OPTIMAL BOND REFUNDING: EVIDENCE FROM THE MUNICIPAL BOND MARKET

Samaresh Priyadarshi

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Department of Finance
Virginia Tech

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by

Samaresh Priyadarshi

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APPROVED:

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Robert S. Hansen, Chair

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Donald M. Chance	**Gregory B. Kadlec**
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Raman Kumar	**John M.R. Chalmers**

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Committee:

Prof. Robert S. Hansen, Chairman

Prof. Donald M. Chance | **Prof. Gregory B. Kadlec**

Prof. Raman Kumar | **Prof. John M.R. Chalmers**

Department of Finance
Pamplin College of Business
Virginia Tech

ABSTRACT

This dissertation empirically examines refunding decisions employed by issuers of tax-exempt bonds. Callable bonds contain embedded call options by virtue of provisions in bond indentures that permit the issuing firm to buy back the bond at a predetermined strike price. Such an embedded American call option has two components to its value, the intrinsic value and the time value. The issuer can realize at least as much as the intrinsic value by exercising immediately, when the option is in-the-money. Usually it is optimal for the holder of an in-the money American option to wait rather than exercise immediately, because the option has time value. It is rational for the holder to exercise the option when the total value of the option is no more than the intrinsic value. Option pricing theory can be used to identify two sub-optimal refunding strategies: those that refund too early, and those that refund too late. In such cases the holder incurs losses.

I analyze the refunding decisions for two different samples of tax-exempt bonds issued between 1986 and 1993: the first consists of 2,620 bonds that are called, and the second contains 23,976 bonds that are never called. The generalized Vasicek (1977) model in the Heath, Jarrow,

and Morton (1992) framework is used to construct binomial trees for interest rates, bond prices, and call option prices. The option pricing lattice is then used to compute the loss in value from sub-optimal refunding strategies, refunding efficiency, and months from optimal time for bonds in these two samples.

Results suggest that sub-optimal refunding decisions cause losses to the issuers, which are present across bond and issuer characteristics. For the pooled sample of 26,596 bonds, the loss in value from sub-optimal refunding decisions totaled $7.2 billion, amounting to a loss of about 1.75% of total principal amount. Results indicate that issuers either wait too long to refund or never refund and cannot realize the present value saving of switching a high coupon bond with a low coupon bond, over a longer period of time. These results critically depend on the assumptions of underlying term structure model and are sensitive to model calibrated parameter values.

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CHAPTER I

INTRODUCTION

Nine-tenths of wisdom consists in being wise in time.

Theodore Roosevelt

Speech, 14 June 1917, Lincoln, Nebraska

I. A Introduction

It is logical to presume that agents behave rationally when holding and exercising derivative securities, that their objective is to maximize their expected wealth. For instance, option pricing theory assumes that holders of American call options exercise at the optimal exercise time. Exercising at times other than the optimal exercise time will result in a loss in value and such an exercise strategy will be sub-optimal. Substantial empirical research has been done on the calling of convertible corporate bonds. Given the large amount of outstanding municipal debt, it is surprising that no empirical study has been conducted to evaluate the calling of municipal bonds. This dissertation empirically examines the refunding decisions employed by issuers of callable tax-exempt debt by analyzing these decisions in an option pricing framework.

The decision to refund is an important one not only from the standpoint of the issuers but also its constituents and investors.[1] In a rational world the "cost" to the issuer of having the call feature is exactly equal to the expected value of having the call option available. This implicitly assumes that the issuer will exercise at the optimal time. Any loss from a sub-optimal refunding strategy comes at a cost to the issuer and consequently the taxpayers.

Traditionally, refundings are undertaken for one or more of the following reasons: refundings for interest rate savings, defeasance refundings to remove burdensome covenants, refundings to stretch out or otherwise restructure debt service, and refundings to take advantage of improved credit rating. This study examines the refunding decisions purely from the perspective of interest rate savings.

At the end of 1995, outstanding public and private debt totaled about $8 trillion, out of which municipal bonds accounted for $1.3 trillion, or 16.3% of the total outstanding debt. In 1993 alone, $338.8 billion of municipal bonds were issued. According to the Public Securities

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[1] From an investor's point of view, advance refunding is a desirable event because credit risk is eliminated by the defeasance with Treasuries. The lower the credit quality of the issue, the greater the price appreciation due to advance refunding. The analysis of refunding affects buyers of generic Treasury issues as well because of the large demand created for Treasury issues to setup escrow accounts via the refunding process. Refundability adds to price volatility and should be taken into account when calculating duration on a portfolio level.

Association, $2.77 trillion of tax-exempt municipal bonds were issued between 1980 and 1995. During the same period $594.8 billion of outstanding municipal debt was refunded by refunding bond issues. During 1993, when interest rates declined to record low levels, $150 billion of outstanding tax-exempt debt was refunded, and refunding issues exceeded the extent of new financing. Figure 1.1 and Table 1.1 show the relative size of tax-exempt debt market to taxable debt market.

Figure 1.2 shows the number of refunding bond issues during the period 1980-1994. Largest numbers of refunding bonds were issued in 1993. Figure 1.3 presents the dollar amounts of tax-exempt refunding bond issues. A peak amount of $150 billion was refunded in 1993. Figure 1.4 shows the level of spot interest rates and refunding amount in billions of dollars. Refunding activity picked up when the interest rates were low. Figure 1.5 shows refunding volume relative to new financing volume. Over the years, refunding has become significant.

Theoretical models of bond refunding have focused on the computation of savings that accrue by refunding, and on the determination of optimal time to refund. Dynamic models of bond refunding, that use stochastic interest rates, were first developed in early 1970s. Since then considerable effort has been expended by academics and practitioners alike to improve upon optimal refunding criteria.

This dissertation is the first attempt to empirically test the efficiency of refunding decisions employed by issuers of tax-exempt bonds. The methodology used in this dissertation builds on the model of Gurwitz, Knez, and Wadhwani (1992), but differs from it in several important aspects. The objective of this study is to examine the actual refunding decisions employed by issuers, while their model is used to obtain option adjusted spreads to price tax-exempt bonds correctly. As such this study can be classified as an empirical study while their paper presents a theoretical model for valuing embedded call options.

I.B Data and Methodology

The municipal bond issuance data in this study is collected from the U.S. Municipal Bonds New Issues Database obtained from *Securities Data Corporation*. This database consists of 135,966 municipal bonds that were issued between January 1980 and March 1995. From this database, a sample of 26,596 callable bonds issued between 1986 and 1993 that are candidates for refunding is obtained. Two sub-samples are created: the first sub-sample consists of 2,620 bonds that are refunded, and the second sub-sample consists of 23,976 bonds that are never refunded.

Municipal bond yields are obtained from Salomon Brothers Index of Municipal Yields. Yields are provided on a monthly basis for bonds with maturity of 1, 5, 10, 20, and 30 years. The available data runs through June 1993. Zero-coupon municipal yield curves are obtained by bootstrapping the municipal bond par yield curve.

Treasury yields are obtained from McCulloch and Kwon (1993) U.S. Term structure database.

To value call options embedded in these bonds, a one-factor generalized Vasicek (1977) model in the Heath, Jarrow, and Morton (1992) framework is implemented. The model is calibrated using non-linear Gauss-Newton optimization procedure by pricing bonds on the municipal yield curve. This model is then used to construct binomial trees for interest rates, bond and embedded call option pricing lattices for each bond in the sample. Using the option pricing lattice, the optimal exercise boundary is determined for each bond.

Two sub-optimal refunding strategies can be identified using option pricing framework: 1. "*exercising too early*," where the holder chooses to exercise an option when it should not be exercised until later, and, 2. "*exercising too late*," where the holder fails to exercise an option when it should be exercised. The first case also includes options that are exercised but optimal exercise boundary is not hit. The second case also includes options that are never exercised but optimal exercise boundary is hit. These two sub-optimal exercise strategies result in a loss in value that can be estimated using standard option valuation techniques. In addition, I check advance refundings for losses arising from investing escrow funds at yields below the reoffering yield.

I.C Results and Conclusions

Results suggest that sub-optimal refunding decisions cause losses to issuers, which are present across bond and issuer characteristics. For the pooled sample of 26,596 bonds, the loss in value from sub-optimal refunding decisions totaled $7.2 billion. For a total principal amount of $410 billion, this is a loss in value of 1.75%. Results indicate that issuers either wait too long to refund or never refund and cannot realize the present value saving of switching a high coupon bond with a low coupon bond, over a longer period of time.

Losses are higher for revenue bonds, bonds rated AA, or BAA and below, issues with larger gross proceeds, bonds of longer maturity, issuers with large amount of outstanding debt, and downgraded bonds. General obligation bonds, non-rated bonds, smaller issue size, bonds of shorter maturity, issuers with lower amount of outstanding debt, and upgraded bonds incur smaller losses. Issuers wait too long to seek opportunities for issuing refunding bonds with lower coupons. Over the years refunding efficiency has improved, the loss in value from sub-optimal refunding strategies is lower, and bonds are called closer to the optimal time. Results suggest that state and local government agencies in California, Florida, Illinois, New York, and Texas accrued relatively more losses due to sub-optimal refunding strategies.

The analysis presented in this study is subject to several potential limitations. The framework used to analyze refunding decisions ignores the role of other criteria in the decision making process involving bond refundings. The results presented in this study are sensitive to modeling assumptions, and model calibration. Other issues such as the desire to restructure debt service or to remove debt with burdensome debt covenants, illiquidity in the secondary market for municipal bonds, investor influence over the issuer, legislative stipulations, political and economic climate may play a role in the refunding decision. Future research to investigate these and other potential reasons for refunding may be warranted. The analysis used in this study can be employed for valuing securities with embedded options, and for evaluating refinancing decisions, or prepayment behavior.

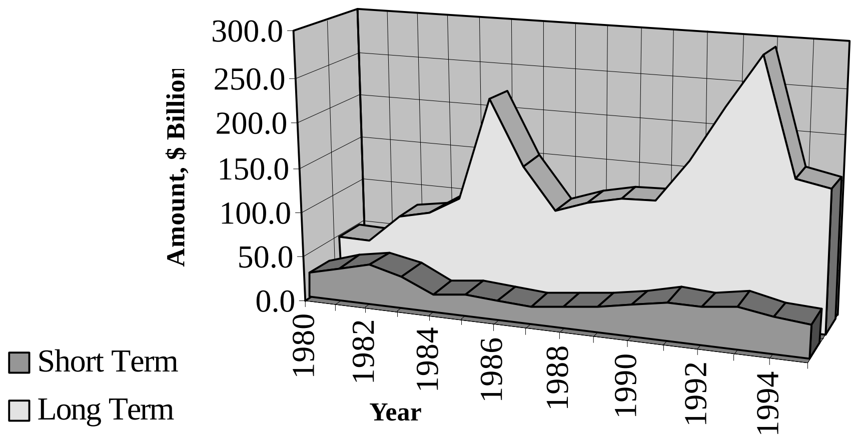

Figure 1.1 Short and Long Term Municipal Bond Issuance, 1980-1995

Sources: Public Securities Association

Securities Data Corporation

Table 1.1

Outstanding Level of Public and Private Debt, 1980-95

($ Billions)

Year	Municipal Bonds	Treasury Bonds(1)	Agency Mortgage Backed Securities(2)	U.S. Corporate Bonds
1980	399.4	616.4	110.9	471.5
1981	443.7	683.2	126.4	495.8
1982	508.0	824.4	176.3	527.5
1983	575.1	1,024.4	244.3	564.6
1984	650.6	1,176.6	289.4	627.3
1985	859.5	1,360.2	372.1	719.8
1986	920.4	1,564.3	534.4	860.9
1987	1,010.4	1,675.0	672.1	958.8
1988	1,082.3	1,821.3	749.9	1,071.1
1989	1,135.2	1,945.4	876.3	1,159.3
1990	1,184.4	2,195.8	1,024.4	1,231.9
1991	1,272.2	2,471.6	1,160.5	1,332.5
1992	1,302.8	2,754.1	1,273.5	1,430.6
1993	1,377.5	2,989.5	1,349.6	1,606.5
1994	1,348.2	3,126.0	1,441.9	1,656.6
1995	1,301.1	3,307.2	1,570.4	1,823.4

(1) Interest bearing marketable public debt.

(2) Includes only GNMA, FNMA, and FHLMC mortgage-backed securities.

Sources: U.S. Department of Treasury
Federal Reserve System
Federal National Mortgage Association
Government National Mortgage Association
Federal Home Loan Mortgage Association
Public Securities Association

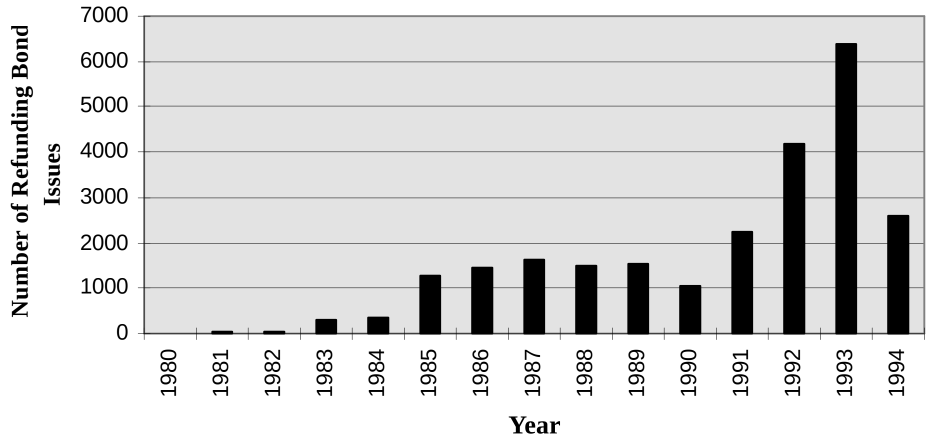

Figure 1.2: Number of Refunding Bond Issues, 1980-1994

Source: *Securities Data Corporation*, U.S. Municipal New Issues Database, 1995

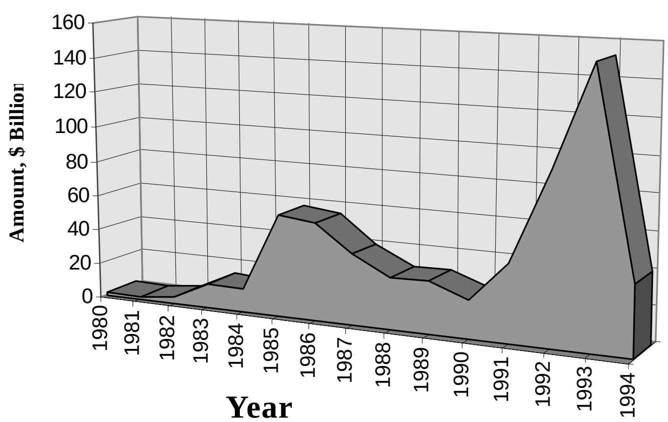

Figure 1.3: Total Refunding, 1980-1994

Source: *Securities Data Corporation*, U.S. Municipal New Issues Database, 1995

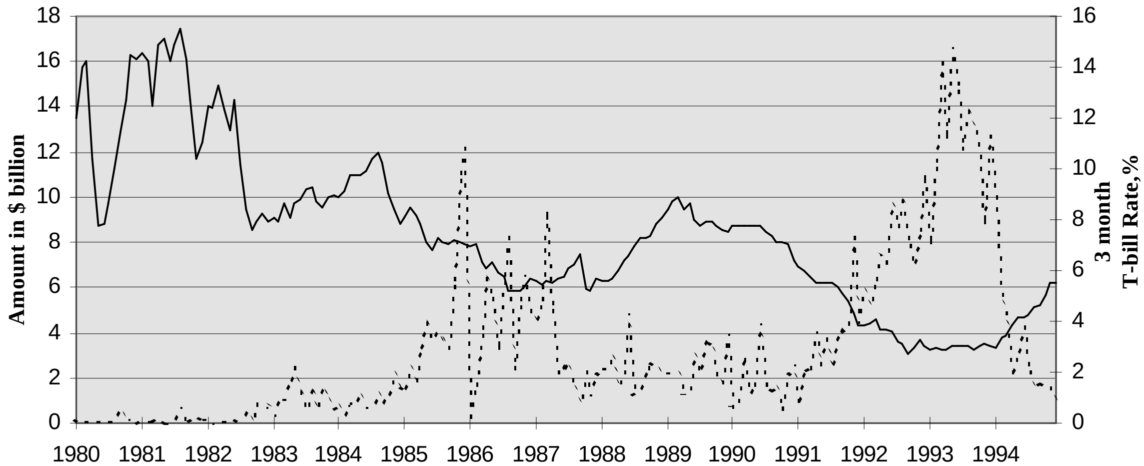

Figure 1.4: Level of Spot Rates and Refunding Volume, 1980 - 1994

Sources: *Securities Data Corporation*, U.S. Municipal New Issues Database, 1995 and the Federal Reserve Bank of Chicago.

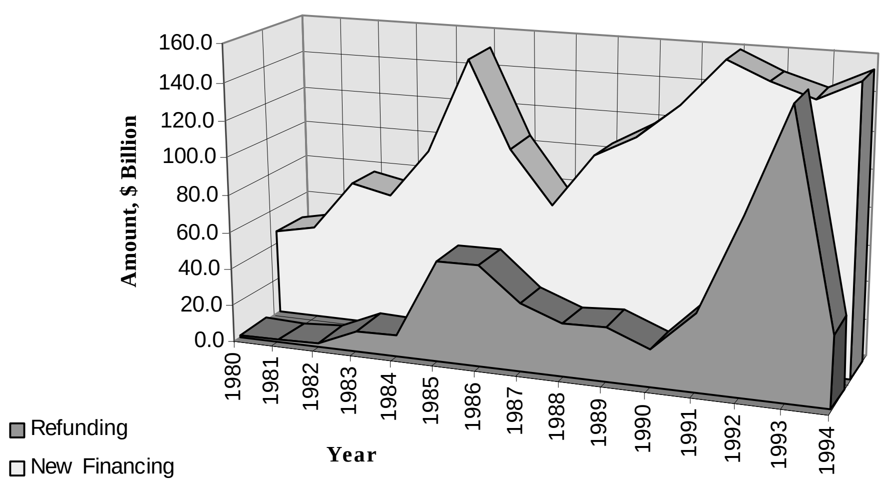

Figure 1.5: Refunding Vs. New Financing, 1980-1994

Source: *Securities Data Corporation*, U.S. Municipal New Issues Database, 1995

CHAPTER II

LITERATURE REVIEW

Our treasure lies in the beehive of our knowledge. We are perpetually on the way thither, being by nature winged insects and honey gatherers of the mind.

Friedrich Nietzsche

The Genealogy of Moral

II.A Introduction

This chapter presents a review of bond refunding literature for both taxable and tax-exempt markets. Models of bond refunding can be categorized as either static or dynamic depending on whether the models are cast in single or multiple periods, respectively.

Interest rate models have been examined in great detail in the literature. However, a brief note on these models is provided to discuss why the chosen framework is appropriate for the purpose of this study.

II.B Corporate Bond Refunding Literature

Much of the literature on bond refunding has focused on two different issues. The first issue is the effect of refunding on shareholder wealth. The second issue deals with the determination of optimal time to refund. To measure the effects of bond refunding researchers have proposed decision models that are motivated by the objective of shareholder wealth maximization. Many of these models are variants of the net present value method, and discuss the appropriate choice of discount rate to accurately measure the benefits of refunding. These models address the problem of refunding both high-coupon debt and discounted debt. Since these models are cast in a one period framework, they can be labeled as "*static models*." Such models do not consider whether it is profitable to wait and refund at some future time and implicitly assume that the option to call expires if unexercised in the period under consideration.

On the other hand, models that address the problem of determining the optimal time to refund are setup in a multi-period framework, and can be called "*dynamic models*". These models consider the stochastic nature of interest rates and its impact on the refunding decision. Dynamic models derive their refunding criteria based on minimizing debt service related costs to shareholders. Some recent models attempt to synthesize the two approaches to the bond refunding problem.

II.B.1 Static Models of Bond Refunding

Bowlin (1966) pointed out that the decision to refund a bond issue for the purpose of reducing interest costs is an investment decision. Refunding operation requires a cash outlay that is followed by interest rate savings in future years. The net cash investment equals the sum of (1) call premium on the refunded bonds, (2) duplicate interest payments, (3) issuance costs on the refunding bonds, and (4) any discount on the refunding bonds less (a) any premium on the refunding bonds and (b) any tax saving obtained because the call premium, duplicate interest, and remaining issue expenses and discounts on the refunded bonds are tax deductible immediately. An unamortized payment on the old bonds would reduce the tax deductible expenses.

Bierman (1972) shows that the amount of debt to be raised via the refunding issue does not effect the present value of net benefits from refunding. However, different amounts of debt will be outstanding and different amounts of cash will be raised.

Bierman and Barnea (1974) consider bond refunding where the decision maker is willing to accept the money market's implicit judgments about future interest rates as reflected in the term structure, and the decision maker uses the expected future (one-period) rates as the basis for his decision. The assumed objective is to minimize the present value of the cost of the currently outstanding debt until its maturity. The newly issued debt may have either a matching maturity or a different maturity.

Mayor and McCoin (1974) posit that the refunding decision can be dichotomized and the desirability of refunding is independent of the desirability of changes in the firm's capital structure. They reason that the firm should analyze the refunding decision on the basis of a pure refunding rather than a mixed refunding, and the appropriate discount rate to use is the risk-adjusted net rate of return for the firm's best alternative use of funds.

Ofer and Taggart (1977) present a framework for evaluating refunding decisions, which incorporates not only the present value of savings in interest payments, but also the tax savings that will result from the change in debt capacity. Yawitz and Anderson (1977) examine the question of the effect of refunding on shareholder wealth by dividing conventional refunding into (1) a pure leverage problem, and (2) a pure refunding problem. This dichotomy allows them to isolate the effects on shareholder wealth resulting solely from the refunding.

Emery (1978) considers the treatment of overlapping interest in bond refundings. The overlap interest cost is determined by the way the interest rate saving are computed. If the interest savings are computed from the date of the retirement of the old bonds, then the overlap interest cost is the interest on the new bonds. However, if the interest savings are computed from the date of issue of the new bonds, as is usually the case, then the appropriate cost of the duplicate interest is the interest on the old bonds for the overlap period.

Laber (1979) discusses the appropriate discount rates and financing assumptions for bond refunding decisions. He suggests using a model where tax shields associated with refunding, form a part of the cash flows from transaction, and all cash flows are discounted at the before-tax cost of debt.

Lewellen and Emery (1981) point that refunding decision should be treated independently of the decision to alter the issuer's leverage. Keeping the future cash flow burden the same under refunding neutralizes any stock valuation effects and eliminates the need to debate possible debt-capacity implications. This debt-service parity approach then enables one to compute the net advantage from a pure refunding.

Reiner (1980) develops a procedure for evaluating the benefits of refunding high-coupon debt. His procedure involves constructing a single refunding issue the debt service requirements of which match those of the refunded issue, keeping the firm's debt capacity unchanged.

Finnerty (1983) modifies the analytical procedure developed by Riener (1980) to accommodate sinking-fund issues. He decomposes the issue into a serial obligation and applies Riener's (1980) procedure for non-sinking-fund issues separately to each series. This procedure leads to the maximum number of bonds that the firm could profitably call for immediate redemption and gives the associated maximum value resulting from exercising the call option.

Emery and Lewellen (1984) analyze the tax advantages from writing off losses connected with refunding high-coupon non-callable debt by the mechanism of an open-market repurchase.

Finnerty's (1984) book presents a comprehensive review of the bond refunding literature and analyzes the bond refunding decision for both high and low coupon bonds. He further discusses the refunding of sinking-fund issues, as well as the defeasement of existing debt. He also addresses the issue of timing of the refunding and suggests using dynamic programming approach similar to Boyce and Kalotay (1979a).

Finnerty, Kalotay, and Farrell's (1988) book provides a comprehensive theory of refunding either high-coupon or discounted debt as well as those with sinking-funds. They develop a model for timing bond refundings which uses optimal stopping time theory (see Maliaris and Brock (1982) or Duffie (1992)); all benefits are analyzed on an after-tax basis, such that all side effects on the financial structure are neutralized.

Maris (1989) discusses ways to take into account overlapping interest in refunding decision models.

Brick and Palmon (1993) compare the tax advantages of issuing callable debt, non-callable but repurchasable debt, and a proposed bond with an indexed-exercise-price put option (BIPO). They show that *ex-ante* tax benefits from refunding, obtained by issuing BIPOs, exceed those obtained by issuing either repurchasable debt or callable debt.

II.B.2 Static Models of Refunding Discounted Debt

Ang (1975) was first to point out that refunding can be profitable even in cases where existing debt is selling at a discount, i.e. when current interest rates rise above the offering yield of the existing debt. Refunding discounted debt results in (1) changing the amount of the periodic interest payments, (2) changing the amount of payment on the maturity date, and (3) incurring transaction costs. Such a refunding would be profitable if the present value of the transaction costs and payments on the refunding issue is lower than the present value of payments on the refunded issue.

Mayor and McCoin (1978) refute Ang's (1975) contention that refunding discounted debt can be profitable. They point out a flaw in Ang's (1975) implementation of dynamic programming model and assert that their calculations do not support Ang's results. Using the same assumptions on transaction costs, they find that Ang's (1975) solution to the debt-exchange issue is actually less desirable than simply maintaining the level of the original debt. Laber (1978) shares the essence of their view. Ang (1978) maintains that it is profitable to refund when interest rates are higher than the current yield on existing debt, when short-term implementation costs are low.

Kalotay (1978) argues that for a profitable refunding of discounted debt, the corporation must be a taxable entity. Tax benefits in such refundings arise from the deferment of capital gains.

Dyl and Spahr (1983) extend Kalotay's (1978) framework to analyze benefits of refunding discounted debt by incorporating provisions of the Bankruptcy Tax Act of 1980. They present evidence, which suggests that these provisions have effectively eliminated any potential economic gains from refunding discounted debt.

Using agency cost rationale Dhaliwal (1985) hypothesizes that one motivating factor for refunding discounted debt is the firm's desire to relax the restrictions imposed by loan covenants. By doing so, the firm may keep itself from getting into technical default and avoid significant direct and indirect bankruptcy costs Furthermore, it may enable firms to undertake certain projects that may cause a wealth transfer from bondholders to stockholders, e.g. issuance of debt in exchange for equity. He provides indirect empirical evidence that is consistent with this hypothesis.

Finnerty (1986) discusses tax advantages of refunding discounted debt. Refunding discounted debt will increase shareholder wealth when the present value of additional tax shields obtained by full utilization of debt capacity created through the refunding exceeds the sum of (1) present value of overall increase in pre-tax debt service requirements, (2) transaction costs that must be paid, and (3) any tax incurred on the gain.

Parker (1986) develops a tax-oriented decision model for measuring the value to shareholders of refunding non-callable bonds trading at a premium. Gramlich, Abramowicz, and Parker (1988) update the Parker (1986) model by incorporating the Tax Reform Act of 1986 and show that the benefits of refunding non-callable bonds diminished since corporate and individual tax rates were lowered and long-term capital gain deduction was eliminated.

II.B.3 Dynamic Models of Bond Refunding

Bierman (1966) and Weingartner (1967) were among the first to highlight that in deciding whether to call a bond at any given time, the issuer must compare the potential savings from current refunding, with those resulting from the decision to postpone. Bierman (1966) proposed using a Markovian representation of interest rate fluctuation to improve short-run timing when refunding a bond. Weingartner (1967) formulates the refunding problem in terms of a dynamic programming model in which predictions of deterministic future term structure of interest rates are utilized.

Elton and Gruber (1971) discuss the applicability of dynamic programming approach to solving the refunding problem. They assume that the debt capacity remains unchanged. At each node in the decision tree, the "keep" versus "refund" decision is evaluated. The appropriate discount rate is the yield that must be offered to sell a bond of equal maturity. The issuers act on point estimates of future interest rates. Alternatively, they employ information about the distribution of future interest rates in making refunding decisions. The authors present the dynamic programming approach in both finite and infinite horizon.

Klaymon (1971) formulates the refunding problem as a multi-period decision process in which future interest rates are determined by a Markovian stochastic process. In each period issuer decides either to refund the existing bonds at current market interest rates or to keep the bonds if unexpired. It is assumed that a penalty cost is charged for not meeting fund requirements, and a bonus is paid for excess funds during any period. This penalty cost or bonus is designed to model costs of minor short-term borrowings or deposits. Klaymon (1971) simultaneously solves for the optimal debt capacity and optimal refunding.

Kraus (1973) points out that interest rate savings obtained by the firm's shareholders through refunding, represent an opportunity loss of interest earnings to holders of the refunded issue. As a consequence, rational investors will demand a higher yield from newly issued callable bonds, if issuers employ optimal refunding decisions.

Kolodny (1974) views the refunding decision as one that involves comparing alternative refunding policies and choosing one that minimizes the systematic risk while maximizing the expected return in the Capital Asset Pricing Model framework of Sharpe (1964) and Lintner (1965). Evaluating this objective function by using the dynamic programming model of Elton and Gruber (1971) identifies optimal decisions. This technique requires that the issuer specify the association between future interest rates and the gross national product.

Brennan and Schwartz (1977) employ the option pricing framework to price callable bonds under the assumption that interest rates follow a Gauss-Wiener process and that the pure expectation hypothesis holds. More specifically, they assume that capital markets are perfect, with no transaction costs, taxes, restrictions on short sales or other institutional frictions, and that the bonds are default-free. Given the stochastic process for the interest rates, they obtain a partial differential equation (equation 30, page 79) that all callable bonds must satisfy subject to the following boundary conditions: the terminal value condition; the limiting interest rate condition; and the call policy condition. Finite difference methods that solve the differential equation subject to these boundary conditions to value callable bonds. A callable bond is shown to be equivalent to a straight bond less the value of an American call option to purchase the bond at the call price.

Boyce and Kalotay (1979a) introduce the concept of refunding efficiency as an alternative to the optimal stopping theory. Refunding efficiency is the ratio of the savings immediately available and the savings expected if one used the optimal strategy in the future, that is the value of the call option at that time. Boyce and Kalotay (1979b) present tax arguments for the preference by corporations to issue callable bonds over noncallable bonds.

Howard and Kalotay (1988) stress the importance of computing refunding efficiency over the present value savings of benefits from refunding. They value embedded call options by a simple binomial interest rate tree. They demonstrate that refunding efficiency is critically determined by (1) assumed volatility of future interest rates, (2) structure of the refunding issue, i.e., whether it is callable or noncallable, and (3) marginal tax rates of the firm.

Chiang and Narayanan (1991) develop a dynamic model of bond refunding in which the objective is to maximize shareholder wealth. This is done by estimating benefits of refunding as the difference between the market price of the bond and the price of the refunding bond, keeping the debt capacity unchanged, and incorporating taxes and issuance costs. If the markets are efficient then rational bond refunding decisions do not affect shareholder wealth. Ling (1991) presents a similar dynamic model of refunding but he includes taxes and transaction costs.

Kalotay, Williams, and Fabozzi (1993) present a model to value embedded options such as those present in callable bonds. This is done by constructing binomial trees for forward rates and then valuing the bonds at each node, checking for optimal exercise, and then obtaining the expected present value of the bond by discounting the cash flows.

Despite the importance of bond refunding decision to corporate and tax-exempt issuers, as evidenced by the numerous papers that attempt to model the refunding decision, there have been very few papers that investigate refunding related issues empirically. Vu (1986) examines call behavior for corporate non-convertible bonds and the impact of calls on the market price of securities. He finds that while some firms wait long enough after the market value of bonds first exceeds the call price before calling their straight bonds, this does not necessarily imply that the firm is acting suboptimally because transaction costs and market imperfections may prevent the firm from calling exactly at the optimal time. When firms finally call their bonds, the market value of the called bonds is usually below the call price. Comparing the refunding rate with the adjusted interest rate on refunded bonds Vu (1986) finds that most refundings are profitable. Although bondholders benefit when firms call bonds whose market value is below the call price, no evidence is found that stockholders are expropriated. An examination of bond indenture agreements reveals that when the call relaxes restrictive covenants, the firm on average pays a larger premium to call debt. He concludes that there are several motives for calls and no single predominant one.

Thatcher and Thatcher (1992) measure how well firms time bond refunding decisions. Using a sample of 161 public utility bond refundings, they compare the actual timing performance with the timing performance achieved by three benchmark models.[2]

II.C Municipal Bond Refunding Literature

The municipal bond market is different from the corporate bond market, not only by virtue of its tax-exemption feature, but also in its institutional and regulatory structure. Miller (1993) provides an excellent explanation of the mechanism of refunding and the regulatory constraints pertinent to refunding by municipal issuers. Some of the salient points from his article are recapitulated below as an understanding of the economic and legal issues germane to refunding are essential to the analysis presented in subsequent chapters.

[2] The first model is random selection model, the second model is the 100 basis-point refunding model (e.g., Finnerty (1984), Boyce and Kalotay (1979a)), and the third model is the stopping-time model of Finnerty, Kalotay, and Farrell (1988).

A refunding involves the issuance of new bonds, the proceeds of which are used to pay debt service (principal, interest, or call premium) on any other bond. Defeasance of a prior bond on the other hand, involves a formal release of the lien of the bondholder on the pledged assets or revenues in exchange for the pledge of cash or highly rated securities sufficient to repay the bond. The source of funds need not be from refunding bond proceeds. The procedure by which a bond may be defeased is provided in the bond resolution or trust indenture authorizing the issuance of the bond; as a general rule, in the absence of a defeasance provision a bond cannot be legally defeased.

A current refunding is defined as a refunding in which refunded bonds are called or mature within 90 days of the issuance of the refunding bonds; all other refundings are treated as advance refundings.

Refundings are often categorized as either "high-to-low" refundings or "low-to-high" refundings. A high-to-low refunding involves the refunding of a high coupon prior bond with lower interest bond for interest rate savings, calling the prior bond before its maturity. By contrast, a low-to-high refunding generally involves escrowing the prior bond to maturity, and is usually undertaken for reasons other than interest rate savings.

Issuers refund for the following four reasons:

1. high-to-low refundings for interest rate savings,
2. defeasance refundings to remove burdensome covenants,
3. refundings to stretch out or otherwise restructure debt service, and
4. refundings to produce economic benefits other than interest rate savings.

A high-to-low refunding is the exercise by the issuer of an in-the-money call right on a callable prior bond at the redemption price. In an advance refunding, the exercise of the call right has been effected in advance of the actual call date through the complexities of an escrow for prior bonds, but the net effect is the same. Hence, unless the prior bond is callable there can be no interest rate savings on a refunding of the prior bond.[3]

The exercise of the call option is a function of many variables which includes:

1. interest rate on the prior bonds,
2. yield on the refunding bonds,
3. maturity date of the prior bonds,
4. call date on the prior bonds,
5. available yield on the refunding escrow investment portfolio, and the possibility of "negative arbitrage,"
6. call premium on prior bonds,

[3] The inclusion of call provision in the initial bond issue is a necessary condition for refunding. Kessel (1971) estimated that about 50% of the tax-exempt bonds issued during 1959-1976 had call options.

7. any possible rebate on funds held by the issuer in connection with the refunding issue, and
8. in certain cases, transferred proceeds penalties that are incurred as a result of the refunding.

Miller (1993) illustrates through examples how the present value savings as a percentage of the refunded bond are higher (1) higher the coupon on prior bonds, (2) longer the maturity of prior bonds, (3) shorter the time to the call date on prior bonds, (4) lower the yield on refunding bonds, (5) lower the call premium and issuance costs, (6) higher the permissible escrow investment yields, and (7) lower the rebate and transferred proceeds penalty if any.

Miller (1993) discusses the tax constraints on refundings.[4] Most of these relate to the circumstances under which state and local governments must restrict the yield on their bond proceeds. Some of the major limitations that affect issuers' willingness or ability to refund outstanding bonds are discussed.

Miller (1993) discusses three different types of advanced refundings. The first and the most dominant type of advance refunding is the "net cash refunding." In a net cash refunding, the principal, interest, and call premium on the prior bond are paid with the proceeds of the refunding issue.

The second type is the "crossover refunding," in which the refunding escrow pays interest on the refunding bonds through the call date of the prior bonds, and then pays the principal and call premium of the prior bond on the call date. In this way, the refunding bond "pays for itself" through the redemption of the prior bonds, after which time the debt service on the refunding bonds is paid out of the revenue stream that would have been used to pay the debt service on the redeemed prior bonds. Conversely, until their redemption, the interest on the prior bonds continue to be a liability of the issuer, and the prior bonds are not defeased and removed from the issuer's balance sheet. Since there is no defeasance, the issuer has the flexibility to invest the refunding escrow and has the potential to earn a higher yield.

The third type of refunding is a "full cash" or "gross" refunding. This type of refunding is archaic and the issuer will undertake this type of refunding only if the prior bond resolution or trust indenture requires an initial deposit to the escrow of the full amount of the principal, interest, and call premium of the prior bonds, disregarding any interest that may be earned on the refunding escrow. However, because the escrow will generate investment income, the investment income can be used to pay the debt service on a portion of the refunding bonds, known as "special obligation bonds." Tax regulations preclude full cash refunding unless the bond documents specifically require it.

All bond resolutions and indentures require the deposit to a defeasance escrow of cash, U.S. Treasuries, or obligations guaranteed by the U.S. government. Sometimes defeasance with bank CDs and pre-refunded municipals, or federal agency obligations is also allowed.

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[4] The tax law limitations with respect to arbitrage, rebate, and advance refundings are found in I.R.C. §§ 148 & 149(d); the regulations with respect to these provisions are found in Treasury Regulations §§ 1.103-13 through -15 & 1.148-1.150.

Dyl and Joehnk (1976) discuss current (which they call “direct”) and advanced refundings and outline the computation of present value savings for these types of refundings. They trace regulations related to restrictions on arbitrage profits via advanced refundings from 1966 through 1973. These restrictions appear to be the precursors of the present day arbitrage restrictions. Dyl and Joehnk (1977) modify their advance refunding model to incorporate a revision in 1976 by the IRS of the regulations related to advanced refundings of municipal bonds.

Ziese and Taylor (1977) explain how the 1976 changes in IRS regulations on arbitrage profits succeeded in eliminating the arbitrage profits of advance refunding to issuers and underwriters. They mention how advance refundings can still provide municipal issuers with significant present value savings, when high-coupon bonds are replaced with low-coupon bonds in a low interest rate market. Higher coupon issue can also refund low coupon bond issues, but such refundings would produce break-even present value savings at best. They mention other compelling reasons for issuers to undertake refundings. These include such factors as prevention of default, cash flow savings, and restructuring of debt.

Gurwitz (1990) discusses the optimal timing of refunding by municipal bond issuers. He advocates using refunding efficiency as a criterion, which overcomes this problem. When an issuer executes a refunding, it is realizing the intrinsic value of the call option and is giving up the time value. Refunding efficiency is defined as the ratio of the intrinsic value of an issuer’s call option (the present value savings) to the total value of the call option. Estimating the later requires assumptions about the future volatility of interest rates. If volatility is low, then the chances of realizing substantially greater savings in the near term are also relatively low. Thus, the higher the anticipated market volatility, the greater will be the time value of the issuer’s call option and the lower will be the efficiency of a refunding generating any given level of present value savings.

Gurwitz, Knez and Wadhwani (1992) develop a model to value call options embedded in municipal bonds. Their model builds on the Litterman and Iben (1991) method of valuing embedded call options in corporate bonds. This methodology obtains the term structure of interest rates for individual issuers by adding the credit risk spread specific to the issuers’ rating class, to a benchmark term structure of interest rates for bonds that are assumed to be default-free. Assessing the credit risk involves a determination of the probabilities of default embedded in bond prices. Using the Black, Derman, and Toy (1990) binomial interest rate tree to characterize future paths of interest rates, they show how to compute the option adjusted yield, assuming rational calling by the issuer and checking for the possibility of advance refunding at each node.

Naparst (1993) explains the advance refunding process and shows how the refundablitity of a bond affects its value and risk. If issuers refund rationally and the market rallies significantly, the present value of the cash flows to the first call will be close to the market price of the bond.

Lack of data on municipal bond prices has been the primary reason for the scarcity of empirical research on municipal bond refunding. A few papers that have researched refunding related issues for the municipal bond markets are discussed below.

In a study on the use of call provision by state and local governments, Kidwell (1976a & 1976b) found only a moderate relationship between interest rates and the frequency of existing call provisions. Based on the low explanatory power of interest rates on exercising call options, he concluded, "refunding was not the dominant motive for exercising the call option for municipalities." He suggests that, for political reasons, a governmental unit may be reluctant to refund bonds at a lower interest rate, which would impose a cost on bondholders, if local financial institutions or constituents held a considerable amount of debt.

Kidwell and Hendershott (1978) conducted an empirical study of advance refunding issues in the state of Indiana to examine whether the issuance of such bonds increases the borrowing costs of issuers. This may be so as advance refunding increases the overall supply of state and local government bonds outstanding because, until the refunded issue is retired, there are two outstanding bond issues representing the same project. They found that the impact upon borrowing costs of advance refunding issues was no different than that caused by other bond issues.

Mitchell (1979) found evidence contrary to Kidwell's (1976b) study. For annual data between 1901-1975, he found that when outstandings, the aggregate state and local government demand to refund deflate annual refunding (supply of refunding bonds) is highly sensitive to cyclical interest rates. This characteristic was typical for both general obligation and revenue bonds, and for "large" and "average" size issues. He concludes that interest rate savings do appear to be an important motivation by state and local governments, although he opines that there are no *a priori* reasons to believe that refundings should be related to cyclical interest rates, as refundings could be undertaken for reasons other than interest rate savings, such as (1) restructuring of debt, (2) removal of restrictive debt covenants, and (3) avoidance of actual or imminent default.

Fischer (1983) studies the response of the municipal bond secondary market to advance refundings. He hypothesizes that advance refundings introduce a reduction in the default risk of the prior bonds, as their debt service is secured by default-free U.S. Treasury securities. He examines the response of yields on pre-refunded bonds to changes in credit quality resulting from advance refundings. Based on a sample of 50 prerefunded bonds during 1977, he finds that news of an advance refunding causes a rapid decline in the prerefunded bond's yield, and the size of the yield response is generally larger for lower-rated bonds. Finnerty (1992) examines conditions under which in-substance defeasance of nonredeemable high coupon debt can be more profitable to the issuer than a cash repurchase.[5] He discusses the application of these concepts to the in-substance defeasance by The Tennessee Valley Authority in 1989 of $6.9 billion of its outstanding non-redeemable high-coupon bonds.

Kalotay, Williams, and Pedvis (1994) discuss the regulatory constraints on refunding of tax-exempt and corporate bonds and review the concept of refunding efficiency and its role in refunding decision. They present a case study in which an application of these techniques is provided.

II.D A Note on the Models of the Term Structure of Interest Rates

[5] Previous studies of in-substance defeasance include Peterson, Peterson, and Ang (1985), Lovata, Nichols, and Philipich (1987), and Johnson, Parl, and Rosenthal (1989).

Interest rate models have been aptly reviewed in the literature (see Abken (1990), Leong (1992), Hull (1993), and Ho (1995).) The purpose of this section is therefore to focus solely on the background and setting of these models and to discuss why the chosen model is appropriate for our purpose.

Since the path breaking article on option pricing by Black and Scholes (1973), contingent claims analysis has revolutionized the approach taken by researchers to term structure modeling. Implementations of these models have vastly benefited from the binomial pricing approach of Cox, Ross, and Rubinstien (1979).

Modern term structure models can be broadly classified into two categories: General equilibrium models and partial equilibrium models.

Among the former are models of Cox, Ingersoll, and Ross (1985), Longstaff (1989), and Wang (1996). Partial equilibrium models of term structure of interest rates include the models of Vasicek (1977), Dothan (1978), Richard (1978), Schaefer and Schwartz (1984), Ho and Lee (1986), Hull and White (1990), Heath, Jarrow, and Morton (1992), Black, Derman, Toy (1990), Longstaff and Schwartz (1992), and Brace and Musiela (1994).

General equilibrium models take investor preferences and unforecastable shocks to physical investment opportunities as given, and the term structure movements are explained endogenously. In partial equilibrium models, on the other hand, the initial term structure and the process generating shift in that structure is determined exogenously. The former class of models have a deeper theoretical foundation, are more ambitious in terms of economic modeling, and do a better job in explaining the liquidity or term premium. The practical distinction, however, is not as sharp when using these models to value bond options. Features such as mean reversion, multiple risk factors, and arbitrage-free valuation have been successfully incorporated into all models. On the other hand, all models suffer from one or more shortcomings such as, the possibility of negative interest rates; preference based valuation; intense computer time required for implementation; difficulty in pricing and hedging; exploding volatility parameter; analytical intractability (more specifically, the absence of closed form solutions for bonds and interest rate sensitive claims); and non-conformity with initial term structure data. Users base their choice on the following desirable features, determined largely by the specific application[6]:

1. ease of "calibration," goodness of fit, and hedge effectiveness,
2. computational speed,
3. analytical tractability, and
4. versatility.

Based on these criteria the Heath, Jarrow, and Morton (hereafter HJM)(1992) model is the preferred framework for this study. The model can be calibrated with relative ease, is bound to conform to the initial term structure of interest rates, provides closed form solutions when the instantaneous short rate is Gaussian, and can be easily adapted to incorporate multiple factors. However, constraining the spot rate to be Gaussian, introduces the possibility of negative interest

[6] See Leong (1992).

rates, a which is deficiency albeit not a serious one.[7] For reasons stated above, recently several related papers in the literature have used the HJM (1992) model.[8]

[7] See Ritchken and Boenawan (1990) for a suggested modification to the Ho and Lee (1986) model to eliminate the possibility of negative interest rates. Black (1995) also comments on these aspects.

[8] See for example Das (1995), Singh and McConnell (1996).

CHAPTER III

THE TERM STRUCTURE OF INTEREST RATES AND RATIONAL EXERCISE OF EMBEDDED BOND OPTIONS

No theory is good except on condition that one use it to go on beyond.

André Gide

Journals 1889–1949.

III.A Introduction

In this chapter the methodology to value interest rate contingent claims in the Heath, Jarrow, Morton (henceforth, HJM) (1992) framework for the term structure of interest rates is discussed. In the context of the HJM (1992) paradigm a one-factor generalized Vasicek (1977) model is implemented. The methodology to calibrate and implement this model is presented. Valuation of call options embedded in bonds, and the computation of the optimal exercise boundary is discussed. Optimal and sub-optimal exercise strategies are identified and the determination of losses resulting from sub-optimal exercise is presented.

III.B The Heath, Jarrow, and Morton Framework

This section reviews the HJM (1992) framework for the term structure of interest rates. Consider a probability space (, *F*, *Q*) with an augmented Brownian filtration $\{F_t$: $t \in [0,\ ]\}$ generated by an *n*-dimensional Brownian motion $\{W_1(t), \ldots, W_n(t)$: $t \in [0,\ ];\ \ < \infty\}$ initialized at zero. Let the trading interval be [0,]. Define $f(t,T)$, 0 = *t* = *T* = , to be the forward rate contracted at time *t* for instantaneous borrowing and lending at time *T*. Forward rates are assumed to follow a diffusion process of the form:

(3.1) $$df(t,T) = \ ^{f}(t,T)dt + \sum_{i=1}^{n} \ _{i}^{f}(t,T)dW_i(t) \text{ for all } 0 \le t \le T \le \ ;$$

given $f(0,T)$: $T \in [0,\ ]$

and where $^{f}(t,T)$ and $_{i}{}^{f}(t,T)$ for $i = 1, \ldots, n$ are the forward rate drift and volatility parameters which could depend on the level of the term structure itself, and $dW_i(t)$ is the Wiener increment. Integrating equation (3.1) with respect to *t* yields the following stochastic equation for the forward rate:

(3.2) $$f(t,T) = f(0,T) + \int_0^t \ ^{f}(u,T)du + \sum_{i=1}^{n}\int_0^t \ _{i}^{f}(u,T)dW_i(u) \text{ for all } 0 = t = T$$

The spot rate at time*t*, $r(t)$, is given by$f(t,t)$. From (3.2) we obtain the process for the spot rate:

$$\text{(3.3a)}\quad r(t) = f(t,t) = f(0,t) + \int_0^t \ ^{f}(u,t)du + \sum_{i=1}^{n} \int_0^t \ _i^{f}(u,t)dW_i(u) \quad \text{for all } t \in [0,T]$$

The dynamics of the spot rate can then be obtained as:

$$\text{(3.3b)}\qquad dr(t) = df(t,s)\big|_{s \to t} + \frac{}{s} f(t,s)\big|_{s \to t} dt$$

Let $P(t,T)$ be the price at time t, of a pure discount bond that matures at time T. By definition, the bond price is given by

$$\text{(3.4)}\qquad P(t,T) = \exp\left(-\int_t^T f(t,s)ds\right) \text{ for all } t \in [0,T],\ T \in [0,\ ].$$

and $P(T,T) = 1$ for all $T \in [0,\ ]$, $P(t,T) > 0$ for all $T \in [0,\ ]$. We also define an accumulation factor, $M(t)$, corresponding to the value of a money market account initialized at time 0 with a dollar investment, i.e.,

$$\text{(3.5)}\qquad M(t) = \exp\left(\int_0^t r(u)du\right) \qquad \text{for all } t \in [0,\ ].$$

From (3.4) it is evident that bond prices depend on forward rates; hence the drift and volatility structure of bond returns must be related to the drift and volatility structure of forward rates. In particular, let

$$\text{(3.6)}\qquad \frac{dP(t,T)}{P(t,T)} = \ ^{p}(t,T)dt + \sum_{i=1}^{n} \ _i^{p}(t,T)dW_i(t)$$

Where $^{p}(t,T)$ and $_i^{p}(t,T)$ for $i = 1, \ldots, n$ are the drift and volatility parameters of bond returns. We assume as in Harrison and Pliska (1981) the absence of arbitrage opportunities given completeness of markets. Arbitrage arguments then lead to[9]:

$$\text{(3.7a)}\qquad -\sum_{i=1}^{n} \ _i(t) \ _i^{p}(t,T) = \ ^{p}(t,T) - r(t)$$

and

$$\text{(3.7b)}\qquad ^{f}(t,T) = -\sum_{i=1}^{n} \ _i^{f}(t,T)\left[\ _i(t) + \ _i^{p}(t,T)\right]$$

and

$$\text{(3.7c)}\qquad _i^{p}(t,T) = -\int_t^T \ _i^{f}(t,s)ds$$

[9]Equation (3.7a) is a standard assumption in finance. For a proof of equations (3.7b) and (3.7c) see Priyadarshi (1996).

where $\ _i$ is the market price of risk associated with the random factors $W_i(t)$ for i = 1,....,n, respectively. Equation (3.7b) is the *forward rate restriction* in the HJM (1992) framework. Using (3.7b) and (3.7c) we can rewrite Equation (3.1) as:

$$(3.8)\quad df(t,T) = -\sum_{i=1}^{n} \ {}_i^f(t,T)\ {}_i(t)dt + \sum_{i=1}^{n} \ {}_i^f(t,T)\int_t^T \ {}_i^f(t,s)ds + \sum_{i=1}^{n} \ {}_i^f(t,T)dW_i(t)$$

and we can rewrite equation (3.6) using (3.7a) as:

$$(3.9)\qquad \frac{dP(t,T)}{P(t,T)} = r(t)dt + \sum_{i=1}^{n} \ {}_i(t)\ {}_i^p(t,T)dt + \sum_{i=1}^{n} \ {}_i^p(t,T)dW_i(t)$$

Assuming the market price of risk satisfies the Novikov condition, $\tilde{E}\left[\exp\left(\frac{1}{2}\int_0 (\ {}_i(t))^2 dt\right)\right] < \infty$, for all t, there exists by Girsanov's theorem an equivalent martingale risk-neutral measure, under which the process $\tilde{W}_i(t) = W_i(t) - \int_0 \ {}_i(u)du$, referred to as the risk-neutral Brownian motion, is a Brownian motion on [0,].

Under these assumptions (3.8) and (3.9) reduce, respectively, to:[10]

$$(3.10)\qquad df(t,T) = \sum_{i=1}^{n} \ {}_i^f(t,T)\int_t^T \ {}_i^f(t,s)ds + \sum_{i=1}^{n} \ {}_i^f(t,T)d\tilde{W}_i(t)$$

$$(3.11)\qquad \frac{dP(t,T)}{P(t,T)} = r(t)dt + \sum_{i=1}^{n} \ {}_i^p(t,T)d\tilde{W}_i(t)$$

The market prices of risk *drop out* of expression (3.10) and (3.11) and they are replaced with an expression involving the volatilities across different maturities of the forward rates, i.e. a "term structure of volatilities."

Integrating (3.10) with respect to t we obtain the preference-free process for the forward rate and the spot rate[11]

$$(3.12)\qquad f(t,T) = f(0,T) + \sum_{i=1}^{n}\int_0^t \ {}_i^f(u,T)\int_u^T \ {}_i^f(u,s)ds.du + \sum_{i=1}^{n}\int_0^t \ {}_i^f(u,T)d\tilde{W}_i(u)$$

$$(3.13)\qquad r(t) = f(0,t) + \sum_{i=1}^{n}\int_0^t \ {}_i^f(u,t)\int_u^t \ {}_i^f(u,s)ds.du + \sum_{i=1}^{n}\int_0^t \ {}_i^f(u,t)d\tilde{W}_i(u)$$

Using (3.4) and (3.12) we obtain

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[10] See Karatzas and Shreve (1988).

[11] Certain regularity conditions, which require the volatility to be Lipshitz continuous, must hold for existence of solutions to equations (3.12) and (3.13). See Carverhill (1995) for details.

(3.14)

$$P(t,T)=\left[\frac{P(0,T)}{P(0,t)}\right]\exp\left\{-\sum_{i=1}^{n}\int_t^T\int_0^t {}_i^f(u,y)\int_u^y {}_i^f(u,s)ds.du.dy-\sum_{i=1}^{n}\int_t^T\int_0^t {}_i^f(u,y)d\tilde{W}_i(u)\cdot dy\right\}$$

From equations (3.12), (3.13), and (3.14), we note that the initial term structure and the volatility structures are the only exogenous elements in the model, and together they completely determine the evolution of the entire term structure.

III.C The Generalized Vasicek Model

The computation of prices in the HJM (1992) framework is non-trivial since the evolution of the term structure under the martingale measure is usually non-Markovian with respect to the finite-dimensioned state space. An exception to this case is when volatilities of all forward rates are non-random. In this case, simplification results and analytical solutions for certain claims are available. For example Jamshidian (1989, 1990, 1991), HJM (1992), and Ritchken and Sankarasubramanian (1995) have developed term-structure-constrained models for debt options in a dynamically complete model.

An Itô process with deterministic drift and diffusion is a Gaussian process, meaning that its value at any time t is normally distributed. Hence the forward rate $f(t,T)$ is Gaussian if $^f(t,T)$ and $_i{}^f(t,T)$ are deterministic for each t and T. This, in particular implies that forward rates and the short rate are normally distributed.[12] Under the equivalent martingale measure, a Gaussian forward rate model has bond prices that are log-normally distributed, with the forward bond price as the mean.

The determination of the evolution of the term structure and the valuation of interest rate sensitive claims becomes computationally efficient when the short rate is Markovian. If in addition, the volatility structure is stationary and non-random, then it must have the Vasicek (1977) form (see Carverhill (1995), pages 307-309):

(3.15) $$ {}_i^f(t,T) = {}_i e^{- {}_i(T-t)}$$

where, $_i = {}_i{}^f(t,t)$, is the i^{th} component of the short rate volatility, and $_i$ is the mean reversion parameter. When $_i = 0$, ${}_i^f(t,T) = {}_i$. We constrain the volatility to be of the generalized Vasicek (1977) form. This allows us to construct simple numerical procedures for option valuation, such as the binomial or trinomial procedures of Nelson and Ramaswamy (1990) or Hull and White (1990b), respectively. For a one-factor exponentially dampened volatility structure, such as $e^{- (T-t)}$ the forward rates and spot rates are normally distributed and the model is path-independent. The spot interest rate becomes the only state variable and the term structure is Markovian with respect to the spot interest rate $r(t)$, and can be completely described by , and .

The stochastic processes for the forward rates and spot rates can be obtained from (3.12) and (3.13) respectively, as:

[12] See Duffie (1992) for details.

$$(3.16) \qquad f(t,T) = f(0,T) + \frac{2}{2 \quad 2}\left[2e^{- \; T}(e^{\; t} - 1) - e^{-2 \; T}(e^{2 \; t} - 1)\right] + \int_0^t e^{- \; (T-u)} d\tilde{W}(u)$$

$$(3.17) \qquad r(t) = f(0,t) + \frac{2}{2 \quad 2}(1 - e^{- \; t})^2 + \int_0^t e^{- \; (t-u)} d\tilde{W}(u)$$

Note from equations (3.16) and (3.17) that forward rates and spot rates can be negative with positive probability. The instantaneous change in the spot rate is given by:

$$(3.18) \qquad dr(t) = \left\{ \; [f(0,t) - r(t)] + \frac{2}{2}\left[1 - e^{-2 \; t}\right] + \frac{}{t} f(0,t) \right\} dt + \; d\tilde{W}(t)$$

Bond prices are obtained as:

$$(3.19) \; P(t,T) = \frac{P(0,T)}{P(0,t)} \exp\left\{ - \frac{2}{4 \quad 3}\left[1 - e^{- \; (T-t)}\right]^2 \left[1 - e^{-2 \; t}\right] + \frac{1}{}\left[1 - e^{- \; (T-t)}\right][f(0,t) - r(t)] \right\}$$

III.D Model Implementation

The implementation of the generalized Vasicek (1977) model in discrete time is accomplished by partitioning the time interval [0, *T*] into *n* subintervals, each of length $\Delta t = T/n$. Instead of taking the spot interest rate as the state variable it is easier to work with the transformed variable[13], $Y(t)$, defined as

$$(3.20) \qquad Y(t) = R(t) - \Phi(t)$$

where

$$(3.21) \qquad R(t) = r(t) - f(0,t)$$

and

$$(3.22) \qquad \Phi(t) = \frac{2}{2}\left[t + \frac{e^{-2 \; t}}{2} - \frac{1}{2} \right]$$

A recombining tree for the transformed variable *Y* is set up. In each time increment *Y* can move up to one of two points. Specifically at any node (*i*,*j*), $Y(i,j)$ can move up to $Y(i+1,j)$ or move down to $Y(i+1,j+1)$, where

$$(3.23a) \qquad Y(i+1, j) = Y(i, j) + \sqrt{\Delta t} \qquad i = 1, \ldots m; \; j = 1, \ldots i.$$

and

$$(3.23b) \qquad Y(i+1, j+1) = Y(i, j) - \sqrt{\Delta t} \qquad i = 1, \ldots m; \; j = 1, \ldots i.$$

as depicted in Figure 3.1.

[13] See Nelson and Ramaswamy (1990) or Priyadarshi (1996) for details.

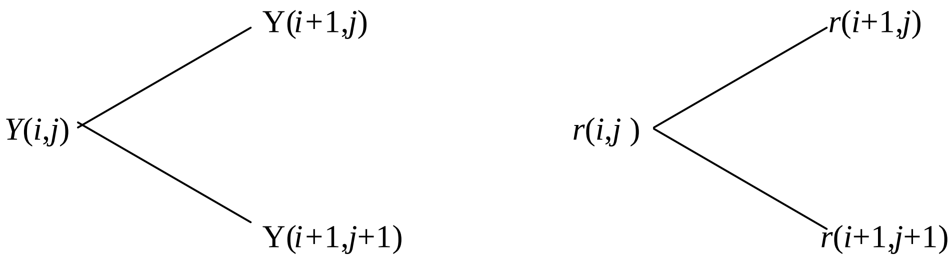

Figure 3.1: Interest Rate Trees

Given the lattice for the transformed variable Y, the interest rate lattice can be constructed as

(3.24a) $$r(i+1, j) = Y(i+1, j) + f(0, i+1) + \Phi(i+1) \text{ with probability,} q$$

and

(3.24b) $$r(i+1, j+1) = Y(i+1, j+1) + f(0, i+1) + \Phi(i+1) \text{ with probability, } 1 - q.$$

where, q, the probability of an up move is given by

(3.25) $$q = \begin{cases} \frac{1}{2} + \frac{\sqrt{\Delta t}}{2}\left\{\frac{2}{2}\left[1 - e^{-2\ t}\right] - \ R(t)\right\}, & \text{if } 0 \le \frac{1}{2} + \frac{\sqrt{\Delta t}}{2}\left\{\frac{2}{2}\left[1 - e^{-2\ t}\right] - \ R(t)\right\} \le 1 \\ 0, & \text{if } \frac{1}{2} + \frac{\sqrt{\Delta t}}{2}\left\{\frac{2}{2}\left[1 - e^{-2\ t}\right] - \ R(t)\right\} < 0 \\ 1, & \text{otherwise} \end{cases}$$

Hence the entire term structure can be computed using equation (3.19). If the time period at which valuation is done coincides with the expiration date of the claim, then we can establish the terminal value of the claim. Once this is done, backward recursion procedure can be used to obtain the fair value of the claim.

Let $B(t,T_m)$ represent the price at time t of a bond with coupon stream D, maturing at time T_m and with a principal amount of \$1. The bond provides a total of m coupons. Let the j^{th} coupon occur at T_j where $1 = j = m$. Hence

(3.26) $$B(t,T_m) = P(t,T_m) + \sum_{j=1}^{m} DP(t,T_j)$$

The interest rate lattice can be used to price coupon bonds using backward recursion. Let the value of the bond at node (i,j) be $B(i,j)$, and the terminal price of the bond be \$1, i.e., $B(m,j)$ = \$1 at the terminal node. Let $B(i+1,j)$, be the value of the bond at node $(i+1,j)$ when the interest rate is $r(i+1,j)$ and let $B(i+1,j+1)$, be the value of the bond at node $(i+1,j+1)$ when the interest rate is $r(i+1,j+1)$. If these values are known then the bond price at node (i,j) can be obtained by discounting the probability weighted average of the next two outcomes by the one period discount factor, $P(i,i+1;j)$, applicable at node (i,j). We can perform backward recursion and the price of the bond at node (i,j) is given by

$$(3.27) \qquad B(i,j) = \left[qB(i+1,j) + (1-q)B(i+1,j+1)\right]P(i,i+1;j)$$

where q is the probability of an up move. If the bond pays the coupon at node (i,j), then coupon D is added to the above value.

Call options on coupon bonds are also computed by backward recursion. Let the price of a call option on the coupon bond at node (i,j) be $C(i,j)$. The value of the American call at node (i,j) is given by

$$(3.28) \qquad C(i,j) = \max[B(i,j) - K,\ qC(i+1,j) + (1-q)C(i,+1,j+1)]P(i,i+1;j)$$

where K is the exercise price.

III.E Model Calibration

Municipal bond yield information was obtained from the Salomon Brothers Municipal Bond Index. This index provides monthly municipal bond yields for maturities of 1, 5, 10, 20, and 30 years. The available data for this index ends in June 1993. Yields for intermediate maturities are obtained by linear interpolation as follows:[14]

let $y(i)$, be the yield for a bond maturing in i years. If $y(i)$, and, $y(i+n)$, are known values then yields for bonds with intermediate maturity is given by:

$$y(i+j) = y(i) + (j/n)\big(y(i+n) - y(i)\big); \quad j = 1,\ldots,n\text{-}1.$$

The zero-coupon municipal yield curve is obtained by the bootstrapping[15] the Salomon Brothers Municipal Bond Index in the following manner:

The model is calibrated by pricing bonds on the municipal yield curve. The spot rate volatility, , and mean reversion parameter, , are obtained using the Gauss-Newton non-linear estimation procedure which regresses the residual onto the partial derivatives of the model with respect to the parameters until the estimates converge. This estimation procedure requires an initial start value, or "guess" for the parameters, and partial derivatives with respect to each parameter.

The municipal forward rates are computed from the term structure of municipal yields as follows

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[14] This is a reasonable approximation since municipal yield information for all maturities and by different credit risk classes for general obligation bonds and for revenue bonds is generally not available. The sparseness of yield data in the Salomon Brothers Index is not much of a problem given the fact that spreads for long term bonds are very close.

[15] See Hull (1993) pages 84-86 for an excellent discussion of the bootstrap method used here.

(3.29) $$f(t,T) = \frac{P(t,T)}{P(t+\Delta t,T)}$$

where, $P(t,T)$ is the price of a discount bond at time t, maturing at time T computed from the municipal zero-coupon yield curve. These forward rates are converted to continuously compounded rates as follows:

(3.30) $$\tilde{f}(t,T) = \frac{\ln f(t,T)}{\Delta t}$$

By adding the credit risk spread specific to the issuer's rating class, to the zero-coupon yield curve, I obtain the term structure of interest rates for individual issuers. The spot rate is the one year municipal bond yield.

The lattice for the transformed variable, $Y(i,j)$ and the corresponding lattice for interest rates, $r(i,j)$ are computed for each bond based on the issuer's term structure of interest rates. To counter the possibility of negative interest rates a reflecting barrier is imposed. Furthermore, if interest rates become high with respect to the initial forward rate curve, the mean reversion phenomenon pulls the spot rate to the long run mean, i.e. the initial forward rate curve. When this happens, the drift becomes negative and up move probabilities can fall below zero when spot rate is very high. The reverse hold true when the spot rate is too low compared to the initial forward rate curve. The drift becomes large and up move probabilities can go above 1 when the spot rate is too low. In such cases the probability is constrained to be zero when negative and restricted to 1 when more than one.[16]

Given these lattices, one period discount bond prices $P(i,i+1;j)$ are obtained for each (i,j) node using equation (3.19). This equation requires the difference between the prevailing spot rate and the initial forward rate curve, which is obtained in the discrete case as $r(i,j) - f(0,i)$. Bond price and call option lattices are constructed based on the interest rate lattice.

III.F Rational Exercise of Call Options Embedded in Callable Bonds and Refunding Efficiency

Callable bonds contain embedded call options by virtue of provisions in the indentures that permit the issuing firm to buy back the bond at a predetermined price or the strike price, at certain times in the future. Essentially, the bond holders have sold a call option to the issuer. These provisions typically allow the issuer to refund the bond, or in other words, exercise the call option at any time after the call protection date. An in-the-money American call option is worth at least as much as its intrinsic value, max $[B(i,j) - K, 0]$, where, $B(i,j)$, is the prevailing bond price and, K, is the predetermined strike price, and the option holder can realize the intrinsic value by exercising immediately. Usually it is optimal for the holder of an in-the-money American option to wait rather than exercise immediately. In such cases the option is said to have time value. The total value of an option can be thought of as the sum of its intrinsic value and its time value.

[16] The reflecting barrier and the constraints on the probabilities introduce arbitrage possibilities. However, this happens only at the extreme nodes near the end of the tree.

The optimal exercise boundary or the critical level of interest rates is obtained by tracing through the lattice for the call option and determining the highest level of interest rates at which early exercise is possible. In particular, let $r^*(i,j^*)$ be level of interest rate in period i, corresponding to the highest possible interest rate when the following two criteria are met:

1. the call option can be exercised optimally, i.e. its intrinsic value is equal to the value of the call, and
2. yield on the escrow funds is higher than the critical interest rate, $r^*(i,j^*)$, before the call protection date.

Rational exercise is one in which the holder exercises the option when the total value of the option is no more than its intrinsic value, and the exercise is optimal. Based on the optimal exercise boundary, $r^*(i,j^*)$, and the actual interest rate evolution, $R_{actual}(i,j)$; one can obtain t^*, as the first instance when:

(3.31) $$R_{actual}(t^*, j^*) \leq r^*(t^*, j^*) \qquad 1 = t^* = i;\ 1 = j^* = i;\ 1 = i = m.$$

This is to the first hit to the optimal exercise boundary, and, t^*, is labeled as the “optimal time to exercise.[17]”

Two sub-optimal exercise strategies are possible:

1. “*exercising too early*,” where the holder chooses to exercise an option when it should not be exercised until later (Figure 3.2). This also includes options that are exercised but optimal exercise boundary is not hit (t^* does not exist: Figure 3.3), and,
2. “*exercising too late*,” where the holder fails to exercise an option when it should be exercised (Figure3.4). This also includes options that are never exercised but optimal exercise boundary is hit (t^* exists: Figure 3.5).

These two sub-optimal exercise strategies result in a loss in value that can be estimated using standard option valuation techniques. In the first case, when the holder exercises too early, the holder is giving up the time value of the option and the loss in value is given by:

Loss in value from exercising too early = Value of the option on date of exercise - Intrinsic value on date of exercise.

(3.32) $$\text{Loss}_{\text{case one}} = C(s,j) - \left[B(s,j) - K\right] \quad 1 = i = m;\ s \subset i;\ 1 = j = s$$

where s is the date of exercise.

In the second case, when the holder exercises too late, the holder is giving up the intrinsic value of the option when exercise was optimal, and the loss in value is given by:

Loss in value from exercising too late = Intrinsic value on date on which exercise is first optimal - Value of the option if left unexercised.

(3.33) $$\text{Loss}_{\text{case two}} = \left[B(t^*, j^*) - K\right] - C_{sub-optimal}(t^*, j^*)$$

[17] Refundings within ±6 months of t^* are deemed optimal.

where t^* optimal time to exercise, as defined in (3.31), and

$$C_{sub-optimal}(s-1, j) = \left[qC(s, j) + (1-q)C(s, j+1)\right]P(s-1, s; j) \quad (3.34)$$

and

$$C_{sub-optimal}(i, j) = \left[qC_{sub-optimal}(i+1, j) + (1-q)C_{sub-optimal}(i+1, j+1)\right]P(i, i+1; j) \quad (3.35)$$

where $t^* = i = s - 2$; $1 = j = i$.

$C_{sub\text{-}optimal}(t^*, j^*)$ is the probability weighted discounted value of the call value arising from the sub-optimal decision at time s, where s is the eventual exercise data or $m - 1$ if not exercised, m is the maturity of the bond, and $P(i,i+1;j)$ is the one period discount factor obtained from (3.19).[18]

Since the terminal price of the bond is $1, the loss in value obtained from equations (3.32) and (3.33) is the per unit loss, and represents cost of sub-optimal refunding strategy as a fraction of each dollar of the principal amount of the bond with the embedded call option.

In addition, I check if there are losses from investing escrow funds at yields below the reoffering yield, for periods when the bond is advance refunded. This loss is computed as follows:

$$\text{Loss from escrow investment} = \max\left\{0, \left[Y_{refunding} - \left(Y_{treasury}(s; x-s) + 0.125\%\right)\right]\right\} * (x-s) * \text{Proceeds of Refunding Bond.} \quad (3.36)$$

where $Y_{refunding}$ is the reoffering yield, $Y_{treasury}(s;x\text{-}s)$ is the yield on U.S. treasury securities at time s, with maturity of x-s, and x is the call protection date on the refunded bond.[19]

The absolute dollar loss can be computed as the sum of (1) product of per unit loss in option value and the principal amount of the bond, and (2) loss from escrow investments, and is given by:

(3.37) Dollar Loss = Per Unit Loss x Gross Proceeds + Loss from escrow investments.

Refunding efficiency from either of the above two sub-optimal exercise strategies can be computed as:

(3.38) Refunding Efficiency, % = (1 - Per Unit Loss) x 100.

Refunding efficiency is the ratio of actual savings realized by exercising the call option on the date of exercise to the potential saving obtainable from optimal exercise.[20]

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[18] The value of the call at bond maturity is zero.

[19] Federal arbitrage rules state that an issuer cannot invest tax-exempt bond proceeds at a higher yield than the interest rate on the bond issue, except in specific circumstances. More accurately, the yield on the investments can only be 1/8 of 1% higher, or arbitrage restrictions apply. For example, if the yield on the refunding bond is 6%, the issuer is limited to a 6.125% return on the investment of the bond proceeds.

[20] This definition of refunding efficiency is slightly different than that in the literature (Boyce and Kalotay (1979a), Howard and Kalotay (1988), and Guruwitz (1990)). This definition does not assume that issuers always refund at the optimal time.

If the model is specified correctly, then interest costs of refunding at the optimal time are lower than the actual interest costs by refunding at a time other than optimal. To test this, an *ex-post* measure of the interest costs is constructed. This *ex-post* measure of the interest costs is the ratio of *ex-post* actual interest costs and, the potential interest costs by refunding optimally. This ratio is computed as follows:

$$(3.39)\quad \text{Ratio of Ex-Post Interest Cost} = \frac{\sum_{i=1}^{s} D_{refunded} P(i,i+1) + \sum_{i=s+1}^{m} D_{refunding} P(i,i+1)}{\sum_{i=1}^{t^*} D_{refunded} P(i,i+1) + \sum_{i=t^*+1}^{m} D_{refunding} P(i,i+1)}$$

where $D_{refunded}$ is the coupon on the refunded bond, $D_{refunding}$ is the coupon on the refunding bond, $P(i,i+1)$ is the one period discount factor obtained from (3.19). If this ratio is more than one, then by refunding at the optimal time issuers save on total interest costs.

Months away from time when first optimal to exercise is given by $s - t^*$.

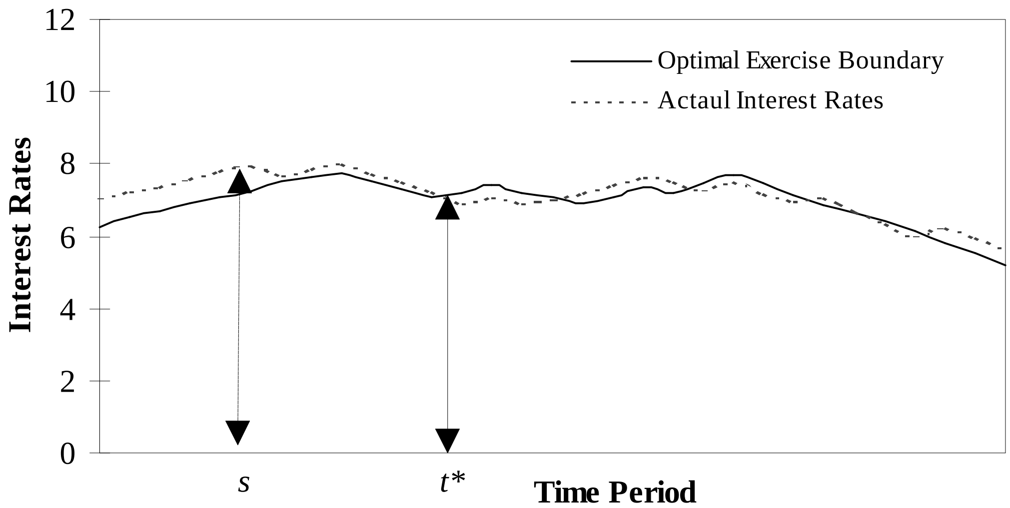

Figure 3.2: Case 1: *Exercising Too Early*. When Bond is Refunded at Time *s*, Before the Optimal Time *t.**

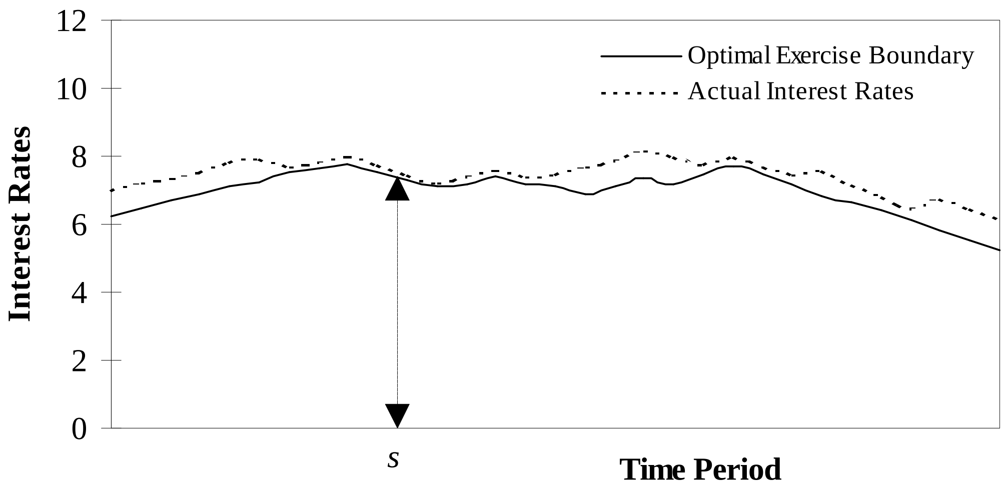

Figure 3.3: Case 1: *Exercising Too Early*. When Bond is Refunded at Time *s*, but the Optimal Exercise Boundary is Not Hit.

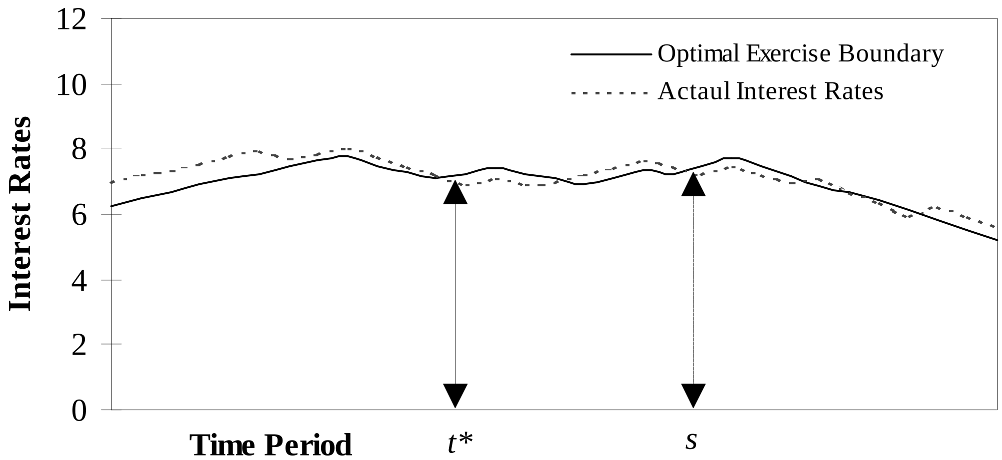

Figure 3.4: Case 2: *Exercising Too Late*. When Bond is Refunded at Time *s*, After the Optimal Time *t.**

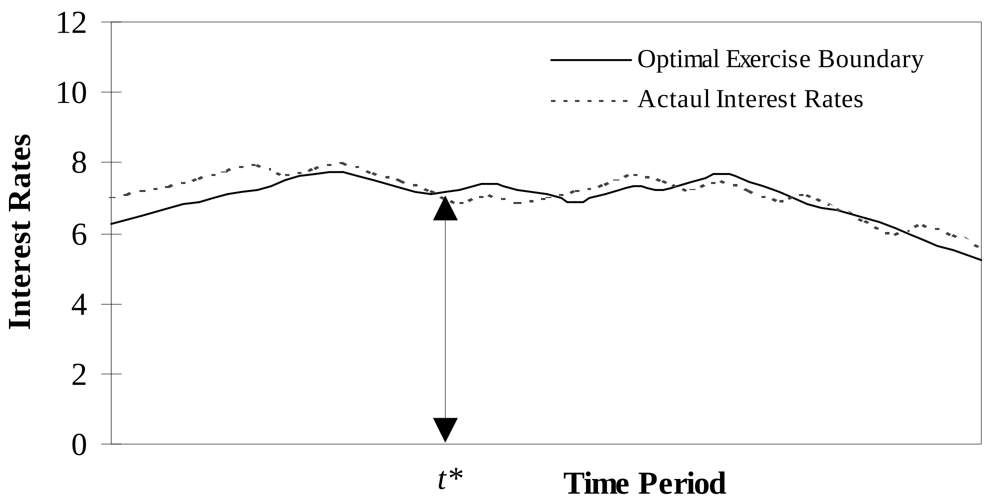

Figure 3.5: Case 2: *Exercising Too Late*. When Bond is Not Refunded, but the Optimal Exercise Boundary is Hit.

CHAPTER IV

BOND REFUNDING EFFICIENCY IN THE MUNICIPAL BOND MARKET

After all, the ultimate goal of all research is not objectivity, but truth.

Helene Deutsch

*The Psychology of Women,*vol. 1.

IV.A Introduction

This chapter presents the results of the analysis of refunding decisions employed by issuers of callable tax-exempt debt. Using the generalized Vasicek (1977) model in the HJM (1992) framework, I construct binomial option pricing trees and obtain the optimal exercise curve for a sample of 26,596 callable bonds. For these bonds, refunding efficiency, ratio of *ex-post* interest costs, loss in value, and months from optimal time are computed from option pricing trees. These are analyzed by several bond and issuer characteristics. The results show widespread refunding inefficiencies and losses in the municipal bond market.

IV.B Data and Sample Characteristics

The data in this study is collected from the U.S. Municipal Bonds New Issues Database obtained from *Securities Data Corporation*. This database consists of 135,966 municipal bonds issued between January 1980 and March 1995. Each observation has over 140 data elements including issuer name, county and state; book and co-managers, financial advisors, legal counsels, trustees and paying agents; offering terms and ratings; use of proceeds; net interest costs, true interest costs, gross spread and breakdown; call features and refunding information. This data is obtained from official statements, news sources, trade publications, proprietary surveys and information from investment bankers and other advisors.

Out of 135,966 bonds issued between January 1980 and March 1995, 78,620 issues or 57.8% contain call provisions which enable issuers to call these bonds. The remaining 57,346 issues are non-callable bonds. Table 4.1 reports the characteristics of the data for callable and non-callable bonds. Analysis of the data according to whether the issue was callable or non-callable, shows interesting results. Non-callable bonds are primarily general obligation bonds, have lower gross proceeds compared to those that are callable, and are issued for much shorter maturities. Table 4.1 indicates that 75.2% of non-callable bonds are general obligation bonds. Non-callable bonds have average gross proceeds of $13.3 million and are issued for an average maturity period of 12.65 years. For comparison, only 41% of the callable bonds are general obligation bonds, have average gross proceeds of $21.5 million and are issued for an average maturity period of 21.11 years. Non-callable bonds are issued at an average yield of 6.01% compared to 7.00% for the callable bonds. Thus the spread between callable bonds and non-callable bonds is approximately 1.00%. Table 4.2 shows the frequency of issuance of callable and non-callable bonds between January 1990 and March 1995. Half of all callable bonds were issued between 1990 and 1993.

Municipal bond yield information was obtained from the Salomon Brothers Municipal Bond Index, the available data for which ends in June 1993. Treasury yields are obtained from McCulloch and Kwon (1993) U.S. Term structure database. Consumer Price Index (CPI) data, obtained from the *Federal Reserve Bank of Saint Louis,* is used to convert all dollar amounts to end 1995 figures.

Out of the 78,620 callable bonds in the *Securities Data Corporation* database, only 7,973 bonds contain information on the matching refunding issue. Two or more issues were used to refunded 489 of these called bonds. I consider only the first instance of refunding.

During the 1980s, the federal government became concerned that municipal governments were abusing their power to issue bonds by issuing bonds unnecessarily in order to try to earn arbitrage.[21] The 1986 Tax Reform Act put into place a variety of restrictions and regulations designed to prevent abuse. Several of the major restrictions are discussed below.

Federal arbitrage rules state that an issuer cannot invest tax-exempt bond proceeds at a higher yield than the interest rate on the bond issue, except in specific circumstances. More accurately, the yield on the investments can only be 1/8 of 1% higher, or arbitrage restrictions apply.

For example, if the yield on the refunding bond is 6%, the issuer is limited to a 6.125% return on the investment of the bond proceeds. The issuer can purchase special low-yield U.S. Treasury securities called the state and local government series to meet this requirement if the normal market instruments are paying more.

Sometimes the issuer does earn prohibited arbitrage that had not been foreseen. If this happens, any earnings in excess of the bond yield must be returned to the U.S. Treasury in a process called "rebating." There are two possible penalties for an issuer who fails to comply with rebate requirements -- the IRS can declare the bonds taxable retroactive to the date of issue, or the IRS can assess a monetary penalty.

Also, private activity bonds cannot be advance refunded at all. This restriction prevents the federal subsidization, through tax-exempt arbitrage earnings, of private activities.

The purpose of this study is to analyze refunding decision from the perspective of interest rate saving. As such, bonds issued before 1986 are excluded from this study, due to the possibility of earning arbitrage. Private Activity Bonds are also excluded from the sample

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[21] Arbitrage in the municipal bond market is the difference in the interest paid on an issuer's tax-exempt bonds and the interest earned by investing the bond proceeds in taxable securities. Proceeds from a bond issue are usually put into short-term investments until either they are spent on their intended use or, in the case of a refunding issue, used to call the original bonds. Both of these situations can generate arbitrage earnings. If interest rates on the investments are below the interest rates on the bonds, then there is "negative arbitrage."

because of the numerous limitations, volume caps, restriction on advance refunding of these bonds; these rules effect the flexibility of the issuers' desire or ability to refund these bonds.

This study looks at bonds that are called and bonds that are not called. Accordingly, two samples are constructed. The first sample consists of 2,620 bonds that are called and meet the following selection criteria:

1. complete pricing information is available for refunding and refunded bonds,
2. original years to maturity at issuance is less than 30 years,
3. bond is issued between January 1986 and June 1993, and
4. it is not a Private Activity Bond.

A second sample consists of 23,976 callable bonds that are not called and meet the following selection criteria:

1. complete pricing information is available for the bond,
2. original years to maturity at issuance is less than 30 years,
3. bond is issued between January 1986 and June 1993, and
4. it is not a Private Activity Bond.

Four refunding strategies can be identified using option pricing theory, two of which are optimal refundings strategies, and the other two are sub-optimal refunding strategies. The two optimal strategies are:

1. calling the bond when it is optimal to refund, and
2. not calling the bond when early exercise is not optimal.

Refunding when optimal results in zero-loss and a refunding efficiency of 100%. For a sub-optimal refunding strategy, the loss in value is non-zero and positive, and refunding efficiency is less than 100%.

The two sub-optimal strategies are:

1. calling too early. This also includes the case when bonds are called but optimal exercise boundary is not hit.
2. calling too late. This also includes the case when bonds are never called but optimal exercise boundary is hit.

The generalized Vasicek (1977) model in the HJM (1992) framework is used to construct binomial option pricing trees as outlined in Chapter III, sections D and E. Optimal exercise boundary is obtained from the option pricing trees. For each bond in the first sample, refunding efficiency, ratio of *ex-post* interest costs, loss in value, and months from optimal time are computed from option pricing trees. For the second sample, the loss from not calling is computed. Computations are based on the option pricing trees as explained in Chapter III, section F. These measures are analyzed by several bond and issuer characteristics.

IV.C Hypotheses

The following hypotheses are tested:

HYPOTHESIS 1: H_0 : *Mean (and median) refunding efficiency is 100%. The purpose of this test is to determine if refunding decisions employed by issuers of callable debt are optimal. This test is conducted for the first sample.*

HYPOTHESIS 2: H_0 : *Mean (and median) ratio of ex-post interest costs is 1. The purpose of this test is to determine the efficacy of model to analyze refunding decisions. This test is conducted for the first sample.*

HYPOTHESIS 3: H_0 : *Mean (and median) dollar loss from refunding is 0. The purpose of this test is to determine if issuers of callable debt incur losses from sub- optimal refunding decisions. This test is conducted for both samples.*

HYPOTHESIS 4: H_0 : *Mean (and median) deviation from the optimal time is 0 months. The purpose of this test is to determine if issuers of callable debt refund at the optimal time. This test is conducted for the first sample.*

IV.D Refunding Efficiency, Optimal Timing, and Associated Costs

Given the large amount of outstanding municipal debt, one would argue that the issuers will carefully analyze refunding opportunities. Any loss from a sub-optimal refunding strategy comes at a cost to tax-payers. Hence it is critical to accurately value the embedded call option in callable bonds. This study empirically examines whether the decision to exercise the call option was rational. The value of this option and its optimal exercise are functions of the following variables:

1. coupon and yield on the refunding and refunded bond,
2. prevailing level of interest rates and the volatility parameters of the interest rate process,
3. remaining years to maturity of the refunded bond,
4. cost of refinancing and issuing new bonds,
5. outstanding long term debt, and
6. credit risk.

The data in the *Securities Data Corporation* U.S. New Municipal issues database, does not provide the cost of refinancing and issuing refunding bonds. In absence of this information, a 0.5% cost of refunding is assumed for all issues.

IV.D.1 Bonds that are refunded

In the first sample of 2,620 bonds that are called, 1,941 are sub-optimally exercised, i.e. they are either called early (253 issues), or late (1,688 issues). Only in 26% of all cases are the bonds called at the optimal time. Table 4.3 reports the refunding efficiency and the loss in value from sub-optimal exercise strategies. Average refunding efficiency of sub-optimal refundings is

97.49%, which suggests that such issuers fail to capture 2.51% of the potential savings that would accrue from refunding at optimal time. Average loss in value is $2.07 million per issue, with a total loss of $4 billion. For an average issue size of $29.95 million, that figure translates to a loss of 6.91% of the principal amount of the bond. Issuers exercise 21.31 months later than the optimal time, on average. These results suggest that issuers who refund late cannot realize the present value savings of switching a high coupon bond with a low coupon bond for a longer period of time. Null hypotheses 1 through 4 are rejected at the 99% confidence interval.

Table 4.4 reports the analysis of refunding efficiency and loss in value where refunding is identified as either advanced refunding or current refunding. A current refunding is defined as a refunding in which refunded bonds are called or mature within 90 days of the issuance of the refunding bonds; all other refundings are treated as advance refundings. Intuition suggests that advanced refundings permit a larger choice of refunding opportunities to the issuer, hence such refundings should be more efficient than current refundings. Table 4.4 presents results to the contrary. The average refunding efficiency is 98.11% for advance refundings and 98.34% for current refundings. The average loss in value is $1.69 million per issue for advance refundings and $0.36 million per issue for current refundings. When the issuers advance refund late, there is a high likelihood of "negative arbitrage;" the attainable yield on escrow funds is below the reoffering yield. This loss is in addition to the loss from the call option value.

Results indicate that revenue bonds seem to incur larger losses compared to general obligation bonds. The average offer size of revenue bonds is $44.68 million, compared to $20.34 million for general obligation bonds. Sub-optimal refunding of revenue bonds results in an average loss of $2.02 million per issue compared to $1.22 million for general obligation bonds as reported in Table 4.5. Total loss in value for revenue bonds is $2.05 billion versus a total loss of $1.96 billion for general obligation bonds.

AAA rated bonds are refunded relatively more efficiently with a refunding efficiency of 98.22% and an average loss of $1.09 million per issue. Bonds rated BAA and below, on the other hand, are refunded less efficiently with refunding efficiency of 97.71% and an average loss of $3.04 million per issue. They are refunded about 22.8 months later than optimal. Table 4.6 shows the analysis of refunding decisions by different bond rating classes. Moody's bond ratings are used when available, otherwise those of S&P Corporation are used. Non-rated bonds refund efficiently with a refunding efficiency of 98% and an average loss of $0.47.

Table 4.7 presents evidence that bonds with larger offering size incur larger losses. On comparing the refunding efficiency and loss in value across quintiles of issue sizes, I find that bonds with an average issue size of $2.00 million are refunded with 98.31% efficiency and only accrue an average loss of $0.14 million per issue, compared to 97.89% refunding efficiency and a loss of about $5.92 million per issue for bonds in the 5th quintile with an average issue size of $115.32 million.

Analysis of refunding decisions by quintiles of original years to maturity at issuance is reported in Table 4.8. Bonds with fewer years to maturity are refunded with 98.31% efficiency, compared to 98.04% for the 5th quintile. The average loss in value is $0.46 million per issue for the 1st quintile, and $3.71 million for the 5th quintile.

Table 4.9 reports refunding efficiency, loss in value, and months from optimal time for quintiles of outstanding long term debt. These suggest that issuers with lower outstanding long term debt refund more efficiently than those with larger outstanding debt, with an average loss per issue of $0.26 million and a refunding efficiency of 98.06% for the 1st quintile compared to an average loss of $4.98 million per issue and a refunding efficiency of 97.83% for the 5th quintile. The total loss from sub-optimal exercise for the 5th quintile is $5.67 billion.

Table 4.10 presents the analysis by upgrades or downgrades in bond rating which is a proxy for perceived changes in credit quality. Since upgrades result in lower interest rate costs to the issuers, i.e., lower coupons, such cases would result in higher savings. This is borne out by the result. Losses are lower for bonds that were upgraded and higher for those that are downgraded. However, 67% of the issuer's debt underwent no rating changes.

If the coupon on refunding bond is lower than the coupon on refunded bond then incentives to refund efficiently are higher. Results suggest that issuers wait too long to issue lower coupon bonds, as shown in Table 4.11. Bonds with the most favorable difference in coupon, i.e. the 1st quintile with a mean coupon difference of -4.5%, are refunded 28 months later than optimal, and achieve a refunding efficiency of 96.75% as compared to 31months later than optimal and a refunding efficiency of 99.08% for the 4th quintile with a mean coupon difference of -1.27%, and compared to 4.66 months later than optimal, and a refunding efficiency of 97.42% for the 5th quintile with a mean coupon difference of -0.24%.

Table 4.12 reports time series analysis of refunding decisions. Over the years refunding efficiency has improved and losses have declined substantially. Table 4.13 shows that bonds used for transportation incurred larger losses. Table 4.14 shows results of analyzing refunding decisions by quartiles of losses from escrow investments. These losses are mainly confined to the 4th quartile, which have larger gross proceeds (average size $61.13 million) and were refunded 25 months later than optimal. The mean and median loss from escrow investments are $4.55 million and $1.5 million per issue.

Table 4.15 reports the refunding decision analysis by issuing state. The states of Florida, Illinois, New York and Texas accumulated total losses of $1.44 billion. The state of New York, which issued tax-exempt debt totaling $7.9 billion for bonds included in the sample, lost an average of $10.74 million per issue due to sub-optimal refunding strategies and was 13 months late in refunding.

IV.D.2 Bonds that are never called

In addition to analyzing bonds that are called, I also analyze bonds that are not called before the bonds mature or before 1993, whichever is earlier. Decisions are sub-optimal if they should have been called according to option pricing theory, but are not called by the issuer. Conversely, optimal decisions are identified as those where the issuer decided not to refunded and it was theoretically the correct decision.

Table 4.16 reports the results of the cross-sectional analysis of the decision not to call for the second sample of 23,976 callable bonds. 52% of the sample, or 12,444 bonds were not called but should have been called. This sub-optimal decision results in an average loss in value of $0.25 million per issue with total losses of about $3.17 billion for 12,444 bonds that were not called. This translates to a loss of about 1.72% of the principal amount.

Loss in value from not calling is analyzed by the type of security and results are presented in Table 4.17. Losses are about the same across general obligation bonds and revenue bonds. Table 4.18 reports results of the analysis by bond ratings. Bonds rated AA incur an average loss of $0.22 million per issue. Total losses for bonds that are not rated and are not called, amount to $2.06 billion.

Analysis of the decisions not to call, when it is optimal to call, split up by quintiles of issue size present results similar to those for the first sample. Bonds with highest gross proceeds (Quintile 5: average issue size $55.31million) incur average losses of $0.53 million per issue, with total losses of $2.54 billion, as can be seen from Table 4.19. Bonds with lowest gross proceeds (Quintile 1: average issue size $0.52 million) do not incur significant losses.

Table 4.20 presents results of analyzing refunding decisions by quintiles of original bond maturity at issuance. Bonds with longest maturities, i.e., in the 5^{th} quintile (median maturity 25 years) incur a loss of $0.29 million per issue on average with a combined loss of about $1.37 billion. Bonds with shortest maturities, i.e., in the 1^{st} quintile (median maturity 9 years) incur a loss of $0.03 million per issue on average with a combined loss of about $151 million. Table 4.21 reports the analysis by quintiles of outstanding long term debt. Bonds in the 5^{th} quintile, with the largest amount of debt outstanding (average outstanding long term debt $1.82 billion) lost $0.45 million per issue with total losses of $2.18 billion. Time series analysis of the losses arising from the decision not to call are presented in Table 4.22. These results indicate that losses have sharply reduced over the years. Table 4.23 shows the results of the analysis by use of proceeds. Finally Table 4.24 presents the analysis by the state of issuance. The states of California, Florida, New York, and Texas accumulated total losses of $1.27 billion by not calling.

Table 4.1

Characteristics of U.S. Municipal Bonds New Issues, 1980-1995

This table reports the characteristics of U.S. Municipal Bonds issued between January 1980 and March 1995. Interest costs are the true interest costs (TIC) or net interest costs (NIC), as reported by the issuers. Gross proceeds are in millions of dollars and include all serial and term maturities contained in the issue. Source: *Securities Data Corporation*; U.S. Municipal New Issues Database, 1995

	Non-Callable		Callable		All Bonds	
	N	Percent	N	Percent	N	Percent
Panel A: Security Type						
General Obligation Bonds	43,140	(75.2%)	32,220	(41.0%)	75,360	(55.4%)
Revenue Bonds	14,206	(24.8%)	46,400	(59.0%)	60,606	(44.6%)
Total	57,346		78,620		135,966	
Panel B: Gross Proceeds, $ million						
Mean	$ 13.30		$ 21.50		$ 18.04	
Median	$ 2.50		$ 6.00		$ 4.34	
Total	$ 762,545		$ 1,690,386		$ 2,452,931	
Panel C: Years to maturity						
Mean	12.65		21.11		17.55	
Median	2		20		15	
Panel D: Yield to Maturity						
Mean	6.01%		7.00%		6.56%	
Median	6.00%		6.84%		6.57%	

Table 4.2

Frequency of U.S. Municipal Bonds New Issues, 1980-1995

This table reports the frequency of U.S. Municipal Bonds issued between January 1980 and March 1995. Source: *Securities Data Corporation*, U.S. Municipal New Issues Database, 1995

	Non-Callable		**Callable**		**Total**	
Year of Issuance	N	Percent	N	Percent	N	Percent
1980	765	1%	1,006	1%	1,771	1%
1981	1,173	2%	845	1%	2,018	1%
1982	1,635	3%	1,337	2%	2,972	2%
1983	1,608	3%	1,565	2%	3,173	2%
1984	1,525	3%	2,302	3%	3,827	3%
1985	2,201	4%	4,540	6%	6,741	5%
1986	4,565	8%	4,493	6%	9,058	7%
1987	3,887	7%	4,438	6%	8,325	6%
1988	5,264	9%	4,644	6%	9,908	7%
1989	6,143	11%	5,467	7%	11,610	9%
1990	4,397	8%	7,221	9%	11,618	9%
1991	5,837	10%	8,831	11%	14,668	11%
1992	5,840	10%	10,593	13%	16,433	12%
1993	6,483	11%	11,672	15%	18,155	13%
1994	5,731	10%	9,179	12%	14,910	11%
1Q 1995	292	1%	487	1%	779	1%
Total	57,346	100%	78,620	100%	135,966	100%

Table 4.3

Refunding Efficiency and Loss in Value from Sub-Optimal Refunding Strategies

The sample includes 2,620 municipal bonds, with original maturity less than 30 years, that were refunded between 1980-1993. This table reports sample characteristics, refunding efficiency, ratio of *ex-post* interest costs, loss in value, and months from optimal time. Refunding decisions are identified as optimal when the bonds are refunded at the optimal time as obtained by using the generalized Vasicek model; otherwise they are identified as sub-optimal. *N-Sub* is the frequency of sub-optimal refunding. Refunding efficiency is the ratio of the actual saving from sub-optimal exercise to potential saving from optimal exercise. Ratio of *ex-post* interest costs is the ratio of actual interest costs to the potential interest costs by refunding optimally. Loss is sum of call option value lost, and the loss from escrow investments. All dollar amounts have been converted to 1995 figures using CPI data. Months from optimal is the difference of the actual month of refunding and the month of optimal refunding. The *p*-values in each panel represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively.

Panel A: Sample Characteristics

Refunding Decision	Gross Proceeds, $ million: Mean	Gross Proceeds, $ million: Total	Frequency: N	Frequency: N-Sub
Optimally Exercised	$ 29.28	$ 19,878.47	679	0
Sub-Optimally Exercised	$ 29.95	$ 58,138.85	1941	1941

Panel B: Refunding Efficiency and Ratio of Ex-Post Interest Costs

	Refunding Efficiency: Mean	Median	*p* (mean)	*p* (med)	Ratio of Ex-Post Interest Costs: Mean	Median	*p* (mean)	*p* (med)
Optimally Exercised	100%	100%			1.00	1.00	0.001	0.001
Sub-Optimally Exercised	97.49%	98.56%	0.001	0.001	1.17	1.04	0.001	0.001

Panel C: Loss, $ million

	Mean	Median	*p* (mean)	*p* (med)	Total
Optimally Exercised	0	0			0
Sub-Optimally Exercised	$ 2.07	$ 0.32	0.001	0.001	$ 4,008.34

Panel D: Months from optimal: Pooled and Absolute

	Pooled Deviation: Mean	Median	*p* (mean)	*p* (med)	Absolute Deviation: Mean	Median	Proportion Calling Early
Optimally Exercised	0	0			0	0	0
Sub-Optimally Exercised	21.31	18.00	0.001	0.001	23.32	18.00	13.03%

Table 4.4

Refunding Opportunities and Rational Exercise

The sample includes 2,620 municipal bonds, with original maturity less than 30 years, that were refunded between 1980-1993. This table reports sample characteristics, refunding efficiency, ratio of *ex-post* interest costs, loss in value, and months from optimal time by type of refunding. Advance refundings are those in which the bond is called before the call protection date, otherwise they classified as current refundings. Refunding decisions are identified as optimal when the bonds are refunded at the optimal time as obtained by using the generalized Vasicek model; otherwise they are identified as sub-optimal. *N-Sub* is the frequency of sub-optimal refunding. Refunding efficiency is the ratio of the actual saving from sub-optimal exercise to potential saving from optimal exercise. Ratio of *ex-post* interest costs is the ratio of actual interest costs to the potential interest costs by refunding optimally. Loss is sum of call option value lost, and the loss from escrow investments. All dollar amounts have been converted to 1995 figures using CPI data. Months from optimal is the difference of the actual month of refunding and the month of optimal refunding. The *p*-values in each panel represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively.

Panel A: Sample Characteristics

Refunding Type	Gross Proceeds, $ million		Frequency	
	Mean	Total	N	N-Sub
Advanced Refunding	$ 31.90	$ 73,792.64	2313	1736
Current Refunding	$ 13.76	$ 4,224.68	307	205

Panel B: Refunding Efficiency and Ratio of Ex-Post Interest Costs

	Refunding Efficiency				Ratio of Ex-Post Interest Costs			
	Mean	Median	*p* (mean)	*p* (med)	Mean	Median	*p* (mean)	*p* (med)
Advanced Refunding	98.11%	99.10%	0.001	0.001	1.12	1.02	0.001	0.001
Current Refunding	98.34%	99.22%	0.001	0.001	1.14	1.01	0.001	0.001

Panel C: Loss, $ million

	Mean	Median	*p* (mean)	*p* (med)	Total
Advanced Refunding	$ 1.69	$ 0.18	0.001	0.001	$ 3,898.14
Current Refunding	$ 0.36	$ 0.03	0.002	0.001	$ 110.21

Panel D: Months from optimal: Pooled and Absolute

	Pooled Deviation				Absolute Deviation		Proportion
	Mean	Median	*p* (mean)	*p* (med)	Mean	Median	Calling Early
Advanced Refunding	15.92	15.00	0.001	0.001	17.35	15.00	9.51%
Current Refunding	14.09	12.00	0.001	0.001	16.11	12.00	12.05%

Table 4.5

Security Type and Refunding Decisions

The sample includes 2,620 municipal bonds, with original maturity less than 30 years, that were refunded between 1980-1993. This table reports sample characteristics, refunding efficiency, ratio of *ex-post* interest costs, loss in value, and months from optimal time by the type of security: either General Obligation Bond or Revenue Bond. Refunding decisions are identified as optimal when the bonds are refunded at the optimal time as obtained by using the generalized Vasicek model; otherwise they are identified as sub-optimal. *N-Sub* is the frequency of sub-optimal refunding. Refunding efficiency is the ratio of the actual saving from sub-optimal exercise to potential saving from optimal exercise. Ratio of *ex-post* interest costs is the ratio of actual interest costs to the potential interest costs by refunding optimally. Loss is sum of call option value lost, and the loss from escrow investments. All dollar amounts have been converted to 1995 figures using CPI data. Months from optimal is the difference of the actual month of refunding and the month of optimal refunding. The *p*-values in each panel represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively.

Panel A: Sample Characteristics

Security Type	Gross Proceeds, $ million: Mean	Gross Proceeds, $ million: Total	Frequency: N	Frequency: N-Sub
General Obligation Bonds	$ 20.34	$ 32,619.04	1604	1174
Revenue Bonds	$ 44.68	$ 45,398.28	1016	767

Panel B: Refunding Efficiency and Ratio of Ex-Post Interest Costs

	Refunding Efficiency				Ratio of Ex-Post Interest Costs			
	Mean	Median	*p* (mean)	*p* (med)	Mean	Median	*p* (mean)	*p* (med)
General Obligation Bonds	98.00%	98.23%	0.001	0.001	1.11	1.03	0.001	0.001
Revenue Bonds	98.14%	99.11%	0.001	0.001	1.15	1.02	0.001	0.001

Panel C: Loss, $ million

	Mean	Median	*p* (mean)	*p* (med)	Total
General Obligation Bonds	$ 1.22	$ 0.11	0.001	0.001	$ 1,959.94
Revenue Bonds	$ 2.02	$ 0.24	0.001	0.001	$ 2,048.41

Panel D: Months from optimal: Pooled and Absolute

	Pooled Deviation				Absolute Deviation		Proportion
	Mean	Median	*p* (mean)	*p* (med)	Mean	Median	Calling Early
General Obligation Bonds	16.53	15.00	0.001	0.001	17.77	15.00	9.41%
Revenue Bonds	14.40	12.00	0.001	0.001	16.32	15.00	10.43%

Table 4.6

Bond Rating and Refunding Decisions

The sample includes 2,620 municipal bonds, with original maturity less than 30 years, that were refunded between 1980-1993. This table reports sample characteristics, refunding efficiency, ratio of *ex-post* interest costs, loss in value, and months from optimal time by bond rating. Bond ratings are those of Moody's when available, otherwise those of S&P Corporation are used. Refunding decisions are identified as optimal when the bonds are refunded at the optimal time as obtained by using the generalized Vasicek model; otherwise they are identified as sub-optimal. *N-Sub* is the frequency of sub-optimal refunding. Refunding efficiency is the ratio of the actual saving from sub-optimal exercise to potential saving from optimal exercise. Ratio of *ex-post* interest costs is the ratio of actual interest costs to the potential interest costs by refunding optimally. Loss is sum of call option value lost, and the loss from escrow investments. All dollar amounts have been converted to 1995 figures using CPI data. Months from optimal is the difference of the actual month of refunding and the month of optimal refunding. The *p*-values in each panel represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively.

Panel A: Sample Characteristics

Rating Class	Gross Proceeds, $ million: Mean	Gross Proceeds, $ million: Total	Frequency: N	Frequency: N-Sub
AAA	$ 25.79	$ 26,844.09	1041	747
AA	$ 59.92	$ 15,040.42	251	193
A	$ 38.26	$ 29,075.76	760	574
BAA and Below	$ 22.16	$ 2,615.43	118	103
Not Rated	$ 9.87	$ 4,441.63	450	324

Panel B: Refunding Efficiency and Ratio of Ex-Post Interest Costs

	Refunding Efficiency: Mean	Median	*p* (mean)	*p* (med)	Ratio of Ex-Post Interest Costs: Mean	Median	*p* (mean)	*p* (med)
AAA	98.22%	99.23%	0.001	0.001	1.14	1.02	0.001	0.001
AA	98.16%	98.84%	0.001	0.001	1.09	1.03	0.001	0.001
A	98.17%	99.03%	0.001	0.001	1.11	1.02	0.001	0.001
BAA and Below	97.71%	98.63%	0.001	0.001	1.11	1.04	0.001	0.001
Not Rated	98.00%	99.19%	0.001	0.001	1.12	1.02	0.001	0.001

Panel C: Loss, $ million

	Mean	Median	*p* (mean)	*p* (med)	Total
AAA	$ 1.09	$ 0.17	0.001	0.001	$ 1,137.41
AA	$ 2.94	$ 0.37	0.001	0.001	$ 737.90
A	$ 2.06	$ 0.18	0.001	0.001	$ 1,563.30
BAA and Below	$ 3.04	$ 0.19	0.042	0.001	$ 358.60
Not Rated	$ 0.47	$ 0.05	0.001	0.001	$ 211.14

Panel D: Months from optimal: Pooled and Absolute

	Pooled Deviation: Mean	Median	*p* (mean)	*p* (med)	Absolute Deviation: Mean	Median	Proportion Calling Early
AAA	14.59	12.00	0.001	0.001	15.75	12.00	9.89%
AA	17.95	15.00	0.001	0.001	18.95	15.00	7.57%
A	16.87	15.00	0.001	0.001	18.32	15.00	7.89%
BAA and Below	22.79	18.00	0.001	0.001	23.26	18.00	3.39%
Not Rated	13.04	12.00	0.001	0.001	15.98	12.00	15.78%

Table 4.7

Issue Size and Refunding Decisions

The sample includes 2,620 municipal bonds, with original maturity less than 30 years, that were refunded between 1980-1993. This table reports sample characteristics, refunding efficiency, ratio of *ex-post* interest costs, loss in value, and months from optimal time by quintiles of gross proceeds. Refunding decisions are identified as optimal when the bonds are refunded at the optimal time as obtained by using the generalized Vasicek model; otherwise they are identified as sub-optimal. *N-Sub* is the frequency of sub-optimal refunding. Refunding efficiency is the ratio of the actual saving from sub-optimal exercise to potential saving from optimal exercise. Ratio of *ex-post* interest costs is the ratio of actual interest costs to the potential interest costs by refunding optimally. Loss is sum of call option value lost, and the loss from escrow investments. Quintiles run from lowest to highest. All dollar amounts have been converted to 1995 figures using CPI data. Months from optimal is the difference of the actual month of refunding and the month of optimal refunding. The *p*-values in each panel represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively.

Panel A: Sample Characteristics

Gross Proceeds	Gross Proceeds, $ million		Frequency	
	Mean	Total	N	N-Sub
Quintile 1	$ 2.00	$ 1,053.01	527	397
Quintile 2	$ 4.99	$ 2,624.42	526	381
Quintile 3	$ 8.88	$ 4,669.47	526	386
Quintile 4	$ 19.55	$ 10,281.18	526	394
Quintile 5	$ 115.32	$ 59,389.24	515	383

Panel B: Refunding Efficiency and Ratio of Ex-Post Interest Costs

	Refunding Efficiency				Ratio of Ex-Post Interest Costs			
	Mean	Median	*p* (mean)	*p* (med)	Mean	Median	*p* (mean)	*p* (med)
Quintile 1	98.31%	99.08%	0.001	0.001	1.14	1.04	0.001	0.001
Quintile 2	98.45%	99.28%	0.001	0.001	1.12	1.03	0.001	0.001
Quintile 3	98.12%	99.02%	0.001	0.001	1.12	1.02	0.001	0.001
Quintile 4	97.92%	99.08%	0.001	0.001	1.14	1.02	0.001	0.001
Quintile 5	97.89%	99.03%	0.001	0.001	1.09	1.02	0.001	0.001

Panel C: Loss, $ million

	Mean	Median	*p* (mean)	*p* (med)	Total
Quintile 1	$ 0.14	$ 0.04	0.001	0.001	$ 73.06
Quintile 2	$ 0.25	$ 0.08	0.001	0.001	$ 129.26
Quintile 3	$ 0.43	$ 0.14	0.001	0.001	$ 224.86
Quintile 4	$ 1.01	$ 0.30	0.001	0.001	$ 530.03
Quintile 5	$ 5.92	$ 1.43	0.001	0.001	$ 3,051.13

Panel D: Months from optimal: Pooled and Absolute

	Pooled Deviation				Absolute Deviation		Proportion
	Mean	Median	*p* (mean)	*p* (med)	Mean	Median	Calling Early
Quintile 1	16.49	15.00	0.001	0.001	18.28	15.00	9.68%
Quintile 2	14.64	12.00	0.001	0.001	15.89	12.00	7.60%
Quintile 3	15.65	12.00	0.001	0.001	17.15	15.00	9.89%
Quintile 4	15.71	12.00	0.001	0.001	17.41	13.50	11.03%
Quintile 5	16.07	12.00	0.001	0.001	17.33	12.00	10.87%

Table 4.8

Bond Maturity and Refunding Decisions

The sample includes 2,620 municipal bonds, with original maturity less than 30 years, that were refunded between 1980-1993. This table reports sample characteristics, refunding efficiency, ratio of *ex-post* interest costs, loss in value, and months from optimal time by quintiles of original bond maturity at issuance. Refunding decisions are identified as optimal when the bonds are refunded at the optimal time as obtained by using the generalized Vasicek model; otherwise they are identified as sub-optimal. *N-Sub* is the frequency of sub-optimal refunding. Refunding efficiency is the ratio of the actual saving from sub-optimal exercise to potential saving from optimal exercise. Ratio of *ex-post* interest costs is the ratio of actual interest costs to the potential interest costs by refunding optimally. Loss is sum of call option value lost, and the loss from escrow investments. Quintiles run from lowest to highest. All dollar amounts have been converted to 1995 figures using CPI data. Months from optimal is the difference of the actual month of refunding and the month of optimal refunding. The *p*-values in each panel represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively.

Panel A: Sample Characteristics

Original Bond Maturity	Gross Proceeds, $ million		Frequency		Original Bond Maturity	
	Mean	Total	N	N-Sub	Mean	Median
Quintile 1	$ 11.04	$ 4,779.69	433	305	10.11	10.50
Quintile 2	$ 15.79	$ 11,023.71	698	538	16.91	17.00
Quintile 3	$ 25.28	$ 15,015.57	594	446	19.99	20.00
Quintile 4	$ 28.57	$ 10,656.70	373	279	22.02	22.00
Quintile 5	$ 70.00	$ 36,541.65	522	373	27.70	28.00

Panel B: Refunding Efficiency and Ratio of Ex-Post Interest Costs

	Refunding Efficiency				Ratio of Ex-Post Interest Costs			
	Mean	Median	*p* (mean)	*p* (med)	Mean	Median	*p* (mean)	*p* (med)
Quintile 1	98.31%	99.22%	0.001	0.001	1.12	1.02	0.001	0.001
Quintile 2	98.26%	99.04%	0.001	0.001	1.14	1.03	0.001	0.001
Quintile 3	98.02%	99.13%	0.001	0.001	1.10	1.02	0.001	0.001
Quintile 4	98.03%	99.08%	0.001	0.001	1.14	1.02	0.001	0.001
Quintile 5	98.04%	99.14%	0.001	0.001	1.1	1.01	0.001	0.001

Panel C: Loss, $ million

	Mean	Median	*p* (mean)	*p* (med)	Total
Quintile 1	$ 0.46	$ 0.05	0.001	0.001	$ 200.81
Quintile 2	$ 0.74	$ 0.12	0.001	0.001	$ 517.25
Quintile 3	$ 1.31	$ 0.18	0.001	0.001	$ 776.80
Quintile 4	$ 1.55	$ 0.21	0.001	0.001	$ 576.90
Quintile 5	$ 3.71	$ 0.39	0.001	0.001	$ 1,936.58

Panel D: Months from optimal: Pooled and Absolute

	Pooled Deviation				Absolute Deviation		Proportion
	Mean	Median	*p* (mean)	*p* (med)	Mean	Median	Calling Early
Quintile 1	13.74	12.00	0.001	0.001	16.14	12.00	16.86%
Quintile 2	18.38	15.00	0.001	0.001	19.53	15.00	6.45%
Quintile 3	16.41	15.00	0.001	0.001	17.54	15.00	6.57%
Quintile 4	16.25	15.00	0.001	0.001	17.3	15.00	6.43%
Quintile 5	12.25	12.00	0.001	0.001	14.28	12.00	14.56%

Table 4.9

Outstanding Long Term Debt and Refunding Decisions

The sample includes 2,620 municipal bonds, with original maturity less than 30 years, that were refunded between 1980-1993. This table reports sample characteristics, refunding efficiency, ratio of *ex-post* interest costs, loss in value, and months from optimal time by quintiles of outstanding long term debt at issuance. Refunding decisions are identified as optimal when the bonds are refunded at the optimal time as obtained by using the generalized Vasicek model; otherwise they are identified as sub-optimal. *N-Sub* is the frequency of sub-optimal refunding. Refunding efficiency is the ratio of the actual saving from sub-optimal exercise to potential saving from optimal exercise. Ratio of *ex-post* interest costs is the ratio of actual interest costs to the potential interest costs by refunding optimally. Loss is sum of call option value lost, and the loss from escrow investments. Quintiles run from lowest to highest. All dollar amounts have been converted to 1995 figures using CPI data. Months from optimal is the difference of the actual month of refunding and the month of optimal refunding. The *p*-values in each panel represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively.

Panel A: Sample Characteristics

Outstanding	Gross Proceeds, $ million		Frequency		Outstanding Debt, $ mi	
Long Term Debt	Mean	Total	N	N-Sub	Mean	Median
Quintile 1	$ 4.72	$ 2,483.14	526	402	$ 3.88	$ 3.98
Quintile 2	$ 7.30	$ 3,838.60	526	369	$ 13.79	$ 13.35
Quintile 3	$ 12.01	$ 6,291.04	524	382	$ 35.44	$ 33.94
Quintile 4	$ 24.45	$ 12,763.18	522	381	$ 116.15	$ 101.00
Quintile 5	$ 100.85	$ 52,641.37	522	407	$ 1,929.36	$ 715.38

Panel B: Refunding Efficiency and Ratio of Ex-Post Interest Costs

	Refunding Efficiency				Ratio of Ex-Post Interest Costs			
	Mean	Median	*p* (mean)	*p* (med)	Mean	Median	*p* (mean)	*p* (med)
Quintile 1	98.06%	99.07%	0.001	0.001	1.14	1.03	0.001	0.001
Quintile 2	98.38%	99.30%	0.001	0.001	1.14	1.02	0.001	0.001
Quintile 3	98.15%	99.11%	0.001	0.001	1.12	1.02	0.001	0.001
Quintile 4	98.27%	99.13%	0.001	0.001	1.11	1.02	0.001	0.001
Quintile 5	97.83%	98.91%	0.001	0.001	1.10	1.02	0.001	0.001

Panel C: Loss, $ million

	Mean	Median	*p* (mean)	*p* (med)	Total
Quintile 1	$ 0.26	$ 0.07	0.001	0.001	$ 137.00
Quintile 2	$ 0.32	$ 0.08	0.001	0.001	$ 166.53
Quintile 3	$ 0.49	$ 0.13	0.001	0.001	$ 258.34
Quintile 4	$ 0.94	$ 0.22	0.001	0.001	$ 488.93
Quintile 5	$ 5.67	$ 0.96	0.001	0.001	$ 2,957.54

Panel D: Months from optimal: Pooled and Absolute

	Pooled Deviation				Absolute Deviation		Proportion
	Mean	Median	*p* (mean)	*p* (med)	Mean	Median	Calling Early
Quintile 1	16.27	15.00	0.001	0.001	17.94	15.00	8.75%
Quintile 2	14.59	12.00	0.001	0.001	15.92	12.00	9.70%
Quintile 3	15.10	12.00	0.001	0.001	16.69	12.00	10.11%
Quintile 4	15.91	12.00	0.001	0.001	17.19	15.00	9.39%
Quintile 5	16.68	15.00	0.001	0.001	18.32	15.00	11.11%

Table 4.10

Bond Rating Changes and Refunding Decisions

The sample includes 2,620 municipal bonds, with original maturity less than 30 years, that were refunded between 1980-1993. This table reports sample characteristics, refunding efficiency, ratio of *ex-post* interest costs, loss in value, and months from optimal time by rating changes, either upgrades or downgrades. Refunding decisions are identified as optimal when the bonds are refunded at the optimal time as obtained by using the generalized Vasicek model; otherwise they are identified as sub-optimal. *N-Sub* is the frequency of sub-optimal refunding. Refunding efficiency is the ratio of the actual saving from sub-optimal exercise to potential saving from optimal exercise. Ratio of *ex-post* interest costs is the ratio of actual interest costs to the potential interest costs by refunding optimally. Loss is sum of call option value lost, and the loss from escrow investments. Quintiles run from lowest to highest. All dollar amounts have been converted to 1995 figures using CPI data. Months from optimal is the difference of the actual month of refunding and the month of optimal refunding. The *p*-values in each panel represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively.

Panel A: Sample Characteristics

Upgrades/ Downgrades	Gross Proceeds, $ million: Mean	Gross Proceeds, $ million: Total	Frequency: N	Frequency: N-Sub
Upgraded 4 classes	$ 30.02	$ 2,761.81	92	66
Upgraded 3 classes	$ 19.18	$ 1,323.66	69	62
Upgraded 2 classes	$ 31.77	$ 11,660.13	367	265
Upgraded 1 class	$ 49.68	$ 5,316.13	107	84
No change in rating	$ 27.20	$ 47,769.53	1756	1276
Dowgraded 1 class	$ 68.49	$ 4,246.36	62	51
Dowgraded 2 classes	$ 25.70	$ 2,492.72	97	82
Dowgraded 3 classes	$ 60.58	$ 1,999.11	33	26
Dowgraded 4 classes	$ 12.10	$ 447.88	37	29

Panel B: Refunding Efficiency and Ratio of Ex-Post Interest Costs

	Refunding Efficiency: Mean	Median	*p* (mean)	*p* (med)	Ratio of Ex-Post Interest Costs: Mean	Median	*p* (mean)	*p* (med)
Upgraded 4 classes	97.66%	99.08%	0.001	0.001	1.12	1.00	0.015	0.002
Upgraded 3 classes	96.53%	98.66%	0.001	0.001	1.15	1.05	0.002	0.001
Upgraded 2 classes	98.23%	99.17%	0.001	0.001	1.10	1.02	0.001	0.001
Upgraded 1 class	97.48%	98.78%	0.001	0.001	1.08	1.03	0.005	0.001
No change in rating	98.24%	99.18%	0.001	0.001	1.12	1.02	0.001	0.001
Dowgraded 1 class	98.28%	98.61%	0.001	0.001	1.16	1.03	0.003	0.001
Dowgraded 2 classes	98.38%	98.88%	0.001	0.001	1.12	1.04	0.001	0.001
Dowgraded 3 classes	97.75%	98.66%	0.001	0.001	1.15	1.04	0.006	0.001
Dowgraded 4 classes	98.10%	98.99%	0.001	0.001	1.22	1.04	0.003	0.001

Panel C: Loss, $ million

	Mean	Median	*p* (mean)	*p* (med)	Total
Upgraded 4 classes	$ 1.52	$ 0.12	0.023	0.001	$ 139.51
Upgraded 3 classes	$ 3.54	$ 0.35	0.13	0.001	$ 244.46
Upgraded 2 classes	$ 1.76	$ 0.18	0.001	0.001	$ 645.49
Upgraded 1 class	$ 2.97	$ 0.30	0.001	0.001	$ 317.73
No change in rating	$ 1.13	$ 0.14	0.001	0.001	$ 1,990.09
Dowgraded 1 class	$ 6.57	$ 0.14	0.026	0.001	$ 407.31
Dowgraded 2 classes	$ 1.18	$ 0.16	0.003	0.001	$ 114.43
Dowgraded 3 classes	$ 4.14	$ 0.17	0.056	0.001	$ 136.75
Dowgraded 4 classes	$ 0.34	$ 0.09	0.044	0.001	$ 12.57

Panel D: Months from optimal: Pooled and Absolute

	Pooled Deviation: Mean	Median	*p* (mean)	*p* (med)	Absolute Deviation: Mean	Median	Proportion Calling Early
Upgraded 4 classes	9.58	9.00	0.001	0.001	13.70	12.00	25.00%
Upgraded 3 classes	22.50	18.00	0.001	0.001	23.32	18.00	8.70%
Upgraded 2 classes	16.02	12.00	0.001	0.001	17.49	12.00	8.72%
Upgraded 1 class	19.80	15.00	0.001	0.001	21.46	15.00	7.48%
No change in rating	15.05	12.00	0.001	0.001	16.42	12.00	9.68%
Dowgraded 1 class	19.11	16.50	0.001	0.001	21.44	18.00	8.06%
Dowgraded 2 classes	17.97	15.00	0.001	0.001	19.53	15.00	7.22%
Dowgraded 3 classes	17.81	24.00	0.001	0.001	19.55	24.00	12.12%
Dowgraded 4 classes	19.08	21.00	0.001	0.001	19.75	21.00	5.41%

Table 4.11

Difference in Coupon and Refunding Decisions

The sample includes 2,620 municipal bonds, with original maturity less than 30 years, that were refunded between 1980-1993. This table reports sample characteristics, refunding efficiency, ratio of *ex-post* interest costs, loss in value, and months from optimal time by quintiles of the difference in coupon of the refunded bond and the refunding bond. Refunding decisions are identified as optimal when the bonds are refunded at the optimal time as obtained by using the generalized Vasicek model; otherwise they are identified as sub-optimal. *N-Sub* is the frequency of sub-optimal refunding. Refunding efficiency is the ratio of the actual saving from sub-optimal exercise to potential saving from optimal exercise. Ratio of *ex-post* interest costs is the ratio of actual interest costs to the potential interest costs by refunding optimally. Loss is sum of call option value lost, and the loss from escrow investments. Quintiles run from lowest to highest. All dollar amounts have been converted to 1995 figures using CPI data. Months from optimal is the difference of the actual month of refunding and the month of optimal refunding. The *p*-values in each panel represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively.

Panel A: Sample Characteristics

Difference	Gross Proceeds, $ million		Frequency		Difference in Coupon, %	
in Coupon	Mean	Total	N	N-Sub	Mean	Median
Quintile 1	$ 22.62	$ 12,123.80	536	473	-3.44	-3.25
Quintile 2	$ 26.05	$ 13,574.10	521	420	-2.12	-2.10
Quintile 3	$ 35.73	$ 18,972.45	531	400	-1.66	-1.65
Quintile 4	$ 32.26	$ 16,485.64	511	315	-1.27	-1.30
Quintile 5	$ 32.36	$ 16,861.32	521	333	-0.24	-0.60

Panel B: Refunding Efficiency and Ratio of Ex-Post Interest Costs

	Refunding Efficiency				Ratio of Ex-Post Interest Costs			
	Mean	Median	*p* (mean)	*p* (med)	Mean	Median	*p* (mean)	*p* (med)
Quintile 1	96.75%	97.54%	0.001	0.001	1.14	1.07	0.001	0.001
Quintile 2	98.53%	98.99%	0.001	0.001	1.17	1.04	0.001	0.001
Quintile 3	98.96%	99.37%	0.001	0.001	1.17	1.03	0.001	0.001
Quintile 4	99.08%	99.57%	0.001	0.001	1.10	1.00	0.001	0.001
Quintile 5	97.42%	99.41%	0.001	0.001	1.04	1.00	0.013	0.008

Panel C: Loss, $ million

	Mean	Median	*p* (mean)	*p* (med)	Total
Quintile 1	$ 1.84	$ 0.29	0.001	0.001	$ 984.95
Quintile 2	$ 1.46	$ 0.14	0.001	0.001	$ 761.97
Quintile 3	$ 1.94	$ 0.14	0.001	0.001	$ 1,027.63
Quintile 4	$ 0.88	$ 0.07	0.001	0.001	$ 447.81
Quintile 5	$ 1.51	$ 0.07	0.001	0.001	$ 785.98

Panel D: Months from optimal: Pooled and Absolute

	Pooled Deviation				Absolute Deviation		Proportion
	Mean	Median	*p* (mean)	*p* (med)	Mean	Median	Calling Early
Quintile 1	28.29	24.00	0.001	0.001	28.48	24.00	1.68%
Quintile 2	18.73	18.00	0.001	0.001	19.02	18.00	3.07%
Quintile 3	15.51	15.00	0.001	0.001	15.78	15.00	3.95%
Quintile 4	9.31	9.00	0.001	0.001	10.68	12.00	10.96%
Quintile 5	4.66	0.00	0.001	0.001	10.58	9.00	29.75%

Table 4.12

Time Series Analysis of Refunding Decisions

The sample includes 2,620 municipal bonds, with original maturity less than 30 years, that were refunded between 1980-1993. This table reports sample characteristics, refunding efficiency, ratio of *ex-post* interest costs, loss in value, and months from optimal time by the year of issuance of the refunded bond. Refunding decisions are identified as optimal when the bonds are refunded at the optimal time as obtained by using the generalized Vasicek model; otherwise they are identified as sub-optimal. *N-Sub* is the frequency of sub-optimal refunding. Refunding efficiency is the ratio of the actual saving from sub-optimal exercise to potential saving from optimal exercise. Ratio of *ex-post* interest costs is the ratio of actual interest costs to the potential interest costs by refunding optimally. Loss is sum of call option value lost, and the loss from escrow investments. All dollar amounts have been converted to 1995 figures using CPI data. Months from optimal is the difference of the actual month of refunding and the month of optimal refunding. The *p*-values in each panel represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively. A "-" entry indicates that the number is insignificant at the second decimal level.

Panel A: Sample Characteristics

Year of	Gross Proceeds, $ million		Frequency	
Issuance	Mean	Total	N	N-Sub
1986	$ 37.07	$ 23,725.43	640	526
1987	$ 26.18	$ 11,909.70	455	284
1988	$ 26.35	$ 14,148.77	537	451
1989	$ 22.82	$ 8,924.54	391	358
1990	$ 28.95	$ 10,622.88	367	222
1991	$ 31.64	$ 6,295.72	199	69

Panel B: Refunding Efficiency and Ratio of Ex-Post Interest Costs

	Refunding Efficiency				Ratio of Ex-Post Interest Costs			
	Mean	Median	*p* (mean)	*p* (med)	Mean	Median	*p* (mean)	*p* (med)
1986	97.15%	98.37%	0.001	0.001	1.20	1.06	0.001	0.001
1987	98.42%	99.20%	0.001	0.001	1.04	1.00	0.001	0.001
1988	98.34%	98.73%	0.001	0.001	1.10	1.04	0.001	0.001
1989	98.63%	99.26%	0.001	0.001	1.24	1.05	0.001	0.001
1990	99.07%	99.71%	0.001	0.001	1.09	1.00	0.001	0.001
1991	98.26%	100.00%	0.001	0.001	0.95	1.00	0.001	0.001

Panel C: Loss, $ million

	Mean	Median	*p* (mean)	*p* (med)	Total
1986	$ 2.99	$ 0.40	0.001	0.001	$ 1,913.04
1987	$ 1.12	$ 0.08	0.001	0.001	$ 508.81
1988	$ 1.05	$ 0.20	0.001	0.001	$ 565.08
1989	$ 0.79	$ 0.18	0.001	0.001	$ 309.12
1990	$ 0.87	$ 0.04	0.047	0.001	$ 320.22
1991	$ 0.81	$ -	0.008	0.001	$ 161.47

Panel D: Months from optimal: Pooled and Absolute

	Pooled Deviation				Absolute Deviation		Proportion
	Mean	Median	*p* (mean)	*p* (med)	Mean	Median	Calling Early
1986	28.18	27.00	0.001	0.001	29.25	27.00	4.8%
1987	10.27	9.00	0.001	0.001	13.41	12.00	10.3%
1988	16.43	18.00	0.001	0.001	17.41	18.00	4.8%
1989	15.71	12.00	0.001	0.001	16.20	12.00	3.6%
1990	6.95	12.00	0.001	0.001	8.29	12.00	10.6%
1991	-1.55	0.00	0.001	0.001	1.55	0.00	34.7%

Table 4.13

Use of Proceeds and Refunding Decisions

The sample includes 2,620 municipal bonds, with original maturity less than 30 years, that were refunded between 1980-1993. This table reports sample characteristics, refunding efficiency, ratio of *ex-post* interest costs, loss in value, and months from optimal time by the use of proceeds of the refunded bond. Refunding decisions are identified as optimal when the bonds are refunded at the optimal time as obtained by using the generalized Vasicek model; otherwise they are identified as sub-optimal. *N-Sub* is the frequency of sub-optimal refunding. Refunding efficiency is the ratio of the actual saving from sub-optimal exercise to potential saving from optimal exercise. Ratio of *ex-post* interest costs is the ratio of actual interest costs to the potential interest costs by refunding optimally. Loss is sum of call option value lost, and the loss from escrow investments. All dollar amounts have been converted to 1995 figures using CPI data. Months from optimal is the difference of the actual month of refunding and the month of optimal refunding. The *p*-values in each panel represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively.

Panel A: Sample Characteristics

Use of Proceeds	Gross Proceeds, $ million		Frequency	
	Mean	Total	N	N-Sub
Education	$ 18.55	$ 20,291.15	1094	777
General Purpose	$ 35.09	$ 27,056.55	771	596
Pollution Control	$ 92.08	$ 552.47	6	5
Transportation	$ 96.43	$ 8,582.32	89	68
Utility	$ 68.11	$ 7,014.90	103	75
Waste Recovery	$ 34.60	$ 1,314.74	38	26
Water/Sewer/Gas	$ 25.44	$ 13,205.19	519	394

Panel B: Refunding Efficiency and Ratio of Ex-Post Interest Costs

	Refunding Efficiency				Ratio of Ex-Post Interest Costs			
	Mean	Median	*p* (mean)	*p* (med)	Mean	Median	*p* (mean)	*p* (med)
Education	98.27%	99.21%	0.000	0.000	1.11	1.02	0.000	0.000
General Purpose	98.09%	99.06%	0.000	0.000	1.13	1.03	0.000	0.000
Pollution Control	95.81%	98.63%	0.172	0.063	0.91	0.95	0.687	0.688
Transportation	97.11%	98.84%	0.000	0.000	1.17	1.02	0.000	0.000
Utility	98.09%	99.19%	0.000	0.000	1.10	1.00	0.014	0.002
Waste Recovery	97.22%	99.18%	0.020	0.000	1.07	1.00	0.273	0.102
Water/Sewer/Gas	98.21%	99.02%	0.000	0.000	1.12	1.02	0.000	0.000

Panel C: Loss, $ million

	Mean	Median	*p* (mean)	*p* (med)	Total
Education	$ 0.84	$ 0.12	0.000	0.000	$ 913.88
General Purpose	$ 2.41	$ 0.14	0.000	0.000	$ 1,854.42
Pollution Control	$ 3.33	$ 0.27	0.315	0.063	$ 20.00
Transportation	$ 4.80	$ 0.46	0.000	0.000	$ 427.40
Utility	$ 1.53	$ 0.30	0.000	0.000	$ 157.12
Waste Recovery	$ 0.66	$ 0.19	0.002	0.000	$ 25.24
Water/Sewer/Gas	$ 1.18	$ 0.18	0.000	0.000	$ 610.28

Panel D: Months from optimal: Pooled and Absolute

	Pooled Deviation				Absolute Deviation		Proportion
	Mean	Median	*p* (mean)	*p* (med)	Mean	Median	Calling Early
Education	14.38	12.00	0.000	0.000	15.71	12.00	9.96%
General Purpose	17.83	15.00	0.000	0.000	19.12	15.00	8.56%
Pollution Control	9.00	9.00	0.748	0.750	17.00	18.00	33.33%
Transportation	15.94	15.00	0.000	0.000	18.47	15.00	14.61%
Utility	10.95	12.00	0.000	0.000	16.12	12.00	21.36%
Waste Recovery	9.88	10.50	0.000	0.000	13.59	12.00	23.68%
Water/Sewer/Gas	16.74	15.00	0.000	0.000	17.74	15.00	6.94%

Table 4.14

Losses From Escrow Investments and Refunding Decisions

The sample includes 2,620 municipal bonds, with original maturity less than 30 years, that were refunded between 1980-1993. This table reports sample characteristics, refunding efficiency, ratio of *ex-post* interest costs, loss in value, and months from optimal time by quartiles of losses from escrow investments. Refunding decisions are identified as optimal when the bonds are refunded at the optimal time as obtained by using the generalized Vasicek model; otherwise they are identified as sub-optimal. *N-Sub* is the frequency of sub-optimal refunding. Refunding efficiency is the ratio of the actual saving from sub-optimal exercise to potential saving from optimal exercise. Ratio of *ex-post* interest costs is the ratio of actual interest costs to the potential interest costs by refunding optimally. Loss is sum of call option value lost, and the loss from escrow investments. All dollar amounts have been converted to 1995 figures using CPI data. Months from optimal is the difference of the actual month of refunding and the month of optimal refunding. The *p*-values in each panel represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively.

Panel A: Sample Characteristics

Losses From Escrow Investments	Gross Proceeds, $ million: Mean	Gross Proceeds, $ million: Total	Frequency: N	Frequency: N-Sub	Losses from Investments: Mean	Losses from Investments: Median
Quartile 1	$ 28.16	$ 38,241.03	1358	944	$ -	$ -
Quartile 2	$ 9.55	$ 2,034.20	213	141	$ 0.04	$ 0.04
Quartile 3	$ 10.78	$ 5,648.25	524	388	$ 0.24	$ 0.22
Quartile 4	$ 61.13	$ 32,093.84	525	468	$ 4.55	$ 1.57

Panel B: Refunding Efficiency and Ratio of Ex-Post Interest Costs

	Refunding Efficiency: Mean	Median	*p* (mean)	*p* (med)	Ratio of Ex-Post Interest Costs: Mean	Median	*p* (mean)	*p* (med)
Quartile 1	98.09%	99.18%	0.001	0.001	1.09	1.02	0.001	0.001
Quartile 2	98.38%	99.27%	0.001	0.001	1.10	1.02	0.001	0.001
Quartile 3	98.62%	99.31%	0.001	0.001	1.16	1.03	0.001	0.001
Quartile 4	97.68%	98.59%	0.001	0.001	1.19	1.04	0.001	0.001

Panel C: Loss, $ million

	Mean	Median	*p* (mean)	*p* (med)	Total
Quartile 1	$ 0.65	$ 0.05	0.001	0.001	$ 876.09
Quartile 2	$ 0.20	$ 0.06	0.007	0.001	$ 42.98
Quartile 3	$ 0.42	$ 0.24	0.001	0.001	$ 220.58
Quartile 4	$ 5.46	$ 1.88	0.001	0.001	$ 2,868.69

Panel D: Months from optimal: Pooled and Absolute

	Pooled Deviation: Mean	Median	*p* (mean)	*p* (med)	Absolute Deviation: Mean	Median	Proportion Calling Early
Quartile 1	12.38	12.00	0.001	0.001	14.98	12.00	14.51%
Quartile 2	12.74	12.00	0.001	0.001	14.16	12.00	9.86%
Quartile 3	15.94	15.00	0.001	0.001	16.15	15.00	4.01%
Quartile 4	25.01	21.00	0.001	0.001	25.08	21.00	3.43%

Table 4.15

Issuing States and Refunding Decisions

The sample includes 2,620 municipal bonds, with original maturity less than 30 years, that were refunded between 1980-1993. This table reports sample characteristics, refunding efficiency, ratio of *ex-post* interest costs, loss in value, and months from optimal time by the state making the refunding decision. Refunding decisions are identified as optimal when the bonds are refunded at the optimal time as obtained by using the generalized Vasicek model; otherwise they are identified as sub-optimal. *N-Sub* is the frequency of sub-optimal refunding. Refunding efficiency is the ratio of the actual saving from sub-optimal exercise to potential saving from optimal exercise. Ratio of *ex-post* interest costs is the ratio of actual interest costs to the potential interest costs by refunding optimally. Loss is sum of call option value lost, and the loss from escrow investments. All dollar amounts have been converted to 1995 figures using CPI data. Months from optimal is the difference of the actual month of refunding and the month of optimal refunding. The *p*-values in each panel represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively.

Panel A: Sample Characteristics

Issuing	Gross Proceeds, $ million		Frequency	
State	Mean	Total	N	N-Sub
AK	$ 49.60	$ 446.42	9	8
AL	$ 41.13	$ 1,233.96	30	23
AR	$ 3.97	$ 241.89	61	43
AZ	$ 39.08	$ 2,657.34	68	56
CA	$ 39.50	$ 5,450.91	138	96
CO	$ 21.34	$ 1,088.19	51	40
CT	$ 124.92	$ 1,249.22	10	8
DE	$ 50.26	$ 402.11	8	7
FL	$ 51.23	$ 8,402.29	164	129
GA	$ 35.22	$ 1,268.02	36	29
HI	$ 49.84	$ 299.06	6	4
IA	$ 5.48	$ 147.93	27	24
ID	$ 8.38	$ 83.81	10	8
IL	$ 42.90	$ 4,247.22	99	75
IN	$ 18.47	$ 1,108.28	60	39
KS	$ 13.52	$ 811.39	60	43
KY	$ 48.88	$ 879.92	18	13
LA	$ 84.29	$ 842.95	10	7
MA	$ 121.25	$ 1,576.31	13	11
MD	$ 68.27	$ 1,228.89	18	15
ME	$ 17.15	$ 17.15	1	1
MI	$ 17.91	$ 1,827.08	102	78
MN	$ 8.74	$ 1,355.00	155	121
MO	$ 28.60	$ 1,086.63	38	31
MS	$ 16.33	$ 212.33	13	12
MT	$ 53.45	$ 213.79	4	3
NC	$ 39.18	$ 1,136.31	29	24
ND	$ 5.75	$ 57.48	10	8
NE	$ 9.53	$ 495.54	52	36
NH	$ 54.69	$ 273.44	5	5
NJ	$ 33.88	$ 2,405.21	71	58
NM	$ 20.84	$ 145.89	7	5
NV	$ 81.35	$ 650.79	8	8
NY	$ 175.69	$ 7,905.88	45	34
OH	$ 36.37	$ 2,109.18	58	48
OK	$ 238.50	$ 1,669.51	7	5
OR	$ 13.52	$ 486.56	36	28
PA	$ 13.12	$ 5,577.65	425	236
PR	$ 346.86	$ 1,734.28	5	5
RI	$ 111.13	$ 555.63	5	3
SC	$ 24.40	$ 658.74	27	20
SD	$ 8.99	$ 179.83	20	14
TN	$ 11.53	$ 991.26	86	71
TX	$ 21.74	$ 4,761.29	219	180
UT	$ 15.06	$ 391.51	26	20
VA	$ 61.32	$ 2,023.48	33	24
VT	$ 29.26	$ 117.04	4	3
WA	$ 28.74	$ 3,362.80	117	95
WI	$ 11.08	$ 1,152.43	104	79
WV	$ 63.24	$ 316.22	5	4
WY	$ 18.89	$ 94.45	5	2

Table 4.15 (Continued)

Issuing States and Refunding Decisions

The sample includes 2,620 municipal bonds, with original maturity less than 30 years, that were refunded between 1980-1993. This table reports sample characteristics, refunding efficiency, ratio of *ex-post* interest costs, loss in value, and months from optimal time by the state making the refunding decision. Refunding decisions are identified as optimal when the bonds are refunded at the optimal time as obtained by using the generalized Vasicek model; otherwise they are identified as sub-optimal. *N-Sub* is the frequency of sub-optimal refunding. Refunding efficiency is the ratio of the actual saving from sub-optimal exercise to potential saving from optimal exercise. Ratio of *ex-post* interest costs is the ratio of actual interest costs to the potential interest costs by refunding optimally. Loss is sum of call option value lost, and the loss from escrow investments. All dollar amounts have been converted to 1995 figures using CPI data. Months from optimal is the difference of the actual month of refunding and the month of optimal refunding. The *p*-values in each panel represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively.

Panel B: Refunding Efficiency and Ratio of Ex-Post Interest Costs

	Refunding Efficiency				Ratio of Ex-Post Interest Costs			
	Mean	Median	*p* (mean)	*p* (med)	Mean	Median	*p* (mean)	*p* (med)
AK	96.75%	97.99%	0.016	0.008	1.10	1.09	0.036	0.063
AL	95.85%	98.84%	0.004	0.000	1.05	1.00	0.387	0.184
AR	98.56%	99.38%	0.000	0.000	1.19	1.02	0.000	0.000
AZ	97.34%	97.60%	0.000	0.000	1.12	1.03	0.000	0.000
CA	98.58%	99.18%	0.000	0.000	1.05	1.01	0.022	0.000
CO	98.83%	99.33%	0.000	0.000	1.37	1.05	0.000	0.000
CT	98.51%	98.22%	0.003	0.008	1.05	1.01	0.052	0.031
DE	98.38%	98.36%	0.007	0.016	1.22	1.05	0.257	0.031
FL	98.12%	99.10%	0.000	0.000	1.15	1.02	0.000	0.000
GA	98.21%	98.44%	0.000	0.000	1.33	1.05	0.001	0.000
HI	98.65%	99.71%	0.144	0.125	1.01	1.01	0.090	0.250
IA	98.35%	98.49%	0.000	0.000	1.11	1.05	0.001	0.000
ID	97.29%	97.29%	0.005	0.008	1.13	1.02	0.078	0.016
IL	98.09%	98.76%	0.000	0.000	1.07	1.02	0.005	0.000
IN	98.65%	99.42%	0.000	0.000	1.06	1.01	0.001	0.000
KS	97.50%	98.59%	0.000	0.000	1.12	1.02	0.031	0.000
KY	97.04%	98.16%	0.008	0.000	1.07	1.00	0.593	0.641
LA	98.43%	99.19%	0.052	0.016	1.18	1.11	0.023	0.016
MA	97.64%	98.45%	0.006	0.001	1.01	1.00	0.679	0.461
MD	95.06%	98.87%	0.069	0.000	1.11	1.02	0.025	0.003
ME	99.37%	99.37%	.	1.000	1.02	1.02	.	1.000
MI	97.76%	98.57%	0.000	0.000	1.07	1.02	0.002	0.000
MN	98.86%	99.00%	0.000	0.000	1.06	1.04	0.000	0.000
MO	98.44%	98.96%	0.000	0.000	1.21	1.03	0.004	0.000
MS	95.90%	95.78%	0.000	0.000	1.10	1.09	0.000	0.001
MT	99.03%	99.44%	0.234	0.250	0.98	1.01	0.728	0.875
NC	98.77%	98.99%	0.000	0.000	1.03	1.03	0.324	0.000
ND	97.79%	98.97%	0.048	0.008	1.11	1.03	0.114	0.016
NE	99.13%	99.43%	0.000	0.000	1.13	1.01	0.038	0.000
NH	98.02%	98.08%	0.001	0.063	1.08	1.12	0.080	0.188
NJ	98.03%	99.12%	0.000	0.000	1.13	1.04	0.005	0.000
NM	95.12%	99.38%	0.284	0.063	1.14	1.02	0.321	0.313
NV	95.37%	97.57%	0.100	0.008	1.04	1.05	0.130	0.219
NY	97.18%	98.82%	0.005	0.000	1.27	1.02	0.013	0.000
OH	97.75%	98.95%	0.000	0.000	1.14	1.04	0.000	0.000
OK	96.65%	97.98%	0.067	0.063	1.15	1.03	0.571	0.844
OR	98.69%	99.33%	0.002	0.000	1.09	1.04	0.004	0.000
PA	99.01%	99.85%	0.000	0.000	1.13	1.00	0.000	0.000
PR	96.83%	97.99%	0.088	0.063	1.04	1.02	0.140	0.250
RI	97.89%	99.17%	0.280	0.250	1.41	1.00	0.178	0.500
SC	98.93%	98.96%	0.000	0.000	1.14	1.03	0.001	0.000
SD	98.67%	99.19%	0.016	0.000	1.12	1.03	0.159	0.020
TN	98.23%	98.95%	0.000	0.000	1.08	1.04	0.000	0.000
TX	96.46%	97.41%	0.000	0.000	1.13	1.05	0.000	0.000
UT	97.24%	99.03%	0.002	0.000	1.08	1.03	0.014	0.000
VA	98.47%	98.79%	0.000	0.000	1.12	1.02	0.005	0.000
VT	99.31%	99.47%	0.151	0.250	1.08	1.01	0.381	0.500
WA	98.11%	98.76%	0.000	0.000	1.17	1.04	0.000	0.000
WI	98.61%	99.16%	0.000	0.000	1.06	1.03	0.045	0.000
WV	98.10%	99.17%	0.204	0.125	1.29	1.10	0.213	0.250
WY	99.46%	100.00%	0.192	0.500	1.02	1.00	0.374	1.000

Table 4.15 (Continued)

Issuing States and Refunding Decisions

The sample includes 2,620 municipal bonds, with original maturity less than 30 years, that were refunded between 1980-1993. This table reports sample characteristics, refunding efficiency, ratio of *ex-post* interest costs, loss in value, and months from optimal time by the state making the refunding decision. Refunding decisions are identified as optimal when the bonds are refunded at the optimal time as obtained by using the generalized Vasicek model; otherwise they are identified as sub-optimal. *N-Sub* is the frequency of sub-optimal refunding. Refunding efficiency is the ratio of the actual saving from sub-optimal exercise to potential saving from optimal exercise. Ratio of *ex-post* interest costs is the ratio of actual interest costs to the potential interest costs by refunding optimally. Loss is sum of call option value lost, and the loss from escrow investments. All dollar amounts have been converted to 1995 figures using CPI data. Months from optimal is the difference of the actual month of refunding and the month of optimal refunding. The *p*-values in each panel represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively. A "-" entry indicates that the number is insignificant at the second decimal level.

Panel C: Loss, $ million

	Mean	Median	*p* (mean)	*p* (med)	Total
AK	$ 3.90	$ 3.17	0.004	0.008	$ 35.09
AL	$ 1.60	$ 0.31	0.042	0.000	$ 48.15
AR	$ 0.10	$ 0.03	0.000	0.000	$ 6.39
AZ	$ 2.23	$ 0.56	0.000	0.000	$ 151.97
CA	$ 1.52	$ 0.31	0.002	0.000	$ 209.28
CO	$ 0.79	$ 0.15	0.001	0.000	$ 40.40
CT	$ 4.27	$ 0.71	0.129	0.008	$ 42.73
DE	$ 4.43	$ 0.50	0.097	0.016	$ 35.43
FL	$ 1.89	$ 0.49	0.000	0.000	$ 310.56
GA	$ 2.43	$ 0.82	0.006	0.000	$ 87.55
HI	$ 3.70	$ 0.23	0.251	0.125	$ 22.20
IA	$ 0.20	$ 0.04	0.084	0.000	$ 5.38
ID	$ 0.78	$ 0.35	0.021	0.008	$ 7.79
IL	$ 3.19	$ 0.11	0.009	0.000	$ 315.83
IN	$ 0.97	$ 0.10	0.033	0.000	$ 58.06
KS	$ 0.76	$ 0.08	0.097	0.000	$ 45.74
KY	$ 1.87	$ 0.16	0.220	0.000	$ 33.75
LA	$ 2.35	$ 1.07	0.056	0.016	$ 23.47
MA	$ 3.14	$ 1.47	0.014	0.001	$ 40.80
MD	$ 3.65	$ 0.93	0.032	0.000	$ 65.64
ME	$ 0.11	$ 0.11	.	1.000	$ 0.11
MI	$ 0.88	$ 0.27	0.000	0.000	$ 89.58
MN	$ 0.22	$ 0.05	0.000	0.000	$ 33.61
MO	$ 1.32	$ 0.18	0.126	0.000	$ 50.29
MS	$ 2.09	$ 0.31	0.276	0.000	$ 27.23
MT	$ 0.21	$ 0.16	0.198	0.250	$ 0.83
NC	$ 1.03	$ 0.30	0.007	0.000	$ 29.87
ND	$ 0.21	$ 0.04	0.135	0.008	$ 2.11
NE	$ 0.29	$ 0.04	0.072	0.000	$ 15.19
NH	$ 4.90	$ 3.40	0.084	0.063	$ 24.49
NJ	$ 1.15	$ 0.39	0.000	0.000	$ 81.70
NM	$ 3.89	$ 0.23	0.151	0.063	$ 27.25
NV	$ 8.55	$ 1.95	0.250	0.008	$ 68.36
NY	$ 10.74	$ 0.79	0.009	0.000	$ 483.24
OH	$ 2.37	$ 0.24	0.011	0.000	$ 137.70
OK	$ 0.83	$ 0.31	0.176	0.063	$ 5.82
OR	$ 0.42	$ 0.14	0.000	0.000	$ 15.16
PA	$ 0.44	$ 0.03	0.000	0.000	$ 188.29
PR	$ 61.12	$ 43.54	0.077	0.063	$ 305.58
RI	$ 7.83	$ 0.21	0.293	0.250	$ 39.14
SC	$ 0.62	$ 0.26	0.002	0.000	$ 16.69
SD	$ 1.07	$ 0.04	0.198	0.000	$ 21.35
TN	$ 0.39	$ 0.14	0.000	0.000	$ 33.29
TX	$ 1.52	$ 0.35	0.000	0.000	$ 332.24
UT	$ 0.76	$ 0.15	0.003	0.000	$ 19.65
VA	$ 2.15	$ 0.33	0.000	0.000	$ 70.99
VT	$ 1.16	$ 0.40	0.289	0.250	$ 4.64
WA	$ 1.47	$ 0.16	0.000	0.000	$ 171.73
WI	$ 0.82	$ 0.05	0.083	0.000	$ 85.33
WV	$ 2.05	$ 1.10	0.164	0.125	$ 10.23
WY	$ 0.17	$ -	0.208	0.500	$ 0.83

Table 4.15 (Continued)

Issuing States and Refunding Decisions

The sample includes 2,620 municipal bonds, with original maturity less than 30 years, that were refunded between 1980-1993. This table reports sample characteristics, refunding efficiency, ratio of *ex-post* interest costs, loss in value, and months from optimal time by the state making the refunding decision. Refunding decisions are identified as optimal when the bonds are refunded at the optimal time as obtained by using the generalized Vasicek model; otherwise they are identified as sub-optimal. *N-Sub* is the frequency of sub-optimal refunding. Refunding efficiency is the ratio of the actual saving from sub-optimal exercise to potential saving from optimal exercise. Ratio of *ex-post* interest costs is the ratio of actual interest costs to the potential interest costs by refunding optimally. Loss is sum of call option value lost, and the loss from escrow investments. All dollar amounts have been converted to 1995 figures using CPI data. Months from optimal is the difference of the actual month of refunding and the month of optimal refunding. The *p*-values in each panel represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively.

Panel D: Months from optimal: Pooled and Absolute

	Pooled Deviation				Absolute Deviation		Proportion
	Mean	Median	*p* (mean)	*p* (med)	Mean	Median	Calling Early
AK	22.13	21.00	0.054	0.070	28.88	27.00	22.22%
AL	11.11	12.00	0.023	0.014	18.67	12.00	23.33%
AR	12.32	12.00	0.000	0.000	13.68	12.00	11.48%
AZ	23.90	24.00	0.000	0.000	24.77	24.00	13.24%
CA	9.65	12.00	0.000	0.000	12.92	12.00	13.04%
CO	17.22	15.00	0.000	0.000	18.90	15.00	7.84%
CT	22.20	18.00	0.010	0.008	22.20	18.00	0.00%
DE	24.86	24.00	0.006	0.031	24.86	24.00	12.50%
FL	13.95	12.00	0.000	0.000	15.55	12.00	12.80%
GA	19.92	19.50	0.000	0.000	20.42	19.50	2.78%
HI	11.40	15.00	0.079	0.250	11.40	15.00	16.67%
IA	25.78	15.00	0.000	0.000	26.44	15.00	3.70%
ID	24.30	24.00	0.006	0.008	24.30	24.00	0.00%
IL	16.86	12.00	0.000	0.000	18.76	15.00	12.12%
IN	11.14	12.00	0.000	0.000	12.36	12.00	6.67%
KS	16.21	12.00	0.000	0.000	17.79	12.00	11.67%
KY	10.13	9.00	0.068	0.029	14.25	9.00	16.67%
LA	16.80	13.50	0.008	0.016	16.80	13.50	0.00%
MA	15.55	12.00	0.012	0.004	15.55	12.00	15.38%
MD	17.60	21.00	0.000	0.000	17.60	21.00	16.67%
ME	12.00	12.00	.	1.000	12.00	12.00	0.00%
MI	17.49	15.00	0.000	0.000	17.87	15.00	8.82%
MN	19.28	18.00	0.000	0.000	19.64	18.00	3.87%
MO	17.51	18.00	0.000	0.000	18.49	18.00	7.89%
MS	28.15	24.00	0.000	0.000	28.15	24.00	0.00%
MT	13.50	15.00	0.078	0.250	13.50	15.00	0.00%
NC	21.72	15.00	0.000	0.000	22.34	15.00	3.45%
ND	14.40	13.50	0.038	0.016	16.20	13.50	10.00%
NE	11.12	12.00	0.000	0.000	13.24	12.00	9.62%
NH	33.60	36.00	0.072	0.125	39.60	36.00	20.00%
NJ	16.50	15.00	0.000	0.000	17.59	15.00	11.27%
NM	10.29	12.00	0.229	0.438	15.43	15.00	14.29%
NV	27.00	24.00	0.007	0.016	27.00	24.00	12.50%
NY	13.46	12.00	0.000	0.000	17.85	15.00	20.00%
OH	16.85	15.00	0.000	0.000	17.62	15.00	8.62%
OK	7.71	0.00	0.510	0.625	21.43	18.00	28.57%
OR	15.33	15.00	0.000	0.000	15.33	15.00	0.00%
PA	8.83	9.00	0.000	0.000	10.28	9.00	11.53%
PR	24.75	21.00	0.059	0.125	24.75	21.00	20.00%
RI	12.00	12.00	0.182	0.500	12.00	12.00	20.00%
SC	13.22	12.00	0.000	0.000	13.22	12.00	0.00%
SD	10.95	15.00	0.006	0.010	15.45	16.50	10.00%
TN	18.74	18.00	0.000	0.000	19.52	18.00	4.65%
TX	24.08	24.00	0.000	0.000	25.13	24.00	6.85%
UT	17.88	12.00	0.000	0.000	19.56	12.00	7.69%
VA	16.18	15.00	0.000	0.000	17.45	15.00	3.03%
VT	3.75	10.50	0.642	0.875	12.75	12.00	25.00%
WA	20.31	15.00	0.000	0.000	21.27	15.00	5.98%
WI	13.19	13.50	0.000	0.000	15.31	15.00	16.35%
WV	16.20	24.00	0.230	0.250	23.40	24.00	20.00%
WY	3.75	0.00	0.391	1.000	3.75	0.00	20.00%

Table 4.16

Loss in Value from Not Calling

The sample includes 23,976 callable municipal bonds, with original maturity less than 30 years, that were not called between 1980-1993. Refunding decisions are identified as optimal when the bonds should have been called at the optimal time as obtained by using the generalized Vasicek model. Decisions are sub-optimal if the bonds were candidates for refunding but issuer never called these bonds. This table reports the loss in value and sample characteristics for optimal and sub-optimal decisions. Loss is the product of the unit loss in value from not calling, and the gross proceeds, in $ millions. All dollar amounts have been converted to 1995 figures using CPI data. The *p*-values in panel B represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively.

Panel A: Sample Characteristics				
Refunding	Gross Proceeds, $ million		Frequency	
Decision	Mean	Total	N	N-Sub
Optimal Decision	$ 12.84	$ 148,051.07	11532	0
Sub-Optimal Decision	$ 14.77	$ 183,835.44	12444	12444

Panel B: Loss, $ million					
	Mean	Median	*p* (mean)	*p* (med)	Total
Optimal Decision	0.00	0.00			0.00
Sub-Optimal Decision	$ 0.25	$ 0.04	0.001	0.001	$ 3,166.19

Table 4.17

Security Type and The Loss in Value from Not Calling

The sample includes 23,976 callable municipal bonds, with original maturity less than 30 years, that were not called between 1980-1993. Refunding decisions are identified as optimal when the bonds should have been called at the optimal time as obtained by using the generalized Vasicek model. Decisions are sub-optimal if the bonds were candidates for refunding but issuer never called these bonds. This table reports sample characteristics, and loss in value for such sub-optimal decisions by type of security: either General Obligation Bonds or Revenue Bonds. Loss is the product of the unit loss in value from not calling, and the gross proceeds, in $ millions. All dollar amounts have been converted to 1995 figures using CPI data. The *p*-values in panel B represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively. A "-" entry indicates that the number is insignificant at the second decimal level.

Panel A: Sample Characteristics

Security Type	Gross Proceeds, $ million		Frequency	
	Mean	Total	N	N-Sub
General Obligation Bonds	$ 10.92	$ 157,027.97	14382	7522
Revenue Bonds	$ 18.23	$ 174,858.55	9594	4922

Panel B: Loss, $ million

	Mean	Median	*p* (mean)	*p* (med)	Total
General Obligation Bonds	$ 0.13	$ -	0.001	0.001	$ 1,824.47
Revenue Bonds	$ 0.14	$ -	0.001	0.001	$ 1,341.71

Table 4.18

Bond Rating and The Loss in Value from Not Calling

The sample includes 23,976 callable municipal bonds, with original maturity less than 30 years, that were not called between 1980-1993. Refunding decisions are identified as optimal when the bonds should have been called at the optimal time as obtained by using the generalized Vasicek model. Bond ratings are those of Moody's when available, otherwise those of S&P Corporation are used. Decisions are sub-optimal if the bonds were candidates for refunding but issuer never called these bonds. This table reports sample characteristics, and loss in value for such sub-optimal decisions by bond rating criteria. Loss is the product of the unit loss in value from not calling, and the gross proceeds, in $ millions. All dollar amounts have been converted to 1995 figures using CPI data. The *p*-values in panel B represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively. A "-" entry indicates that the number is insignificant at the second decimal level.

Panel A: Sample Characteristics

Rating Class	Gross Proceeds, $million		Frequency	
	Mean	Total	N	N-Sub
AAA	$ 16.17	$ 5,157.32	319	226
AA	$ 20.76	$ 4,068.99	196	120
A	$ 16.97	$ 90,003.74	5305	3051
Not Rated	$ 12.81	$ 232,656.46	18156	9047

Panel B: Loss, $ million

	Mean	Median	*p* (mean)	*p* (med)	Total
AAA	$ 0.17	$ 0.03	0.001	0.001	$ 55.43
AA	$ 0.22	$ 0.03	0.001	0.001	$ 42.41
A	$ 0.19	$ 0.01	0.001	0.001	$ 1,011.94
Not Rated	$ 0.11	$ -	0.001	0.001	$ 2,056.41

Table 4.19

Issue Size and The Loss in Value from Not Calling

The sample includes 23,976 callable municipal bonds, with original maturity less than 30 years, that were not called between 1980-1993. Refunding decisions are identified as optimal when the bonds should have been called at the optimal time as obtained by using the generalized Vasicek model. Decisions are sub-optimal if the bonds were candidates for refunding but issuer never called these bonds. This table reports sample characteristics, and loss in value for such sub-optimal decisions by bond rating criteria. Loss is the product of the unit loss in value from not calling, and the gross proceeds, in $ millions. All dollar amounts have been converted to 1995 figures using CPI data. The *p*-values in panel B represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively. A "-" entry indicates that the number is insignificant at the second decimal level.

Panel A: Sample Characteristics

Gross Proceeds	Gross Proceeds, $million: Mean	Gross Proceeds, $million: Total	Frequency: N	Frequency: N-Sub
Quintile 1	$ 0.52	$ 2,496.63	4796	2106
Quintile 2	$ 1.68	$ 8,063.63	4795	2403
Quintile 3	$ 3.77	$ 18,065.35	4796	2514
Quintile 4	$ 7.92	$ 37,933.56	4792	2655
Quintile 5	$ 55.31	$ 265,327.34	4797	2766

Panel B: Loss, $ million

	Mean	Median	*p* (mean)	*p* (med)	Total
Quintile 1	$ -	$ -	0.001	0.001	$ 16.95
Quintile 2	$ 0.02	$ -	0.001	0.001	$ 72.13
Quintile 3	$ 0.03	$ 0.01	0.001	0.001	$ 165.34
Quintile 4	$ 0.08	$ 0.02	0.001	0.001	$ 372.41
Quintile 5	$ 0.53	$ 0.09	0.001	0.001	$ 2,539.36

Table 4.20

Bond Maturity and The Loss in Value from Not Calling

The sample includes 23,976 callable municipal bonds, with original maturity less than 30 years, that were not called between 1980-1993. Refunding decisions are identified as optimal when the bonds should have been called at the optimal time as obtained by using the generalized Vasicek model. Decisions are sub-optimal if the bonds were candidates for refunding but issuer never called these bonds. This table reports sample characteristics, and loss in value for such sub-optimal decisions by original bond maturity at issuance. Loss is the product of the unit loss in value from not calling, and the gross proceeds, in $ millions. All dollar amounts have been converted to 1995 figures using CPI data. The *p*-values in panel B represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively. A "-" entry indicates that the number is insignificant at the second decimal level.

Panel A: Sample Characteristics

Original Bond Maturity	Gross Proceeds, $ million: Mean	Gross Proceeds, $ million: Total	Frequency: N	Frequency: N-Sub	Original Bond Maturity: Mean	Original Bond Maturity: Median
Quintile 1	$ 4.81	$ 24,449.99	5081	1977	7.25	9.00
Quintile 2	$ 6.90	$ 38,621.63	5599	3133	13.69	14.00
Quintile 3	$ 11.44	$ 40,420.48	3534	2008	17.56	18.00
Quintile 4	$ 15.00	$ 74,706.56	4982	2817	20.00	20.00
Quintile 5	$ 32.15	$ 153,687.85	4780	2509	25.03	25.00

Panel B: Loss, $ million

	Mean	Median	*p* (mean)	*p* (med)	Total
Quintile 1	$ 0.03	$ -	0.001	0.001	$ 151.11
Quintile 2	$ 0.08	$ -	0.001	0.001	$ 432.76
Quintile 3	$ 0.10	$ 0.01	0.001	0.001	$ 370.52
Quintile 4	$ 0.17	$ 0.01	0.001	0.001	$ 844.33
Quintile 5	$ 0.29	$ 0.01	0.001	0.001	$ 1,367.46

Table 4.21

Outstanding Long Term Debt and The Loss in Value from Not Calling

The sample includes 23,976 callable municipal bonds, with original maturity less than 30 years, that were not called between 1980-1993. Refunding decisions are identified as optimal when the bonds should have been called at the optimal time as obtained by using the generalized Vasicek model. Decisions are sub-optimal if the bonds were candidates for refunding but issuer never called these bonds. This table reports sample characteristics, and loss in value for such sub-optimal decisions by quintiles of outstanding long term debt at the time of issuance of the refunded bond. Quintiles run from lowest to highest. Loss is the product of the unit loss in value from not calling, and the gross proceeds, in $ millions. All dollar amounts have been converted to 1995 figures using CPI data. The *p*-values in panel B represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively. A "-" entry indicates that the number is insignificant at the second decimal level.

Panel A: Sample Characteristics

Outstanding	Gross Proceeds, $ million		Frequency		Outstanding Debt, $ mi	
Long Term Debt	Mean	Total	N	N-Sub	Mean	Median
Quintile 1	$ 1.42	$ 6,830.99	4795	2131	$ 1.48	$ 1.34
Quintile 2	$ 3.32	$ 15,918.64	4796	2355	$ 6.92	$ 6.63
Quintile 3	$ 5.92	$ 28,399.43	4795	2510	$ 21.32	$ 20.26
Quintile 4	$ 11.54	$ 55,333.70	4796	2686	$ 75.14	$ 66.24
Quintile 5	$ 47.02	$ 225,403.76	4794	2762	$ 1,820.79	$ 544.16

Panel B: Loss, $ million

	Mean	Median	*p* (mean)	*p* (med)	Total
Quintile 1	$ 0.01	$ -	0.001	0.001	$ 64.47
Quintile 2	$ 0.03	$ -	0.001	0.001	$ 144.05
Quintile 3	$ 0.05	$ -	0.001	0.001	$ 257.38
Quintile 4	$ 0.11	$ 0.01	0.001	0.001	$ 520.98
Quintile 5	$ 0.45	$ 0.02	0.001	0.001	$ 2,179.30

Table 4.22

Time Series Analysis of The Loss in Value from Not Calling

The sample includes 23,976 callable municipal bonds, with original maturity less than 30 years, that were not called between 1980-1993. Refunding decisions are identified as optimal when the bonds should have been called at the optimal time as obtained by using the generalized Vasicek model. Decisions are sub-optimal if the bonds were candidates for refunding but issuer never called these bonds. This table reports sample characteristics, and loss in value for such sub-optimal decisions by the year of issuance of the refunded bond. Loss is the product of the unit loss in value from not calling, and the gross proceeds, in $ millions. All dollar amounts have been converted to 1995 figures using CPI data. The *p*-values in panel B represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively. A "-" entry indicates that the number is insignificant at the second decimal level.

Panel A: Sample Characteristics

Year of Issuance	Gross Proceeds, $ million: Mean	Gross Proceeds, $ million: Total	Frequency: N	Frequency: N-Sub
1986	$ 22.57	$ 53,128.62	2354	2206
1987	$ 16.01	$ 37,785.40	2360	2031
1988	$ 14.93	$ 36,515.49	2445	2319
1989	$ 13.42	$ 38,326.65	2856	2722
1990	$ 11.73	$ 41,424.37	3530	3141
1991	$ 12.82	$ 55,210.19	4306	25

Panel B: Loss, $ million

	Mean	Median	*p* (mean)	*p* (med)	Total
1986	$ 0.48	$ 0.07	0.001	0.001	$ 1,126.52
1987	$ 0.23	$ 0.04	0.001	0.001	$ 542.33
1988	$ 0.28	$ 0.04	0.001	0.001	$ 675.10
1989	$ 0.17	$ 0.04	0.001	0.001	$ 480.59
1990	$ 0.10	$ 0.02	0.001	0.001	$ 338.57
1991	$ -	$ -	0.051	0.001	$ 3.07

Table 4.23

Use of Proceeds and The Loss in Value from Not Calling

The sample includes 23,976 callable municipal bonds, with original maturity less than 30 years, that were not called between 1980-1993. Refunding decisions are identified as optimal when the bonds should have been called at the optimal time as obtained by using the generalized Vasicek model. Decisions are sub-optimal if the bonds were candidates for refunding but issuer never called these bonds. This table reports sample characteristics, and loss in value for such sub-optimal decisions by use of proceeds of the refunded bond. Loss is the product of the unit loss in value from not calling, and the gross proceeds, in $ millions. All dollar amounts have been converted to 1995 figures using CPI data. The *p*-values in panel B represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively.

Panel A: Sample Characteristics

Use of Proceeds	Gross Proceeds, $ million Mean	Total	Frequency N	N-Sub
Education	$ 10.31	$ 76,428.63	7410	3826
General Purpose	$ 15.30	$ 147,191.99	9620	5048
Pollution Control	$ 37.22	$ 11,016.02	296	151
Transportation	$ 29.18	$ 28,540.77	978	507
Utility	$ 21.49	$ 14,356.87	668	343
Waste Recovery	$ 19.87	$ 9,834.29	495	234
Water/Sewer/Gas	$ 9.87	$ 44,517.94	4509	2335

Panel B: Loss, $ million

	Mean	Median	*p* (mean)	*p* (med)	Total
Education	$ 0.11	0.00	0.001	0.001	$ 830.58
General Purpose	$ 0.14	0.00	0.001	0.001	$ 1,381.68
Pollution Control	$ 0.19	0.00	0.001	0.001	$ 57.15
Transportation	$ 0.20	0.00	0.001	0.001	$ 196.06
Utility	$ 0.31	0.00	0.003	0.001	$ 208.25
Waste Recovery	$ 0.15	0.00	0.001	0.001	$ 72.26
Water/Sewer/Gas	$ 0.09	0.00	0.001	0.001	$ 420.20

Table 4.24

Issuing States and The Loss in Value from Not Calling

The sample includes 23,976 callable municipal bonds, with original maturity less than 30 years, that were not called between 1980-1993. Refunding decisions are identified as optimal when the bonds should have been called at the optimal time as obtained by using the generalized Vasicek model. Decisions are sub-optimal if the bonds were candidates for refunding but issuer never called these bonds. This table reports sample characteristics, and loss in value for such sub-optimal decisions by states making the refunding decisions. Loss is the product of the unit loss in value from not calling, and the gross proceeds, in $ millions. All dollar amounts have been converted to 1995 figures using CPI data. The *p*-values in panel B represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively.

Panel A: Sample Characteristics				
Issuing	Gross Proceeds, $ million		Frequency	
State	Mean	Total	N	N-Sub
AK	$ 24.09	$ 1,300.74	54	42
AL	$ 11.13	$ 5,021.20	451	207
AR	$ 3.15	$ 1,481.24	470	231
AZ	$ 15.05	$ 7,389.15	491	320
CA	$ 21.68	$ 41,647.91	1921	1045
CO	$ 11.04	$ 6,129.79	555	356
CT	$ 39.42	$ 7,883.61	200	97
DC	$ 147.96	$ 2,367.35	16	12
DE	$ 41.98	$ 1,301.43	31	19
FL	$ 36.49	$ 20,032.16	549	302
GA	$ 19.67	$ 3,717.86	189	102
GU	$ 84.71	$ 338.83	4	1
HI	$ 60.60	$ 1,939.12	32	24
IA	$ 3.16	$ 2,946.17	933	461
ID	$ 5.84	$ 612.69	105	47
IL	$ 12.74	$ 13,745.04	1079	500
IN	$ 9.45	$ 5,035.48	533	258
KS	$ 6.42	$ 3,804.63	593	269
KY	$ 9.92	$ 5,646.47	569	305
LA	$ 18.01	$ 7,277.84	404	240
MA	$ 27.57	$ 9,511.55	345	164
MD	$ 38.85	$ 6,488.03	167	103
ME	$ 15.34	$ 644.11	42	17
MI	$ 6.90	$ 8,230.17	1192	658
MN	$ 3.94	$ 7,432.53	1887	1019
MO	$ 7.61	$ 4,677.79	615	266
MS	$ 6.50	$ 1,813.19	279	142
MT	$ 9.17	$ 1,192.38	130	50
NC	$ 13.21	$ 3,565.96	270	136
ND	$ 2.95	$ 645.77	219	98
NE	$ 2.26	$ 1,072.17	474	182
NH	$ 22.37	$ 2,348.66	105	62
NJ	$ 25.98	$ 15,667.37	603	278
NM	$ 9.80	$ 970.45	99	54
NV	$ 14.18	$ 1,375.64	97	61
NY	$ 69.75	$ 37,106.54	532	222
OH	$ 13.31	$ 7,490.77	563	235
OK	$ 8.83	$ 1,571.91	178	73
OR	$ 7.77	$ 2,789.63	359	215
PA	$ 15.43	$ 17,886.48	1159	678
PR	$ 220.37	$ 2,644.48	12	6
RI	$ 14.00	$ 1,483.61	106	60
SC	$ 10.74	$ 3,017.44	281	164
SD	$ 5.33	$ 671.91	126	50
TN	$ 10.79	$ 4,553.52	422	206
TX	$ 12.07	$ 18,625.72	1543	974
UT	$ 14.39	$ 2,259.38	157	98
VA	$ 26.29	$ 7,229.70	275	154
VI	$ 51.96	$ 311.75	6	3
VT	$ 17.16	$ 497.70	29	21
WA	$ 9.31	$ 8,888.82	955	480
WI	$ 5.32	$ 7,990.28	1501	646
WV	$ 29.72	$ 1,248.41	42	16
WY	$ 6.43	$ 167.13	26	14

Table 4.24 (Continued)

Issuing States and The Loss in Value from Not Calling

The sample includes 23,976 callable municipal bonds, with original maturity less than 30 years, that were not called between 1980-1993. Refunding decisions are identified as optimal when the bonds should have been called at the optimal time as obtained by using the generalized Vasicek model. Decisions are sub-optimal if the bonds were candidates for refunding but issuer never called these bonds. This table reports sample characteristics, and loss in value for such sub-optimal decisions by states making the refunding decisions. Loss is the product of the unit loss in value from not calling, and the gross proceeds, in $ millions. All dollar amounts have been converted to 1995 figures using CPI data. The *p*-values in panel B represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively. A "-" entry indicates that the number is insignificant at the second decimal level.

Panel B: Loss, $ million

	Mean	Median	*p* (mean)	*p* (med)	Total
AK	$ 0.62	$ 0.07	0.143	0.000	$ 33.47
AL	$ 0.06	$ -	0.000	0.000	$ 26.40
AR	$ 0.01	$ -	0.000	0.000	$ 5.30
AZ	$ 0.31	$ 0.04	0.000	0.000	$ 151.81
CA	$ 0.21	$ 0.01	0.000	0.000	$ 403.94
CO	$ 0.07	$ 0.01	0.000	0.000	$ 40.51
CT	$ 0.33	$ -	0.000	0.000	$ 65.73
DC	$ 1.23	$ 0.59	0.005	0.000	$ 19.67
DE	$ 0.22	$ 0.04	0.001	0.000	$ 6.69
FL	$ 0.29	$ 0.01	0.000	0.000	$ 156.93
GA	$ 0.16	$ -	0.000	0.000	$ 30.56
GU	$ 0.08	$ -	0.391	1.000	$ 0.34
HI	$ 0.52	$ 0.31	0.000	0.000	$ 16.69
IA	$ 0.02	$ -	0.000	0.000	$ 17.32
ID	$ 0.05	$ -	0.000	0.000	$ 5.45
IL	$ 0.13	$ -	0.000	0.000	$ 143.21
IN	$ 0.04	$ -	0.000	0.000	$ 23.19
KS	$ 0.06	$ -	0.000	0.000	$ 35.51
KY	$ 0.08	$ -	0.013	0.000	$ 48.30
LA	$ 0.31	$ 0.02	0.000	0.000	$ 124.17
MA	$ 0.20	$ -	0.003	0.000	$ 68.47
MD	$ 0.30	$ 0.04	0.000	0.000	$ 49.32
ME	$ 0.07	$ -	0.009	0.000	$ 2.83
MI	$ 0.09	$ -	0.000	0.000	$ 106.18
MN	$ 0.02	$ -	0.000	0.000	$ 41.47
MO	$ 0.12	$ -	0.036	0.000	$ 72.09
MS	$ 0.15	$ -	0.000	0.000	$ 42.29
MT	$ 0.06	$ -	0.022	0.000	$ 7.30
NC	$ 0.06	$ -	0.000	0.000	$ 16.25
ND	$ 0.02	$ -	0.001	0.000	$ 5.09
NE	$ 0.01	$ -	0.000	0.000	$ 3.79
NH	$ 0.19	$ 0.03	0.000	0.000	$ 20.31
NJ	$ 0.11	$ -	0.000	0.000	$ 64.50
NM	$ 0.16	$ -	0.095	0.000	$ 16.15
NV	$ 0.40	$ 0.01	0.003	0.000	$ 38.68
NY	$ 0.54	$ -	0.000	0.000	$ 285.90
OH	$ 0.08	$ -	0.000	0.000	$ 46.98
OK	$ 0.13	$ -	0.001	0.000	$ 23.28
OR	$ 0.08	$ 0.01	0.000	0.000	$ 29.23
PA	$ 0.09	$ 0.01	0.000	0.000	$ 105.75
PR	$ 0.78	$ 0.12	0.039	0.031	$ 9.33
RI	$ 0.09	$ 0.02	0.000	0.000	$ 9.63
SC	$ 0.12	$ 0.02	0.000	0.000	$ 34.78
SD	$ 0.05	$ -	0.187	0.000	$ 6.02
TN	$ 0.08	$ -	0.000	0.000	$ 32.00
TX	$ 0.27	$ 0.03	0.000	0.000	$ 423.26
UT	$ 0.16	$ 0.01	0.001	0.000	$ 24.56
VA	$ 0.20	$ 0.02	0.000	0.000	$ 56.10
VI	$ 0.26	$ 0.12	0.167	0.250	$ 1.56
VT	$ 0.12	$ 0.03	0.002	0.000	$ 3.41
WA	$ 0.09	$ -	0.000	0.000	$ 86.69
WI	$ 0.05	$ -	0.004	0.000	$ 70.47
WV	$ 0.11	$ -	0.014	0.000	$ 4.53
WY	$ 0.04	$ -	0.008	0.000	$ 1.02

Table 4.25

Loss in Value from Sub-Optimal Refunding Strategies: Pooled Sample

The pooled sample includes 26,596 municipal bonds. Sample 1 contains 2,620 callable bonds, with original maturity less than 30 years, that were refunded between 1980-1993. Sample 2 includes 23,976 callable bonds, with original maturity less than 30 years, that were not called between 1980-1993. This table reports sample characteristics, and loss in value from sub-optimal refunding strategies. Refunding decisions are identified as optimal when the bonds are refunded at the optimal time as obtained by using the generalized Vasicek model; otherwise they are identified as sub-optimal. Loss is sum of call option value lost, and the loss from escrow investments. All dollar amounts have been converted to 1995 figures using CPI data. The *p*-values in panel B represent the significance level of the *t*-tests and of the Wilcoxon sign-rank tests of the difference from hypothesized mean and median values, respectively.

Panel A: Sample Characteristics

	Gross Proceeds, $ million		Frequency		Proportion
Samples	Mean	Total	N	N-Sub	Sub-Optimal
Sample 1	$ 29.78	$ 78,017.32	2620	1941	74.1%
Sample 2	$ 13.84	$ 331,886.51	23976	12444	51.9%
Pooled Sample	**$ 15.41**	**$ 409,903.83**	**26596**	**14385**	**54.1%**

Panel B: Loss, $ million

	Mean	Median	*p (mean)*	*p(med)*	Total
Sample 1	$ 1.53	$ 0.14	0.0001	0.0001	$ 4,008.34
Sample 2	$ 0.13	$ 0.0012	0.0001	0.0001	$ 3,166.19
Pooled Sample	**$ 0.27**	**$ 0.003**	**0.0001**	**0.0001**	**$ 7,174.53**

CHAPTER V

CONCLUSION

The universe is wider than our views of it.

Henry David Thoreau

Walden

V. A Introduction

This dissertation empirically examines the refunding decisions employed by issuers of callable tax-exempt debt by analyzing 2,620 bonds that were called, and 23,976 bonds that were never called. I use the generalized Vasicek (1977) model in the HJM(1992) framework to construct binomial trees for interest rates, and compute the optimal exercise boundary for call options embedded in these bonds. For the first sample of 2,620 bonds that are called, refunding efficiency, loss in value from sub-optimal refunding strategies, ratio of *ex-post* interest costs, and months from optimal time are computed using the option pricing lattice. For the second sample of 23,976 bonds that are not called, I compute the loss in value using the option pricing lattice.

V. B Synopsis of Results

This study documents efficiencies in bond refunding decisions by state and local government agencies. For the pooled sample of 26,596 bonds, the combined loss from sub-optimal refunding is $7.17 billion. For a total principal amount of $410 billion, this is a loss in value of 1.75%, as reported in Table 4.25.

Results suggest that losses seem to be higher for revenue bonds, bonds rated AA, issues with larger gross proceeds, bonds of longer maturity, issuers with large amount of outstanding debt, and downgraded bonds. General obligation bonds, AAA rated bonds, smaller issue size, bonds of shorter maturity, issuers with lower amount of outstanding debt, and upgraded bonds incur lower losses. Over the years refunding efficiency has improved, the loss in value from sub-optimal refunding strategies is lower and bonds are called closer to the optimal time. Results presented in Chapter 4, suggest that states of California, Florida, New York, and Texas accrued relatively higher losses due to sub-optimal refunding. Results suggest that issuers either wait too long to refund or never refund.

V. C Implications

Gurwitz (1990) points out that the embedded call option is a “wasting asset;” its value decreases as it approaches expiration. By waiting too long, issuers cannot realize the present value savings of switching a higher coupon bond with a lower coupon bond, for a longer period of time. Gurwitz (1990) mentions that municipal bond issuers typically establish a target level of present value savings, measured as a percentage of refunding bond issue. Once a bond passes its first call date such a target rule begins to become less appropriate, since the interest rate required to achieve any given level of present value savings decreases, slowly at first and then rapidly.

Apart from financial considerations, other issues such as investor influence over the issuer, bond indentures, federal and local regulations, political and economic climate may play a role in the refunding decision. This study ignores the role of such criteria in the decision making process involving bond refundings and examines refunding decisions purely from the perspective of interest rate savings.

Miller (1993) mentions that issuers undertake refundings for reasons other than interest rate savings. These include defeasence, debt restructuring, and other economic benefits. Defeasing existing debt might be done to remove burdensome covenants, generally limited to the refunding of older revenue bonds which might have antiquated covenant structures that do not reflect modern financial practices applicable to the issuer. Issuers also undertake refunding to defer or stretch out their existing debt service. Finally, refundings may also be done in order to realize an economic benefit other than interest rate savings. This may include (1) investing the escrow at a rate higher than the arbitrage yield limit so as to offset negative arbitrage in other escrows, or (2) releasing reserve funds so as to invest them in assets with a higher yield.

The are limitations on advanced refundings that might hinder issuers’ desire or ability to refund optimally. These are listed below:

1. If the original “new money” financing was issued on or after January 1, 1986, those bonds, or any successor current refunding bonds, may be advance refunded once. New money bonds issued prior to January 1, 1986, may be advance refunded twice. All advance refundings done prior to March 15, 1986, count as one advance refunding towards the two refunding limit
2. Private activity bonds may not be advance refunded.
3. If the refunding prior bonds may produce present value savings, the prior bonds must be called on the first call date.
4. The yield on the portion of the escrow fund provided from refunding bonds proceeds may not be invested at a yield above the aggregate reoffering yield of the refunding issue.

5. There may be industry-specific limitations that will affect the ability of an issuer to advance refund bonds.[22]
6. Finally, certain advance refunding structures or techniques that have been labeled as "abusive," are prohibited under the Tax Code.[23]

In contrast, the only major limitations on current refundings is that for private activity bonds - other than bonds for airports, docks and wharves - the "amount" of the refunding bonds cannot exceed the "amount" of the prior bonds. Other limitations, applicable to both current and advanced refundings, include the payment of "rebates" and "transferred proceeds penalty."[24]

Another reason that might prevent issuers from refunding optimally is that bonds of a particular series may be subject to "inverse order call requirement" that they may be called in inverse order of maturity. If so, the viability of refunding of a particular maturity may be affected by the existence of a lower coupon bond with a later maturity that would cost the issuer if called.

Ziese and Taylor (1977) mention that interest rate savings might not be the motivating reason to undertake refunding. Other compelling reasons for issuers to undertake refundings include such factors as prevention of default, cash flow savings, and restructuring of debt.

In a study on the calling of non-convertible corporate bonds, Vu (1986) finds that such bonds are called late. He suggest that transaction costs and market imperfections may prevent the firm from calling exactly at the optimal time. The same reason apply to issuers of tax-exempt debt.

Kidwell (1976a & 1976b) studies the use of call provision by state and local governments, found only a moderate relationship between interest rates and the frequency of existing call provisions. Kidwell concludes that "refunding was not the dominant motive for exercising the call option for municipalities." He suggests that, for political reasons, a governmental unit may be reluctant to refund bonds at a lower interest rate, which would impose a cost on bondholders, if local financial institutions or other constituents held a considerable amount of debt.

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[22] For example, "501(c)(3)" organizations, which include nonprofit hospitals, private higher educational institutions, and other nonprofit organizations, are limited to a $150 million volume cap on the amount of bonds that can be held by investors for non-hospital projects; both advance refunding bonds and the refunded prior bonds count against this limit until prior bonds are retired.

[23] These structures include: (1) certain combinations of taxable and tax-exempt refundings, (2) investment of the debt service fund and/or prior bond construction funds in the escrow for a longer period of time than would otherwise be the case had the refunding not taken place, (3) factoring into the arbitrage yield on the refunding bonds the gross bond insurance premium on any refunding bonds, and (4) a reduction in the coupon on the prior bonds as a result of the refunding and defeasance not offset a by matching reduction in the yield on the refunding escrow.

[24] Rebate is a requirement that 100% of the investment earnings in excess of the bond yield be rebated to the U.S. Treasury. The transferred proceeds penalty is an economic adjustment to the yield on the refunding escrow equal to the present value of the spread between the yield on the escrow established with the prior bonds proceeds and the yield on the refunding bond issue from and after the call date of the prior bond. This penalty will occur most often in a high-to-low refunding of a prior issue that was itself a low-to-high refunding. This penalty, however, does not apply to taxable refundings or to a defeasance with the issuer's own revenues.

Illiquidity in the secondary market for municipal bonds may also play a part in the refunding decision. Another reason for the inefficient refunding may be legislative stipulations requiring a minimum rate of present value savings to initiate refunding. Future research to investigate these and other potential reasons for inefficient refunding may be of interest.

V. D Limitations of This Study

The analysis presented in this study has several potential limitations. As mentioned above, this study examines refunding decisions purely from the perspective of interest rate savings. Many refundings in the sample under consideration might have been undertaken for reasons other than interest rate savings and these refundings might have been efficient from that point of view; for example, if a refunding is undertaken to restructure debt, or to remove burdensome covenants then it is efficient from in that respect.

The results of this analysis critically depend on the following:

1. choice of term structure model,
2. underlying assumptions of the chosen model,
3. model calibration or parameter values, and,
4. sample selection bias.

It is quite likely that under a different set of assumptions and another term structure model the results may be vastly different.[25] The results are sensitive to the values of volatility and mean reversion parameters. Measurement and calibration errors might cause potential flaws in the analysis and therefore this study is subject to the same criticism that applies to studies of similar nature, such as the joint hypotheses problem common in empirical finance. Also, sample selection criteria might introduce a potential selection bias. Since, this study examines only 34% of the all callable bonds issued during the period under consideration, it is likely that those that have been left out due to incomplete information have relatively higher refunding efficiencies.

The analysis used in this study can be employed for valuing securities with embedded options, and for evaluating refinancing decisions, or prepayment behavior.

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[25] Chiang and Narayanan (1991) argue that refunding criteria is independent of the type of stochastic process followed by interest rates, since current prices reflect all information regarding investors' expectations of future interest rates. However, in order to implement their dynamic programming model to evaluate refunding an interest rate model is required. This implementation is accomplished by employing the finite difference method similar to that outlined in Brennan and Schwartz (1977).

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VITA

Samaresh Priyadarshi, was born on October 21, 1963 to Hari Narayan and Indu Sahay, in Dhanbad, India. He completed his B.S. in Mechanical Engineering from Birla Institute of Technology, Ranchi, India in 1984, and his M.B.A. from the Indian Institute of Management, Calcutta, India in 1989. He worked for six years in manufacturing, consulting, and corporate treasury with different companies in India. He is married to Sarita, and has one daughter, Aparna. He enrolled in the doctoral program in Finance at Virginia Tech in Fall 1992. He will join Lincoln Investment Management, Inc. as a Quantitative Research Analyst in May 1997.