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Are Negative Option Prices Possible? The Callable U.S. Treasury-Bond Puzzle*

Market prices for callable Treasury bonds often imply negative values for the implicit call option. I consider a variety of possible explanations for these negative values including the Treasury's track record in calling bonds optimally, tax-related effects, tax-timing options, and bond liquidity. None of these factors accounts for the negative values. Although the costs of short selling may explain why these apparent arbitrage opportunities persist over time, why these implicit call values become negative in the first place remains a puzzle.

I. Introduction

Few concepts in option-pricing theory are as well known and intuitive as the result that option prices cannot be negative.[1] A negative call price implies that the option writer pays the option purchaser to take the option. In the absence of significant market frictions, negative option prices should not be observed in well-functioning financial markets.

In this article, I document that callable U.S. Treasury-bond prices frequently imply negative values for the implicit call option. For example, I find that nearly two-thirds of the call values implied by a sample of recent callable bond prices are negative. Most of these negative values exceed the bid-ask-spread-related costs of implementing a simple arbitrage strategy to take advantage of the negative values. These apparent arbitrage opportunities persist over time and occur for callable bonds with widely varying coupon rates and maturity dates.

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1. For example, see Merton (1973) and Harrison and Kreps (1979).

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These puzzling findings raise a number of interesting issues. For example, I consider whether there is some feature of the implicit call option that justifies a negative price. I show that negative prices could occur if the Treasury calls bonds when the implicit call option is out of the money—a policy often followed by corporations. I address this issue by examining the Treasury's call policy during the postwar period. On the one hand, I find that bonds are called only when it is rational to do so. On the other hand, the Treasury has a tendency to wait too long before calling eligible bonds. In general, however, the Treasury's performance in calling bonds optimally is superior to that of many U.S. corporations. Surprisingly, the price of each bond called by the Treasury was in excess of par at the time the call was made.

Given that the Treasury only makes rational calls, I next consider whether there are features of the callable bond itself that could account for the negative call values. I find that callable bonds are generally less liquid than noncallable bonds. Thus, the results in Amihud and Mendelson (1986) imply that the negative values are not artifacts of liquidity differences. I also consider the effects of differences in the taxation of callable and noncallable bonds, differences in the taxation of premium and discount bonds, tax-trading options in bond prices, the Treasury's STRIPs (Separate Trading of Registered Interest and Principal) program, deliverability against the Chicago Board of Trade's Treasury-bond futures contract, and tax clienteles. These factors are unable to explain the negative call values.

The persistence of these negative values over time raises the important issue of why these negative values are not arbitraged away. To address this, I consider the effects of a number of costs and market frictions. I find that the most likely explanation for the persistence of the negative call values is the cost and difficulty of establishing the short component of the arbitrage strategy—these costs make the arbitrage strategy uneconomic for all but current holders of callable bonds.

In summary, I am unable to account for the negative call values implicit in callable Treasury-bond prices. Although these negative call values may not represent actual arbitrage opportunities for all investors, they are still puzzling given that the Treasury-bond market is one of the most actively traded and efficient financial markets in the world. At a minimum, these results suggest that market frictions and imperfections can have first-order effects on security prices.

The remainder of this article is organized as follows. Section II describes how the call option values are estimated. Section III describes the data, and Section IV presents the empirical estimates. Section V focuses on the Treasury's policy in calling eligible bonds. Section VI examines a variety of possible explanations for the negative call values. Section VII considers several market frictions and their effects on an arbitrageur's ability to profit from negative call values. Concluding remarks are made in Section VIII.

II. Estimating Call Option Values

Beginning with the 2% consol bonds issued in 1900 and callable after 1930, the Treasury has marketed many issues of callable bonds during the twentieth century.[2] The Treasury's use of this financing vehicle, however, has been sporadic. For example, 42 of the 47 outstanding issues of Treasury bonds in mid-1945 were callable, while only seven of the 22 outstanding issues in mid-1972 were callable. Most of the currently outstanding issues of callable bonds were issued during the 1973–84 period, when a total of 23 different issues were sold. The Treasury stopped issuing callable bonds in 1984 because of the introduction of the STRIPs program.[3] The majority of the currently outstanding callable issues were originally 30-year issues and have terminal maturity dates ranging from 2007 to 2014 and coupon rates ranging from 7% to 14%.[4] The total par amount of callable Treasury bonds currently outstanding is roughly $98 billion, representing nearly one-fourth of the total par value of all Treasury bonds.

The call feature of these bonds gives the U.S. Treasury the right, but not obligation, to redeem the bonds (call the bonds) at the par value of 100 (the call price). The Treasury can exercise this option, upon 4 months' notice, on any of the semiannual coupon payment dates during the 5-year period prior to the final maturity date. Since the call can only be exercised during the last 5 years of the bond's life, the call is not strictly an American-style option. However, the call is not strictly a European-style option since it can be exercised prior to the maturity of the bond.

Economically, purchasing a callable bond is equivalent to purchasing a noncallable bond with the same coupon rate and maturity date and then selling a call option on the bond to the Treasury. Thus, a callable bond can be viewed as a long position in a noncallable bond and a short position in a call option. Since the call will presumably be exercised when it is to the Treasury's advantage and, therefore, to the callable bondholder's disadvantage, the equilibrium price of a callable

2. The use of callable bonds was also common during the nineteenth century. For example, the 3.5% bonds of 1881 and the 2% bonds of 1889 were callable "at the pleasure of the Government."

3. This program allows new issues of 10-year notes and 30-year bonds to be stripped via the book-entry system. New issues of callable bonds could not be stripped since the actual maturity date of callable bonds is unknown at the time the bonds are issued.

4. There are also several callable flower bonds current outstanding (bonds redeemable at par by the estate of the bondholder for the purposes of paying estate taxes). Because of their special tax features, I abstract from these bonds in this discussion.

bond should be less than that of a comparable noncallable bond by the amount of the call value.

Although a callable bond can be viewed as a portfolio of a bond and a call option, the two components do not trade separately. Consequently, market prices for the call option are not directly observable. In recent years, however, the increase in the size of the deficit has led the Treasury to issue many noncallable bonds, a number of which have maturities that coincide with the final maturity date of a callable bond. From these noncallable bonds, I can exactly replicate the bond component of the callable bond. By subtracting the callable bond price from the price of the replicating noncallable bond, I can infer directly the value of the call option implicit in the market price of the callable bond.

Let c denote the annual coupon rate for a callable bond and P_c be its price. Similarly, let s and P_s denote the annual coupon rate and price of a noncallable bond with the same coupon payment dates and final maturity date. Finally, let P_0 be the price of zero-coupon bond with maturity date coinciding with the final maturity date of the other bonds, and let C be the value of the call option. Using this notation, the value of the call option is given by the following expression:[5]

$$C = (c/s)P_s + (1 - c/s)P_0 - P_c. \tag{1}$$

This approach to estimating the value of the call option in callable Treasury-bond prices is possible only when there are multiple bonds with identical maturity dates. Thus, my approach relies on the completeness of the markets for some maturities. In this sense, my approach is similar to Litzenberger and Rolfo (1984), Cornell and Shapiro (1989), and Maloney (1991), who use triplets of bonds with the same maturity date to examine the relative pricing of noncallable Treasury bonds. The need to match callable bonds with two noncallable bonds necessarily restricts the size of the sample as well as the applicable sample period. By using only maturities for which redundant securities exist, however, I am able to estimate the call option value directly without having to make additional assumptions about the marginal tax rates of Treasury bondholders.[6]

5. The first term in this expression represents the value of a noncallable bond with coupon rate c that pays c/s dollars at maturity. The second term represents the value of a bond that pays $(1 - c/s)$ dollars at maturity. Together, the first two terms equal the value of a noncallable bond with coupon rate c. Subtracting the third term, the price of a callable bond with coupon rate c gives the value of the implicit call.

6. Schaefer (1982) discusses the effects of tax clienteles on bond prices in incomplete markets in his study of arbitrage opportunities in the market for British government securities.

III. The Data

In order for a callable Treasury bond to be included in the sample, a noncallable coupon bond and a zero-coupon bond with the same maturity date must also be traded during the sample period.[7] Flower bonds are excluded. These criteria restrict the callable bonds in the sample to the following five issues: the 7.500 August 1988–93, 7.000 May 1993–98, 8.500 May 1994–99, 8.000 August 1996–2001, and 8.250 May 2000–2005 issues.

Bond price data are obtained from the *Wall Street Journal*. The sample begins in June 1989 since this is when the *Wall Street Journal* first began reporting zero-coupon bond data. The data consist of Thursday closing bid and ask prices for the triplets of callable bonds and their associated coupon and zero-coupon bonds.[8]

Table 1 presents summary statistics for the data including the number of observations for the triplets; the high, low, and mean prices; the mean bid-ask spread for the bonds; the total principal amount of the issue outstanding; and the percentages of the total principal amount held by the public and stripped via the STRIPs program.[9]

IV. The Call Option Estimates

Estimates of the value of the implicit bond call option in the callable bonds are obtained directly from equation (1). In computing the call option price, I use the midpoint of the bid-ask spread as the point estimate of the value of the bonds. Summary statistics for the estimated call option values are given in table 2.

As shown, 209 out of 340 call value estimates are negative, representing 61.5% of the total. Negative estimates are obtained for each of the five callable bonds and cover the entire sample period and range of coupon rates and maturity dates. Many of the negative values are large in absolute terms; the mean value of the negative call values is −.343, and a number are less than −1.00.[10] Table 2 shows no apparent

7. Alternatively, two noncallable coupon bonds with the same maturity date as the callable bond could be used. This is not possible, however, because there is at most one noncallable coupon bond for each of the currently outstanding callable bonds.

8. In some cases, there is more than one price quotation for a zero-coupon bond. In these cases, we use the price quotations for the zero-coupon bond consisting of a stripped coupon payment. The reason for this is that stripped principal payments must be used in reconstituting the principal portion of a Treasury security stripped via the STRIPs program. This characteristic may affect the pricing of stripped principal payments.

9. Treasury bonds not held by the public include bonds held by the Federal Reserve, states, municipalities, and federal agencies.

10. All call values are computed assuming that the par value of the bond is 100.

TABLE 1 Summary Statistics for the Callable U.S. Treasury Bonds and the Corresponding Noncallable Coupon and Zero-Coupon U.S. Treasury Bonds with the Same Maturity Date

Bond	Mean Price	High Price	Low Price	Mean Bid-Ask	Issued	Public	Stripped
7.500 August 1988–93	97.67	99.47	95.52	.239	1,814	.52	.00
8.625 August 1993	101.17	103.38	98.75	.244	1,768	.91	.00
.000 August 1993	75.24	79.06	70.78	.266	N.A.	N.A.	N.A.
7.000 May 1993–98	91.82	95.38	88.03	.502	692	.67	.00
9.000 May 1998	103.54	107.34	99.34	.125	9,165	.96	.00
.000 May 1998	50.29	52.19	47.50	.406	N.A.	N.A.	N.A.
8.500 May 1994–99	100.18	103.28	96.47	.381	2,378	.40	.00
9.125 May 1999	104.65	108.97	100.06	.109	10,047	.98	.09
.000 May 1999	46.24	48.06	44.19	.417	N.A.	N.A.	N.A.
8.000 August 1996–2001	97.79	100.88	91.88	.206	1,485	.50	.00
13.375 August 2001	135.68	142.00	129.28	.199	1,753	.89	.00
.000 August 2001	38.16	40.02	36.14	.423	N.A.	N.A.	N.A.
8.250 May 2000–2005	98.00	102.31	92.50	.198	4,224	.49	.00
12.000 May 2005	129.29	135.41	121.88	.176	4,261	.98	.64
.000 May 2005	27.79	29.83	25.72	.410	N.A.	N.A.	N.A.

SOURCE.—The issued, public, and stripped data are from the U.S. Department of the Treasury (1990).

NOTE.—N = 68. Bond prices are Thursday closing prices from the *Wall Street Journal* for the period June 1989–September 1990. Issued denotes the total par value of the issue outstanding in millions of dollars. Public denotes the proportion of the total par value of the issue held by the public. Stripped denotes the proportion of the total par value of the issue that has been stripped into separate coupon and principal payments by the Treasury's STRIPs program. N.A. = not available.

TABLE 2 Summary Statistics for the Estimated Call Values

Callable Bond	Mean	Standard Deviation	High	Low	Number Positive	Number Negative	Percentage Negative	ρ_1	ρ_2	ρ_3
7.500 August 1988–93	.1131	.1181	.4708	−.2914	58	10	14.7	.376	.440	.251
7.000 May 1988–93	−.1130	.4344	.9861	−1.2604	23	45	66.2	.771	.697	.527
8.500 May 1994–99	.4660	.7416	1.9315	−.7810	42	26	38.2	.920	.823	.745
8.000 August 1996–2001	−.3003	.2581	.0828	−.9820	5	63	92.6	.634	.512	.464
8.250 May 2000–2005	−.4304	.2217	.1377	−.9629	3	65	95.6	.747	.561	.417
Total	−.0519	.5284	1.9315	−1.2604	131	209	61.5			

NOTE.—$N = 68$. The variable ρ_n denotes the n-order autocorrelation coefficient. The values are obtained by subtracting the price of the callable bond from the value of the portfolio of noncallable and zero-coupon bonds that replicates the bond component of the callable bond. Bond prices are measured at the midpoint of the bid-ask spread. The data are weekly for the sample period June 1989–September 1990.

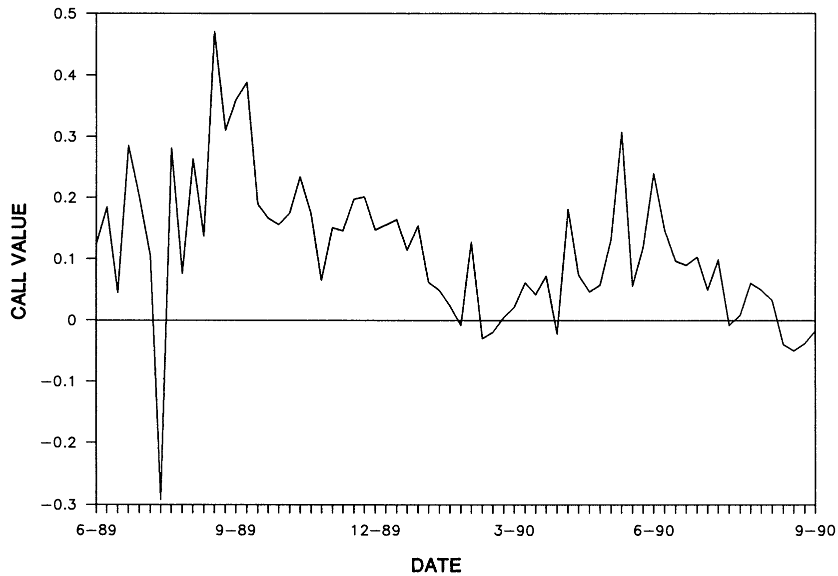

FIG. 1.—The value of the call option in the 7.500 August 1988–93 U.S. Treasury bond.

relation between the maturity or coupon rate of the callable bond and the percentage of negative call estimates. Similarly, correlations of the call values with the price of the callable bond indicate no systematic relation between the value of the call and the bond price. Negative call estimates are obtained for the 7.500 August 1988–93 issue that is currently callable as well as for bonds that are not callable for 5–10 years.

Table 2 also reports the first three autocorrelations of the call option estimates. These autocorrelations are all positive. This is seen in figures 1–5, which plot the time series of call value estimates for each of the callable bonds. As shown, negative call values tend to persist throughout the sample period.

In the absence of market imperfections, these negative values would allow a trader to generate arbitrage profits by the strategy of selling the callable bond and then buying the portfolio of coupon and zero-coupon bonds that replicates the bond component of the callable bond. The cash flows associated with this strategy are shown in table 3. The intuition behind this strategy is that the cash flows of a noncallable coupon bond and a zero-coupon bond replicate the cash flows for any other noncallable bond with the same maturity date. By selling the callable bond and buying the replicating portfolio, the initial cash flow is

$$P_c - (c/s)P_s + (1 - c/s)P_0, \tag{2}$$

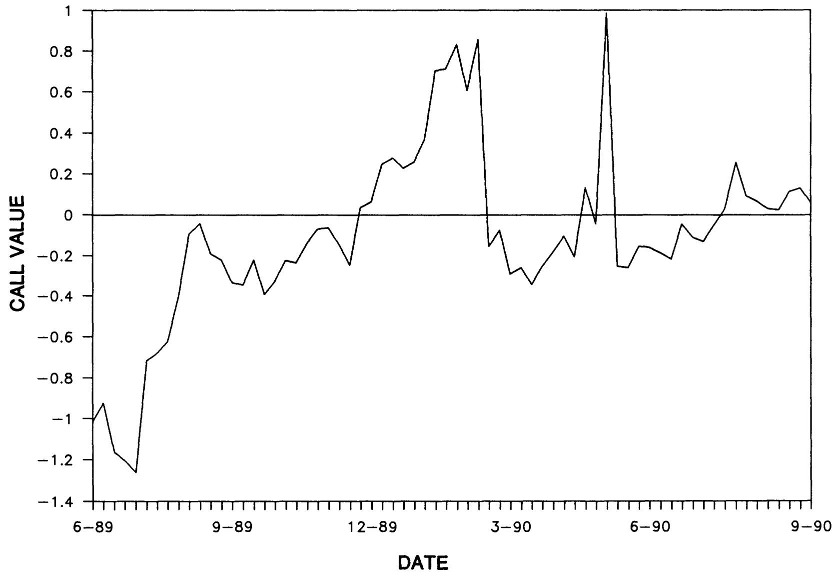

FIG. 2.—The value of the call option in the 7.000 May 1993–98 U.S. Treasury bond.

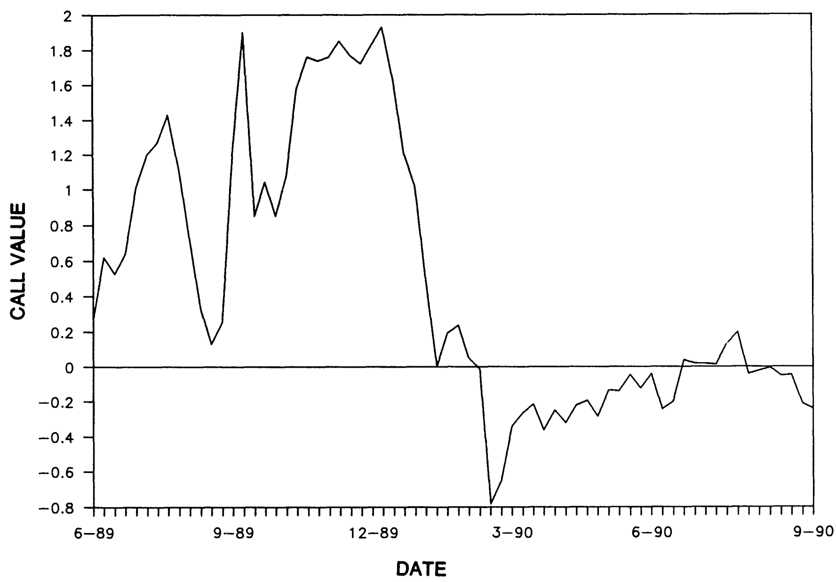

FIG. 3.—The value of the call option in the 8.500 May 1994–99 U.S. Treasury bond.

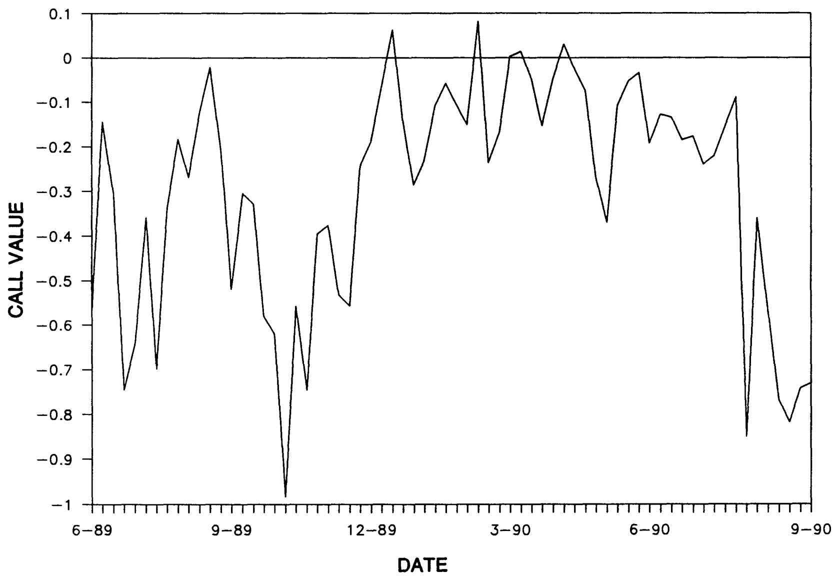

FIG. 4.—The value of the call option in the 8.000 August 1996–2001 U.S. Treasury bond.

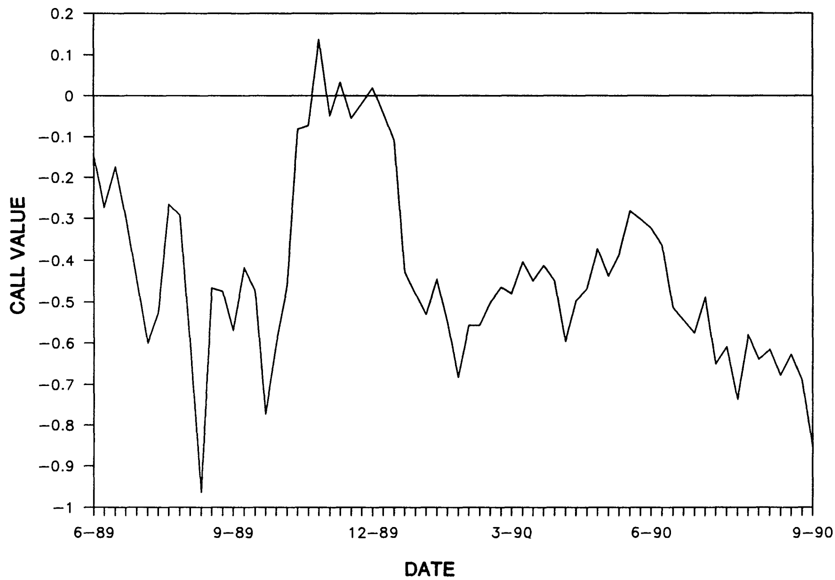

FIG. 5.—The value of the call option in the 8.250 May 2000–2005 U.S. Treasury bond.

TABLE 3 **Arbitrage Table**

Bond Position	Current Cash Flow	Coupon Date Cash Flow	Cash Flow If Called	Cash Flow at Maturity
Short callable bond	P_c	$-c$	-100	-100
Long c/s coupon bonds	$-(c/s)P_s$	c	$(c/s)P_s$	$(c/s)100$
Long $(1 - c/s)$ zero-coupon bonds	$-(1 - c/s)P_0$	0	$(1 - c/s)P_0$	$(1 - c/s)100$
Total	must be ≤ 0, else arbitrage	0	≥ 0	0

NOTE.—This arbitrage table shows the cash flows from a short position in a callable U.S. Treasury bond with coupon rate c and price P_c and a long position in a portfolio replicating the cash flows for the bond portion of the callable bond. The replicating portfolio consists of noncallable bonds with coupon rate s and price P_s and zero-coupon bonds with price P_0. This table assumes that the U.S. Treasury calls the bond if the bond portion of the callable bond exceeds the redemption price of 100.

TABLE 4 **Summary Statistics for the Profitable Arbitrages**

Callable Bond	Number of Arbitrages	Mean	Standard Deviation	High	Low
7.500 August 1988–93	1	.1522			
7.000 May 1993–98	10	.4521	.3055	.8715	.0069
8.500 May 1994–99	7	.1739	.2003	.5505	.0056
8.000 August 1996–2001	32	.2650	.2064	.6942	.0001
8.250 May 2000–2005	56	.2928	.1504	.7266	.0293

NOTE.—This table contains summary statistics for the profits from implementing the arbitrage strategy. The profits are computed net of the bid-ask-spread-related transaction costs for implementing the arbitrage strategy by using the bid price for the callable bond and the ask prices for the noncallable coupon and zero-coupon bonds.

which, from (1), is $-C$. Thus, if the call price is negative, the initial cash flow in (2) is positive. The net effect of this strategy is to take a long postion in the call option. Note that no distributional assumptions about future bond prices are needed for the strategy to result in arbitrage profits—as in Merton (1973), these results are distribution free.

In actuality, however, the Treasury-bond market is not perfect, and market frictions impose costs on arbitrageurs. Foremost among these costs is the bid-ask spread. The call value estimates in table 2 are based on the midpoint of the bid-ask spread for the bonds. In actuality, the arbitrageur would only be able to sell the callable bond at the bid price but would have to buy the replicating portfolio at the ask price. To determine whether there are profitable arbitrage opportunities after considering the bid-ask-spread-related transaction costs, we compute the arbitrage profits from the strategy presented in table 3 using the bid price for the callable bond (the short position) and the ask prices for the noncallable coupon and zero-coupon bonds (the long position). Summary statistics for the arbitrage profits are given in table 4.

As shown, 106 of the original 209 negative call estimates are sizable enough to lead to arbitrage profits after controlling for bid-ask spreads. Thus, 50.7% of the negative estimates, and 31.2% of all of the call estimates, are large enough in absolute terms to generate arbitrage profits after considering bid-ask-spread-related transaction costs. Furthermore, the arbitrage profits can be large in economic terms. For example, the mean values for the arbitrage profits range from 15 to 45 cents per $100.00 par value. These results indicate that the negative call estimates are not explained by size of the bid-ask spreads for the bonds.

V. The Treasury's Call Policy

One of the most fundamental principles of option-pricing theory is that securities that provide positive payoffs should have positive prices. An immediate corollary of this is that negative call prices are possible only if the purchaser of a call faces the possibility of negative cash flows in the future. This could only happen, however, if the callholder exercises the option when it is out of the money. This type of behavior is not as unlikely as it may appear. For example, Vu (1986) shows that many U.S. firms call bonds when the market price is below the call price. Similarly, Gay, Kolb, and Yung (1989) report a number of cases where out-of-the-money Treasury-bond futures options were exercised.

In the current context, negative call values could occur only if the Treasury was committed to a policy (for some exogenous reason) of calling eligible bonds when it was to the bondholders' advantage. Intuitively, this is because the implicit short call option would then actually be a long put option. In this situation, we would expect the callable bond to be worth more than its noncallable counterpart, resulting in negative estimates for the value of the implicit call option.

Although there is no apparent reason why the Treasury should call bonds when it is to the bondholders' advantage, some insights about the Treasury's current and prospective call policy can be obtained by considering its historical policy. To do this, I collected data on each callable Treasury bond that could have been called during the postwar period. Vu (1986) shows that the optimal policy for calling bonds is to call when their price first reaches the call price. Data collected includes the number of times a bond should have been called and was not, the length of time that a call was delayed, and the bond price at the time that the bond was actually called. Summary statistics for the data are given in table 5.

As shown, the Treasury generally calls bonds optimally. During the post-1945 period, there were 42 possible occasions on which it was optimal to call a bond. Of these 42 opportunities, the Treasury called

TABLE 5 Summary of Postwar U.S. Treasury Call Policy

	Callable Bond	Optimal Call Date	Called	Price
1	3.000 June 1946–48	June 1946	Yes	101.000
2	3.125 June 1946–49	June 1946	Yes	101.031
3	2.000 Mar. 1948–50	Mar. 1948	Yes	100.343
4	2.000 Dec. 1948–50	Dec. 1948	Yes	100.434
5	2.750 Mar. 1948–51	Mar. 1948	Yes	100.688
6	2.000 June 1949–51	June 1949	Yes	100.313
7	2.000 Sept. 1949–51	Sept. 1949	Yes	100.297
8	2.000 Dec. 1949–51	Dec. 1949	Yes	100.434
9	2.000 Mar. 1950–52	Mar. 1950	Yes	100.359
10	2.000 Sept. 1950–52	Sept. 1950	Yes	100.359
11	2.500 Sept. 1950–52	Sept. 1950	Yes	100.625
12	4.250 Oct. 1947–52	Oct. 1947	Yes	100.281
13	3.125 Dec. 1949–52	Dec. 1949	Yes	100.922
14	2.000 Sept. 1951–53	Sept. 1951	No	100.016
15	2.000 Sept. 1951–53	Mar. 1952	No	100.094
16	2.000 Sept. 1951–53	Sept. 1952	No	100.188
17	2.000 Sept. 1951–53	Mar. 1953	No	100.031
18	2.500 Dec. 1949–53	Dec. 1949	Yes	100.688
19	2.250 Dec. 1951–53	Dec. 1951	Yes	100.719
20	2.750 June 1951–54	June 1951	Yes	100.594
21	2.000 Dec. 1952–54	June 1954	No	100.281
22	2.250 June 1952–55	June 1952	No	100.156
23	2.250 June 1952–53	Dec. 1952	No	100.188
24	2.250 June 1952–53	June 1954	Yes	100.531
25	3.000 Sept. 1951–55	Sept. 1951	Yes	100.063
26	2.000 June 1953–55	June 1953	Yes	100.188
27	2.000 Dec. 1951–55	Dec. 1951	No	100.031
28	2.000 Dec. 1951–55	June 1954	No	100.188
29	2.000 Dec. 1951–55	Dec. 1954	Yes	100.656
30	3.750 Mar. 1946–56	Mar. 1946	Yes	101.125
31	2.250 June 1954–56	June 1954	Yes	100.594
32	2.375 Mar. 1957–59	Sept. 1958	Yes	100.406
33	2.250 Sept. 1956–59	Sept. 1958	Yes	100.375
34	2.750 Sept. 1956–59	Sept. 1956	Yes	100.406
35	2.875 Mar. 1955–60	Mar. 1955	Yes	100.844
36	2.750 June 1958–63	June 1958	Yes	100.375
37	2.750 Dec. 1960–65	Dec. 1960	No	100.156
38	2.750 Dec. 1960–65	June 1961	No	100.438
39	2.750 Dec. 1960–65	Dec. 1961	No	100.531
40	2.750 Dec. 1960–65	June 1962	No	100.625
41	2.750 Dec. 1960–65	Dec. 1962	Yes	100.313
42	7.500 Aug. 1988–93	Apr. 1991	No	100.625

NOTE.—This table lists each of the Treasury bonds that should have been called during the 1946–90 period. Optimal call date indicates the month in which the Treasury had the opportunity to make a call for a bond that was trading at or above par at the beginning of the call notice month (4 months prior to the actual date on which the bond could be called). Called indicates whether the Treasury made the call. The price is the bid price given in the U.S. Treasury *Bulletin* at the beginning of the call notice month.

the bond in 28 cases.[11] Thus, the Treasury made timely bond calls 66.7% of the time. For the 28 bonds called, 25 were called at the first date on which it was optimal to call the bond—the mean delay in calling these bonds is only 2.4 months. Thus, the Treasury's track record in making bond calls compares favorably with the performance of many U.S. firms. For example, Ingersoll (1977) finds that 170 out of 179 calls in a sample of convertible corporate bonds were delayed.[12] Similarly, Vu (1986) finds that 41 out of 108 calls of nonconvertible corporate bonds were delayed.

Table 5 shows that none of the calls made by the Treasury were for bonds with market prices below par. In contrast, Vu (1986) shows that more than two-thirds of his sample of nonconvertible bonds were called when the market price was below the call price. On average, he finds that the difference between the market value of the bond and the call price is −4.7%. He argues that firms make these "irrational" calls in order to avoid restrictions imposed by bond covenants. My results provide indirect evidence in favor of this hypothesis since the Treasury does not face these types of restrictive bond covenants.

One particularly surprising result in table 5 is that the callable bond price is often substantially above the call price of 100 at the time the Treasury calls the bond. On average, the market price for the callable bond was 61 cents (based on a par value of $100) above par at the time the call was made.[13] This result is itself almost as puzzling as finding negative implicit call values. This is because a callable bond price in excess of par implies that the value of the call option is below its intrinsic value, although not necessarily negative.[14] A mitigating factor, however, is that the call notice period is 4 months long. Thus, if the called bond has a coupon rate above current market yields, the bond could rationally trade at a slight premium above par during the period after the call was announced but prior to the actual call date.[15] Never-

11. For example, if the Treasury missed an opportunity to call a bond, but then called the bond at the next opportunity 6 months later, this would be reflected in table 5 as two opportunities and one bond call.

12. A number of recent papers have addressed this apparent deviation from value maximizing behavior on the part of corporate managers. For example, see Harris and Raviv (1985) and Dunn and Eades (1989).

13. From table 5, the average price of bonds that should have been called, but were not, is 25 cents above par.

14. For example, assume that the price of the callable bond is 103, while the price of an equivalent noncallable bond is 104. The implicit price of the call option is positive but is below its intrinsic value of four dollars. While the arbitrage strategy given in table 3 would not apply, an alternative arbitrage strategy could be used to generate arbitrage profits in this situation.

15. For example, if the yield to maturity was 30 basis points lower than the coupon rate of the bond (an extreme case), the price of the callable bond could exceed par by as much as 10 cents.

theless, the call notice period cannot account for an average premium of 61 cents over par.[16]

It is interesting to consider the most recent opportunity that the Treasury had to call a callable bond. As shown in table 5, this occurred in April 1991 for the 7.500 August 1988–93 issue. The closing price for the bond on the day prior to the last call date was 100.625. Despite this large premium over par, the Treasury did not call the issue. Since the total par value outstanding (from table 1) is $1,814,000,000, the failure to call the bond represents an economic cost to the Treasury of more than $11,000,000.

Since the Treasury could have called these bonds, why were these bonds priced above par immediately before the last call date? Some anecdotal evidence about traders' perceptions of the risk of the Treasury calling the bonds is given in an article in the April 10, 1991, issue of the *Wall Street Journal,* published 5 days prior to the last call date. One money-market economist is quoted as saying, ''Many investors aren't aware that the Treasury can call bonds . . . because the Treasury hasn't done it in so long.'' Another practitioner noted that the Treasury's savings on calling the issue of callable bonds ''would be relatively tiny for a nation that expects to make $286 billion in interest payments on its public debt this fiscal year. 'I don't think it makes a whole lot of sense to call such a small issue.' '' Interestingly, the article reports that ''the Treasury said that calling bonds is under consideration, but that it hasn't made any decision yet. Analysts speculate that the agency might hold off until interest rates fall further. Dealers on Wall Street said they have discussed the issue with Treasury officials who appear eager to find ways to reduce interest costs.''

Although the results of this section provide us with several new puzzles, there is no evidence that the Treasury follows a policy that benefits bondholders at the expense of the Treasury. In contrast, the Treasury appears to follow a near-optimal policy in calling eligible callable bonds. Thus, the negative call values cannot be explained on the basis of the Treasury's call policy.

VI. Other Potential Explanations

If the negative call values are not due to the Treasury's call policy, can they be explained by bond-specific features such as liquidity or

16. Cecchetti (1988) documents that during the 1930s a number of Treasury securities traded at prices that implied negative yields. He argues that the reason for this was that these securities came with the option to exchange them at maturity on favorable terms for new Treasury securities. There is, however, no evidence that this was possible during the postwar period. Thus, the premium prices for callable bonds are probably not due to the value of this exchange option.

tax treatment? In this section, I investigate these and a number of other possibilities.

A. Liquidity

Amihud and Mendelson (1986) present a model in which the liquidity of a security, as measured by its bid-ask spread, affects the equilibrium value of the security. This is because the bid-ask spread affects the cost of exercising the option to trade. If the liquidity of callable bonds is substantially higher than that of noncallable bonds, this effect could account for the negative call option values.

Table 6 compares the bid-ask spread for the callable bonds with those for the replicating noncallable bonds. The mean bid-ask spreads for the callable bonds are generally higher than those for the replicating portfolio of noncallable bonds. This suggests that the callable bonds are actually less liquid than the noncallable bonds.[17] Thus, any liquidity-induced price effects would actually imply that the negative call values are larger in magnitude than estimated.

B. Differential Tax Treatment for Callable Bonds

In general, the federal income taxation of callable and noncallable Treasury bonds is the same. The major exception is that section 171 of the Internal Revenue Code of 1986 allows any premium paid on the acquisition of callable bonds to be amortized over the period of time ending at the first call date rather than the maturity date. In actuality, this difference in tax treatment has little effect on the results. This is because most of the callable bonds trade at a discount during the sample period. Thus, the provision for accelerated amortization is generally not applicable.

C. Premium Amortization

Although the right to amortize bond premium may not affect the majority of the callable bond prices in the sample, it may still affect the prices of the noncallable coupon bonds. Section 171 of the Internal Revenue Code gives the holder of any bond acquired at a premium the option to amortize the premium over the remaining life of the bond.[18] If the bondholder elects to amortize the premium, the amortized premium offsets a portion of the interest income received, resulting in lower taxes. Thus, if the option is valuable to the bondholder, the option should increase the value of premium bonds relative to other bonds.

17. Another metric for bond liquidity would be average trading volume during the sample period. Unfortunately, trading volume data are not available.

18. This option is not available to dealers in securities. Once the election to amortize is made, it is binding for all bonds owned at the date of election and all subsequently acquired.

TABLE 6 Mean Bid-Ask Spreads for the Callable Treasury Bonds and for the Corresponding Noncallable Treasury Bonds

Callable Bond	Mean Bid-Ask Spread	Mean Bid-Ask Spread for the Noncallable Bond
7.500 August 1988–93	.239	.247
7.000 May 1993–98	.502	.187
8.500 May 1994–99	.381	.130
8.000 August 1996–2001	.206	.170
8.250 May 2000–2005	.198	.249

NOTE.—$N = 68$ for each bond. The bid-ask spread for the noncallable bonds is equal to c/s times the bid-ask spread for a noncallable bond with annual coupon rate s, where c is the annual coupon rate for the callable bond, plus $(1 - c/s)$ times the bid-ask spread for the zero-coupon bond with the same maturity date as the other bonds. The sample period is June 1989–September 1990.

In the sample, the coupon rate for the noncallable coupon bond is always greater than the coupon rate for the callable bond. Thus, the effect of the amortization option would be to increase the value of the noncallable coupon bonds relative to the callable bonds. Again, this effect cannot be used to explain the negative call option estimates since it goes in the wrong direction.

D. Tax-timing Options

Constantinides (1983), Constantinides and Ingersoll (1984), and Dammon, Dunn, and Spatt (1989) discuss the implicit tax option given to the holder of a capital asset by having the right to choose when gains and losses are realized. If a portion of the value of a Treasury bond is due to these tax-timing options, then differences in the value of these options across bonds could affect the analysis.

To examine this possibility, recall that Litzenberger and Rolfo (1984) show that noncallable bonds with the same maturity should be convex functions of their coupon rate if there are tax options associated with owning a capital asset. The intuition for this follows from Merton (1973), who shows that a portfolio of options is worth more than an option on a portfolio. Since $0 < c < s$ for each triplet in the sample, these results suggest that the effect of tax-timing options would again be to make the negative call estimates larger in magnitude. Thus, tax-timing options cannot explain the negative values.

E. Other Explanations

There are several other bond-specific features that should be considered as possible explanations. For example, some of the noncallable bonds in the sample are eligible for the STRIPs program. Since eligibility may increase the value of a bond (eligibility cannot reduce the value of a bond because participation is the bondholder's choice), these noncallable bonds would have a higher price relative to the callable bonds. Again, the net result would be to make the anomaly more pronounced.

Another consideration is the price effect for a bond that is eligible for delivery against the Chicago Board of Trade's Treasury-bond futures contract. The only eligible bond in the sample is the 12.000 May 2005 issue, which was eligible only for the first two-thirds of the sample period. As shown in figure 5, there is no apparent change in the implied call option value after May 1990, when the bond was no longer deliverable.

Finally, in incomplete markets, tax clienteles could affect the relative valuation of securities. In complete markets, however, the price of a redundant security should be equal to the price of a portfolio that replicates its payoffs—independent of who owns the redundant security. In this article, the bond component of the callable bond can be replicated by a portfolio of noncallable bonds. Thus, the marginal tax rate of the callable bondholder should not affect the relative valuation of the bonds.

VII. Market Frictions and Arbitrage

The frequency, magnitude, and persistence of the negative call option values is perplexing. If there are no market frictions, these negative values would allow a trader to generate arbitrage profits (even after considering bid-ask spreads). In actuality, however, there are other frictions and transaction costs that could limit the ability of arbitrageurs to drive bond prices toward their theoretical values. If these costs exceed the gains, then the arbitrage strategy should not be initiated. This could provide an explanation for the continued existence of negative call values.

A. Taxes

Taxes could make the arbitrage strategy unprofitable for some investors. This is not immediately apparent from table 3 since the arbitrage strategy does not generate any intermediate taxable cash flows—the coupon expense from the short portion of the strategy exactly offsets the coupon income from the long position. The tax aspect enters the arbitrage strategy because of the original issue discount (OID) provisions. Original issue discount occurs when a bond is initially sold in the market at a substantial discount from its par value. In this situation, taxable bondholders must include a ratable share of the discount into their taxable income each year as imputed interest. The zero-coupon bonds in the sample are subject to these provisions. Because of the imputed interest, a taxable arbitrageur would incur negative cash flows throughout the life of the arbitrage in the form of taxes on the imputed interest income.[19]

19. I am grateful to Margaret Monroe for making this point.

Although the OID provisions could make the arbitrage strategy unprofitable for a taxable investor, it is important to note that a tax-exempt (or low-marginal-tax-rate) arbitrageur could still generate arbitrage profits from negative call prices. Arbitrage should drive call prices toward their appropriate values as long as there is even one trader in the market who can generate arbitrage profits at current market prices. Given that many large institutional holders of Treasury bonds are nontaxable, the tax-related costs of the arbitrage strategy do not explain the persistence of the negative call values.

B. Short-selling Costs

The arbitrage strategy in table 3 requires that the arbitrageur take a short position in the callable bond. If there are significant costs or impediments to short selling, the arbitrageur may not be able to implement the arbitrage strategy. Short selling is far more common in the Treasury-bond market than in the stock market. Furthermore, there are fewer regulatory and institutional restrictions on short selling in the Treasury-bond market. In general, there are two ways in which a trader can take a short position in a bond. These are through a short sale or through a reverse repurchase agreement.

In a short sale, the trader borrows the specific bond to be shorted, posts collateral as security for the bond borrowed, sells the bond, and then later covers the short sale by purchasing the bond from a third party. There are a number of costs associated with this type of transaction. First, it is often difficult to locate the specific issue to be shorted. It may be necessary to pay a fee to a broker to locate the specific issue needed for the short sale. Second, the institution lending the bond charges a borrowing fee to the short seller. A typical borrowing fee might be 50 basis points per year.[20] Costs this large would be sufficient to eliminate a 50-cent arbitrage opportunity if the horizon exceeded 1 year; a one-dollar arbitrage opportunity if the horizon exceeded 2 years, and so forth. Finally, most borrowing agreements can be terminated at the option of the lender of the security with as little as one day's notice.

The second way of short selling Treasury bonds is through a reverse repurchase agreement. In a reverse repurchase agreement, the short seller lends funds and accepts a specific Treasury bond as security for the loan. The short seller than sells the bond and later repurchases it and returns it to the borrower at the end of the repurchase agreement. There are also a number of costs associated with this transaction. First, the short seller has to locate a counterparty willing to reverse out the specific issue. Again, this might require paying a fee to a broker who has information about who owns a specific issue. Second, the rate

20. See Stigum (1990), ch. 13.

paid by the lender of the securities on the funds acquired through the reverse repurchase agreement is generally less than the usual repurchase agreement rate. In effect, the short seller is paying the lender of the bond a fee for the use of the bond. This fee often reflects the fact that the lender knows that the short seller in going to short sell the bond as part of an arbitrage transaction and that the price of the bond is likely to be driven lower. In effect, the lender of the security can appropriate some of the arbitrage profits available through offering a lower rate on the funds borrowed. A recent estimate of the typical cost to the short seller for a ''special'' issue is 12.5–25 basis points per year (see Rogg 1990).

An arbitrageur who wanted to implement the arbitrage strategy in table 3 would face several additional difficulties. First, the arbitrage strategy requires shorting the callable bond until maturity. Although reverse repurchase agreements of up to 6 months are common, longer-maturity reverse repurchases are difficult to negotiate. This would make it difficult to implement the strategy for all but the shortest-maturity callable bonds. Second, the cost of short selling the callable bond over a multiyear period could be large relative to the size of the potential arbitrage profit. For example, an arbitrage opportunity of 50 cents on a 10-year bond would be completely eliminated by having to pay even 5 basis points per year for the reverse repurchase agreement.

It is important to acknowledge, however, that short-selling costs cannot provide a complete explanation for the continued existence of implied negative call values. This is because current holders of a callable bond can implement the arbitrage strategy by selling the bond out of their inventory and then taking a long position in the replicating portfolio of noncallable bonds. This type of strategy is known as a quasi arbitrage. Since these bondholders already own the bond, they incur no short-selling costs.

C. Actual Arbitrage Strategies

In order to determine whether the arbitrage strategy is feasible in practice, I contacted a number of major U.S. investment banks. I found that some practitioners are aware of the apparent mispricing of callable Treasury bonds. For example, in a recent description of the market for STRIPs, Shapiro and Johnson (1990), of Drexel Burnham Lambert, write, ''One other example of a synthetic bond is the combination of a non-callable coupon bond with STRIPs to stimulate a callable coupon bond. By creating this kind of synthetic, it is possible to isolate the implicit market value of the embedded option component of the callable bond. In many cases, the market seems to price this option below its intrinsic value.''

Most of the practitioners we spoke with agreed that the multiyear costs of short selling the callable bond would make the arbitrage difficult to implement. A number, however, pointed out that the quasi arbitrage was still possible. Since the major bond dealers tend to trade only recently issued or "on-the-run" issues, these dealers do not have many of the "off-the-run" callable bonds in their inventory. Hence, these dealers cannot implement the quasi arbitrage. Several practitioners said that the most likely holders of the bulk of the "off-the-run" callable bonds would be smaller, less sophisticated institutions who tend to have buy-and-hold bond portfolios. These types of institutions, they felt, would be unlikely to have the expertise to initiate arbitrage strategies of the type necessary to profit from the negative call values.

VIII. Conclusion

Nearly two-thirds of the implicit call values in a recent sample of callable Treasury-bond prices are negative. These negative values are large in magnitude and tend to persist over time. I examined a number of possible reasons for these negative values. I found that the cost of short-selling bonds may explain why these negative values are not immediately arbitraged away. This explanation for their persistence, however, breaks down for current holders of the callable bonds.

Even if negative call values cannot be arbitraged away, the more fundamental issue of why they exist in the first place remains. This question is of particular importance since the Treasury-bond market is one of the most active financial markets in the world. In addition, Treasury-bond prices are widely disseminated. Clearly, standard option-pricing theory cannot even get the sign correct for these call option prices. Even if the negative values can ultimately be attributed to some form of market friction or imperfection, however, these results will still serve to show that market frictions can have first-order effects on security prices.

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