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IS THE CORPORATE BOND MARKET FORWARD LOOKING?

by Jens Hilscher

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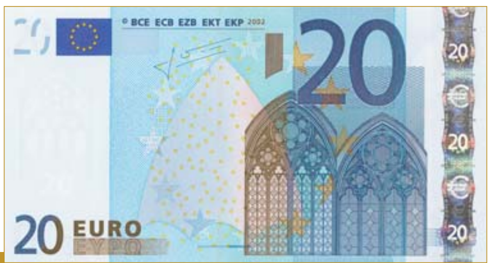

In 2007 all ECB publications feature a motif taken from the €20 banknote.

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Abstract

This paper presents empirical evidence that the corporate bond market is forward looking with respect to volatility. I use the Merton (1974) model to calculate a measure of implied volatility from corporate bond yield spreads. I find that corporate bond transaction prices contain substantial information about future volatility: When predicting future volatility in a regression model, implied volatility comes in significantly and increases the R^2 when added to historical volatility. Consistent with this finding, single stock option implied volatility helps explain the variation in bond yield spreads when included together with historical volatility.

JEL classifications: G12, G13

Keywords: Corporate bond spreads, Merton model, Implied volatility, Equity volatility, Bond pricing

Non-technical summary

A common way to model corporate bond prices is to view a risky bond as a combination of a safe bond and a short position in a put option. At maturity, the firm has the option of defaulting if firm value lies below the face value of debt. Bondholders bear the risk of a reduced payoff and demand compensation for this risk. Therefore, the yield on risky debt is typically higher than the yield on risk free government bonds; the difference is commonly referred to as the yield spread.

At $6.8 trillion outstanding, the U.S. corporate bond market's value is equal to almost 40% of that of the equity market (2004). However, in contrast to the equity market's high frequency trading on exchanges, corporate debt does not trade on an exchange and a typical bond issue trades only once every few months. We might therefore expect investors to look to the equity market rather than the bond market for information. We may also expect bond prices to be slow to incorporate information and news.

In this paper I examine the U.S. corporate bond market using transaction prices from 1995 to 1999. I investigate whether or not information about future volatility is incorporated into current bond prices. If future volatility is expected to be high, the firm is more likely to default, the option to default is more valuable, and the bond price is smaller. This means that an efficient and forward looking corporate bond market should react to news about future volatility. To consider this question empirically, I use the structural form Merton (1974) bond pricing model to back out the level of volatility that, given other observable company characteristics, matches the yield spread over U.S. Treasuries. This is the same idea as calculating implied volatility from option prices. I then use this level of implied volatility to forecast future volatility and find that it has significant incremental explanatory power. This is evidence that information about future volatility is reflected in current bond prices.

If it is the case that the bond market incorporates news about future volatility into bond prices, pricing will be more accurate when using a forward looking measure of volatility as

compared to using a historical measure. Consistent with this intuition I find that single stock option implied volatility helps explain the variation in bond yield spreads when included together with historical volatility.

I also use the Merton (1974) model to calculate model predicted spreads using both historical and forward looking measures of volatility as inputs. I find that spreads calculated using predicted volatility are better at explaining variation in observed spreads than spreads calculated using only historical volatility.

I interpret these findings as evidence that the corporate bond market is forward looking with respect to volatility. The results also have implications for the usefulness of structural bond pricing models. The results provide insight about the sensitivity of bond spreads to volatility and suggest that the theoretical and empirical sensitivities are quite close. The results also have broader implications for prices in different markets. The evidence that the bond market reflects information available in the equity and option markets may shed light on the possibility of implementing profitable capital structure arbitrage strategies: If a firm's outstanding equity and bonds are priced efficiently it is less likely that such a strategy will return positive economic profits. More generally, the results in this paper suggest that credit, equity and option markets share the same information.

1 Introduction

At \$6.8 trillion outstanding, the U.S. corporate bond market's value is equal to almost 40% of that of the equity market.[1] However, in contrast to the equity market's high frequency trading on exchanges, corporate debt does not trade on an exchange and a typical bond issue trades only once every few months. We might therefore expect investors to look to the equity market rather than the bond market for information. We may also expect bond prices to be slow to incorporate information and news.[2]

In this paper I investigate the extent to which corporate bond prices reflect information about future volatility. An increase in volatility increases the probability of default which in turn decreases the bondholder's expected payoff. This should lead an efficient and forward looking corporate bond market to react to news about future volatility.[3]

To quantify the level of expected volatility reflected in bond prices, I calculate implied volatilities from current bond prices using the structural form Merton (1974) model. In the model, the bond price and the volatility of firm value are linked. Risky debt is priced as a combination of safe debt and a short position in a put option. A higher level of volatility implies a higher value of the option and a lower bond price. The yield spread is a function of volatility, leverage, and time to maturity. Except for volatility all of the inputs are observable. We can therefore use the pricing relation to calculate a level of implied volatility that matches the observed spread level. This is the same idea as calculating option implied volatility.

If the corporate bond market is forward looking with respect to volatility, two things will be true: first, implied volatility will be able to predict future volatility and, second, using a forward looking measure together with a historical measure of volatility will improve bond pricing. I examine both of these predictions in turn and confirm that they both hold.

My empirical work proceeds as follows. Using panel data of bond transaction prices from 1995-1999 I calculate the level of implied volatility that matches the bond's yield spread over U.S. Treasuries. To test whether or not implied volatility can predict future

[1]Board of Governors of the Federal Reserve System Flow of Funds Accounts Q4/2004, corporate bonds owed by non-financial and financial sectors.

[2]Kwan (1996) finds that firm-specific information is first reflected in equity prices. Hotchkiss and Ronen (2002) find that a subset of high yield bonds with high levels of transparency react to firm-specific information contemporaneously with equity prices, while Goldstein, Hotchkiss, and Sirri (2006) document low average levels of transparency for a set of BBB bonds.

[3]Campbell and Taksler (2003) document the strong relationship between bond spreads and equity volatility. Cremers, Driessen, Maenhout, and Weinbaum (2006) find that single stock option implied volatility is a significant determinant of bond spreads.

volatility, I run regressions of future volatility on implied and historical volatility.[4] Implied volatility is a statistically and economically significant predictor of future volatility. Including implied volatility in the regression increases the explanatory power. I also find that implied volatility has explanatory power mainly in the time-series.

To investigate the robustness of the predictive power I add single stock option implied volatility, a common measure of expected future volatility, to the analysis. When included in the regression together, both option implied volatility and implied volatility calculated from bond prices are significant and add predictive power.

I next use the model to calculate spreads using both historical and forward looking measures of volatility as inputs. I construct a forward looking measure of volatility by regressing future on historical and option implied volatility. I find that spreads calculated using predicted volatility, the fitted values of this regression, are better at explaining variation in observed spreads than spreads calculated using only historical volatility.

To abstract from the specific nonlinear structure of the model, I also price bonds using historical and option implied volatility in a linear model. Option implied volatility comes in significantly and increases the fit when included with historical volatility. I interpret these findings as evidence that the corporate bond market is forward looking with respect to volatility.

There is a large related literature which investigates the empirical determinants of bond prices.[5] Several studies focus specifically on the relation between yield spreads and volatility. Campbell and Taksler (2003) demonstrate that equity volatility helps explain variation in bond prices. They fit a linear model and find significant incremental explanatory power of historical volatility when a large range of explanatory variables are included. Cremers, Driessen, Maenhout, and Weinbaum (2006) also use a reduced form linear model to show that option implied volatility and skew help price bonds. Other related work has examined the recently expanding credit derivatives market, considering the information flow between CDS spreads and stock options (Berndt and Ostrovnaya 2007, Cao, Yu, and Zhong 2007). Results are consistent with the patterns in bond prices documented in this paper.

The remainder of the paper is organized as follows. Section 2 discusses the Merton

[4] This exercise is very much in the spirit of the literature that examines whether or not option implied volatility can forecast future volatility (e.g. Canina and Figlewski 1993, Christensen and Prabhala 1998).

[5] The empirical bond pricing literature is very large and has gone in several directions. Duffie and Singleton (2003) provide an overview. Some examples include empirical implementation of structural models (e.g. Eom, Helwege, and Huang 2004 among others), development and implementation of reduced form models (e.g. Duffee 1998, Duffie and Singleton 1999 among others), and empirical investigation of determinants of variation in spreads in regression based frameworks (e.g. Collin-Dufresne, Goldstein, and Martin 2001, Avramov, Jostova, and Philipov 2007).

model and the link between the yield spread and volatility. Section 3 describes the data, the construction of implied volatility, and presents summary statistics. In Section 4, I use bond implied volatility to predict future volatility. This section also considers the effect of leverage and maturity on implied volatility and adds single stock option implied volatility to the analysis. In Section 5, I calculate model predicted spreads using different measures of volatility. I use a linear regression framework to explore the determinants of spread variation. Section 6 concludes.

2 Bond prices and volatility in the Merton model

A corporate bond promises investors a fixed stream of payments as long as the firm is not in default. If the firm defaults, bondholders receive less. To compensate investors for this risk, corporate bonds tend to have higher yields than safe government debt. In the Merton (1974) model, risky corporate debt is priced as a portfolio of safe debt and a short put option; at maturity the bondholders receive the minimum of the face value of debt and the value of the firm.[6]

If future volatility is expected to be higher, the default option is worth more and the bond price declines.[7] However, the magnitude of this effect is not constant. Since the spread is a nonlinear function of volatility, the sensitivity of spreads to changes in volatility (in option terminology, the vega) will vary. I therefore use the model to calculate the level of volatility which, given observables, matches the model predicted to the observed yield spread. Changes in this measure will then be directly comparable to changes in observed volatility. Following the option pricing literature, I refer to the measure as implied volatility. This section outlines the Merton model which I use to calculate implied volatilities in the next section. Section 5 then calculates model predicted spreads given different measures of volatility.

In the Merton model, firm value follows a geometric Brownian motion, i.e. under the

[6] The Merton (1974), which is based on the Black and Scholes (1973) option pricing model, is arguably the first modern structural bond pricing model. A large and rich literature followed. Black and Cox (1976), Geske (1977), Leland (1994), Leland and Toft (1996), Longstaff and Schwartz (1995), Anderson and Sundaresan (1996), Mella-Barral and Perraudin (1997), and Collin-Dufresne and Goldstein (2001), among others, have made important contributions. Also see Huang and Huang (2003) and Duffie and Singleton (2003) for an overview and discussion of this literature. In principle the exercise of calculating implied volatility could be done using another model. The results would, however, be qualitatively similar, given the focus on the time series variation in volatility (this point is discussed further in the next section).

[7] Both structural bond pricing models as well as many option pricing models assume that volatility is constant. Nevertheless, it is common to use constant volatility models to assess the impact of changes in future volatility on current prices. In the option pricing literature, Hull and White (1987) point out that implied volatility is a measure of average future volatility if stochastic volatility is not priced.

real measure,

$$\frac{dV}{V} = \mu dt + \sigma_A dZ \tag{1}$$

where V is the value of the firm, μ and σ_A are the drift and volatility, and dZ is a standard Wiener process. At maturity, bondholders are paid first. If firm value lies above the face value of debt, the firm does not default and bondholders receive face value; if the firm defaults, creditors take over. The payoff at maturity is $\min\{F, V_{t+T}\}$, where T is the time to maturity and F is the face value of debt. The debt is zero coupon and matures at time $t+T$. Using the standard Black Scholes (1973) valuation model, the price of the risky bond B_t is equal to:

$$B_t = V_t N(-d_1) + F \exp(-rT) N(d_2) \tag{2}$$

$$\text{where } d_1 = \frac{\log\left(\frac{V_t}{F}\right) + \left(r + \frac{1}{2}\sigma_A^2\right)T}{\sigma_A\sqrt{T}}, \; d_2 = d_1 - \sigma_A\sqrt{T},$$

and $N(.)$ is the normal c.d.f.

To make this model operational empirically, I rewrite the above equation to give an expression for the yield spread over the risk free rate defined as $s_t = -\frac{1}{T}\log\left(\frac{B_t}{F}\right) - r$. I then rewrite the model in terms of the current level of leverage $w_t = \frac{B_t}{V_t}$. If the bond is valued at a yield to maturity of y, substituting for the value of debt gives $w_t = \frac{B_t}{V_t} = \exp(-yT)\frac{F}{V_t}$. Since leverage, yield, and firm value (w_t, y, V_t) are observable, this relation defines the face value of debt F. Defining face value in this way is like assuming that firms can roll over their debt. For example, while keeping the same level of leverage, a firm could convert a 5 year bond into a 10 year bond with a higher face value.[8] It also means that there is no explicit dependence of leverage on maturity. If instead the face value were fixed, leverage would vary with maturity since the present value of a zero coupon bond depends on its maturity.[9] For simplicity I use the yield $y = r + \bar{s}$ to calculate the face value of debt, where $\bar{s}$ is the average spread for the bond's rating. This means that the face value of debt is not affected by the observed yield on the bond, which makes the calculations of predicted spreads in Section 5 simpler and more transparent.

Given observables, the following spread equation relates the spread on the bond to

[8] In addition, a fixed face value automatically implies a specific spread term structure. A fixed face value implies declining leverage which means that long maturity model predicted spreads are implausibly low. Defining face value in this way counteracts this aspect of the Merton model. It has a similar effect as the assumption of a stationary leverage ratio in Collin-Dufresne and Goldstein (2001).

[9] In the model, the firm only has one discount bond so this problem would never come up. However, firms generally have bonds of different maturities outstanding. Since data on maturity structure is often not available it is not possible to use the maturity structure as an input to a pricing model.

the level of volatility (see the Appendix for a more detailed derivation):

$$\frac{N(-d_1)}{w_t} + \exp(s_t * T) N(d_2) = 1. \tag{3}$$

$$d_1 = -\frac{\log w_t + \left(\bar{s} - \frac{1}{2}\sigma_A^2\right) T}{\sigma_A \sqrt{T}}, \; d_2 = d_1 - \sigma_A \sqrt{T}.$$

The bond spread s_t is a function of asset volatility σ_A, leverage w_t, time to maturity T, and the average spread $\bar{s}$. Using (3) I can calculate a level of asset volatility that is consistent with the spread and the inputs to the model. Intuitively, because a higher level of volatility results in a more valuable default (put) option, higher volatility leads to a higher spread.

To investigate empirically whether or not the corporate bond market is forward looking, one approach would be to compare implied to future asset volatility. However, asset value and asset returns are not easily observable which means that a measure of future asset volatility cannot be constructed.[10] Therefore, I instead calculate a measure of implied equity volatility from implied asset volatility. The relation between the two depends on the sensitivity of equity to changes in asset value, i.e. the hedge ratio (in option terminology, the delta). The model implies that equity volatility $\sigma_t^{implied}$ depends on asset volatility σ_A in the following way:

$$\sigma_t^{implied} = \sigma_A \frac{V_t}{S_t} \frac{\partial S}{\partial V} = \sigma_A \frac{1 - N(-d_1)}{1 - w_t}, \tag{4}$$

where S_t is the value of equity. Using this equation I can calculate a level of implied equity volatility $\sigma_t^{implied}$ given a measure of implied asset volatility σ_A and observables.[11]

3 Data description

In order to calculate implied volatility I need measures of bond spreads and the inputs to the model. I construct a measure of the yield spread using transactions data from the

[10] One strategy to calculate asset volatility could be to use the model's implication for the relation between leverage, equity value, and equity volatility. In the context of bankruptcy prediction, several studies have constructed a measure of asset volatility to calculate a firm's distance to default (e.g. Vassalou and Xing 2004, Bharath and Shumway 2004, Duffie, Saita, and Wang 2007, and Campbell, Hilscher, and Szilagyi 2007). This method is also used in Jones, Mason, and Rosenfeld (1984). I do not pursue this possibility since this method has the potential of introducing correlation between implied an future volatility due to differences in leverage which may obscure from detecting bond prices reflecting news about volatility.

[11] For ease of exposition I refer to this measure as implied volatility (not implied equity volatility), a terminology which does not explicitly distinguish it from asset volatility.

National Association of Insurance Commissioners (NAIC) and bond characteristics data from the Fixed Income Securities Database (FISD). Both are distributed by Mergent. Both of these data sets were also used by Campbell and Taksler (2003), Cooper and Davydenko (2004), and Ericsson, Reneby, and Wang (2005). The NAIC transactions data set replaces the no longer available Lehman Brothers data that was widely used in the literature (e.g. Collin-Dufresne, Goldstein, and Martin 2001, Eom, Helwege, and Huang 2004, Bakshi, Madan, and Zhang 2006 among others). The NAIC data reports transactions by insurance companies and includes all transactions from 1995-1999. It is particularly useful to use transacation prices for this study since such data will reflect all the most recent available information. Dealer quotes or so called "matrix" prices may be stale and not reflect current market conditions as well.

I consider bond prices of all fixed-rate U.S. dollar bonds in the industrial, financial and utility sectors that are rated AA, A, or BBB.[12] I keep only those bonds that are non-callable, non-putable, non-sinking fund and non-convertible and drop those bonds that are asset-backed or have credit-enhancement features. I make these restrictions since the Merton model prices bonds that have only the value of the firm as collateral and do not have any special features such as embedded options. These restrictions result in the same initial subset of bond transactions used by Campbell and Taksler (2003). I add U.S. Treasury yield data in a particular month using the CRSP Fixed Term indexes and measure the yield spread as the difference between the yield to maturity of the bond and the closest benchmark U.S. Treasury.

Next, I construct measures of volatility and the other inputs to the model. Each bond transaction is matched with equity data from CRSP and accounting data from COMPUSTAT to construct measures of leverage and volatility. Leverage is equal to total debt to capitalization measured as total long term debt plus debt in current liabilities plus average short-term borrowings all divided by total liabilities plus market value of equity (taken from CRSP).[13] The set of inputs to calculate implied volatility is now complete.

As outlined in the previous section, the calculation of implied volatility consists of two steps. Given the observable inputs to the model, equation (3) in the previous section implies a level of asset volatility that matches the observed spread. Equation (4) then gives a measure of implied volatility given a level of implied asset volatility. Before implementing these steps, I exclude bond spread observations with levels of leverage below 0.1% and above 99.9%. If leverage is almost zero, volatility will have to be very high to fit the spread; if leverage is very high the only way not to get a large spread is if

[12] Following Campbell and Taksler (2003) I exclude all AAA bonds since the data for these bonds exhibit several problems.

[13] The corresponding COMPUSTAT annual variable numbers are 9, 34, 104, and 181.

volatility is almost equal to zero. It is impossible to fit the model to bonds with zero or negative spreads and so I exclude bond spreads below 10 basis points (bps). I exclude observations with bond spreads above 20%.[14] I drop bonds with maturity below 1/10 of a year. These bonds tend to be originally longer maturity bonds that are about to mature. Studies that focus specifically on pricing short maturity debt and commercial paper will be better suited to understand pricing in this segment of the market (e.g. Kashyap, Stein and Wilcox 1993). In all of these cases, fitting the model would return implausible values of implied volatility.

Finally, I measure historical volatility as the sample standard deviation of the level stock return over the 180 days previous to the bond transaction and future volatility over the 180 days following the transaction. In order to ensure that outliers are not driving the results, I drop the top and bottom 0.5% of realized and historical volatility as well as the bottom one and top two percent of implied volatility. The main sample has 20,716 observations over a total of 60 months from 1995-1999, for 3,015 bond issues across 606 issuers. The median number of transactions per issuer in the sample is 16 with 5 transactions for each bond issue. This sample forms the base regression sample.

3.1 Summary statistics

Table 1 Panel A reports summary statistics for spreads, characteristics, and volatility measures for the main sample. There is large variation in observed bond spreads and in bond maturity. The median bond spread is 92 bps and the sample standard deviation of spreads is 65 bps. Bond maturity ranges from 0.14 to 30 years with a median time to maturity of 6.9 years. The distribution of leverage ratios is also variable. Median leverage is 20% and the sample standard deviation is 20%. Median bond implied volatility is 38%. Historical and future volatility are close together with medians of 30% and 31%.

Surprisingly, implied volatility levels are roughly in line with historical and future volatility. If structural models only capture a fraction of the spread (Huang and Huang 2003), levels of implied volatility should be much higher. One reason that median implied volatility is not higher may be because of important nonlinearities in the model. For instance, it could be the case that a rather modest difference between implied and actual volatility is large enough to match the observed spread levels. Implied volatility levels may also be the result of the face value of debt calculation discussed in the previous section. I return to this discussion in Section 5, where I calculate predicted spreads using different measures of volatility.

[14] Bonds with high spread levels tend to have quite different price characteristics. They tend to trade at a fraction of par rather than at a particular spread level and often have a flat term structure.

If the corporate bond market is forward looking, implied volatility will be able to forecast future volatility and both measures will be correlated. If, however, there is firm or bond specific heterogeneity, implied and future volatility may not be highly correlated in the cross-section. Such variation will result in a seemingly weak link between the two measures. To determine whether or not such heterogeneity is present, I calculate both the overall and the time-series correlation of implied and future volatility. I do this by adding a bond specific fixed effect when calculating the correlation.

Table 1 Panel B reports both the overall and the time-series correlations of log volatility. Interestingly, the 48% time-series (within group) correlation of implied and future volatility is much larger than the 4% overall correlation. Meanwhile, the overall correlation between historical and future volatility is equal to 69% while the time-series correlation is 47%. The relatively higher overall correlation is caused by the high firm level persistence in volatility; the cross-sectional (between group) correlation of historical and future volatility is 95%. I interpret the much larger time-series correlation as evidence of important unmodeled heterogeneity in implied volatility across bonds. In the next section I investigate both the time-series and the cross-sectional patterns in implied volatility further.

4 Predicting future volatility

If the corporate bond market is forward looking, news about future volatility will be incorporated into current bond prices. Implied volatility calculated from bond prices is a measure of the market's updated expectation. To test whether or not there is information about future volatility in current prices I use implied volatility to forecast future volatility. This investigation is related to the options literature which has performed a similar analysis using option price data.[15] To explore the relation for the bond market, I run a regression of future volatility on historical and implied volatility.

Table 2 reports results for the baseline predictive regressions using the full panel data set. The results are in line with the correlation patterns in the summary statistics: Historical volatility enters with a coefficient of 0.71 and explains 48% of the variation in future volatility. Implied volatility has an economically insignificant coefficient and does not improve explanatory power when included together with historical volatility.

I next focus on explaining the time-series variation by running fixed effects regres-

[15] Canina and Figlewski (1993) and Christensen and Prabhala (1998) investigate the predictive power of implied volatility in the options market. Jorion (1995) explores the predictive power of implied volatility in the foreign exchange market. Bates (2003) presents an overview and discusses the empirical option pricing literature.

sions.[16] In order to ensure sufficient time-series variation I restrict the sample to observations of bonds with at least eight transactions in the data set. I run three regressions including both measures separately and including them together. The results are quite different from the previous regressions. Implied volatility has more predictive power than historical volatility both when included by itself and when included with historical volatility. In the univariate regressions, the coefficient on implied volatility is 0.73 and the coefficient on historical volatility is 0.49. The measures can explain 24% and 22% of the time-series variation respectively. When both measures are included together, the coefficients are equal to 0.49 for implied and 0.31 for historical volatility. The R^2 is equal to 30% which represents a 34% (7.5 percentage point) increase in explanatory power relative to using historical volatility only. All coefficients are statistically and economically significant in all three specifications.

These results are quite striking. If we are interested in forecasting volatility at the firm level, implied volatility calculated from bond prices is as good as historical volatility. This is especially surprising when keeping in mind the empirical track record of structural form bond pricing models, the different factors affecting bond prices outside the model, and the probably high levels of noise associated with observed prices.

As a robustness check, I also run the same regressions but requiring a minimum of 15 observations for each bond issue. The results are essentially unchanged. The patterns in statistical and economic significance and the magnitude of coefficients across regressions with and without fixed effects are similar. The pattern in explanatory power across different specifications is also very similar.

4.1 Cross-sectional heterogeneity in implied volatility

An important component of the empirical analysis is the inclusion of a bond specific fixed effect. The fixed effect captures cross-sectional bond and firm specific heterogeneity in implied volatility and focuses the regression on variation in the time-series. I now briefly explore what determines variation in the fixed effect empirically and consider whether or not the predictable variation is consistent with the empirical structural bond pricing literature. This investigation adds to the evidence that the empirical analysis needs to take the heterogeneity into account.

Why might we expect strong cross-sectional variation in implied volatility? From

[16] If the model does not price bonds perfectly, the level of implied volatility will be a combination of expected future volatility and a pricing error. As long as the pricing error (or the component of the spread not related to credit risk) does not vary over time, I expect variation in implied volatility to predict variation in future volatility. I also expect the results to be robust qualitatively across different structural models.

the empirical structural bond pricing literature (e.g. Eom, Helwege, Huang 2004) we know that fitting structural models to data often results in large pricing errors. In addition, there is a lot of issue specific heterogeneity that is outside the model and is unlikely to be priced accurately. If there were no unmodeled cross-sectional heterogeneity present, average historical volatility would explain most of the variation in average implied volatility. Put differently, firms with low equity volatility would have correspondingly low implied volatility. In fact, average historical volatility accounts for only 3% of the cross-sectional variation in average implied volatility.

I therefore investigate if other characteristics can explain the cross-sectional variation in implied volatility. Implied volatility will vary with the characteristics both of the individual firm as well as the specific bond issue. The summary statistics in Table 2 reflect the large variation in maturity across bonds and in leverage and volatility across firms. There is also large variation in bonds' coupon rates. In a regression[17] of average implied volatility on average historical volatility, maturity, leverage, and the coupon rate, the R^2 is equal to 71%.[18] The most important determinants are maturity and leverage. Both enter with a negative coefficient and are statistically and economically significant. The regression results line up with what we would expect: First, lower leverage is associated with higher implied volatility. This is consistent with the fact that structural models account for a lower percentage of the spread for lower credit risk bonds (Huang and Huang 2003). In other words, if leverage is low, spreads are lower than implied by the model and implied volatility is high. Second, shorter maturity is associated with higher implied volatility which means that the model underpredicts spreads especially for short maturity bonds. In the data the "credit risk puzzle" is especially pronounced for short maturity bonds.[19]

These patterns also relate to the volatility smile documented in the option pricing literature (e.g. Derman and Kani 1994, Dumas, Fleming, Whaley 1998 among many others). The strong relation between implied volatility and both leverage and maturity is similar to the option implied volatility smile; the default option of a short maturity bond and that for a firm with low leverage are both deep out of the money.

[17] I do not report results in a Table; they are available on request.

[18] The Merton model implies a term structure of spreads that does not fit the data very well (Helwege and Turner 1999). Collin-Dufresne and Goldstein (2001) argue that the term structure of bond spreads will depend on the level of expected future leverage. Elton, Gruber, Agrawal, and Mann (2001) point out that a large part of the spread is due to tax effects. The tax effect will vary with the coupon size.

[19] The strong negative relation between average implied volatility is driven mainly by bonds of short maturity. When considering only bonds of maturity larger than 5 years and 12 years, the size of the coefficient drops to 1/2 and 1/4 of its originial size respectively.

4.2 Maturity and leverage interactions

I now examine variation in the sensitivity of future on implied volatility. In the regression in Table 2, the coefficient on implied volatility is assumed to be fixed across firms and bonds. However, it is plausible that, for instance, a change in implied volatility for a short maturity bond has different information about future volatility than the same change in implied volatility for a long maturity bond.

To explore heterogeneity in the effect of implied on future volatility, I allow the coefficient on implied volatility to vary across maturity and leverage groups. As before, the focus is on explaining time-series variation. I group the set of observations into five maturity and five leverage groups with cutoffs near the quintiles of the data. For maturity I choose below 3 years, 3-5, 5-8, 8-12, and 12-30 years. For leverage, I choose below 0.1, 0.1-0.2, 0.2-0.3, 0.3-0.5, and 0.5-1. Table 3 reports results from regressions of future volatility on historical and implied volatility where the coefficient on implied volatility varies either across maturity or leverage groups. To make the regressions comparable I use the same sample as in Table 2.

I find significant differences in the magnitude of the coefficient on implied volatility across maturity and leverage groups. Changes in future volatility are more sensitive to changes in implied volatility for bonds of longer maturity and of firms with lower leverage. For bonds below three years to maturity, the coefficient on implied volatility is 0.16, compared to a coefficient of 0.62 for bonds with more than 12 years to maturity. Allowing the sensitivity to vary increases the R^2 from 30% to 33%.

This difference in sensitivity is not surprising if implied volatility is a measure of expected volatility over the life of the bond. Intuitively, the same increase in expected volatility over the next period (which may represent a shock to a mean reverting heteroskedastic volatility process) will affect the implied volatility of longer maturity bonds by less. In such a setting, an increase in implied volatility for longer maturity bonds will be associated with a larger increase in expected future volatility than it will for shorter maturity bonds.[20] For leverage, there is also a significant difference in coefficient magnitudes. For firms with leverage below 0.1, the coefficient on implied volatility is equal to 0.61, compared to a coefficient of 0.41 for firms with leverage above 0.5. Allowing the coefficient to vary increases the R^2 from 30% to 31%.

[20] Another reason for the lower coefficient on short maturity bonds may be that implied volatility tends to be very high for those bonds, which means that variation in implied volatility is higher.

4.3 Adding single stock option implied volatility

The most common measure used to predict future volatility is option implied volatility (Canina and Figlewski 1993, Christensen and Prabhala 1998, Jorion 1995 among others). So far I have used only a measure of implied volatility calculated from bond prices in predictive regressions. I now consider option implied volatility as a predictor of future volatility to test whether bond implied volatility[21] remains significant when included together with option implied volatility in the predictive regression.

The option data is from the Ivy DB OptionMetrics data base. I match each bond transaction to option data. Since option data is available starting in 1996, matched option data runs from 1996-1999. In order to ensure that the option data is actual transaction data, I include data only when the volume traded is positive and require the transaction to be entered as having been last traded that day. The option data set reports option implied volatility and option delta. To calculate levels of implied volatility for European options, the Black Scholes model is used; for American options a binomial model is used.[22]

Option data is not always available daily, so I use data from the day of the bond transaction and the previous two days to increase the number of matched bond transactions. Following the literature, I use implied volatility of at the money options to forecast future volatility. I use the option delta, the sensitivity of the option price to the stock price, to measure moneyness. I measure option implied volatility as the average of all the put and call option implied volatilities with a delta between 0.4 and 0.6 (an at the money option has a delta close to 0.5). If no such data is available, I instead use the average of implied volatilities for all available options. I control for outliers by winsorizing the data of at the money observations at the 0.5% level and all other observations at the 1% level before calculating averages. This means that I replace observations below the 0.5th percentile with the 0.5th percentile and observations above the 99.5th percentile with the 99.5th percentile (and make adjustment accordingly for the 1% case). I choose different cutoff points since there are fewer outliers in implied volatility for at the money options. I am able to calculate a measures of option implied volatility for 83% of bond transactions over the sample. I use a total of 142,414 option price observations with a median of 5 observations for each matched bond transaction. The median option implied volatility is 32% and the correlation between option implied and future volatility is 66%.

Table 4 reports results from predictive regressions of future volatility on current

[21] To distinguish between implied volatility calculated from bond and option prices, I now refer to the measures as option implied volatiltiy and bond implied volatility.

[22] For details of the implied volatility calculations please see the OptionMetrics data documentation.

measures. As before, I consider only observations with at least eight transactions for each bond issue and focus on the time-series variation. For comparability of coefficients and regression fit I use the same sample across all specifications which contains 9,766 observations. I first consider all three measures in univariate regressions. Option implied volatility explains the largest share of the time-series variation. When including historical volatility and one of the measures of implied volatility, the regression with bond implied volatility has a slightly higher R^2 than the one with option implied volatility. This result is again quite striking and worth repeating: when predicting future volatility, bond implied volatility does as well as option implied volatility. When including all three measures, bond and option implied volatility both are statistically and economically significant. The regression has a 31.6% R^2, higher than both the R^2 of 26.4% when including option and historical volatility and the R^2 of 19.2% when using only historical volatility. In the regression with all three measures, the coefficient on historical volatility declines to 0.06, and is less statistically significant.

Overall, there is strong evidence that bond implied volatility contains information about future volatility. I interpret these results as evidence of a forward looking corporate bond market.

5 Pricing using different measures of volatility

I now consider the implications of a forward looking bond market for pricing. If bond prices reflect information about future volatility, a pricing model should fit better when using a forward looking instead of a historical measure. To investigate this, I construct a measure of predicted volatility, defined as the fitted values from a regression of future volatility on historical and option implied volatility. Since both historical and option implied volatility are known at time t, it is possible to calculate predicted volatility at the time the bond is traded. I implement the pricing model for all three measures of volatility: historical, option implied, and predicted. I use the Merton model to calculate predicted spreads given the different measures of volatility. This exercise relates to a large literature of empirical implementations of structural form models.[23] These studies construct measures of volatility using historical data. I add to this literature by exploring the effect of using a forward looking measure of volatility.

[23] For example, Jones, Mason, and Rosenfeld (1984) fit the Merton model to corporate bond data and compare bond prices to a benchmark of risk free debt. Anderson and Sundaresan (2000) look at averages of yields and find that fitted default probabilities match the historical experience if a risk premium of 5% is assumed. Huang and Huang (2003) consider structural models explicitly taking into account predictions of default probabilities. Eom, Helwege and Huang (2004) fit a range of structural form models and find that the fit varies a lot across models. Cooper and Davydenko (2004) fit the Merton model to get estimates of the equity premium for different rating classes. Ericsson, Reneby, and Wang (2005) consider structural models and CDS spreads.

I start by calculating predicted volatility. Consistent with the option pricing literature, I find that option implied volatility helps predict future volatility. In univariate regressions, option implied volatility does as well as historical volatility and increases the R^2 by 13% (5 percentage points) to an overall R^2 of 47% when included together with historical volatility.[24]

In the Merton model, leverage, time to maturity, and the face value of debt imply a predicted spread given a measure of volatility. For each bond transaction, I calculate three predicted spreads given the three measures of volatility. I impose some restrictions[25] for consistency and comparability reasons which leaves a set of 13,710 spread observations for which I calculate a predicted spread for all volatility measures.

Table 5 reports summary statistics of observed and predicted spreads. Predicted spread levels exhibit the characteristics common when implementing structural form bond pricing models the: low predicted spreads are unrealistically small and predicted spreads overall are lower than observed spreads.[26] The median predicted spread is 53 bps when using historical volatility or option implied volatility and is 64 bps when using predicted volatility, which are all lower than the median observed spread of 95 bps. The model does not, however, underpredict large spreads. Large predicted spreads are much larger than large observed spreads. The 95th percentile predicted spread lies between 543 bps and 630 bps, the 95th percentile of observed spreads is 223 bps.[27]

In order to test which measure of volatility is best at pricing bonds, I regress observed spreads on model predicted spreads. Table 6 Panel A reports the results. I again restrict attention to those observations with at least 8 transactions per bond issue. To control for outliers, I also drop the top and bottom 0.5% of predicted spreads. I first run a regression of observed on predicted spreads without an issue fixed effect. Not surprisingly, the coefficient on the predicted spread and the fit do not change much

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[24] I do not report the regression results in a Table; they are available on request. For consistency and comparability reasons, I construct the sample as follows: I drop outliers and run the regression excluding the top and bottom 0.5% of realized and historical volatility. I do not include a fixed effect in the regression since there is no reason to expect cross-sectional heterogeneity. The sample includes 15,797 bond transactions matched to option data.

[25] I use the same criteria as in the implied volatility calculation to choose the set of bonds for which I calculate a model predicted spread.

[26] Another reason for this difference is the fact that not the entire spread is due to credit risk (see e.g. Elton, Gruber, Agrawal, and Mann 2001, Huang and Huang 2003). However, assuming that the other spread components are stable over time, variation in predicted spreads will be able to explain variation in observed spreads. In addition, the bond specific fixed effect allows the size of the other spread components to vary across bonds.

[27] Overall, the "credit spread puzzle" is a little less present. This is most likely due to the particular implementation of the Merton model. It is consistent with the variation in severity of the underprediction of credit spreads across structural models (Eom, Helwege, and Huang 2004).

across choice of volatility measures. I next focus on time-series variation by including a bond issue fixed effect. In this regression specification the spread calculated using predicted volatility has the highest coefficient and explanatory power. The coefficient increases from 0.14 when using historical volatility to 0.26 for the spread calculated using predicted volatility. The R^2 improves from 11.1% for historical to 14.7% for predicted volatility, which is a 33% increase (3.6 percentage points).

To summarize, when using a forward looking measure of volatility to calculate model predicted spreads, the explanatory power in the time-series improves relative to using a historical measure.

5.1 Pricing bonds using a linear model

The Merton model imposes a lot of structure on the pricing relation. I therefore also fit a linear model using the same inputs as the Merton model. Following Campbell and Taksler (2003) who show that historical volatility helps price bonds in a linear setting, I regress observed spreads on explanatory variables and different measures of volatility. I include leverage, time to maturity and average rating spread (the same as the model inputs).

Table 6 Panel B reports the results. I report results from three different specifications: including historical volatility and option implied volatility separately and including both together. I do not use predicted volatility because this would impose a restriction on the relative importance of the two measures in the regression. When including the measures separately, both historical and option implied volatility come in with the expected sign and are significant. The regression including option implied volatility has a slightly higher fit than the regression including historical volatility. When both measures are included together, both are significant. Relative to including only historical volatility, the R^2 improves from 24.5% to 27.4%. I next focus on the time-series variation and include an issue fixed effect. Both measures of volatility are significant, both when included separately and when included together. The R^2 improves from 17.8% to 22.6% when including both measures of volatility relative to using only historical volatility.[28] These results provide evidence that it is better to use a forward looking measure of volatility when pricing bonds.[29]

[28] These results are consistent with independent work by Cremers, Driessen, Maenhout, Weinbaum (2006) who also use single stock option implied volatility and skewness to price bonds in a linear specification similar to that reported in Table 6 Panel B.

[29] Nevertheless, the resulting R^2 of 27.4% (of overall variation) and 22.6% (of time series variation) are far from perfect. These results are therefore consistent with the evidence in Collin-Dufresne, Goldstein, and Martin (2001) that changes in fundamentals cannot explain most of the variation in observed credit spread changes.

6 Conclusion

This paper contributes to the existing empirical corporate bond pricing literature by demonstrating in two ways that the corporate bond market is forward looking with respect to volatility. First, I find that implied volatility, calculated from yield spreads, contains substantial information about future volatility. Added to a regression of future on historical volatility, implied volatility is a statistically and economically significant predictor of future volatility and provides noticeable incremental explanatory power. This is true mainly in the time-series. Implied volatility retains explanatory power when included together with stock option implied volatility. These results are consistent with Hotchkiss and Ronen (2002) who find a high level of informational efficiency in the bond market. The results also suggest that the bond market, though in parts not very transparent (Goldstein, Hotchkiss, and Sirri 2006), nevertheless reflects important information about future market conditions.

Second, I find that using predicted volatility is better at pricing bonds than historical volatility. Calculating model implied spreads using the information from the options market results in better explanatory power of the time-series variation in yield spreads. In a linear regression of spreads on explanatory variables, option implied volatility comes in significantly and improves the fit when included together with historical volatility. This evidence is consistent with Cremers, Maenhout, Driessen and Weinbaum (2006) who price bonds in a linear setting.

In addition, the results have implications for the usefulness of structural bond pricing models. Schaefer and Strebulaev (2004) argue that structural models are useful since they give accurate predictions of how bond prices respond to changes in the firm's equity value (the hedge ratio or delta). In this paper, I use a structural model to explore the relation between changes in expected future volatility and current bond prices. The results provide insight about the sensitivity of bond spreads to volatility (option vega) and suggest that the theoretical and empirical sensitivities are quite close. This evidence further underscores that structural models can help to explain patterns in bond prices.

The results also have broader implications for prices in different markets. The evidence that the bond market reflects information available in the equity and option markets may shed light on the possibility of implementing profitable capital structure arbitrage strategies: If a firm's outstanding equity and bonds are priced efficiently it is less likely that such a strategy will return positive economic profits. In related work, Carr and Linetsky (2006) and Carr and Wu (2006) model joint pricing of credit and equity derivatives, specifically considering the effect of credit events on option valuation. The results in this paper suggest that, more generally, credit, equity and option markets share the same information.

A The Merton model

In the Merton (1974) model, risky debt is priced as safe debt plus a short put option. Using the Black Scholes (1973) option pricing formula for a put option and collecting terms, the value of risky debt is given by

$$B_t = V_t N(-d_1) + F \exp(-rT) N(d_2).$$

Since $s_t = -\frac{1}{T}\log\left(\frac{B_t}{F}\right) - r$ and defining $w = \frac{B_t}{V_t} = \exp(-(r+\bar{s})T)\frac{F_t}{V_t}$ this expression can be rewritten as

$$\frac{N(-d_1)}{w} + \exp(s_t * T) N(d_2) = 1$$

where

$$\begin{aligned} d_1 &= -\frac{\log(w_t) + \left(\bar{s} - \frac{1}{2}\sigma_A^2\right)T}{\sigma_A\sqrt{T}} \\ d_2 &= d_1 - \sigma_A\sqrt{T}. \end{aligned}$$

In order to calculate equity volatility from asset volatility, it is necessary to know the equity delta, the sensitivity of the equity value with respect to changes in asset value. Since the value of equity at any point in time is given by

$$S_t = V_t - B_t = V_t(1 - N(-d_1)) - \exp(-rT) F_t N(d_2),$$

the sensitivity of equity to asset value is

$$\frac{\partial S}{\partial V} = 1 - N(-d_1).$$

The level of implied equity volatility can then be calculated as

$$\sigma_t^{implied} = \sigma_A \frac{V_t}{S_t}\frac{\partial S}{\partial V} = \sigma_A \frac{V_t}{S_t}(1 - N(-d_1)) = \sigma_A \frac{1 - N(-d_1)}{1 - w}.$$

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Table 1: Summary statistics

Panel A reports summary statistics for bond spreads, maturity, leverage, and measures of volatility for the baseline sample. Spread is the yield spread in basis points over the closest U.S. Treasury on fixed-rate U.S. dollar, non-callable, non-puttable, non-sinking fund, non-convertible bond price observations from 1995-1999 with available accounting and rating data. Leverage is total debt to capitalization, maturity is the remaining time to maturity of the bond. Implied volatility is the level of volatility needed to match the bond spread. Historical and future volatility are calculated for 180 days before and after the bond price observation. In Panel B time-series correlation is the bond issue de-meaned correlation of volatility measures. Correlations are computed for the sub-sample with at least 8 observations for each bond issue.

Panel A: Baseline regression sample

	Spread	Maturity	Leverage	Implied volatility	Historical volatility	Future volatility
Mean	107	9.2	0.26	0.40	0.32	0.33
Median	92	6.9	0.20	0.38	0.30	0.31
St. Dev.	65	7.7	0.20	0.14	0.12	0.12
Min	10	0.1	0.001	0.13	0.13	0.10
Max	1355	30.0	0.97	0.95	0.88	0.92

Observations: 20,716

Panel B: Correlations of log volatility measures

correlation	Future volatility	Historical volatility
Historical volatility	0.69	1
Implied volatility	0.04	0.04

Observations: 20,716

correlation (time-series)	Future volatility	Historical volatility
Historical volatility	0.47	1
Implied volatility	0.48	0.54

Observations: 14,599

Table 2: Predictive regressions

This table reports results from regressing log future volatility on historical volatility and implied volatility. Historical and future volatility are measured as the sample standard deviation of daily returns over a 180 day period before and after the bond transaction respectively. The sample corresponds to the baseline sample discussed in Table 1. For the regressions (4) - (6), the sample is restricted to observations for issues with at least 8 transactions for each bond issue. Constants and fixed effects are not reported for the fixed effect regressions.

Regression of future volatility on historical and implied volatility

	(1)	(2)	(3)	(4)	(5)	(6)
Historical volatility	0.708		0.707	0.494		0.308
	(139.04)**		(138.84)**	(61.92)**		(34.01)**
Implied volatility		0.044	**0.016**		0.733	**0.492**
		(6.22)**	(3.08)**		(64.47)**	(37.81)**
Constant	-0.307	-1.116	-0.292			
	(48.08)**	(152.36)**	(36.80)**			
Observations	20716	20716	20716	14599	14599	14599
# of firms	606	606	606	355	355	355
# of bonds	3015	3015	3015	1074	1074	1074
Bond fixed effect				X	X	X
min # of obs./bond	1	1	1	8	8	8
R-squared	0.483	0.002	0.483			
within R-squared				**0.221**	**0.235**	**0.295**

Absolute value of t-statistics in parentheses
* significant at 5%; ** significant at 1%

Table 3: Maturity and leverage effects

This Table reports results from regressing log future volatility on historical volatility and implied volatility. The sample corresponds to that used in Table 2, specifications (4)-(6). Constants and fixed effects are not reported. Specification (1) is the same as specification (6) in Table 2.

Regression including maturity and leverage interactions

	(1)	(2)	(3)
Historical volatility	0.308	0.237	0.286
	(34.01)**	(25.57)**	(31.09)**
Implied volatility	0.492	0.160	0.612
	(37.81)**	(7.83)**	(30.97)**
3<maturity<=5*implied volatility		0.149	
		(12.89)**	
5<maturity<=8*implied volatility		0.272	
		(19.12)**	
8<maturity<=12*implied volatility		0.391	
		(23.85)**	
12<maturity<=30*implied volatility		0.462	
		(20.49)**	
0.1<leverage<=0.2*implied volatility			-0.014
			(1.23)
0.2<leverage<=0.3*implied volatility			-0.071
			(5.25)**
0.3<leverage<=0.5*implied volatility			-0.141
			(9.47)**
0.5<leverage<=1*implied volatility			-0.202
			(9.45)**
Observations	14599	14599	14599
Bond fixed effect	X	X	X
Number of bonds	1074	1074	1074
within R-squared	0.2954	0.329	0.305

Absolute value of t-statistics in parentheses
* significant at 5%; ** significant at 1%

Table 4: Predictive regressions including option implied volatility

This table reports results from regressing log future volatility on historical, bond implied and option implied volatility. The sample is restricted to observations for bond issues with at least 8 transactions for each issue. To compare R-squareds, results are reported for the same sample throughout.

Future volatility on historical, bond, and option implied volatility

	(1)	(2)	(3)	(4)	(5)	(6)
Historical volatility	0.466			0.257	0.164	0.057
	(46.23)**			(22.24)**	(11.66)**	(4.01)**
Bond implied volatility		**0.752**		**0.540**		**0.444**
		(52.46)**		(31.92)**		(26.23)**
Option implied volatility			0.637		0.495	0.389
			(55.11)**		(29.57)**	(23.42)**
Observations	9766	9766	9766	9766	9766	9766
Bond fixed effect	X	X	X	X	X	X
within R-squared	**0.192**	**0.234**	**0.253**	**0.274**	**0.264**	**0.316**

Absolute value of t-statistics in parentheses
* significant at 5%; ** significant at 1%

Table 5: Predicted yield spreads using different measures of volatility

This table reports summary statistics for observed and model implied spreads using historical, option implied and predicted volatility as inputs. Predicted volatility is measured as the fitted value from a regression of future volatility on historical and option implied volatility. The sample includes the set of observations for which there are predicted spreads for all measures of volatility.

Realized and model implied spreads (in basis points)

	Spread	Spread (historical volatility)	Spread (option implied volatility)	Spread (predicted volatility)
Mean	109	152	144	141
Median	95	53	53	64
St. Dev.	65	220	202	181
Min	10	0.001	0.001	0.002
5th percentile	38	0.04	0.07	0.26
95th percentile	223	630	594	543
Max	1355	1392	1192	1002

Observations: 13,710

Table 6: Pricing bonds with different measures of volatility

Panel A reports results from regressing realized spreads on predicted spreads. Predicted spreads are calculated using historical, option implied and predicted volatility. Panel B reports results from regressions of spreads on characteristics, historical and option implied volatility. The sample is restricted to observations for bond issues with at least 8 transactions for each issue.

Panel A: Regression of spreads on predicted spreads

	(1)	(2)	(3)	(4)	(5)	(6)
Spread (historical volatility)	0.092			0.144		
	(30.21)**			(31.48)**		
Spread (option implied volatility)		0.108			0.201	
		(32.52)**			(36.71)**	
Spread (predicted volatility)			0.109			0.259
			(29.93)**			(37.00)**
Constant	91.071	89.851	89.545			
	(121.51)**	(119.81)**	(114.53)**			
Observations	8603	8603	8603	8603	8603	8603
Bond fixed effect				X	X	X
R-squared	0.096	0.110	0.094			
within R-squared				0.111	0.145	0.147

Panel B: Regression of spread on explanatory variables

	(1)	(2)	(3)	(4)	(5)	(6)
Historical volatility	192.728		70.649	243.733		109.161
	(39.87)**		(9.25)**	(42.36)**		(13.97)**
Option implied volatility		249.083	183.714		325.950	233.241
		(44.35)**	(20.38)**		(47.65)**	(24.60)**
Leverage	-2.252	-7.987	-9.261	132.505	99.202	103.852
	(0.83)	(2.97)**	(3.46)**	(10.84)**	(8.25)**	(8.72)**
Rating spread	0.772	0.690	0.699	0.313	0.322	0.268
	(29.36)**	(26.43)**	(26.83)**	(4.03)**	(4.23)**	(3.55)**
Maturity	1.620	1.560	1.592			
	(23.11)**	(22.62)**	(23.15)**			
Constant	-58.115	-65.251	-68.115			
	(18.90)**	(21.38)**	(22.29)**			
Observations	10422	10422	10422	10422	10422	10422
Bond fixed effect				X	X	X
R-squared	0.245	0.268	0.274			
within R-squared				0.178	0.211	0.226

Absolute value of t-statistics in parentheses
* significant at 5%; ** significant at 1%

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