ability to sell debt. In a repeated game setting, the cost of an auction failure could easily far outweigh the market-impact costs of an individual buyback auction. In buying back the total stated amount of debt, however, the Treasury usually accepted offers for only a subset of the bonds included in the auction.

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. In contrast to the debt

[2] Multi-item or multiunit auctions have received much attention from theoretical auction studies (see Wilson (1979), Demange, Gale, and Sotomyaer (1986), Admati and Pfleiderer (1989), Back and Zender (1993), Cramton (1998), Milgrom (2000), Ausubel and Milgrom (2002), Wang and Zender (2002), and many others). However, despite the many important theoretical advances in this area, relatively little is known about how well multiitem or multiunit auctions perform in practice.

sales auctions conducted by the Treasury, there was no provision for noncompetitive participation.[3]

Offers had to be submitted by the closing time indicated in the buyback auction announcement, which was always 11:00 a.m. Eastern Time on the day of the auction. Offers were binding and the Treasury announced results within 2 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 and highest price of accepted offers.

The common-value element of these auctions was inherent in the timing of the offers and the acceptance decision. All bidders were required to submit offers by 11:00 a.m. on 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, was what the value of a bond would be at the time that the results of the auction were announced. The uncertainty about the price of a bond 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 per $100 notional amount. 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 were announced, all participants could directly observe the secondary market price of the bonds, which was clearly the common value of the bonds to the bidders. Thus, this auction comes close to representing a pure common-value auction.

II. The Data

Our study uses a data set 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 the U.S. Treasury securities. The data set 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* data set is used by industry analysts, dealers, traders, brokers, as well as investors. In addition, we use information released by the Treasury about eligible bonds and auction results.[4]

Since the buybacks were procurement auctions, one issue of interest is the average cost to the Treasury of the auction, where the cost is defined as the

[3] For details about the rules governing Treasury buyback operations, see *Federal Register*, Vol. 65, No. 12, January 19, 2000 (available at ftp://ftp.publicdebt.treas.gov/gsrfr1192000.pdf).

[4] Treasury buyback and buyback result announcements can be found at http://www.publicdebt.treas.gov/of/ofbuybakpr.htm.

difference between the average accepted offer price and the corresponding secondary market ask price for the bonds in each buyback.[5] As the measure of the secondary market price for each bond, we use the last market quotation in the *GovPX* data set available at the time that the auction results were announced (the auction result announcement is time-stamped to the nearest minute).[6] 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% of the last market quotes occurs 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.[7]

Table I presents descriptive statistics for the Treasury buybacks. Altogether, there were 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 between 1980 and 2001, and every 30-year bond issued between 1980 and 1997 was included in at least one buyback operation. In total, the 45 buyback operations involved exactly 45 unique bonds. The number of bonds in a redemption operation ranged from 6 to 26, with a median of 11 and mean of 11.4. The maximum total par amount of bonds that the Treasury proposed to buy back in any single operation (as stated in the Treasury redemption operation announcement) was between 0.75 to 3 billion dollars, with a mean of 1.5 billion dollars. The Treasury always redeemed the maximum amount, but did not always spread repurchases evenly among all the eligible bonds. In fact, Table I shows that in virtually every auction, there were a number of bonds for which the Treasury accepted no offers at all. (Note that in every auction, market participants submitted offers for every bond listed on the buyback announcement). On average, only about 70% of the eligible bonds had at least some offers accepted. Thus, the Treasury clearly did not simply buy bonds back using a $1/N$ rule based on the amount outstanding, amount offered, or the number of bonds on the list. Furthermore, even when the Treasury accepted some offers for a particular bond, the amount accepted was always only a fraction of the total amount offered. The amount offered was on average 4.4 times that of the amount accepted. Finally, although not shown in Table I, the average maturity of bonds included in the buybacks was 18.19 years and the quoted bid-ask spread for virtually all the bonds in the sample was 6.20 cents per

[5] 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. The average accepted offer prices are reported by the Treasury in the announcement of auction results.

[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 produces results almost identical to those we report.

[7] 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 data set. Thus, we exclude the 37th buyback from the buyback cost analysis.

Table I

Descriptive Statistics for the Treasury Buybacks

Bonds denotes the number of bonds eligible for buyback in each auction. Not Bought denotes the number of bonds for which no offers were accepted. Total Offered and Total Accepted are the aggregate amounts across all bonds in an auction and are measured in millions of dollars. Delay is the number of minutes between the close of the auction and the Treasury's announcement of auction results. Variation In Marginal is the standard deviation taken over all bonds bought back of the marginal buyback cost for those bonds, where the marginal buyback cost for a bond is the difference between the maximum price paid by the Treasury for a bond and the market ask price for the bond immediately before the announcement of auction results. Average Cost is the average buyback cost in cents per $100 national amount for bonds bought back, weighted by amount bought back. The buyback cost for a bond is the difference between the weighted-average accepted price and the corresponding ask price for the bond in the secondary market at the time the auction results are announced. The averages at the bottom of the table are simple averages of the values reported for each buyback auction.

Buyback Number	Date	Bonds	Not Bought	Total Offered	Total Accepted	Delay	Variation in Marginal	Average Cost
1	March 9, 2000	13	4	8,627	1,001	111	0.029	0.073
2	March 16, 2000	11	0	6,444	1,001	104	0.050	0.188
3	April 20, 2000	14	2	8,524	2,000	40	0.045	0.300
4	Aprril 27, 2000	26	2	10,82	3,000	50	0.086	0.390
5	May 17, 2000	12	2	9,116	2,001	72	0.052	−0.060
6	May 25, 2000	13	1	8,114	2,000	63	0.064	−0.393
7	June 22, 2000	12	1	7,340	2,000	54	0.072	0.181
8	June 29, 2000	13	2	7,023	2,000	36	0.035	−0.006
9	July 20, 2000	8	1	4,440	1,500	32	0.128	−0.014
10	July 27, 2000	6	1	3,641	1,000	30	0.025	−0.036
11	August 17, 2000	11	3	6,879	1,500	40	0.071	0.047
12	August 24, 2000	10	7	4,950	750	35	0.058	−0.051
13	September 21, 2000	11	1	5,888	1,500	29	0.056	−0.159
14	September 28, 2000	10	8	5,660	1,000	31	0.003	0.056
15	October 19, 2000	10	1	4,785	1,501	25	0.105	−0.165
16	October 26, 2000	11	2	5,308	1,500	28	0.064	0.081
17	November 9, 2000	11	1	4,796	1,250	95	0.061	0.037
18	November 16, 2000	10	7	4,903	1,000	88	0.018	0.004
19	December 7, 2000	11	5	4,984	1,250	115	0.067	−0.135
20	December 14, 2000	9	2	4,194	1,251	97	0.068	0.071
21	January 18, 2001	12	2	5,242	1,750	93	0.093	0.143
22	January 25, 2001	10	6	5,158	1,000	90	0.112	−0.343
23	February 21, 2001	12	3	5,536	1,750	87	0.058	−0.010
24	March 1, 2001	11	0	5,490	1,750	85	0.062	0.201
25	March 22, 2001	11	1	3,750	1,750	95	0.085	0.112
26	March 29, 2001	10	6	6,197	1,000	93	0.092	0.217
27	April 19, 2001	12	2	8,040	2,000	28	0.064	0.187
28	April 26, 2001	12	1	7,138	2,001	26	0.128	−0.254
29	May 17, 2001	12	3	5,775	1,750	22	0.046	−0.066
30	May 24, 2001	10	6	6,733	750	40	0.043	0.130
31	June 21, 2001	12	5	8,415	1,750	24	0.083	0.125
32	June 28, 2001	12	1	7,643	1,750	20	0.054	0.119
33	July 19, 2001	11	5	6,079	1,500	33	0.028	0.099
34	July 26, 2001	10	8	6,078	1,000	23	0.019	−0.005
35	August 16, 2001	12	5	10,452	1,751	23	0.039	0.138

(*continued*)

Table I—*Continued*

Buyback Number	Date	Bonds	Not Bought	Total Offered	Total Accepted	Delay	Variation in Marginal	Average Cost
36	August 23, 2001	12	2	6,765	1,750	18	0.049	−0.077
37	October 18, 2001	11	6	5,632	1,500	66	–	–
38	October 25, 2001	10	8	5,044	1,000	24	0.163	0.254
39	November 15, 2001	12	2	7,617	1,750	92	0.108	−0.083
40	November 29, 2001	10	1	4,654	1,500	89	0.068	−0.548
41	December 13, 2001	12	3	5,393	1,500	84	0.062	1.208
42	December 20, 2001	10	7	4,906	1,250	78	0.056	−0.154
43	April 18, 2002	13	5	6,213	1,000	25	0.078	0.006
44	April 23, 2002	10	2	5,088	1,500	20	0.043	0.048
45	April 25, 2002	12	4	5,186	1,500	17	0.026	0.067
Average		11.40	3.31	6,237	1,500	54.89	0.064	0.0438

$100 notional amount. Virtually all of the buyback bonds were selling at a premium.

III. Key Decisions in the Buyback Process

In this section we analyze the key decisions made throughout the buyback auction process by both the Treasury and the auction participants. Specifically, our goal is to understand better the determinants of the Treasury's decisions about which bonds to include in each buyback, the auction participants' decisions about offering bonds to the Treasury, and the Treasury's decisions about which offers to accept.

A. Which Bonds Were Included?

As we discuss earlier, the set of eligible bonds consisted of 51 separate bonds with coupon rates ranging from 3.375 to 14.000%. From Table I, an average of about 11 bonds were included in each of the 45 buyback auctions. The number of bonds included in each auction, however, ranged from 6 to 26. Thus, the decision about which bonds to include in a buyback likely was not entirely based on a simple mechanical rule.

To explore the Treasury's decision, we estimate a simple logit regression in which the dependent variable takes the value of one if a bond is included in a buyback, and zero otherwise. As explanatory variables, we include a dummy variable for whether the bond is callable, the coupon rate and maturity of the bond, and the total amounts (in millions of dollars) of the bond that were offered and accepted in previous buybacks. To capture the possibility that there was a systematic or rotating pattern to the inclusion of a bond in an auction, we also include dummy variables for whether the bond was included in the first through fourth previous buyback auctions.

Finally, given the Treasury's stated objective in introducing the buyback program of replacing its illiquid debt with newer and more liquid debt, it is also important to control for some measure of bond liquidity. Ideally, we would like to include the bid-ask spread of the bond or a measure of its trading volume as a proxy for its liquidity. Unfortunately, however, the quoted bid-ask spreads for all of the bonds in the sample are essentially equal and trading volume data are not available. Thus, as a proxy for the liquidity of a bond, we use the average number of price quotation revisions for the bond during the 5 days immediately preceding the buyback announcement. This measure has been used as a proxy for bond liquidity in many other studies.[8] To provide some descriptive statistics, we note that the eligible callable bonds in the study had an average of 220–240 daily quotations. The oldest noncallable bonds were generally the most liquid of all off-the-run bonds, with averages of roughly 480–510 daily quotations. Bonds that were roughly 3 to 5 years old were the least liquid of all noncallable bonds, with averages ranging from about 370–400 daily quotations. The most liquid bonds were the two or three most recently auctioned on-the-run bonds, with averages ranging from 500 to over 1,500 daily quotations. For noncallable bonds, the correlation between the age of the bond and its liquidity is −0.512.

Table II reports the results from the logit regression. As shown, there is a strong systematic pattern in how the Treasury decided to include bonds in the buyback auctions. In particular, the Treasury tended to include the same bond in every fourth auction. Thus, bonds included in the previous, second-previous, and third-previous auctions were much less likely to be included in the current auction. This pattern does not completely explain the Treasury's decisions, however. In particular, callable bonds were significantly less likely to be included in buybacks than noncallable bonds. This might be due to the fact that the Treasury has an additional channel for retiring these bonds. Specifically, the Treasury has the option to call these bonds. Similarly, bonds with higher coupons were more likely to be included in buybacks. Perhaps the most striking result in Table II is the highly significant negative relation between the inclusion of a bond in a buyback auction and its liquidity measure. This result is very consistent with the Treasury's stated objective of buying back its illiquid debt; the most-illiquid bonds tended to be included in buyback auctions more frequently.

B. Which Bonds Were Offered?

To understand fully the decisions made by auction participants in offering their bonds to the Treasury, it would be necessary to have complete price and quantity data about every offer made. Unfortunately, this information is not available to us. However, we do have information about the total notional amount of each bond that was offered in each buyback auction. These data may be able to provide some insight into the auction participants' decisions. Toward this end, we regress the total notional amount offered (normalized by

[8] For example, see Fleming (2003).

Table II
Results from the Logit Regression of the Inclusion of Bonds in the Buybacks

This table reports the results from the logit regression of whether a bond is included in an auction (yes = 1, no = 0) on the indicated explanatory variables. Maturity is measured in years. Amount Previously Offered and Amount Previously Accepted are the cumulative amounts (in millions of dollars) of the bond offered by market participants or accepted by the Treasury in previous buybacks. Included in n^{th} Previous Buyback denotes dummy variables that take the value of one if the bond was included in the first, second, third, and fourth previous buybacks. Liquidity is the average number of daily quotations for the bond during the 5 days immediately preceding the buyback announcement date. The logit regression uses pooled data across 45 buybacks for 51 bonds eligible for inclusion in the Treasury buyback program. Bonds for which no quotations are available are excluded from the sample.

Variable	Coefficient	z-Statistic
Intercept	−2.17318	−4.42
Callable Dummy	−1.65969	−5.41
Coupon Rate	0.17033	2.27
Maturity	0.04024	1.51
Amount Previously Offered	0.00005	1.05
Amount Previously Accepted	−0.00019	−1.32
Included in Previous Buyback	−1.14895	−6.48
Included in 2nd Previous Buyback	−0.83422	−4.82
Included in 3rd Previous Buyback	−0.33494	−2.06
Included in 4th Previous Buyback	3.00195	20.87
Liquidity	−2.17318	−5.09
N		2116
McFadden R^2		0.327

the total size of the corresponding buyback, that is, the notional amount of bonds to be bought back in the buyback) for each of the bonds included in a buyback on a number of potential explanatory variables.

As explanatory variables, we again include a callable dummy, the coupon rate and maturity of the bond, and the total notional amounts of the bond offered and accepted in previous buybacks. In addition, we include the total number of bonds in the buyback since this could affect the types of strategies employed by auction participants. We also include the total notional amount of the bond outstanding since this provides some measure of the supply of the bond in the market. Finally, we again include the liquidity measure of the bond in the regression. As with the dependent variable in the regression, all explanatory variables that are expressed in notional amounts (amount offered previously, amount accepted previously, and amount outstanding) are also normalized by the total size of the buyback.

Table III shows that the most important determinant of the amount of bonds offered to the Treasury is simply the outstanding notional amount of the bond in the market. Thus, the greater the supply of the bond in the market, the

Table III
Regression Results for the Amount of Bonds Offered

This table reports the results from the regression of the amount (standardized by the size of the buyback) offered by market participants to the Treasury for each bond included in a buyback on the indicated explanatory variables. Maturity is measured in years. Number of Bonds is the total number of bonds included in the corresponding buyback. Amount Previously Offered and Amount Previously Accepted are the cumulative amounts (standardized by the size of the buyback) of the bond offered by market participants or accepted by the Treasury in previous buybacks. Amount Outstanding is the total outstanding par amount of the bond (standardized by the size of the buyback). Liquidity is the average number of daily quotations for the bond during the 5 days immediately preceding the buyback announcement date. Bonds for which no quotations are available are excluded from the sample.

Variable	Coefficient	*t*-Statistic
Intercept	−0.25773	−1.29
Callable Dummy	0.05484	0.82
Coupon Rate	0.04996	4.43
Maturity	0.00427	0.93
Number of Bonds	−0.00334	−1.11
Amount Offered Previously	0.02662	2.98
Amount Accepted Previously	0.01034	0.33
Amount Outstanding	0.02876	11.84
Liquidity	−0.00039	−2.51
N		513
R^2		0.418

greater the total amount of that bond offered to the Treasury. Beyond this simple supply-related relation, however, there are a number of other interesting effects identified in the regression. In particular, Table III shows that bonds with higher coupons tend to be offered in greater amounts. In addition, there is a tendency for bonds that have been offered in previous buybacks to be offered again in the current buyback auction. In contrast, there is no evidence that the amount of the bond accepted in previous buybacks affects the amount offered in the current buyback auction. Finally, Table III shows that there is again a significant relation between auction participants' decisions and the liquidity of the bonds. Specifically, there is a significant negative relation between the amount of the bond offered and the liquidity of the bond, implying that auction participants have a propensity to offer illiquid bonds in greater amounts. This result is consistent with auction participants viewing the buyback auction as an opportunity to divest their portfolios of bonds that have become illiquid and would otherwise be difficult to sell.[9]

[9] We are very grateful to the referee for this insight. These results could also be consistent with the evidence of Goldreich (2005b) about the bidding behavior of dealers in the U.S. Treasury auctions.

C. Which Bonds Were Accepted?

Turning now to the Treasury's decisions about which offers to accept, we again follow the approach of regressing the notional amount of each bond accepted (normalized by the buyback size) on a number of explanatory variables. Intuitively, the normalized amount of each bond accepted provides direct information about the Treasury's buyback strategy. For example, if the Treasury were to follow a strategy of buying back debt equally across bonds, then this measure would be equal across bonds within an auction. Alternatively, if the Treasury bought back bonds in proportion to the amount in which they were offered, this measure would be perfectly correlated with the ratio of the amount of each bond offered to the total amount of bonds offered.

As explanatory variables, we again include the coupon rate and maturity of the bonds. If the Treasury were to attempt to minimize its accounting interest expense rather than its buyback costs, these variables might be related to the acceptance decision.[10] We again include the number of bonds, the notional amounts previously offered and accepted, and the total notional amount outstanding as explanatory variables. Also, we include the total notional amount of each bond offered to the Treasury in the buyback auction. As with the dependent variable, all explanatory variables measured in notional amounts (amount offered, amount previously offered, amount previously accepted, amount outstanding) are normalized by the size of the corresponding buyback auction. As an additional explanatory variable, we include the change in the price of the bond between the 11 a.m. close of the buyback auction and the time at which the Treasury announced the auction results. As Table I shows, the time between the two events ranged from 17 to 115 minutes and averaged about 55 minutes. Because of the lag between the 11 a.m. cutoff for submitting offers and the time when the Treasury announced its acceptance decisions, the Treasury had a potentially valuable timing option. For example, the Treasury could have tilted its acceptance decisions toward bonds with prices that had increased relatively more than those of other bonds during the delay period. In this sense, the Treasury could have potentially exploited auction participants who were in effect giving a call option to the Treasury with a time horizon of up to two hours. Finally, we also include the liquidity measure for each bond to examine the relation between bond liquidity and the Treasury's acceptance decision.

Table IV reports the regression results.[11] As shown, the amount offered is by far the most significant explanatory variable in the regression. The slope coefficient for this variable is 0.176 with a t-statistic of 8.09. This result indicates that acceptance decisions were strategic in the sense that the Treasury adapted its decisions to the menu of choices presented by auction participants. In addition, the table shows that both the slope coefficients for the coupon rate and the

[10] Since the buybacks consisted of either only noncallables or only callables, the callable dummy variable is not meaningful in the Treasury's acceptance regression and is therefore not included.

[11] The number of observations in Table IV is slightly smaller than in Table III since a few of the bonds included in auctions are missing pricing data for some dates.

Table IV
Regression Results for the Amount of Bonds Accepted

This table reports the results from the regression of the amount (standardized by the buyback size) accepted by the Treasury for each bond included in a buyback on the indicated explanatory variables. Maturity is measured in years. Number of Bonds is the total number of bonds included in the corresponding buyback. Amount Offered is the amount of the bond offered by market participants to the Treasury (standardized by the size of the buyback). Amount Previously Offered and Amount Previously Accepted are the cumulative amounts (standardized by the size of the buyback) of the bond offered by market participants or accepted by the Treasury in previous buybacks. Price Difference is the difference between the last price of the bond before the announcement of auction results and the last price of the bond before the close of the auction at 11 a.m. on the date of the buyback. Amount Outstanding is the total outstanding par amount of the bond (standardized by the size of the buyback). Liquidity is the average number of daily quotations for the bond during the 5 days immediately preceding the buyback announcement date. Bonds for which no quotations are available are excluded from the sample.

Variable	Coefficient	*t*-Statistic
Intercept	−0.30213	−2.89
Coupon Rate	0.01800	3.05
Maturity	0.00782	3.45
Number of Bonds	−0.00102	−0.70
Amount Offered	0.17552	8.09
Amount Previously Offered	−0.00138	−0.30
Amount Previously Accepted	0.02304	1.44
Price Difference	0.00208	0.11
Amount Outstanding	−0.00483	−2.55
Liquidity	0.00013	2.29
N		499
R^2		0.223

maturity are positive and highly significant. The signs of these coefficients are consistent with the view that the Treasury had some propensity to buy back bonds that lowered its accounting interest expenses. As we discuss in the introduction, this is analogous to the Treasury putting some weight on an IRR rule rather than using the NPV rule exclusively in buying back its debt. Table IV also shows that the Treasury had no propensity to accept more of a bond that had increased in value relative to the others during the auction delay period. This strongly suggests that the Treasury did not attempt to exploit its timing option at the expense of market participants. Intuitively, this is consistent with the notion that Treasury auctions are repeated games and that predatory behavior in one auction might have long-lasting negative reputational consequences for the Treasury.

Finally, Table IV shows that after controlling for the notional amount offered, the total notional amount outstanding actually had a negative relation with the amount accepted. Similarly, the Treasury tended to accept more of the least-illiquid bonds offered. This contrasts starkly with the previous evidence that the Treasury tended to include the most-illiquid bonds more frequently in its

auctions, and that auction participants tended to offer the most-illiquid bonds in greater amounts. These results indicate that the increased activity for the most-illiquid bonds during the first stages of the buyback process did not map into more of these bonds being repurchased by the Treasury. Note that since we do not have detailed information about the individual offers made to the Treasury, we cannot determine whether the most-illiquid bonds were less likely to be bought back because of the way in which the Treasury used its option to pick and choose, or because the prices at which these bonds were offered were not as attractive as those for more-liquid bonds.[12]

IV. The Treasury's Buyback Costs

In this section, we examine the cost to the Treasury of buying back its debt. To calculate the cost to the Treasury for an individual auction, we first calculate the buyback cost for the individual bonds in that auction. Recall that the cost of buying back a bond is the difference between the weighted-average accepted price and the corresponding price for the bond in the secondary market at the time the auction results were announced. As the measure of the cost for each auction, we take the average (weighted by the notional amount bought back) of the costs for all bonds in that buyback. These averages are reported in the last column of Table I.

The average cost over all buybacks is 4.38 cents (all costs are measured per \$100 notional amount of the bonds). The average cost for the individual buybacks ranges from a minimum of −39.3 cents to a maximum of 120.8 cents. The average cost is positive for 59% of the auctions. The standard deviation of the mean of the average costs is 3.83 cents. To put these average costs into perspective, we observe that the average bid-ask spread for auctioned bonds is 6.20 cents per \$100 notional amount. Thus, the 4.38 cent point estimate of the average cost to the Treasury is only about 70% of the average bid-ask spread. This result is remarkable as it implies that the Treasury suffered virtually no market-impact costs in buying back its debt. For example, recent empirical evidence by Babbel et al. (2004) estimates 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 was \$184.4 million.

The average buyback cost also compares well with estimates of the market-impact costs incurred by the Treasury in its auctions of on-the-run bills and bonds. For example, Goldreich (2005a) estimates that the average underpricing of notes and bonds in Treasury auctions during the 1991 to 2000 period is on

[12] Another possibility is that the Treasury faces conflicting objectives in making decisions. On the one hand, the Treasury may wish to minimize its financing costs. On the other hand, the Treasury may wish to enhance the efficiency of the Treasury debt market. For example, in a standard multiunit Treasury auction setting, Nyborg and Strebulaev (2004) show how these objectives contradict each other, especially in discriminatory auctions. We are grateful to the referee for this insight.

the order of 3.50 cents per $100 notional amount. Cammack (1991), Nyborg and Sundaresan (1996), and others provide similar estimates.

In the idealized situation in which market participants provide atomistic offers across a continuum of prices for all bonds, the optimal way for the Treasury to have exploited the cherry-picking option would have simply been to equate the marginal buyback costs across bonds in each auction. In reality, of course, offers were likely "lumpy" and not equally distributed across bonds. Thus, it may not have been possible for the Treasury to equate its marginal buyback costs across bonds. With this caveat in mind, we next examine the extent to which marginal buyback costs were equalized.

The marginal buyback costs can be calculated by simply taking the difference between the maximum price paid by the Treasury for a bond and the market ask price for the bond immediately before the announcement of the auction results. Table I reports the standard deviation of the marginal buyback costs across bonds for each buyback auction. As shown, there is considerable variation in the marginal buyback costs. The standard deviation of the marginal buyback costs ranges from 0.3 cents to 16.3 cents across the auctions. The average value of these standard deviations is 6.4 cents. Thus, marginal buyback costs were clearly not equated across bonds in the buyback auctions. Again, however, this does not necessarily imply that the Treasury failed to act optimally in its acceptance decisions.

To analyze the buyback costs in more depth, we regress the average buyback costs for the auctions on a number of explanatory variables. Recall that one of the Treasury's motivations for the buyback program was to replace higher-cost off-the-run bonds with on-the-run bonds. Thus, it is possible that accounting issues could also have influenced the Treasury's decisions and, therefore, the average cost of the auctions. To control for this possibility, we include the average coupon rate, average maturity, and a dummy variable for callable bond buybacks as explanatory variables in the regression. We also control for the possibility of persistence in costs by including the lagged cost as an additional explanatory variable. To control for the degree to which a buyback auction is oversubscribed, we also include the ratio of the total notional amount of bonds offered to the total notional amount of bonds accepted.

Intuitively, it is clear that the ex post value of the Treasury's option to pick and choose should be an increasing function of the number of bonds over which it can choose. Thus, if the Treasury were to have used its option optimally, one might expect that the realized buyback cost would be a decreasing function of the number of bonds on the buyback list.

Theory also 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 buyback 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 price changes over 20-minute intervals between 8:00 a.m. and 3:00 p.m. each day during the five trading days prior to

the buyback announcement date (and convert it to a 1-day volatility by multiplying it by the square root of 21). As the volatility measure for each auction, we use the average of the volatility measures for the individual bonds bought back in the auction.

To explore the extent to which the scale of the auction affected the Treasury's buyback costs, we also include as an explanatory variable the total par or notional amount of bonds to be bought back (in $ millions) as per the Treasury's buyback announcement, normalized by the number of bonds eligible for buyback in that auction. Thus, this measure captures the average amount per bond that the Treasury intends to repurchase. To test for the possibility that learning occurred in a way that affected the Treasury's costs over time, we also include the number of the buyback 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 observed all of the prices and quantities offered, but only released 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. Finally, we include the average liquidity of the bonds in each buyback as an explanatory variable.

Table V reports the results from the regression. The coefficient for the number of bonds included in each auction is positive and significant. Specifically, the regression coefficient implies that the Treasury's expected cost increased by about 3.65 cents for every additional bond included in a buyback auction. This result is very counterintuitive since it indicates that the Treasury actually did *worse* as its opportunities to cherry pick increased.

In contrast, the coefficient for the average notional amount of bonds being auctioned is not significant. Thus, the size or scope of the individual buyback auctions does not appear to affect the Treasury's cost directly. This is consistent with recent evidence by Keloharju et al. (2005) on the price-quantity relation in Treasury auctions.

The coefficient for price volatility is both positive and significant. This supports the hypothesis that auction participants adjusted 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 et al. (2002), 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 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.[13] With the exception of the lagged cost variable, none of the

[13] 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

Table V
Regression Results for the Buyback Costs

This table reports the results from the regression of the weighted-average cost paid by the Treasury in each buyback on the indicated explanatory variables. The Callable Dummy variable takes the value of one if the buyback includes callable bonds. The Average Coupon Rate, Maturity, Volatility, and Liquidity variables are averages of the values for the bonds included in a buyback, weighted by the total amount of the bond bought back by the Treasury. Maturity is measured in years. Volatility is the daily volatility of a bond's price during the 5 days immediately preceding the buyback announcement date (based on observations at 20-minute intervals). Liquidity is the average number of daily quotations for the bond during the 5 days immediately preceding the buyback announcement date. Number of Bonds is the total number of bonds included in the corresponding buyback. Average Notional Amount is the ratio of the size of the buyback (in millions of dollars) divided by the number of bonds included in the corresponding buyback. The Total Offered Ratio is the ratio of the total amount of bonds offered in a buyback divided by the size of the buyback. Buyback Number ranges from 1 to 45. The number of buyback auctions in the sample is 43 since market price data for bonds in one buyback are missing and we include the lagged buyback cost as an explanatory variable.

Variable	Coefficient	*t*-Statistic
Intercept	−1.26186	−1.19
Lagged Cost	−0.41362	−2.43
Callable Dummy	0.74446	1.74
Average Coupon Rate	−0.08012	−1.01
Average Maturity	0.01549	0.72
Average Notional Amount	0.00162	0.63
Number of Bonds	0.03648	2.24
Total Offered Ratio	0.09253	1.76
Average Volatility	0.49599	2.06
Buyback Number	−0.00095	−0.24
Average Liquidity	0.00093	1.17
N		43
R^2		0.388

control variables are significant. This latter result indicates that there is a clear difference between the Treasury's buyback costs and its prospective interest expense savings. If the Treasury's goal was exclusively to retire bonds with the highest interest expense (rather than trying to minimize buyback costs), then the coupon and maturity control variables would likely be significant.

Finally, the average liquidity of the bonds included in a buyback auction has no significant effect on the Treasury's realized buyback costs. This result is striking since it indicates that while illiquidity had important effects on auction *quantities*, it had little apparent effect on auction *prices*.

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). Also see Bindseil, Nyborg, and Strebulaev (2004).

V. The Impact on Prices and Liquidity

To follow up on the last point above, this section investigates whether the liquidity and valuation of the bonds included in a Treasury buyback differed from those for the eligible bonds that were not included in the buyback.

To examine whether there was a change in the relative liquidity of included and excluded bonds during the buyback auction, we first calculate the average daily number of price quotations for each bond during each of three periods: the 5-day period before the buyback announcement, the 2- or 3-day period from the buyback announcement date to the buyback auction date, and the 5-day period after the buyback auction date. For each bond, we calculate the percentage change in the average daily number of quotations across these three periods. We then compute the difference between the average value taken over all bonds included in an auction and the average value taken over all bonds not included in that auction. Table VI reports summary statistics for differences in the average percentage changes in liquidity.

Surprisingly, bonds included in a buyback actually become *less* liquid relative to the bonds not included in a buyback during the period from the buyback announcement date to the buyback auction date. The relative change in liquidity is about −1.52%, with a t-statistic of −2.17. During the five-day period after the buyback auction, however, the relative change in liquidity is reversed as the included bonds become 1.28% more liquid than the bonds that were not included. The t-statistic for this relative difference is 2.21. Overall, the relative liquidity of the two sets of bonds during the 5 days after the buyback

Table VI

Buyback Auction Effects on Bond Liquidity and Prices

This table reports the changes in the relative liquidity and excess yields of bonds included in buyback auctions. Relative Change in Liquidity denotes the average percentage change in the liquidity of included bonds minus the average percentage change in the liquidity of excluded bonds, where the changes are measured from the 5-day pre-announcement period to the 2- to 3-day buyback period (including the announcement and auction dates), from the two- to 3-day buyback period to the 5-day post-announcement period, and from the 5-day pre-announcement period to the five-day post-announcement (overall) period. Liquidity is the average number of daily quotations for the bond during the relevant period. Relative Change in Excess Yield denotes the average excess yield change for included bonds (relative to the four-factor model) minus the average excess yield change for excluded bonds (relative to the four-factor model) for the indicated periods, where excess yields are expressed in basis points.

	Announcement to Auction		5-Day Post Auction		Overall	
	Change	t-Statistic	Change	t-Statistic	Change	t-Statistic
Relative Change in Liquidity	−1.521	−2.17	1.283	2.21	0.019	0.03
Relative Change in Excess Yield	−0.129	−0.73	0.080	0.29	−0.049	−0.14

date is virtually identical to that during the 5 days prior to the buyback announcement date. Thus, the effects of the buybacks on relative liquidity are very temporary.[14]

To examine whether there is a change in the relative value of included and excluded bonds, we first need to control for the differences in the bonds' characteristics. We do so by implementing a simple four-factor model of bond yields. Specifically, we compute the 20-minute yield changes for each bond in the sample during the 5-day period beginning 10 days prior to the buyback announcement date. We then regress these changes on the corresponding yield changes for the on-the-run 2-year, 5-year, 10-year, and 30-year Treasury bonds. We next use the fitted regression for each bond as a "market model" throughout the buyback auction period. For example, during the period from the buyback announcement date and the buyback date, the expected yield change for each bond is given by substituting the yield changes for the on-the-run bonds into the fitted regression. Differences between actual yield changes and the fitted values of the regression are designated as excess basis point changes. This approach can be viewed as equivalent to calibrating a four-factor affine term structure model to the on-the-run bonds and then applying it to individual bonds.[15]

To examine whether the relative prices of bonds change throughout the buyback auction process, we calculate the average cumulative excess basis point change for included bonds during the 2- or 3-day period from the buyback announcement date and the buyback date, and for the 5-day period after the buyback date. We calculate the same measure for the excluded bonds for the same two horizons, and then subtract them from the corresponding average for the included bonds. Table VI reports the results. As shown, there is no discernable difference in the relative pricing of the two sets of bonds. The difference in the average cumulative excess basis point changes is insignificant for both periods, as well as for the overall period.

VI. Conclusion

We study the U.S. Treasury's buyback program in which the Treasury retired $67.5 billion of its illiquid debt from 2000 to 2002. Using high-frequency intraday data, we find that the Treasury paid an average of only 4.38 cents per $100 notional amount more than the prevailing market ask price to buy back its debt. This cost is about two-thirds the size of the usual bid-ask spread for bonds that are bought back. On average, the Treasury buyback program appears to have been very effective in retiring its less-liquid debt with a minimum of

[14] These results are consistent with Fleming and Remolona (1999), who find that Treasury bonds become temporarily less liquid after public announcements of economic information. One possible explanation for this effect could be related to repo market activity. If market participants attempt to predict which bonds will be bought back and then short them, the resulting repo activity could temporarily depress the liquidity of the bonds. Without repo market data, however, we cannot test this hypothesis.

[15] As examples of this approach, see Dai and Singleton (2000) and Liu, Longstaff, and Mandell (2006).

"market-impact" costs. Since we do not have data on individual offers made to Treasury, we are unfortunately unable to fully resolve the issue of whether the Treasury's success was due to the design of the auction, to discounted bidding by auction participants anxious to unwind illiquid bond positions, or some combination of both. This is clearly an issue that would be worth additional future research.

An additional interesting aspect of the study is that the illiquidity of the Treasury bonds involved played an important and complex role throughout the buyback process. We find that the Treasury tended to include the most-illiquid bonds in buyback auctions more frequently. Furthermore, auction participants tended to offer more of the most-illiquid bonds in their portfolios. However, the Treasury ended up tilting its repurchases toward the least-illiquid bonds offered by auction participants.

These results also have implications for the design of Treasury auctions. For example, we find that the buyback cost to the Treasury was an increasing function of the number of bonds included in each buyback. Since increasing the number of bonds in a buyback allowed the Treasury a greater option to pick and choose, this evidence suggests that the cost of the option outweighed the benefits the Treasury was able to extract from it. We find evidence that the Treasury may have attempted to minimize its accounting interest costs at the expense of its buyback costs.

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