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Some Empirical Estimates of the Risk Structure of Interest Rates

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ABSTRACT

This paper investigates the risk structure of interest rates using pure discount bonds. The most striking feature of our estimates of default-risk premia is the resemblance of their time profile to the theoretical time profile obtained by Merton (1974).

WHEN A BOND IS issued, a promise to pay certain amounts on predetermined dates is made. The price of such a bond is a function of both the pattern of the promised payments (e.g., the level and periodicity of coupon payments) and the probability that this obligation will be met. Accordingly, there are bond-market studies of both the term structure and the risk structure of interest rates. This is the first paper to investigate the risk structure of interest rates using pure discount bonds.

Previous empirical studies of the risk structure of corporate bonds (e.g., Fisher (1959), Johnson (1967), Cohan (1967), Silvers (1973), and Boardman and McEnally (1981)) examine the differences between yields on coupon-paying corporate bonds and yields on coupon-paying government bonds of the same maturity. The use of these data is problematical. First, most corporate bonds promise more than a single payment (i.e., periodical coupon payments are promised). Since the price of a coupon-paying bond is the sum of the values of all of its cash flow components, one cannot estimate the default-risk premium for a single future date. Second, most of these bonds have sinking fund provisions and some of them are callable. (Henceforth, such bonds will be termed "complicated" bonds.) While closed-form solutions exist for some complicated corporate bonds (c.f., Black and Cox (1976)), most analysis of the pricing of such bonds is done via numerical analysis (e.g., Brennan and Schwartz (1977), Mason (1986), Kim, Ramaswamy, and Sundaresan (1987)). Hence, no analytic results are available to which the empirical results can be directly compared. Moreover, the prices (and, consequently, yields) of complicated bonds reflect their sinking fund provisions, callability, etc. Hence, when analyzing the prices of complicated bonds, one cannot empirically isolate the effect of risk alone on the yields of these bonds.

Recently, the federal government and corporations have issued increasing numbers of pure discount bonds. This increase, which initially was motivated by

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tax considerations, is intended to satisfy investors' desire to better tailor their security portfolio to the time pattern of their cash flow needs. The issuance of such pure discount bonds allows us, for the first time, to isolate empirically the effect of default risk on corporate bond yields. Here, we analyze the prices of pure-discount corporate bonds of various ratings and maturities and compare their yields to the yields of similar maturity pure-discount government bonds. The use of these data alleviates the problems that existed in the previous studies: first, these bonds have no sinking fund provisions; second, none are (economically) callable; third, all these bonds have only one promised payment. Therefore, our data allow us to compare observed default-risk premia to the theoretical premia suggested by Merton (1974) and its refinements (e.g., Lee (1981) and Pitts and Selby (1983)).

The remainder of the paper is organized as follows. In Section I we describe the data; in Section II we describe our findings; and in Section III we conclude.

I. The Data

Zero coupon bond prices were collected from the data tapes of Shearson Lehman Brothers (SLB)[1] for the period February 1985 through September 1987. During that period the set of pure discount bonds contains 119 U.S. Treasury "strips"[2] and 137 corporate issues representing forty-two different companies. The yields of corporate bonds above the yield on Treasury "strips" of the same maturity are the focus of our analysis.

Before describing the use of the data, attention must be paid to the raw data themselves. Unlike stocks, bonds are traded by personal contacts between traders in various investment banks. In particular, for most bonds, there exists no central exchange where real-time market clearing prices can be observed. Consequently, SLB recorded prices are determined at the end of a trading day by SLB and its traders. (For a more detailed description of bond trading and its implications for bond market studies, see Sarig and Warga (1989).)

Bond pricing at SLB is done by two principal methods. (Similar methods are employed at other investment banks.) When transaction prices are known, these will be reported by the traders. For many bonds, days, and even months, can go by without any transaction taking place in the bond. In these cases, the trader responsible for the bond will be asked for a quote based on his/her experience with the bond. The trader may be aided by a "matrix" algorithm that uses observed prices of "similar" bonds to estimate the price of the thinly traded bond.

In order to avoid using price estimates rather than real prices, we filtered out all price records that were based on "matrix pricing". (SLB's data base indicates such records by a flag.) In addition, SLB data were filtered to eliminate all cases in which 1) a rating change occurred in the sample period; or 2) the reported

[1] Shearson Lehman Brothers is now called Shearson Lehman Hutton.

[2] "Stripped" U.S. Treasury issues are zero coupon government bonds. They are originally issued as coupon-paying bonds with each coupon carrying its own identifier (CUSIP number). The existence of separate identifiers for each coupon payment allows for trading in individual coupons. Hence, any holder of the original bond may "strip" it by selling its coupons to separate buyers. The separately sold coupons remain obligations of the U.S. Government.

price was below (above) the price of zero-coupon bonds of shorter (longer) maturity issued by the same firm; or 3) the bond was economically callable.

The last two filters require some explanation. If, in a given month, a bond whose maturity is bounded by the maturity of otherwise identical instruments had a price which was not bounded by the prices of the surrounding instruments, we deemed it likely that an error occurred in the recording of this instrument's price.[3]

While we wished to restrict ourselves to non-callable bonds, over half of our sample of bonds have call features in their debentures. In reality most of these call features should not be rationally exercised since the exercise price is par or above and these are pure discount instruments. Curiously, the debentures of coupon-paying bonds issued by the firms in our sample were often used for their zero-coupon "cousins" without modification. Therefore, the third filter above screened out bonds that could be called for a call price below par.[4]

In addition, it is worthwhile noting that all of the corporate and Treasury bonds whose yields we compare are subject to identical Federal tax treatment. However, unlike the corporate issues, the U.S. "strips" are not subject to state and local taxes. For comparison purposes, local taxes may still be ignored because cross-sectionally all yield spreads are subject to the same local tax.[5]

The Appendix reports the firms and the number of bonds available for analysis. (Note that not all bonds had price records covering the entire sample period.) Since we will be focusing on yield spreads between pure-discount corporate bonds and U.S. Treasury bonds, the sample must begin in February 1985 when the U.S. Treasury first issued stripped (or zero-coupon) bonds. This does not severely restrict the use of corporate pure-discount bond data because most such instruments were issued beginning in 1983, with the bulk coming "on line" in late 1984 and early 1985.

II. Empirical Results

Each month, we subtract from the yield of each zero-coupon corporate bond the yield of a zero-coupon government "strip" with identical maturity. If no government strip with identical maturity exists, the yields on the two "strips" with maturities most closely bounding the corporate bond are interpolated to obtain the appropriate risk-free zero-coupon yield. These yield differences are then averaged across bonds in a given month and then across time to produce our results.

Table I presents these average yield spreads for corporate zero-coupon bonds for the period February 1985 through September 1987 (32 months of observations)

[3] This selection criterion resulted in the elimination of twelve observations. The prices eliminated were of bonds that were part of a series issued by the firm under the same indenture. Therefore, all bonds were of the same seniority.

[4] Corporate bonds may also be called if their convenants are too restrictive but cannot be renegotiated. For a discussion of this point, see Vu (1986).

[5] The estimates reported in Table I and plotted in Figure 1 represent the risk premia for a tax exempt investor (e.g., a pension fund). Market participants claim that these are the dominant players (i.e., the marginal holders) in this segment of the bond market.

Table I

Yield Spreads for Corporate Zero Coupon Bonds

Average yield spreads are calculated over the period February 1985 through September 1987 as follows: in each month the yield to an individual corporate bond has subtracted from it the yield to a zero coupon government "strip" with identical maturity. If no government strip with identical maturity existed, the yield on the two "strips" with maturities most closely bounding the corporate bond were interpolated to obtain the appropriate risk-free zero coupon yield. These yield differences were then averaged across bonds in a given month and then across time to produce the results reported for each cell. The unrated column contains bonds from a mixture of ratings and should not be taken to be the lowest rating group. The figures are in percent per annum, and the number of observations is reported below the yield.

Maturity	AAA	AA	A	BBB	BB	B/C	Unrated
0.5–2.5 Years	0.410	0.621	0.775	1.326	1.670	4.996	3.081
	21	74	123	48	64	41	38
2.5–4.5 Years	0.232	0.562	0.736	1.275	1.495	4.650	3.232
	11	99	251	152	79	117	96
4.5–6.5 Years	NA	0.620	0.778	1.405	2.730	3.365	3.197
		114	221	59	58	125	119
6.5–8.5 Years	NA	0.620	0.660	NA	1.878	2.959	3.443
		96	138		51	80	119
8.5–10.5 Years	0.626	0.575	0.816	NA	0.989	2.912	3.099
	24	69	97		10	10	88
10.5–12.5 Years	NA	0.566	0.854	NA	NA	NA	2.478
		64	110				64
12.5 Plus Years	0.544	0.544	0.740	NA	NA	NA	2.516
	64	501	510				278

grouped by ratings and time to maturity. Figure 1 provides a graphical presentation of these data.

In Figure 1, the most striking feature seems to be its close resemblance to the theoretical plot obtained by Merton (1974) and others. Merton (1974), following the insight of Black and Scholes (1973), who argue that the equity of a levered firm can be viewed as an option on the assets of that firm, valued a pure discount bond of a firm whose assets' value evolves as geometric Brownian motion. Two subsequent notes—Lee (1981) and Pitts and Selby (1983)—refine Merton's analysis of the time profile of the risk premium on such a bond. Holding the risk of the assets and the risk-free rate of return constant, these papers show the dependency of the default risk premia on the bond's time to maturity and the leverage of the firm. Following Merton, they define the "quasi" debt-to-firm-value ratio d by

$$d = F \exp\{-rt\}/V,$$

where F is the face value of the pure discount bond, r is the risk-free rate of return, t is the time to maturity of the bond, and V is the value of the firm's

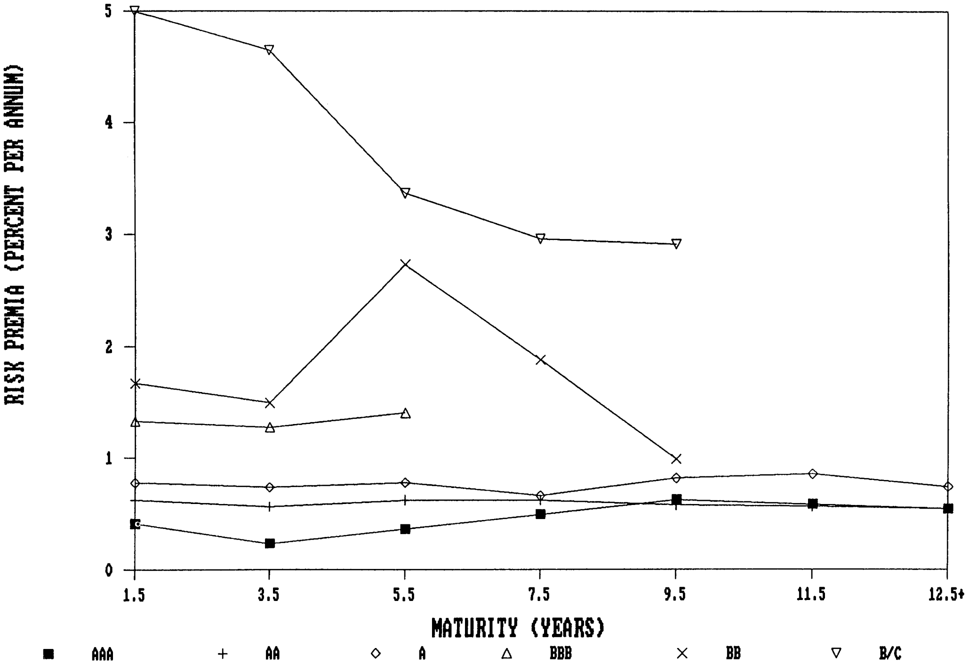

Figure 1. The term structure of risk premia. Yield spreads for corporate zero coupon bonds, February 1985 through September 1987. Maturity numbers (horizontal axis) correspond to the average maturity of each cell in Table I. Average yield spreads are calculated as follows: in each month the yield to an individual corporate bond has subtracted from it the yield to a zero coupon government "strip" with identical maturity. If no government strip with identical maturity existed, the yields on the two "strips" with maturities most closely bounding the corporate bond were interpolated to obtain the appropriate risk-free zero coupon yield. These yield differences were then averaged across bonds in a given month and then across time to produce the results.

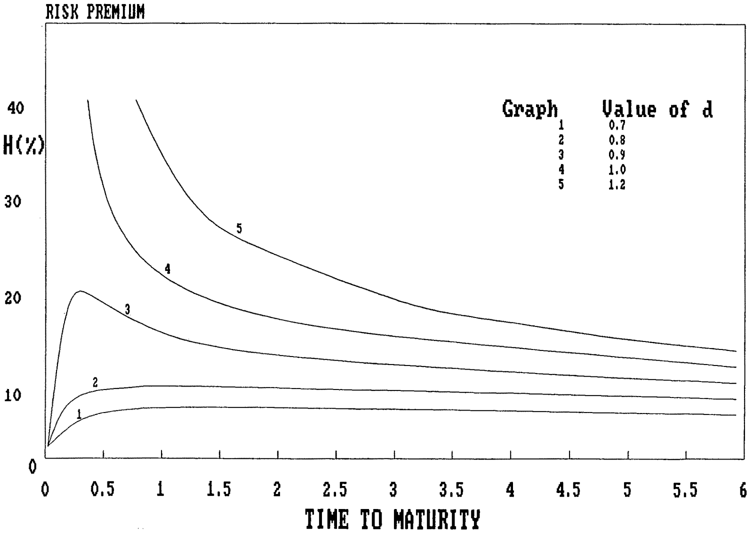

Figure 2. Risk premium (H) as a function of time to maturity. Source: Pitts and Selby (1983). Note that the risk premium is expressed in terms of percent per unit of time. However, the unit of time is arbitrary and need not be one year.

assets. "d" is the ratio of the value of the firm's debt if it were risk free to the total value of the firm. (This ratio obviously exceeds the true debt-to-firm-value ratio.)

Figure 2 reproduces from Pitts and Selby (1983) the relation between time to maturity and the risk premium on a pure discount bond. The risk premium is defined as the difference between the yield to maturity on the corporate pure-discount bond and the yield to maturity on a risk-free (i.e., government) pure-discount bond of the same maturity. The yield to maturity on the corporate bond (y) is defined by

$$P \exp\{(1 + y)t\} = F,$$

where P is the price of the bond. P is found by using the put-call parity relation and the Black-Scholes option pricing formula.

Figure 2 suggests that the term structure of risk premia is downward sloping for highly leveraged firms (i.e., d exceeding 1), humped for medium leveraged firms, and upward sloping for low leveraged firms (i.e., d less than 1). If we assume that high (low) leveraged firms roughly correspond to firms with low (high) debt ratings,[6] Pitts and Selby's (1983) results may be viewed as depicting the relation between the term profile of corporate bond risk premia and the ratings of these bonds.

Looking again at Figure 1, one observes that the estimated term structure of the risk premia is upward sloping for high rating pure discount bonds, humped for medium rating bonds, and downward sloping for low rating bonds. If leverage

[6] Exhibit 18 in Ederington and Yawitz (1987) empirically documents an inverse relationship between ratings and leverage.

and rating are negatively correlated, the shape of Figure 1 resembles the results of Merton (1974) and its refinements.[7] The small number of observations per cell does not allow us an extensive and more formal study of these premia (e.g., a comparison to default experience), but it is nevertheless encouraging to see the theoretical and empirical graphs match up.[8]

In a recent paper, Kim, Ramaswamy, and Sundaresan (1987) examine an expanded model for the valuation of corporate debt. In their model, the issuing firm pays a dividend, the holders of the bond receive a continuous stream of "coupon" payments, default is possible prior to the maturity of the bond, and the return on the firm's assets is correlated with the stochastically varying instantaneous risk-free rate of return. Using numerical analysis and considering only the case of low leveraged firms (d less than 1), Kim, Ramaswamy, and Sundaresan got the same "humped" shape term structure of default premia. This suggests that the relation between time to maturity and risk premia depicted in Figure 2 is not confined to the simple world modeled by Merton (1974) and Lee (1981).

In order to see the shape of the risk premia's time profile when multiple payments are promised, we looked at two firms in our sample, Pepsico and Rapid American, who have issued large series of pure discount bonds (twenty-seven and twenty bonds, respectively). Pepsico's bonds are AA rated, while Rapid American's bonds were not rated ("junk"). In later periods, outside our sample period, Rapid's bonds were rated BB. In Figure 3 we separately draw the yield spreads for these companies to illustrate the term structure of the default risk premia for firms that have a series of pure discount bonds outstanding. Such a situation is equivalent to having a coupon-paying bond outstanding and attaching a separate risk premium to each component of the cash flow stream. As the graph shows, the high rating firm's risk premia profile is relatively flat, while the low rating firm's risk premia profile is downward sloping. This is the shape predicted for a single pure discount bond outstanding. One may view this as an empirical demonstration that Merton's results describe the profiles of risk premia of corporate bonds even when more than a single bond is outstanding. This is a reaffirmation of the similarity between the profiles obtained by Merton (1974) and those obtained by Kim, Ramaswamy, and Sundaresan (1987).

III. Conclusion

In this paper we provide the first empirical description of the risk structure of interest rates using pure discount bonds. Corporate zero-coupon bonds are used to calculate yield spreads over zero-coupon U.S. Treasury bonds. Existing theoretical results on the term structure (e.g., Merton (1974)) appear to conform with

[7] The hump in Figure 1 seems to appear at a later point on the x-axis than is suggested in the theoretical graph (Figure 2). It is difficult to know whether this is really the case because the unit of time in Figure 2 is not well defined. In particular, it may be different from the time unit employed in Figure 1 (one year).

[8] A caveat is in place: Merton's analysis assumes that the pure discount bond whose price is analyzed is the only debt issued by the firm. All issuers in our sample had, in addition to the pure discount bond, some other debt outstanding.

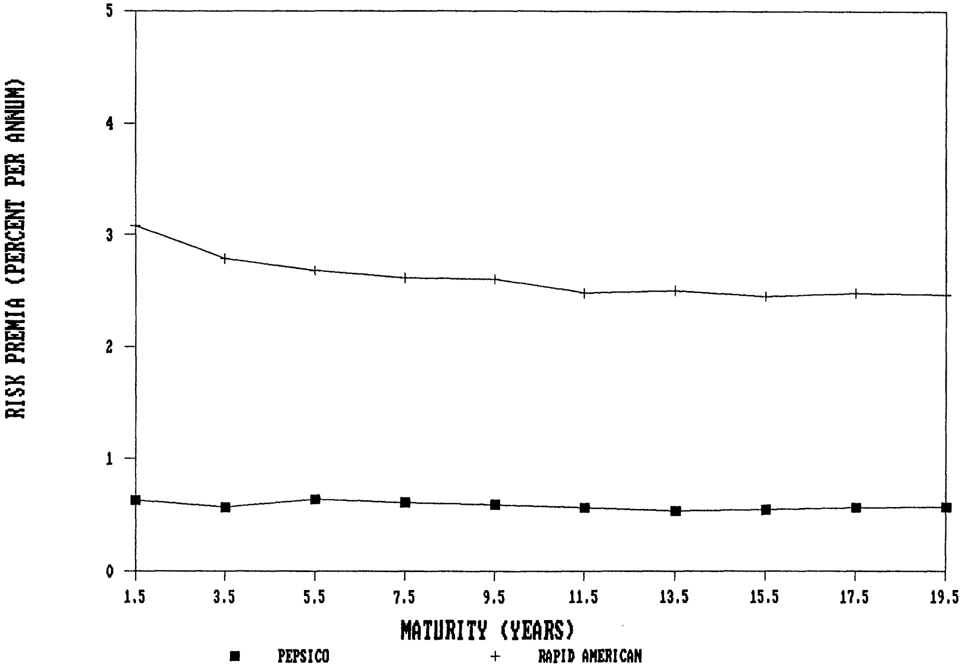

Figure 3. Examples of the term structure of risk. Average yield spreads for Pepsico and Rapid American are calculated as follows: in each month (from February 1985 through September 1987) the yield to an individual corporate bond has subtracted from it the yield to a zero coupon government "strip" with identical maturity. If no government strip with identical maturity existed, the yields on the two "strips" with maturities most closely bounding the corporate bond were interpolated to obtain the appropriate risk-free zero coupon yield. These yield differences were then averaged across bonds in a given month and then across time to produce the results.

the data. The results presented here must be considered only a preliminary investigation awaiting a richer and longer time series that will enable more formal tests.

Appendix

Firms and Maximum Number of Bonds in Any Given Month (FEB 1985–SEPT 1987)

1	ALLIED CORP	5
2	AMAX INC	1
3	ARCHER-DANIELS-MIDLAND	2
4	ASIAN DEVELOPMENT BANK	1
5	ASSOCIATED DRY GOODS	2
6	AVCO FINANCIAL SERVICES	1
7	BALLY MANUFACTURING CORP	3
8	BANKAMERICA CORP	3
9	BARCLAYS AMERICAN CORP	1
10	CIT GROUP HOLDINGS	1
11	CHASE MANHATTAN CORP	1
12	CHRYSLER FINANCIAL	2

13	CITIES SERVICE	2
14	COMMERCIAL CREDIT	1
15	CONAIR ACQUISITION CORP	6
16	CONTINENTAL ILL CORP	1
17	COOK INLET COMMUNICATION	3
18	CREDITHRIFT FINANCIAL	1
19	EXXON SHIPPING CO	1
20	FLUOR CORPORATION	2
21	FORD MOTOR CREDIT	1
22	FRANKLIN SAVINGS ASSOC	1
23	GENERAL MOTORS ACPT CORP	3
24	GEORGIA PACIFIC	4
25	GREYHOUND LEASE + FIN	1
26	HOSPITAL CORP OF AMERICA	6
27	IBM CREDIT CORPORATION	1
28	ITT FINANCIAL	6
29	INTEL OVERSEAS CORP	1
30	MANUFACTURERS HANOVER CORP	1
31	MCDONALDS CORP	2
32	METROMEDIA BROADCASTING	6
33	NRM ENERGY CO, L.P.	1
34	OWENS ILLINOIS INC	1
35	PENNEY J C	2
36	PEPSICO CAP. RES. INC	27
37	PRICE COMMUNICATIONS CORP	1
38	PRUDENTIAL REALTY SEC. I	1
39	RAPID AMERICAN CORP	20
40	TELEMUNDO GROUP, INC	2
41	TRANSAMERICA FINANCIAL	5
42	TURNER BROADCASTING SYS	4
	Total	137

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