The Term Structure of Credit Spreads on Euro Corporate Bonds

van Landschoot, A.

Publication date:
2003

CentER

Discussion Paper

No. 2003–46

THE TERM STRUCTURE OF CREDIT SPREADS ON EURO CORPORATE BONDS

By Astrid Van Landschoot

April 2003

ISSN 0924-7815

TILBURG ◆ UNIVERSITY

The Term Structure of Credit Spreads on Euro Corporate Bonds

Astrid Van Landschoot
Ghent University*
Finance department

Abstract

Although there is a broad literature on structural credit risk models, there has been little empirical testing of these models. In this paper we examine the term structure of credit spreads on euro corporate bonds and the empirical validation of structural credit risk models. The latter provide a framework to analyze the main determinents of credit spreads. Using a dataset of 1577 investment grade corporate and 250 AAA rated government bonds, we first estimate the term structure of credit spreads for different (sub)rating categories with an extension of the Nelson-Siegel method. Within each rating category, credit spreads on plus rated bonds have significantly higher credit spreads than minus rated bonds. According to the structural models, the results indicate that credit spread changes are significantly negatively correlated with changes in the level and the slope of the default-free term structure. While changes in the slope affect all rating categories, changes in the level are more important for higher rated bonds (AAA and AA). The stock return and the implied volatility of the stock price seem to significantly influence credit spread changes. The lower the rating category and the longer the maturity of the bond the stronger both effects. For BBB rated bonds, changes in liquidity -measured as the bid-ask spread- significantly influence credit spread changes. Higher rated bonds (AAA and AA) are also driven by past credit spread changes.

JEL: C22, E45, G15
Keywords: Credit risk, Structural models, Nelson-Siegel

*I would like to thank Jan Annaert, John Fell and Bas Werker for helpful comments and suggestions. I am grateful to Deloitte and Touche who helped me to obtain part of the data. Part of this research has been conducted during an internship at the European Central Bank and a Marie Curie Fellowship at CentER, Tilburg University. All errors are my own.

1 Introduction

From 1998 onwards, the euro corporate bond market has become wider and more liquid. The number of corporate bonds has doubled over the last five years from just over 500 to around 1100. The development of the A and BBB rated market segment has been particularly impressive, coming from virtual non-existence in early 1998, to account for almost half the individual rated bond issues outstanding in late 2002. This evolution has reinforced the need to study the markets of default-risky instruments such as corporate bonds. In the past few years, credit derivatives were the fastest growing derivative products. They provide a convenient tool to control for credit risk exposure. In order to accurately price credit derivatives a good understanding of the determinants of the underlying yields and credit spreads is necessary. Furthermore, the changing regulatory framework, more specifically the Basle II Accord has even enhanced the focus on modeling default-risky instruments. Credit risk models can be used as a basis for calculating a banks' regulatory capital. As a response to the request of information by investors and regulators and to the internal risk monitoring, (central) banks and firms invest heavily in systems to measure credit risk and to understand the behavior of default-risky instruments. Banks have developed credit risk models in an attempt to quantify and manage risk across geographical and product lines. Firms want to price credit exposure and develop a system of internal capital allocation. For a central bank, it is important to analyze the link between corporate bonds and money markets to understand the transmission mechanism of monetary policy. Furthermore, as a leading indicator, credit spreads might be a useful indicator for monetary policy.

Many studies concentrate on the pricing of corporate bonds and theoretical models for credit risk. However, there has been little empirical testing of these models. As the US has a large and mature corporate bond market, most empirical studies on corporate credit spreads concentrate on US data (Duffee (1998), Collin-Dufresne et al. (2001), Elton et al. (2001) and others). Collin-Dufresne et al. (2001) relate US credit spread changes to common and firm-specific factors. They conclude that proxies that should measure changes in default probability and recovery rate, as suggested by traditional models, explain only about one quarter of the variation of credit spreads. Duffee (1998) finds a significant negative correlation between on the one hand credit spread changes and on the other hand the level and the slope of the default-free term structure. Changes in the level and the slope appear to have a much stronger effect on callable (compared to noncallable) bonds and on lower (compared to higher) rated bonds. Cossin & Hricko (2001) investigate the main factors driving a cross-section of credit default swap rates. They conclude that the rating category is the most important source of information. Besides, the level and the slope of the yield curve, leverage and the stock price seem to have a significant influence. Empirical studies on the determinants of European credit spreads is rather limited. Annaert & De Ceuster (2000) analyze credit spreads on eurobonds for different rating categories and time to maturity buckets. They find a negative correlation between credit spreads changes and changes in the level and the slope of the default-free term structure.

The main contribution of this paper is that we analyze the term structure of credit spreads on euro corporate bonds. Up till now, most studies on the euro corporate bond market concentrate on the time series properties of bond indices. In this paper however we use individual data to estimate the term structure. We then empirically investigate the main factors driving credit spread changes for different types of bonds based on (sub)rating categories and time to maturity. The *structural models,* initiated by Black & Scholes (1973) and Merton (1974), provide a theoretical framework to determine the main factors, namely the level and the slope of the default-free term structure, the stock return and the implied volatility of stock price. Furthermore, we also take into account differences in liquidity, measured as the bid-ask spread. We use a data set of 1577 individual corporate bonds and 250 government bonds from January 1998 until December 2002 included in the Merrill Lynch Broad Market indices. On a weekly basis, we extract the term structure of spot rates for different (sub)rating categories using an extension of the Nelson-Siegel model. We add four additional factors to the original Nelson-Siegel model that should capture differences in liquidity, taxation and subrating categories. Credit spreads are defined as the difference between the spot rates on corporate and government bonds.

A first analysis of the term structure shows that the changes in the level and the slope of the default-free term structure are two important determinants. While changes in the slope affect all rating categories, changes in the level mainly affect the higher rating categories, namely AAA and AA rated bonds. The stock return and the implied volatility of the stock price seem to significantly influence credit spread changes. The lower the rating category and the longer the maturity of the bond the stronger both effects. For BBB rated bonds, changes in liquidity - measured as the average bid-ask spread - are an important determinant. Higher rated bonds (AAA and AA) are also driven by past credit spread changes.

The paper is organized as follows. Section 2 presents the main determinants of credit spreads according to structural credit risk models. Section 3 gives an overview of the methodology to extract spot rates (Extended Nelson-Siegel model) and four measures of fit. In Section 4, we first present the data and the estimation results of the term structure of credit spreads. Then, we empirically analyze the main determinants of credit spread changes for different (sub)rating categories and years to maturity. Eventually, Section 5 concludes.

2 Determinants of Credit Spreads

The default risk of a bond is the possibility that the bondholder does not receive (in full) the payments stated in the contract, such as principal amount and interest payments. Credit risk is a more general concept, it is the risk associated with any kind of credit-linked events: changes in credit quality which also includes downgrading or upgrading in rating, changes in credit spreads, and the default event (see, for example, Bielecki & Rutkowski (2002)). Credit pricing approaches can usually be divided in two categories: (1) *structural or contingent-claim models* and (2) *reduced-form models*. The former type relates the credit event to the firm's value and the firm's capital structure. Therefore, these models are also called firm-value models. The reduced-form models do not attempt to model the asset value and the capital structure of the firm. Instead they specify the credit event as an unpredictable event governed by a hazard-rate process. These models are more tractable mathematically and therefore more suitable for credit derivatives pricing. For the purpose of this paper, however, we will concentrate on the structural models.[1] They provide an intuitive framework to determine the main factors that drive credit spreads changes.

In the structural models, initiated by Black & Scholes (1973) and Merton (1974), default occurs when at the maturity T the firm's asset value, $V_{A,T,}$ falls below a specified critical value. In the Merton model (1974), the critical value is given by the face value of the firms zerobond debt, L, which is by assumption the only source of debt. In case of default, debt holders receive the amount $V_{A,T}$. The value of a defaultable zero-coupon bond at time T can be written as

$$D(T) = \min(L, V_{A,T}) = L - \max(0, L - V_{A,T}) \tag{1}$$

The value of a defaultable zero-coupon bond is thus equal to the difference of the value of a default-free zero-coupon bond with face value L and the value of European put option written on the firm's assets, with strike price L and exercise date T.[2] The payoff, $L - V_{A,T}$, is often called the *put-to-default*. Since $V_{A,T}$ is the sum of the firm's debt and equity, the value of the equity at time T equals

$$E(V_T) = V_{A,T} - \min(V_{A,T}, L) = \max(0, V_{A,T} - L) = C(T)$$

The firm's equity can thus be seen as the value of a call option on the firm's assets. Issuing debt is similar to selling the firm's assets to the bond holders while the equity holders keep a call option to buy back the assets. Using the put-call parity, this is equivalent to saying that the equity holders own the firm's assets and buy a put option from the bond holders.

Merton (1974) derived a closed-form solution for the price of a defaultable zero-coupon bond by combining equation (1) with the Black and Scholes formula for the arbitrage price of a European put option. Having an analytical expression for the price of a defaultable bond, we can deduce the related credit spread (S) on a defaultable bond

$$S(t,T) = -\frac{\ln\left(\Phi\ (h_2)\ +\ 1/l\exp(-\kappa(T-t))\ \Phi(-h_1)\right)}{T-t} \tag{2}$$

[1] In practice, the firm value is typically not observable. This makes it difficult to specify and estimate an empirically valid process for the firm value. Furthermore, as a firm's capital structure is often quite complicated, these models may quickly become too complex to analyze in practice (Jones et al. (1984)).

[2] The bond holder has written a put option from the equity holders, agreeing to accept the assets in settlement of the payment if the value of the firm falls below the face value of the debt.

with

$$h_{1,2}(\Gamma, T-t) = \frac{-\ln(l) - \kappa\,(T-t) \;\; \pm \; 0.5 \; \sigma_V^2 \; (T-t)}{\sigma_V \sqrt{T-t}}$$

and

$$l_t = \frac{L_t}{V_{A,t}} = \frac{L \; e^{-r \; (T-t)}}{V_{A,t}}$$

where Φ denotes the cumulative probability distribution function of a standard normal.[3] κ is the payout ratio, $L_t = LB(t,T)$ is the present value of the promised claim (the face value) at the maturity of the bond (T) and $B(t,T)$ represents the value of a unit default-free zero-coupon bond. l is the leverage ratio, r the continuously compounded risk-free rate and σ_V the volatility of the firm assets value.

The Merton credit risk model for zero-coupon bonds has been extended in several ways by relaxing some restrictive assumptions. Geske (1977), for example derives closed-form solutions for risky coupon bonds. Black & Cox (1976) introduced the so-called first passage time models, which allow for bankruptcy before maturity of the bond. They extend the model with safety covenants that allow bondholders to force bankruptcy if certain conditions are satisfied. Cox et al. (1980) apply the Merton model to credit-risky debt with a variable interest rate to identify variable coupon payout structures that eliminate or reduce interest rate risk. Turnbull (1979) extends the model to an economy with both corporate tax and bankruptcy costs. Leland (1994, 1998) and Leland & Toft (1996) analyze corporate debt in the context of optimal capital structure. These studies conclude that in the presence of bankruptcy costs and strategic debt service, credit spreads are significantly higher. Longstaff & Schwartz (1995) further adapt the Black and Cox model by allowing interest rates to be stochastic. Furthermore, they do not require the recovery to be equal to the boundary value upon first passage but assume that the recovery is exogenously given. Although the Merton model has been extended in several ways, some factors such as the leverage ratio, the risk-free rate and the volatility of the firm's assets value.are common to most of the structural models.

The following macroeconomic and financial factors, which are discussed in more detail below, are included in the empirical analysis: the risk-free interest rate, the slope of the default-free term structure, the stock return, the implied volatility of the stock price and a measure of differences in liquidity (the bid-ask spread). Except for the liquidity proxy, the choice of the factors is justified by the existing literature on structural credit risk models,

2.1 Risk-free interest rate

According to the structural models, an increase in the risk-free rate implies a smaller credit spread. The interest level appears in the Black and Scholes formula as the

[3] $\lim_{t\to T} \Phi(-h_1) = \begin{matrix} 0, \; on \; \{V_{A,T} < L\} \\ 1, \; on \; \{V_{A,T} < L\} \end{matrix}$ and $\lim_{t\to T} \Phi(h_2) = \begin{matrix} 1, \; on \; \{V_{A,T} < L\} \\ 0, \; on \; \{V_{A,T} < L\} \end{matrix}$ hold.

discount rate of the expected cash flows of the option at maturity. As such, the interest rate can have an indirect effect on credit spreads. An increase of the interest rate reduces the present value of the cash flows or the price of the option. This effect implies a lower credit spread. Furthermore, the drift of the risk-neutral process in a Merton setup, which is the expected growth of the firm's value, equals the risk-free interest rate. An increase of the interest rate implies an increase of the expected growth rate of the firm value. This will in turn lower the price of the put option and the credit spread. Longstaff & Schwartz (1995)and Duffee (1998) find a negative correlation between changes in the three month Treasury bill rate and credit spreads changes on US investment-grade corporate bonds.

2.2 The slope of the term structure

As documented in Litterman & Scheinkman (1991) and Chen & Scott (1993), the vast majority of variation in the term structure can be expressed by changes in the level and the slope. Therefore, we also include changes in the slope of the default-free term structure. An increase in the slope implies an increase in the expected short-term interest rates. Similar to the motivation for the risk-free interest rate above, an increase in the slope is expected to lower the price of the put option and reduce a firm's default risk. Furthermore, the slope of the term structure is often related to future business cycle conditions. A decrease in the slope is considered to be an indicator of a weakening economy. Estrella & Hardouvelis (1991) conclude that a positively sloped yield curve is associated with an improving economic activity, measured by consumption, consumer durables and investment. Improving economy growth might in turn increase the growth rate of the firm value and reduce the default risk. Therefore, we expect a negative correlation between changes in the slope of the default-free term structure and the credit spread changes.

2.3 Stock price

Equation (2) includes the distance to default or the pseudo asset-to-debt ratio. The lower the distance to default, the higher the probability of default. According to the structural models, a firm defaults when the distance to default becomes one. An increase in the face value of a firms' debt (or a decrease in the value of the equity given a fixed asset value) increases the distance to default and the value of the put option. Structural models typically assume that the assets of the firm is a tradable security. In practice, however, the value of the assets is usually replaced by the value of the equity. A fall in a firm's stock price may increase the value of the put option as well as the credit spread. Ramaswami (1991) and Shane (1994) find that noninvestment grade bonds are correlated with equity returns. Kwan (1996) analyses the relation between individual stock returns and yield changes of individual bonds issued by the same firm. The author concludes that stocks lead bonds in firm-specific information. Lagged stock returns have explanatory power for current bond yield changes, while current stock returns are unrelated to lagged bond yield changes. Furthermore, the return on an equity index gives an indication of the business climate. Chen (1991), Fama & French (1989), Friedman & Kuttner (1992) and Guha & Hiris (2002) conclude that credit spreads behave counter-cyclically i.e. credit spreads tend to increase during recessions and narrow during expansions. Collin-Dufresne et al. (2001) include the S&P500 return to proxy for the overall state of the economy and find a negative correlation with credit spread changes.

Although we use individual bonds to extract spot rates for different (sub)rating categories, the estimated term structure is equal for all bonds in that risk class. Therefore, we use the return on market index as a possible determinant of credit spread changes instead of individual debt or stock returns (see 5.1). To test the hypothesis that stocks lead bonds, we include a one-period lag of the return. We expect a negative correlation between credit spread changes and the lagged return.

2.4 Implied Volatility

Equation (2) shows that credit spreads are affected by changes in the volatility of the firm assets value. The higher the volatility the more likely that the value of the firm falls below the value of the debt or the more likely the put option will be exercised. This will widen credit spreads. Ronn & Verma (1986) and Jones et al. (1984) link the volatility of the firm value to the volatility of the stock price. As pointed out before, the equity of a firm can be represented as a call option on the value of the assets of the firm with a maturity similar to the firm's debt and a strike price similar to the maturity value of the debt. A firm with a higher equity volatility is more likely to hit the boundary condition for default. An increase in the volatility of the stock price reduces the expected payoff and hence increases credit spreads. Campbell & Taksler (2002) find that equity variation explains as much variation in corporate credit spreads as do credit ratings.

Changes in the future volatility of the stock price can be extracted from the implied volatility of publicly traded options of the firm. This data is, however, not available for most bonds in the sample. Furthermore, we estimate the term structure of credit spreads for a group of bonds. Therefore, we use the implied volatility on a market index instead of the individual stock prices. .

2.5 Measure of Liquidity

Option models typically used in the structural approach assume perfect and complete markets where trading take places continuously. These assumptions imply no differences in liquidity between bonds. However, Collin-Dufresne et al. (2001) find that credit spread changes are significantly effected by measures of liquidity changes: (1) the difference between the on- and off-the-run Treasury yields and (2) the difference between the 10-year swap yield and the 10-year Treasury yield. Elton et al. (2001) conclude that besides taxation, recovery rate and bond age, liquidity is an important factor influencing bond pricing. Houweling et al. (2002) find a yield premium between liquid and illiquid euro-denominated bonds from 0.2 to 47 basis points depending on the liquidity indicator. Although we attempt to remove illiquid bonds, the credit spreads might still be influenced by changes in liquidity.[4] As in Amihud & Mendelson (1986, 1991) and Chakravarty & Sarkar (1999), we use the bid-ask spread as a measure for illiquidity. The quoted ask price includes a premium for the immediate buying, while the quoted bid price reflects a concession for immediate sale (Amihud & Mendelson (1986)). Since illiquidity can be measured by the cost of immediate execution, the bid-ask is natural measure of illiquidity. Narrowing bid-ask spreads indicate greater liquidity. We expect a positive relationship between changes in the average bid-ask spread and credit spread changes.

3 Modeling the Term Structure of Credit Spreads

A large part of the literature deals with the term structure of credit spreads (Sarig & Warga (1989), Fons (1994), Jarrow et al. (1997) and others). The idea is that spreads on corporate bonds depends on the time to maturity. Fons (1994) finds that for investment grade bonds marginal default probabilities and credit spreads increase as the time horizon lengthens but decrease for speculative grade bonds. This implies an increasing term structure of credit spreads for investment grade bonds and a decreasing term structure for speculative grade. To explain this phenomenon, the author suggests an underlying mean reversion in company credit outlooks. For highly rated bonds there are only two possibilities, or stable ratings or declining ratings. A lower rated firm may face a higher probability of default in the short term. Over the long run, low-rated firms that survived the first few years tend to evolve to the middle ratings, top-rated firms tend to decrease to the middle ratings and the middle rating tend to stay in that category. This implies a mean-reversion of ratings as well as credit spreads. In this paper, we concentrate on the investment grade bonds (AAA, AA, A and BBB rating) and therefore expect to find an increasing term structure. To estimate the term structure of credit spreads we use an extension of the Nelson-Siegel model, which will be discussed in more detail below.

3.1 Extended Nelson-Siegel Approach

The term structure of credit spreads is calculated as the difference between the term structure of spot rates on corporate and government bonds. There are a few reasons for using the spot rates instead of yields to maturity. The yield to maturity depends on the coupon rate. The yield to maturity of bonds with the same maturity but different coupons may vary considerably. As such, the credit spread will depend on the coupon rate. Furthermore, if we use yields to maturity to calculate the credit spread, we compare bonds with different duration and convexity. On the other hand, spot rates are not observable. Therefore, we use an extension of the parametric model introduced by Nelson & Siegel (1987) to extract the spot rates for different rating categories (AAA, AA, A and BBB). This Nelson-Siegel (NS) model

[4] We attempt to remove illiquid bonds by excluding bonds that have on average less than one price quote a week.

offers a conceptually simple and parsimonious description of the term structure of interest rates. It avoids over-parametrization while it allows for monotonically increasing or decreasing yield curves and hump shaped yield curves. Diebold & Li (2002) conclude that the NS method produces one-year-ahead forecasts that are strikingly more accurate than standard benchmarks. Furthermore, it avoids the problem in spline-based models to choose the best knot point specification.[5]

The idea of the NS method is to fit the empirical form of the yield curve with a pre-specified functional form for the spot rates, which is a function of the time to maturity of the bonds.

$$i_{t,j}(m,\boldsymbol{\theta}) = \beta_0 + \beta_1 \tfrac{1-\exp(-m_t\ /\tau_1)}{(-m_t\ /\tau_1)} + \beta_2 \left(\tfrac{1-\exp(-m_t\ /\tau_1)}{(-m_t\ /\tau_1)} - \exp\left(-m_t\ /\tau_1\right)\right) + \varepsilon_{t,j}$$
$$\text{with } \varepsilon_{t,j}\tilde{}N\left(0,\sigma_j^2\right) \tag{3}$$

i_t denotes the spot rates at time t, $j = \{\text{AAA, AA, A and BBB}\}$, m is the time to maturity of the bonds and $\boldsymbol{\theta} = (\beta_0, \beta_1, \beta_2, \tau_1)$ is the vector of parameters. β_0 represents the long-run level of interest rates, β_1 the short-run component and β_2 the medium-term component. If the time to maturity goes to infinity, the spot rate converges to β_o. If the time to maturity gets to zero, the spot rate converges to $\beta_0 + \beta_1$. To avoid negative interest rates, β_0 and $\beta_0 + \beta_1$ should be positive. β_0 can be interpreted as the long-run interest rate and $\beta_o + \beta_1$ as the instantaneous interest rate. This implies that $-\beta_1$ can be interpreted as the slope of the yield curve. The curve will have a negative slope if β_1 is positive and vice versa. β_1 also indicates the speed with which the curve evolves towards its long-run trend (Bolder & Streliski (1999)). β_2 determines the magnitude and the direction of the hump or through in the yield curve. The parameter τ_1 is a time constant that should be positive in order to assure convergence to the long-term value β_0. This parameter specifies the position of the hump or through on the yield curve.[6]

However, in accordance with Elton et al. (2001), we find that the NS method results in systematic errors that are a function of liquidity, the coupon rate and subcategories within a rating category (plus, flat and minus rating). Therefore, we extend the original NS model with four additional factors. First, to capture differences in liquidity within a rating category, we add the bid-ask spread as an additional factor (Liq). If liquidity decreases, bid-ask spreads and hence spot rates might go up. Second, to capture part of the taxation effect, we include the difference between the coupon of a bond and the average coupon rate in a rating

[5]For comparison with other methods, see Green & Odegaard (1997)

[6]Svensson (1994) extended the NS model with an additional exponential term that allows for a second possible hump or through. However, Geyer & Mader (1999) find that the Svensson method does not perform better in the form of smaller yield errors in the objective function compared to the NS method. Furthermore, Bolder & Streliski (1999) conclude that the Svensson model requires approximately four times as much time in estimation.

category $\left(C-\overline{C}\right)$. The underlying idea is that low coupon bonds are tax advantaged compared to high coupon bonds. Finally, another reason why bonds might have different yields within a rating category is that they are not viewed as equally risky. Moody's and Standard and Poors both introduced subcategories within a rating category. Bonds that are rated with a plus or a minus might be considered as having a different probability of default compared to the flat letter rating. Therefore, we include a dummy for the plus subcategory (Dum_pl) and a dummy for the minus subcategory (Dum_mi). For simplicity, we assume that the additional factors may only affect the level of the term structure and not the slope. The following extended version of the NS model is estimated

$$\begin{aligned} i_{t,j}(m,\widetilde{\boldsymbol{\theta}}) &= \beta_o+\beta_1\tfrac{1-\exp(-m_t\ /\tau_1)}{(-m_t\ /\tau_1)}+\beta_2\left(\tfrac{1-\exp(-m_t\ /\tau_1)}{(-m_t\ /\tau_1)}-\exp\left(-m_t\ /\tau_1\right)\right) \\ &+\beta_3\ Liq_t+\ \beta_4\ (C_t-\overline{C}_t)+\ \beta_5\ Dum\_pl_t+\ \beta_6\ Dum\_mi_t+\widetilde{\varepsilon}_{t,j} \\ &\text{with } \widetilde{\varepsilon}_{t,j}\,\tilde{}\,N\left(0,\sigma_j^2\right) \end{aligned} \tag{4}$$

$\beta_o, \beta_1, \beta_2, \tau_1$ represent the parameters in the original NS model while β_3, β_4, β_5 and β_6 represent the sensitivities of the spot rates to the additional factors.

Every set of parameters $(\widetilde{\boldsymbol{\theta}})$ translates in different spot rates and bond prices. Therefore, we estimate the parameters as such as to minimize the sum of squared errors between the estimated and observed yields to maturity that belong to specific rating category j at time t.[7]

$$\widehat{\boldsymbol{\theta}}_{t,j}=\min_{\boldsymbol{\theta}_{t,j}}\sum_{i=1}^{N_t}\left(y_{t,j}^{NS}-y_{t,j}\right)^2$$

We apply maximum likelihood to estimate the parameters on a weekly basis for AAA rated government bonds and different types of corporate bonds. This allows us to estimate the term structure of credit spreads for different types of bonds.

3.2 Goodness of Fit Statistics

In order to compare the extension with the original NS method and to test how well the (extended) NS model describes the underlying data, we estimate three in-sample measures: (1) the *average absolute yield errors* (AAE_{yield}), (2) the percentage of bonds that have a yield outside a 95% confidence interval (*hit ratio*) and (3) the *conditional and unconditional frequency of pricing errors.* Finally, we examine the

[7] Alternatively, bond prices could be approximated and price errors could be minimized. Deacon & Derry (1994), however, find that minimizing yields improves the fit of the yield curve because greater weight is given to bonds with maturities up to about ten years.

out-of-sample *forecasting performance*. For each measure, we compare the results of the NS model with those of the extended NS model.

1. The first measure of goodness of fit is the root mean squared yield errors ($RMSYE_{yield}$).

$$AAE_{yield,t} = \sqrt{\frac{\left|(y_{i,t}^{NS} - y_{i,t})\right|}{n}} = \sqrt{\frac{|\varepsilon_{i,t}|}{n}}$$

   $y_{i,t}$ and $\widehat{y}_{i,t}$ are the observed and estimated yields to maturity at time t in rating category i. n is the number of bonds at time t. The higher the $AAE_{yield,t}$ the less good the quality of the fit.

2. The second measure is the percentage of bonds that have an observed yield to maturity outside a 95% confidence interval around the estimated term structure of yields to maturity. We use the delta method and the maximum likelihood results to obtain a 95% confidence interval for the term structure of estimated yields to maturity.

$$\Pr\left(\mathbf{f}(\widehat{\boldsymbol{\theta}}) - \sqrt{\mathbf{diag}\,(\mathbf{H})} \leq \mathbf{f}(\boldsymbol{\theta}) \leq \mathbf{f}(\widehat{\boldsymbol{\theta}}) + \sqrt{\mathbf{diag}\,(\mathbf{H})}\right) = 95\%$$

   with $H = \frac{\vartheta\ \mathbf{f}(\boldsymbol{\theta})}{\vartheta\ \boldsymbol{\theta}}\Sigma\frac{\vartheta\ \mathbf{f}(\boldsymbol{\theta})}{\vartheta\boldsymbol{\theta}}$ where Σ denotes the variance-covariance matrix of the estimated parameters $\widehat{\boldsymbol{\theta}}$. $\mathbf{f}(\widehat{\boldsymbol{\theta}})$ denote the estimated yields to maturity according to the (extended) NS method.

3. As a third measure, we report the conditional frequency of pricing errors. We examine the pricing errors of individual bonds at time t and classify them in three categories: positive, zero or negative. Errors are assumed to be zero if the absolute value of the yield error is below the bid-ask spread. We then look at pricing errors of these bonds at time $t + 1$ and report the changes (transition matrix). If pricing errors are white noise, there should be no clear pattern in the transition matrices. Bliss (1997) and Diebold & Li (2002) find that regardless of the term structure estimation method, there is a persistent difference between estimated and actual bond prices.

4. The previous measures are in-sample goodness of fit measures. Bliss (1997), however, concludes that in-sample results may give a distorted view of a method's performance. Therefore, we also examine the out-of-sample forecasting performance. First, we estimate the vector of parameters $\boldsymbol{\theta}$ at time t. Then, we use $\widehat{\boldsymbol{\theta}}_t$ to estimate the term structure of the yields to maturity at time $t+k$. $\widetilde{y}_{t+k} = f(m, \widehat{\boldsymbol{\theta}}_t)$ are the forecasts of the yields to maturity at time $t + k$, with $k = \{1, 2, 4\}$. We estimate the AAE_{yield} for the forecasted yields resulting from the (extended) NS model.

4 Empirical Analysis

4.1 Data Description

The analysis uses individual bond data of the EMU Broad Market indices from January, 1 1998 until December, 30 2002 constructed by Merrill Lynch. The EMU Broad Market indices are based on secondary market prices of bonds issued in the eurobond market or in EMU-zone domestic markets and denominated in euro or one of the currencies that joined the EMU. Besides bond prices, the dataset contains data on the coupon rate, the time to maturity, the rating, the industry classification, and the amount issued. Ratings are composite Moody's and Standard & Poors ratings. The Merrill Lynch Broad Market index covers investment-grade firms. Hence the analysis is restricted to corporate bonds rated BBB and higher. Further, all bonds have a fixed rate coupon and pay annual coupons. To be included in the Merrill Lynch index, bonds should have a minimum size of 100 million euro for corporate bonds and 1 billion euro for government bonds. Because the EMU Broad Market index has rather low minimum size requirements, it provides a relatively broad coverage of the underlying markets.

Several filters are imposed to construct the sample of defaultable corporate bonds. First, we exclude bonds for which there is no rating available. Second, in order to have a sample of liquid bonds, we exclude all bonds which have less than one price quote a week on average. Third, to ensure that we consider bonds backed solely by the creditworthiness of the issuer, we eliminate such bonds as asset-backed securities. For consistency, only regulated bonds are considered. Fourth, as in Duffee (1999), we only use bonds with at least one year remaining to maturity. Finally, we eliminate bonds that have a price that is out of line with surrounding prices (pricing errors). These filters leave us with a data set of 1577 corporate bonds issued by 448 firms. Concerning government bonds, if a country issued two bonds in one month, we exclude the bond that has less price quotes. We have 250 AAA rated government bonds.[8]

The credit rating is the most widely observed measure of credit quality. We make a distinction between four rating categories: AAA, AA, A and BBB. From the 1577 corporate bonds that enter the Merrill Lynch index between January 1998 and December 2002, 408 bonds have an AAA rating, 509 an AA rating, 484 an A rating and 176 a BBB rating. If a bond is downgraded to a speculative grade rating (below BBB) or matured, it is removed from the index. Graph 1 shows the number of bonds in each rating category over the sample period. While the number of AAA and AA rated bonds has been stable over the sample period, the number of A and BBB rated bonds has increased enormously. Between January 1998 and April 2000, the Merrill Lynch includes less than 50 BBB rated bonds on average. Moreover, less than half of the BBB rated bonds included are quoted during that period. Graph 2 presents, for each rating category, the number of bonds that are

[8]The sample of 250 AAA bonds consists of 114 German, 58 Austrian, 55 French, 37 Dutch, 8 Irish, 4 Spanish and 3 Finish bonds.

not quoted in percentage of the total number of bonds in that rating category. If a higher trading frequency reflects more liquidity, this graph gives a rough indication of liquidity. It seems that for BBB rated bonds, less than 50% of the bonds were quoted on a weekly basis from January 1998 until January 2000. From June 2000, the indicator sharply decreases below 20% and converges to a level comparable to higher rated bonds.

Panel A of Table 1 presents the average number of corporate bonds in maturity buckets of 2 or 3 years and for different rating categories. The number of AAA rate bonds decreases with the time to maturity. For AA and A rated bonds the number of bonds is equally spread over the maturities. On average, there are less bonds in the BBB rating category compared to the other ratings. Furthermore, no BBB has a maturity beyond ten years to maturity. Panel B of Table 1 presents the average number of bonds based on rating category and sector. We make a distinction between bonds issued in the financial, industrial and utilities sector.[9] Panel C shows that the majority of the AAA and AA rated bonds are financials, 96% and 81% respectively, whereas the majority of the BBB rated bonds are industrials, 84%. A rated bonds are a mixture of financials and industrials, 54% and 39% respectively. Since the utilities represent only a small group in each rating category, we do separately analyze them.

Panel A of Table 2 contains information on the time to maturity of the corporate bonds and the number of weeks that a bond is quoted. For each bond, we calculate three statistics (mean, minimum and maximum) of the time to maturity. Then, we calculate the mean of the means, the minimum of the minima and the maximum of the maxima for each rating category. The minimum years to maturity (of the minima) is one and that the maximum (of the maxima) varies between 10 for BBB rated bonds and almost 22 for A rated bonds.[10] Although higher rated bonds have a higher time to maturity, the number of bonds beyond 10 years to maturity is limited. The average number of weeks that a bond is included in the index is 145 weeks.

4.1.1 Probability of Rating Transition

If a bond is downgraded, it will be perceived as riskier by the market. This may result in a decrease in bond value. Thus, even if no default occurs, a downgrading might influence the value of a bond. Panel B of Table 2 presents the average yearly ratings transition matrix that is an average of five transition matrices from Jan. 1998 until Dec. 2002. For each rating category, panel C of Table 2 gives the probability that a bond has the same rating or has been up- or downgraded after one year. Each row corresponds to the initial rating and each column corresponds to the rating after one year. The largest probabilities are on the diagonal, which indicates that most bonds do not change rating within a period of one year. Some

[9] Securitized bonds, quasi & foreign government bonds and Pfandbriefe are not included in the analysis.

[10] We only consider bonds that have a time to maturity of at least one year and are included in the index for at least 12 weeks.

probabilities are equal to zero. For BBB rated bonds, for example, the probability of being upgraded to AAA or AA within one year is negligible. The last column gives the probability that a bond is removed from the index although it has more then one year to maturity.[11] For example, when a bond is downgraded to speculative grade, it is removed from the index and its rating becomes NA (Not Available). The first column gives the average number of bonds with an initial AAA, AA, A or BBB rating.

Second, we estimate the time-varying probability of being upgraded or downgraded, using a moving window of 6 months. The probability of being upgraded is rather stable over time (not presented in the paper). The probability of being downgraded varies significantly over time (graph 3). The probability for being downgraded from A to BBB is especially high in 2001 and the beginning of 2002. The probability of being downgraded from AA to A rating is around 6% in 2000. From the second half of 2002, it sharply increased to almost 16%.

4.2 Estimating the Term Structure of Credit Spreads

4.2.1 Yield Errors of the Nelson-Siegel model

Before comparing the extended with the original NS model, we first analyze the yield errors $\left(\varepsilon_t = y_t^{NS} - y_t\right)$ of the original NS model. Within each rating category and on a weekly basis, we split the sample into (1) plus and minus-rated bonds, (2) bonds with above and below average coupon rates and (3) bonds with above and below average bid-ask spreads. For each rating category, yield errors of the plus-rated bonds are on average positive while those of minus-rated bonds are on average negative (see panel A of Table 3). The difference between the plus and the minus subcategory is more pronounced for lower rated bonds. Thus, it is most important to make a distinction for BBB. Panel B presents the t-test for equality of means. The null hypothesis that plus and minus rated bonds have equal mean yield errors is rejected at a 1% level. Second, bonds with above average coupon rates seem to have higher yields compared to bonds with below average coupon rates. Yield errors are on average negative (positive) for bonds with above (below) average coupon rates. The null hypothesis of equal means is rejected. Finally, we make a distinction between bonds with above and below average bid-ask spreads. Bonds with high bid-ask spreads have higher yields and thus negative yield errors. The t-test rejects the null hypothesis of equal means.

To capture the simultaneous effect of the factors, we regress the yield errors on a dummy for a plus rating, a dummy for a minus rating, the bid-ask spread and the deviation from the average coupon rate on a weekly basis.

$$\varepsilon_{t,j} = \gamma_1 Dum\_pl_{t,j} + \gamma_2 Dum\_mi_{t,j} + \gamma_3 Liq_{t,j} + \gamma_4 (C_{t,j} - \overline{C}_{t,j}) + \eta_{t,j}$$

with $j = \{$AAA, AA, A and BBB$\}$ and $(\gamma_1,\ \gamma_2,\ \gamma_3,\ \gamma_4)$ the vector of parameters. We use weekly data from January 1998 until December 2002. Regression analysis

[11] Bonds are normally removes from the Merrill Lynch Broad EMU index one year before maturity.

confirms the previous results, namely that yield errors are a function of the subrating categories (plus, flat or minus), liquidity and the coupon rate. Panel C of Table 3 presents the percentage of regressions (weeks) that have the expected sign and are significant at a 5% level. The tax effect seems to be most important for higher rating categories, namely AAA and AA. The latter effect has a significant coefficient in 94%, respectively 70%, of the regressions for AAA, respectively AA, rated bonds. As expected, the effect of the bid-ask spread is most important for BBB rated bonds. In almost half of the regressions the bid-ask spread has a significant effect. The distinction between plus, flat and minus rating seem to be an important determinant of differences in yield errors. Bonds that are rated plus or minus are viewed as having a different risk profile compared to bonds with a flat rating. Splitting the group of bonds in three subgroups would have the disadvantage of having less bonds in each group. Therefore we will include two dummies. For BBB rated bonds we make a distinction between on the one hand BBB plus rated bonds and on the other hand BBB flat and BBB minus rated bonds. We do not have enough BBB minus rated bonds to make it an additional subrating category.

4.2.2 Extended Nelson-Siegel Model: Results

We have shown that additional factors besides the time to maturity can cause systematic yield errors. Therefore, we reestimate the term structure of credit spreads using the extended NS model (see equation 4). Graph 4 to 7 present the credit spreads on AAA, AA, A and BBB rated bonds with 3, 5, 7 and 10 years to maturity. The spreads on AA, A and BBB rated bonds are a weighted average of the spreads in the subrating categories (plus, flat and minus). The weights at time t are the number of bonds in the subrating categories in percentage of the total number of bonds in that rating category at time t. In the case of BBB rated bonds, we only make a distinction between two subcategories, (1) BBB plus and (2) BBB flat and minus, due to the fact that there are only few BBB minus rated bonds. Most of the time, credit spreads are an increasing function of the time to maturity. From January 1998 until August 1998, however, the term structure of credit spreads is flat or downward sloping. From the beginning of 2000 until the beginning of 2001, credit spreads of all rating categories increased. This coincides with a period of zero or negative growth rate of the OECD leading indicator for the EMU area. In the first quarter of 2001, credit spreads decline as investors believe that the downturn in growth and the rise in default rates have been priced in bond yields. After September 11, 2001 credit spreads on AA, A and BBB rated bond sharply increase. From January 2002, credit spreads slowly decrease to their level before September 11. At the same time, the growth rate of the OECD leading indicator become positive, with a peak growth rate in December 2001. From mid 2002, credit spreads in virtually all rating categories widen again. These evolutions seem to indicate that credit spreads behave counter-cyclically, i.e. credit spreads tend to widen during recessions and narrow during expansions.

As in Collin-Dufresne et al. (2001), Elton et al. (2001) and Duffee (1998), we find that issuers of lower rated bonds pay a higher credit spread. Table 4 presents the average and the standard deviation of credit spreads in subrating categories of bonds with 2 to 10 years to maturity. Bonds with an AA plus rating have a credit spread that is on average fifteen basis points lower compared to the AA minus rating category. For the A rating category, the difference between the plus and minus subcategory is even more pronounced. The credit spread on A minus rated bonds is on average double the spread on A plus rated bonds. For the BBB rated bonds, there is a difference of fifty basis points between on the one hand the plus rating and on the other hand the flat and the minus rating. Even tough we only make a distinction between two subrating categories instead of three, there are not as much bonds in each subrating category compared to the AA and the A rating category. The disadvantage of having only few bonds in a subrating category is that one or two outliers can drive the results. This explains why flat and minus BBB rated bonds have a spread that is on average fifty basis points higher. Therefore, in the remainder of the paper, we will concentrate on the weighted average of the BBB credit spreads. For AA and A, we will distinguish between plus, flat and minus subrating categories. For AAA and AA rated bonds, credit spreads on bonds with 2 years to maturity have a credit spread that is on average a few basis points higher compared to bonds with 3 years to maturity. A possible explanation is that bonds with 2 years to maturity pay a higher liquidity premium and thus have a higher spread.

Besides rating categories, we also make a distinction between three sectors: financial, industrial and utility. Panel B of Table 1 shows that AAA and AA rated bonds are mainly financials whereas BBB rated bonds are mainly industrials. The group of A rated bonds is the only category for which there is an equal mixture of financials and industrials and thus we are able to estimate a separate term structure[12]. The term structure of credit spreads for industrial bonds is on average higher compared to financials (the results are not shown). Panel B of Table 2, however, shows that more than 85% of the A financials are rated plus or flat whereas 77% of A rated industrials are rated flat or minus. It is very likely that industrials have a higher credit spread simply because they mainly consist of lower rated bonds compared to financials. Therefore, in what follows, we will only concentrate on different ratings and their subcategories instead of sectors.

4.2.3 Measures of Fit

Graph 8 presents the average yield errors (AAE_{yield}) for AAA, AA, A and BBB rated bonds using the NS model (solid lines) and the extended NS model (dotted lines). The results indicate that the AAE_{yield} for all rating categories are lower if the extended model is used to estimate the term structure of spot rates. Up till the first half of 2000, yield errors are similar across rating categories (except BBB). From October 2000, yield errors as well as credit spreads in all rating categories start to diverge. It seems that periods of higher credit spreads coincides with periods of higher volatility of yields. Table 5 present the average and standard deviation of the yield errors and the results of the t-test (p-values are given between brackets).

[12]Utilities are not analyzed separately because we do not have enough bonds.

The null hypothesis of equal yield errors of the NS and the extended NS model is rejected at 5% level for all rating categories. Panel B shows that, except for AA, yield errors are on average higher for bonds with a short to medium term to maturity compared to bonds with a long time to maturity. Although the difference between yield errors is small, it seems more difficult to estimate the term structure at the longer maturity end. Panel C presents the hit ratio, i.e. the percentage of bonds that have an observed yield to maturity outside a 95% confidence interval around the estimated term structure of yields to maturity. The results show that between 2% and 3% of the bonds have a yield outside a 95% confidence interval if we use the NS model. Using the extended NS model results in much lower hit ratios, between 0.5% and 1.3%. For AA, A and BBB rated bonds, most yields outside the confidence interval are above the interval.

The third measure of fit is the transition matrix of the fitted yield errors (6). For each rating category, fitted yield errors of the NS model (panel A) and extended NS model (panel B) are classified in three groups: negative, zero or positive. Column 3 of Table 6 gives the percentage of fitted yield errors in a certain category (unconditional frequency). Columns 4 to 6 present the percentage of fitted yield errors in a category at time t conditional on the category at time $t+1$ (conditional frequency). If errors are random, the classification at time t should have no effect on the classification at time $t+1$. This means that the unconditional and conditional frequency of being positive should be similar. Table 6, however, shows that the probability of being positive at time $t+1$ if the yield errors is positive at time t is above 50% for all rating categories. Although the difference is very small, the persistence of the yield errors is smaller for the extended NS model. Furthermore, for AAA rated bonds there is a higher probability that the yield errors fall within the interval between the bid and the ask yield, 29% for AAA rated bond compared to 7% for BBB rated bonds. If we use the extended NS model even more AAA rated bonds have yield errors within the bid-ask spread (33% compared to 9%).

Finally, we test the out-of-sample forecasting performance of both the NS and the extended NS model. We estimate one-week, two-week and one-month ahead forecasts of the yields. Table 7 presents the AAE_{yield} of the original model and the forecasts, for both the NS and the extended NS model. The AAE_{yield} of a one month ahead forecast of AAA and AA rated bonds are more than double the in sample AAE_{yield} of the original (extended) NS model. A one week ahead forecast results in yield errors that are only slightly higher than the original model. The forecast yield errors resulting from the extended NS model are always smaller than those from the NS model.

4.3 Determinants of credit spread changes

4.3.1 Model

For the regression analysis, we use credit spreads on AAA, AA, A and BBB rated bonds with 2 to 10 years to maturity. Credit spreads on AA, A and BBB rated bonds are a weighted average of the credit spreads on subrating categories within each rating (plus, flat and minus). The weights are the number of bonds in each subrating category in percentage of the total number of bonds in that rating category. Beyond 10 years to maturity there are not enough bonds to estimate the term structure properly (see Table 1). For the same reason, we do not include credit spreads of BBB rated bonds with 2 years to maturity. The underlying data covers the period January 1998 until December 2002. Table 4 presents the summary statistics of the level of the dependent variable in the regression analysis. In order to analyze the main determinants of credit spread changes of a rating category j, with $j = \{$AAA, AA plus, AA flat, AA minus, A plus, A flat, A minus and BBB$\}$, we estimate the following equation

$$\begin{aligned}\triangle CR_{t,j} = \beta_o + \beta_{\triangle i_3} \triangle i_{3,t} + \beta_{\triangle slope} \triangle i_{slope,t} + \beta_m R^m_{t-1,j} + \beta_{\triangle IV} \triangle IV_t \\ + \beta_{\triangle Liq} \triangle Liq_{t,j} + \beta_{lag} \triangle CR_{t-1,j} + \nu_{t,j}, \text{ with } \nu_{t,j} \tilde{} N\left(0, \sigma^2\right)\end{aligned} \tag{5}$$

where $\beta = (\beta_o, \beta_m, \beta_{\triangle i_{3,t}}, \beta_{\triangle slope}, \beta_{\triangle IV}, \beta_{\triangle Liq}, \beta_{lag})$ is the vectors of parameters. $\triangle i_3$ and i_{slope} are the changes of the level and the slope of the default-free term structure. As in Duffee (1998), we define the slope as the spread between the 10-year constant maturity EMU government bond yield minus the 3 month euro rate. The level is defined as the 3 month euro rate. R^m_j is a weighted average of the return on the DJ Euro Stoxx Financials and the DJ Euro Stoxx Industrials. The weights are the number of bonds in rating category j that are issued in the financial sector, respectively industrial sector, in percentage of the total number of financial and industrial bonds in rating category j. For the AAA rating category for example R^m_{AAA} will almost coincide with the return on the DJ Euro Stoxx Financials whereas for the BBB rating category R^m_{BBB} is mainly driven by the return on the DJ Euro Stoxx Industrials. $\triangle IV$ is the change in the implied volatility on the DJ Euro Stoxx. The implied volatility is the average of the put and the call implied volatility. $\triangle Liq_{t,j}$ is the change in the average bid-ask spread of the bonds included in the analysis at time t and $t+1$ in rating category j. Weekly data of the explanatory variables are obtained from Datastream and Bloomberg.

4.3.2 Results

Table 8 presents the regression results for different rating categories, AAA, AA, A and BBB, and for different years to maturity ranging from 2 to 10 years. For the AA and A rating, we make a distinction between three subrating categories, namely plus, flat and minus rating. The reason is that we find substantial differences in credit spreads between subrating categories. For AAA rating, there are no subrating categories and for BBB rating we do not make a distinction between subrating categories. Since there are only few BBB rated bonds in the subrating categories, we concentrate on the total BBB rating category. Furthermore, the regression results for BBB bonds are not directly comparable with the other results since the analysis of the former covers a shorter period (June 2000-December 2002). We test the residuals of each regression for serial correlation with the Breusch-Godfrey test. The null hypothesis of the LM test is that there is no serial correlation up to lag order p, where p is a pre-specified integer. The LM test statistic is asymptotically distributed as a χ^2(p).[13] Furthermore, we test the residuals for heteroskedasticity using the White heteroskedasticity test. The null hypothesis is that of no heteroskedasticity against heteroskedasticity of some unknown general form. Whites test statistic is asymptotically distributed as a χ^2 with degrees of freedom equal to the number of slope coefficients (excluding the constant) in the test regression.[14] Because most of the results reject the null hypothesis of homoskedasticity and/or no autocorrelation, we report Newey-West heteroskedasticity and autocorrelation consistent (HAC) standard errors.

Our first observation is that changes in the level ($\triangle i_3$) and the slope ($\triangle i_{slope}$) of the default-free term structure are two important determinants of credit spread changes. As in Longstaff & Schwartz (1995) and Duffee (1998) and in accordance with the Merton type of models, we find a negative correlation between changes in the level and the slope and credit spread changes. While the slope effect is significant for all (sub)rating categories and for most maturity ranges, the level effect is mainly significant for the higher rating categories, namely AAA and AA rated bonds, with a maturity up to 7 years. For bonds with a long term to maturity changes in the level of the default-free term structure do not have a significant influence. The slope effect appears to be hump shaped, i.e. the effect first increases with the time to maturity with a maximum around five or six years and then decreases with the time to maturity. It seems that on average the effect of the level and the slope do not depend on the (sub)rating category.

In all regressions, the sensitivity to the lagged equity return $\left(R^m_{t-1}\right)$ has the expected negative sign. If we include R^m_{t-1}, we find that in 57 of the 70 regressions the coefficient β_m is significant at the 5% level whereas if we include the current market return (R^m_t) the coefficient is significant at the 5% level in only 10 of the 70 regressions. This is in accordance with the results of Kwan (1996) who finds that stocks lead bonds in firm-specific information. Lagged stock returns have explanatory power for current credit spread changes. For all (sub)rating categories the effect becomes stronger the longer the maturity of the bonds. For bonds with 10 years to maturity the effect on credit spread changes is almost double the effect on bonds with 2 years to maturity. Furthermore, the effect depends on the (sub)rating category. AA rated bonds are more affected by the lagged market return compared to AAA rated bonds, A rated bonds more than AA rated bonds and BBB rated bonds more than A rated bonds. Even within the AA and A rating category, the effect depends on the subrating. Minus rated bonds are more affected than minus rated bonds.

Changes in the implied volatility of the DJ Euro Stoxx ($\triangle IV$) have the expected positive sign, which is in accordance with the findings of Campbell & Taksler (2002).

[13] The advantage of the Breusch-Godfrey test is that the original regression may include AR and MA terms, in which case the test regression will be modified to take account of the ARMA terms.

[14] White also describes this approach as a general test for model misspecification, since the null hypothesis underlying the test assumes that the errors are both homoskedastic and independent of the regressors, and that the linear specification of the model is correct. Failure of any one of these conditions could lead to a significant test statistic. Conversely, a non-significant test statistic implies that none of the three conditions is violated.

An increase in the implied volatility increases the probability of default and hence causes a widening of credit spreads. In the majority of cases, the effect is significant at the 5% level. The effect increases the longer the maturity of the bond. Furthermore, the effect is higher for lower rated bonds. Even within the AA and A rating category, we find that the effect is stronger for minus rated bonds compared to plus rated bonds.

As in Collin-Dufresne et al. (2001) and Houweling et al. (2002), differences in liquidity affect corporate yield spreads. Changes in our measure of liquidity ($\triangle Liq$) - the average bid-ask spread - are significantly positively related to credit spread changes of BBB rated and AA plus rated bonds and A flat rated bonds. The effect strongly depends on the rating category. The coefficients for BBB rated bonds are more than double the coefficients for the A flat rated bonds while the latter are more than double the coefficients of the AA plus rated bonds. For the BBB rating category, the effect strongly increases with the time to maturity. BBB rated bonds with 10 years to maturity are much more affected than BBB rated bonds with 2 years to maturity.

Lagged Credit spreads changes (one period) have a significant effect on AAA and AA rated bonds with a short to medium term to maturity. An increase in credit spread changes at time t causes a decrease of credit spread changes at time $t+1$. Bonds with a short time to maturity are more affected by lagged changes compared to bonds with a medium time to maturity.

Although none of the constant terms ($\beta_o\prime s$) are significant at the 5% level, those of the AAA, AA and A rating category appear to be a function of the time to maturity and the rating category. The longer the time to maturity and the lower the rating category the higher the constant term. Even within the AA and A rating category, the constant is higher for minus compared to plus rated bonds. The constant terms for the BBB rating are not in line with the other rating categories. The reason might be that the analysis for BBB rated bonds covers a much shorter period.

Finally, the adjusted R^2 (last row of each panel) shows that between 1% and 32% of credit spread changes can be explained by the included variables, depending on the rating and time to maturity. For BBB rated bonds the adjusted R^2 is much higher compared to the other rating categories.

4.3.3 Robustness

So far, the level and the slope of the default-free term structure are proxied by the three-month euro rate and the difference between the 10-year EMU government bond yield and the three-month euro rate. In the NS model, however, the $\beta_0 + \beta_1$ and the $-\beta_1$ (see equation 4) are assumed to be the level and the slope of the default-free term structure. These parameters are estimated on a weekly basis for a sample of 250 AAA rated government bonds. To check the robustness of our results, we reestimate the regression model (5) and include changes in $\beta_0 + \beta_1$ and $-\beta_1$ to proxy for changes in the level and the slope of the default-free term structure. The correlation between $\beta_0 + \beta_1$ and the three month euro rate is 0.8 while the correlation between $-\beta_1$ and the difference between the 10-year EMU government bond yield and the three-month euro rate is 0.7. Although the adjusted R^2 slightly decreases, the results (not show here) are similar to the previous results. Changes in the level and the slope of the default-free have the expected negative sign. Both effects are significant at the 5% level for bonds with a maturity up to 7 years. For long term bonds the level and the slope effect is not significant anymore. Including the $\beta_0+\beta_1$ and the $-\beta_1$ slightly increases the coefficients and the significance of the stock return and the changes in the volatility of the stock return. The coefficients and the p-values of the changes in the bid-ask spread and the lagged dependent variable are not altered.

5 Conclusion

In this paper we examine the term structure of credit spreads on euro corporate bonds and the empirical validation of structural credit risk models. Although the pricing of corporate bonds and the theoretical models of credit risk cover a broad literature, there has been little empirical testing on structural credit risk models. We use a dataset of 1577 investment grade corporate and 250 AAA rated government bonds included in the Merrill Lynch Broad EMU Market indices. We model the term structure of credit spreads for homogenous risk classes -(sub)rating categories- by using an extension of the Nelson-Siegel model. The extension includes four additional factors that should capture differences in liquidity, taxation and subrating categories. Then, we analyze the changes in the term structure of credit spreads for AAA, AA, A and BBB rated bonds. For AA and A, we make a distinction between the plus, flat and minus subrating category. The structural or firm-value models provide a framework to determine the main factors included in the analysis: changes of the level and the slope of the default-free term structure, the stock return, changes of the implied volatility of the stock return. Although the assumptions of perfect and complete markets made in the structural models imply no differences in liquidity, empirical findings suggest that it might be an important factor. Therefore, we include a measure of (il)liquidity -the bid-ask spread. Finally, we include a lagged dependent variable. The econometric analysis of credit spread changes shows that the changes in the level and the slope of the default-free term structure are two important determinants. While changes in the slope affect all rating categories, changes in the level mainly affect the higher rating categories, namely AAA and AA rated bonds. The stock return and the implied volatility of the stock price seem to significantly influence credit spread changes. The lower the rating category and the longer the maturity of the bond the stronger both effects. Our results are in line with those reported by Collin-Dufresne et al. (2001) that on average one quarter of the credit spread changes are explained by the variables suggested by the structural models. For BBB rated bonds, changes in the bid-ask spread significantly influence credit spread changes. Higher rated bonds (AAA and AA) are also driven by past credit spread changes.

References

Amihud, Y. & Mendelson, H. (1986). Asset pricing and the bid-ask spread, *Journal of Financial Economics* **17**: 223–249.

Amihud, Y. & Mendelson, H. (1991). Liquidity, maturity, adn the yields on US treasury securities, *Journal of Finance* **46**(4): 1411–1425.

Annaert, J. & De Ceuster, M. (2000). Modelling european credit spreads, *Deloitte and Touche, Research Report* .

Bielecki, T. R. & Rutkowski, M. (2002). *Credit Risk: Modeling, Valuation and Hedging*, Springer Berlin.

Black, F. & Cox, J. C. (1976). Valuing corporate securities: Some effects of bond indenture provisions, *Journal of finance* **31**(2): 351–367.

Black, F. & Scholes, M. (1973). The pricing of options and corporate liabilities, *Journal of political economy* **81**(3): 637–654.

Bliss, R. (1997). Testing term structure estimation methods, *Advances in Futures and Options Research* **9**: 197–231.

Bolder, D. & Streliski, D. (1999). Yield curve modelling at the bank of canada, *Technical Report, Bank of Canada no. 84* (84).

Campbell, J. Y. & Taksler, G. B. (2002). Equity volatility and corporate bond yields, *NBER Working Paper 8961* .

Chakravarty, S. & Sarkar, A. (1999). Liquidity in US fixed income markets: A comparison of the bid-ask spread in corporate, government and municipal bond markets, *Staff Reports 73, Federal Reserve Bank of New York* .

Chen, N. (1991). Financial investment opportunities and the macroeconomy, *Journal of Finance* **46**: 529–554.

Chen, R.-R. & Scott, L. (1993). Maximum likelihood estimation for a multifactor equilibrium model of the term structure of interest rates, *Journal of Fixed Income* **3**: 14–31.

Collin-Dufresne, P., Goldstein, R. S. & Martin, J. S. (2001). The determinants of credit spread changes, *Journal of Finance* **56**(6): 2177–2207.

Cossin, D. & Hricko, T. (2001). Exploring for the determinants of credit risk in credit default swap transaction data, *Working Paper of the University of Lausanne* .

Cox, J., Ingersoll, J. & Ross, S. A. (1980). An analysis of variable rate loan contracts, *Journal of Finance* **35**(2): 389–403.

Deacon, M. & Derry, A. (1994). Estimating market interest rates and inflation expectations from the prices of UK government bonds, *Bank of England Quarterly Bulletin* **24**: 232–240.

Diebold, F. X. & Li, C. (2002). Forecasting the term structure of government bond yields, *Center for Financial Institutions Working Paper, Wharton School* .

Duffee, G. R. (1998). The relation between treasury yields and corporate bond yield spreads, *Journal of Finance* **53**(6): 2225–2241.

Duffee, G. R. (1999). Estimating the price of default risk, *Review of Financial Studies* **12**(1): 197–226.

Elton, E. J., Gruber, M. J., Agrawal, D. & Mann, C. (2001). Explaining the rate spread on corporate bonds, *Journal of Finance* **56**(1): 247–277.

Estrella, A. & Hardouvelis, G. (1991). The term structure as a predictor of real economic activity, *Journal of Finance* **46**(2): 555–576.

Fama, E. F. & French, K. R. (1989). Business conditions and expected returns on stocks and bonds, *Journal of Financial Economics* **25**(1): 23–49.

Fons, J. S. (1994). Using default rates to model the term structure of credit risk, *Financial Analyst Journal, Moody's Investors Service* pp. 25–33.

Friedman, B. & Kuttner, K. (1992). Money, income, prices and interest rates, *American Economic Review* **82**: 472–492.

Geske, R. (1977). The valuation of corporate liabilities as compound options, *Journal of Financial and Quantitative Analysis* **12**(4): 541–552.

Geyer, A. & Mader, R. (1999). Estimation of the term structure of interest rates: A parametric approach, *Workin Paper No. 37, Austrian National Bank* .

Green, R. C. & Odegaard, B. A. (1997). Are there tax effects in the relative pricing of u.s. government bonds?, *Journal of Finance* **LII**(2): 609–633.

Guha, D. & Hiris, L. (2002). The aggregate credit spread and the business cycle, *International Review of Financial Analysis* **11**: 219–227.

Houweling, P., Mentink, A. & Vorst, T. (2002). Is liquidity reflected in bond yields? evidence from the euro corporate bond market, *Working Paper, Erasmus Universiteit Rotterdam* .

Jarrow, R., Lando, D. & Turnbull, S. (1997). A markov model for the term structure of credit spreads, *The Review of Financial Studies* **10**: 481–523.

Jones, E. P., Mason, S. P. & Rosenfeld, E. (1984). Contingent claim analysis of corporate capital structures: An empirical investigation, *Journal of Finance* **39**(3): 611–625.

Kwan, S. H. (1996). Firm-specific information and the correlation between individual stocks and bonds, *Journal of Financial Economics* **40**: 63–80.

Leland, H. (1998). Agency costs, risk management, and capital structure, *Journal of finance* **53**(4): 1213–1243.

Leland, H. E. (1994). Corporate debt value, bond covenants, and optimal capital structure, *Journal of finance* **49**(4): 1213–1252.

Leland, H. & Toft, K. (1996). Optimal capital structure, endogenous bankruptcy, and the term structure of credit spreads, *Journal of Finance* **51**: 987–1020.

Litterman, R. & Scheinkman, J. (1991). Common factors affecting bond returns, *Journal of Fixed Income* **1**: 54–61.

Longstaff, F. A. & Schwartz, E. (1995). A simple approach to valuing risky fixed and floating rate debt, *Journal of Finance* **50**(3): 789–821.

Merton, R. C. (1974). On the pricing of corporate debt: The risk structure of interest rates, *Journal of Finance* **29**(2): 449–470.

Nelson, C. R. & Siegel, A. F. (1987). Parsimonious modeling of yield curves, *Journal of Business* **60**(4): 473–489.

Ramaswami, M. (1991). Hedging the equity risk of high-yield bonds, *Financial Analyst Journal* **47**: 41–50.

Ronn, E. I. & Verma, A. K. (1986). Pricing risk-adjusted deposit insurance: An option-based model, *Journal of Finance* **41**(4): 871–895.

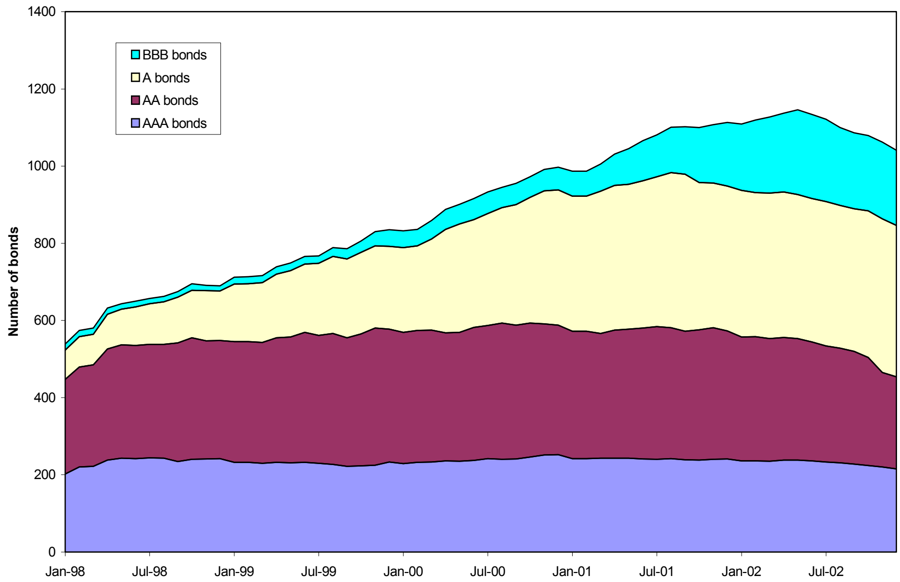
Sarig, O. & Warga, A. (1989). Some empirical estimates of the risk structure of interest rates, *Journal of Finance* **44**(4): 1351–1360.

Shane, H. (1994). Comovements of low-grade debt and equity returns of highly leveraged firms, *Journal of fixed Income* **3**: 79–89.

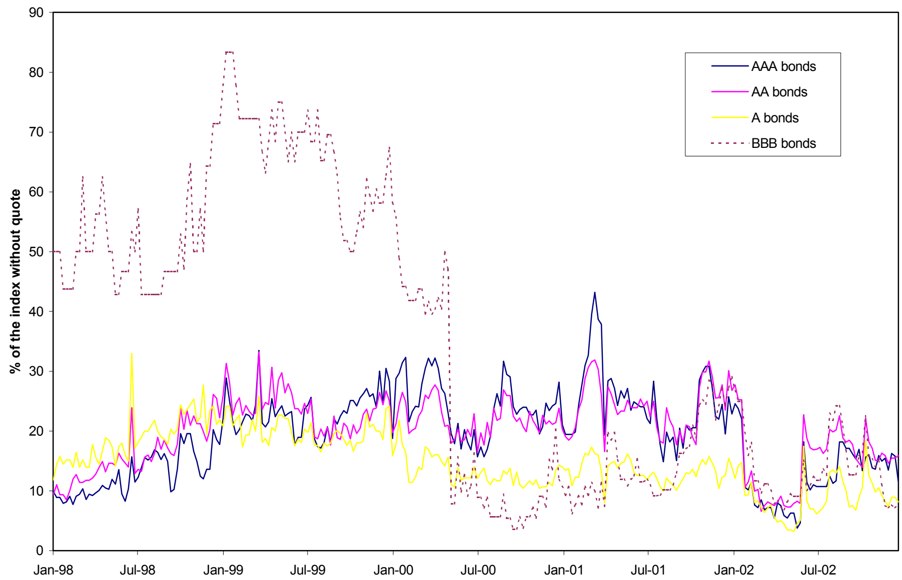
Svensson, L. E. (1994). Estimating and interpreting forward interest rates: Sweden 1992-1994, *NBER Working Paper* **4871**.

Turnbull, S. (1979). Debt capacity, *Journal of Finance* **34**: 931–940.

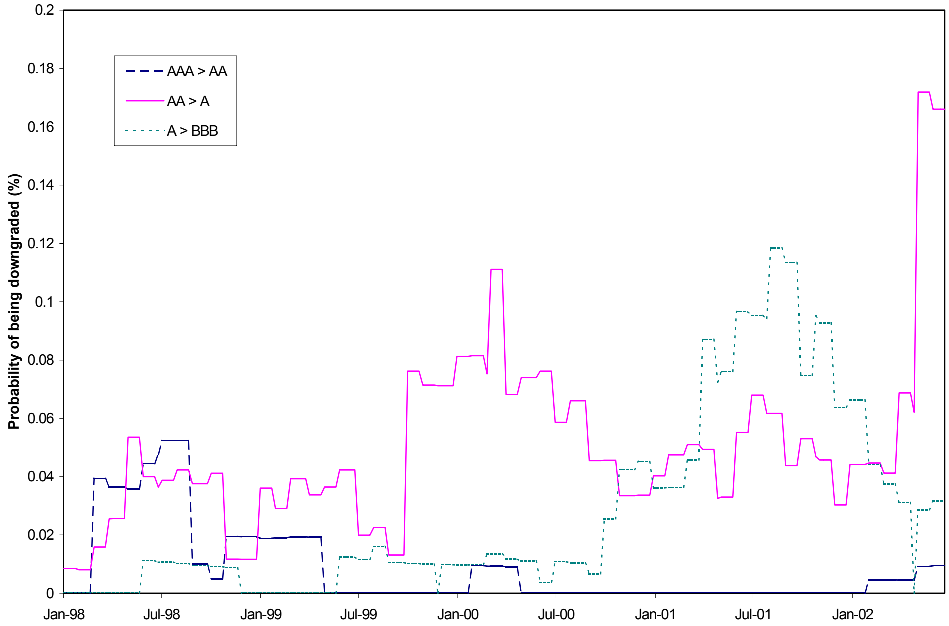
Graph 1: Number of bonds in different rating categories



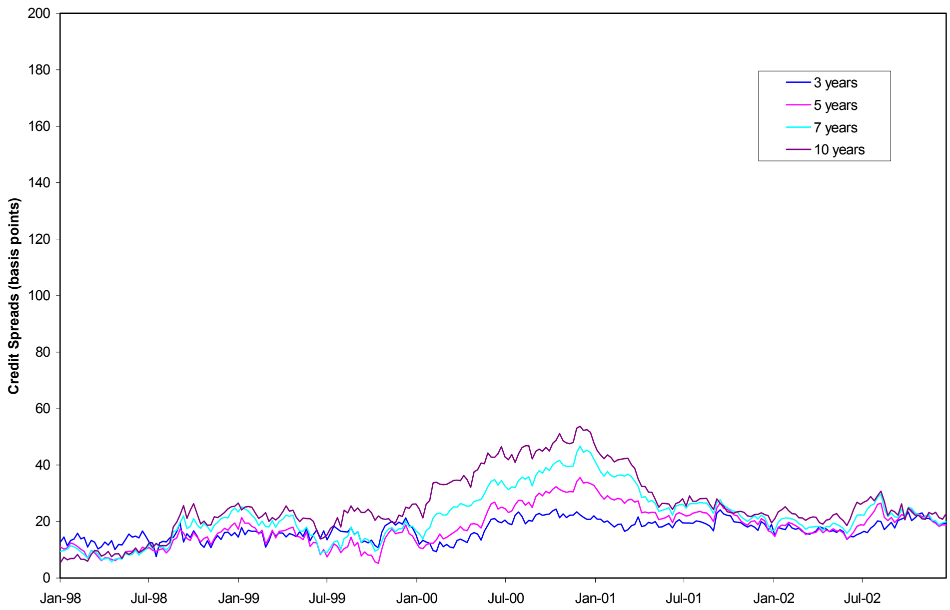
Graph 2: Liquidity, % of index not quoted



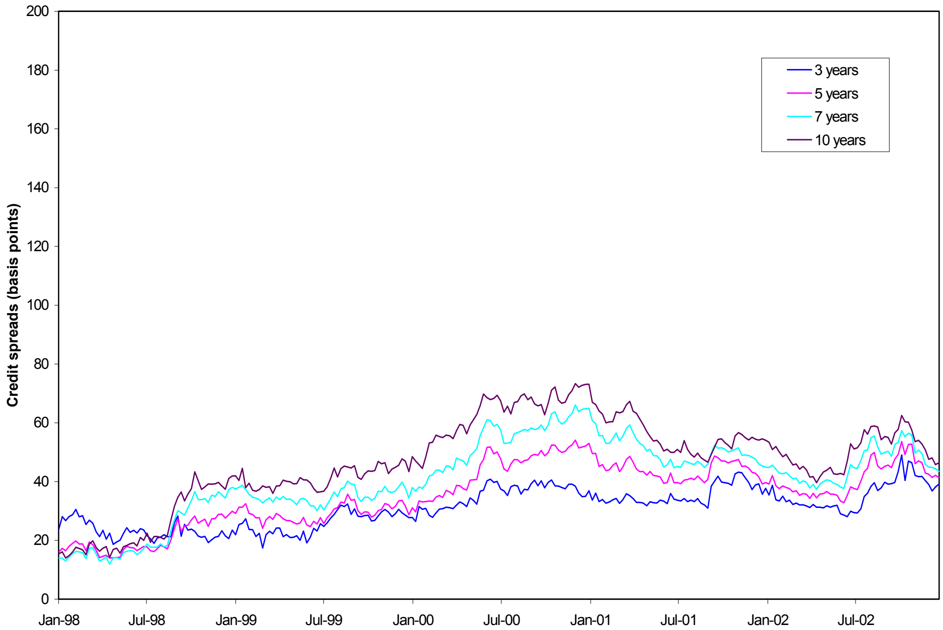
Graph 3: Time-varying Probability of Downgrade



Graph 4: Credit Spreads on AAA Rated Bonds with 3, 5, 7 and 10 Years to Maturity

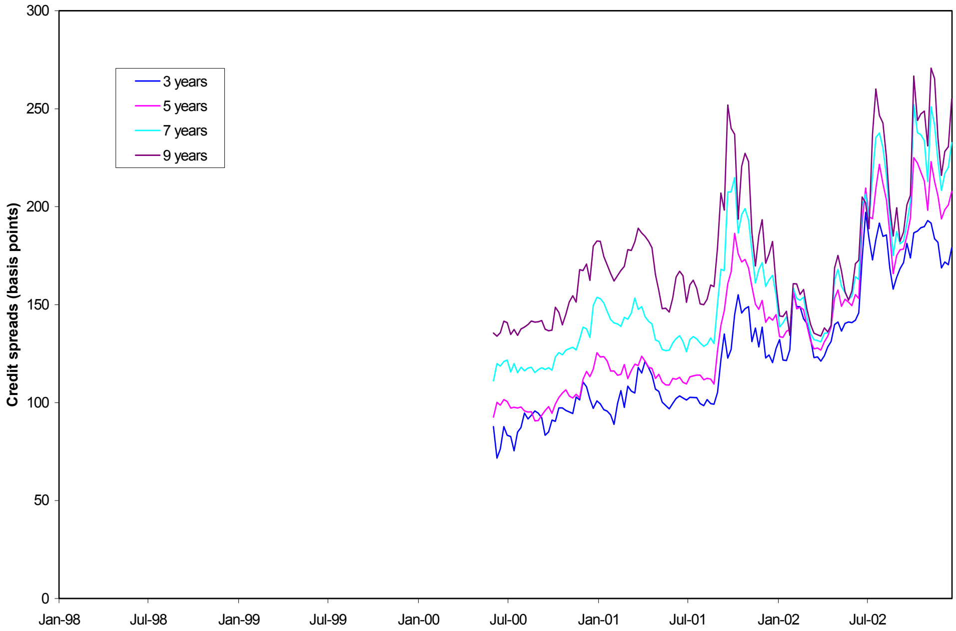


Graph 5: Credit Spreads on AA Rated Bonds with 3, 5, 7 and 10 Years to Maturity



Graph 6: Credit Spreads on A Rated Bonds with 3, 5, 7 and 10 Years to Maturity

Graph 7: Credit Spreads on BBB Rated Bonds



Graph 8: Comparison between Average Absolute Yield Errors between NS and extended NS model for Different Ratings

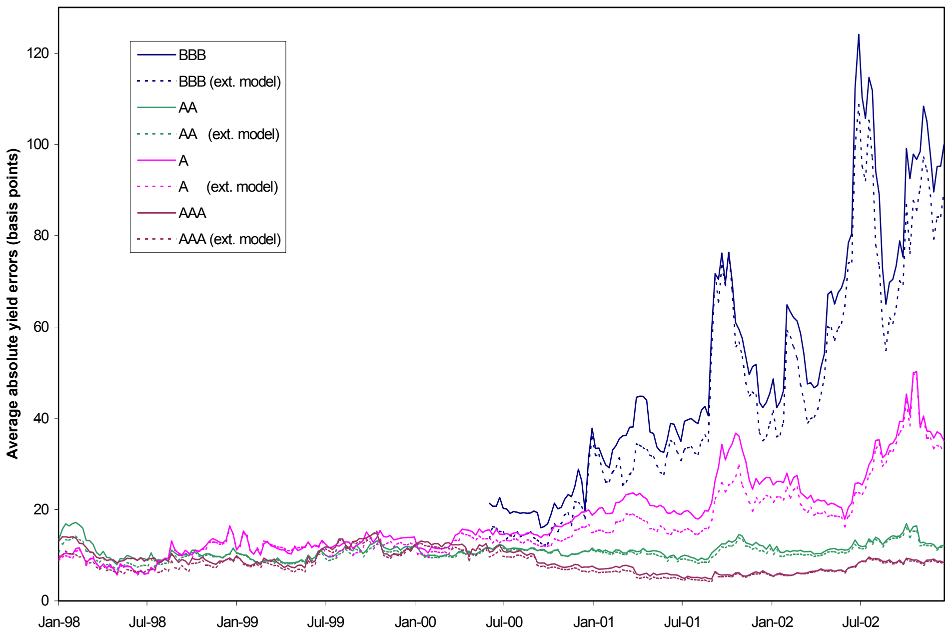


Table 1: Average Number of Bonds in Different Rating categories, Sectors and Maturity Ranges

Panel A: Average number of bonds based on rating and maturity

	AAA		AA		A		BBB	
Total	193	[18]	259	[20]	236	[103]	115	[53]
1-3 years	65	[9]	72	[7]	50	[23]	24	[21]
3-5 years	52	[6]	67	[11]	63	[30]	42	[21]
5-7 years	30	[5]	40	[11]	45	[22]	32	[7]
7-10 years	32	[4]	67	[14]	69	[32]	17	[5]
+10 years	15	[4]	14	[3]	8	[3]	-	

Panel B: Average number of bonds based on rating and sector

	AAA		AA		A		BBB	
Total	235	[9]	318	[28]	265	[112]	131	[63]
Finanacials	225	[10]	258	[17]	142	[47]	8	[7]
Industrials	4	[1]	32	[9]	103	[53]	111	[51]
Utilities	1	[2]	19	[5]	16	[13]	8	[3]

Panel C: Average percentage of bonds based on rating and sector

	AAA	AA	A	BBB
Finanacials	96%	81%	54%	6%
Industrials	2%	10%	39%	84%
Utilities	1%	6%	6%	6%

Note: This table presents the average number of bonds based on rating and time to maturity (Panel A) and rating and sector (Panel B). Standard deviations are given between brackets. The average percentage of bonds based on rating and sector are presented in Panel C. The data set consists of weekly data from Jan. 1 1998 until Dec. 31, 30 2002 *For BBB, the data starts from Jun. 2000.

Table 2: Summary statistics of the time to maturity and the number of weeks

Panel A: Summary statistics of years to maturity and number of weeks

		Mean	Stdev	Min	Max
Years to Maturity					
	AAA	4.94	3.16	1.00	19.91
	AA	5.28	2.96	1.00	14.98
	A	5.59	2.79	1.00	21.89
	BBB	5.07	1.97	1.00	10.19
Number of weeks					
	Total	145	75		

Panel B: % of bonds in subrating categories and sectors

	subrating categories		
	plus	flat	minus
AA	24.6%	33.2%	42.2%
A	39.9%	33.9%	26.2%
BBB	54.5%	34.1%	11.4%
A financials	52.0%	34.5%	13.5%
A industrials	23.4%	37.7%	38.9%

Panel C:

	Initial rating	**AAA**	**AA**	**A**	**BBB**	NA
AAA	202	98.2	1.6	0.2	0	0.1
AA	279	0.3	88.9	10.2	0	0.6
A	214	1.3	2.8	89.9	4.5	1.6
BBB*	90	0	0	8.3	86.5	5.3

Note: Panel A presents the summary statistics (mean, standard deviation, minimum and maximum) of the time to maturity and the number of weeks that a bond is included in the index between Jan. 1998 and Dec. 2002. Panel B presents the percentage of bonds in each rating category (AA, A, BBB, A financials and A industrials) that have a plus, flat or minus rating. Panel C presents the probability that a bond has the same rating or has been up- or downgraded after one year. This table presents the average of five yearly transition matrices. *For BBB rated bonds, the analysis covers the period Jan. 2000 until Dec. 2002.

Table 3: The effect of subratings, liquidity and differences in coupon rates on yield errors within rating categories

Panel A: Yield errors within subsamples of rating categories

		AA		A		BBB	
		mean	stdev	mean	stdev	mean	stdev
Subratings	plus	0.07	[0.04]	0.12	[0.08]	0.25	[0.13]
	minus	-0.04	[0.02]	-0.12	[0.09]	-0.57	[0.40]
Coupon	high	-0.04	[0.02]	-0.02	[0.02]	-0.04	[0.04]
	low	0.03	[0.01]	0.02	[0.02]	0.06	[0.06]
Liquidity	high	-0.01	[0.01]	-0.03	[0.04]	-0.14	[0.16]
	low	0.01	[0.01]	0.01	[0.02]	0.14	[0.16]

Panel B: Test for equality of mean

	AA		A		BBB	
	Value	Prob	Value	Prob	Value	Prob
Subratings	40.8	[0.00]	32.6	[0.00]	22.6	[0.00]
Coupon	57.7	[0.00]	16.5	[0.00]	15.6	[0.00]
Liquidity	25.1	[0.00]	14.8	[0.00]	13.8	[0.00]

Panel C: Regression results: % signficant at 5% level

	AAA	AA	A	BBB
Plus rating		29.2%	82.7%	80.6%
Minus rating		57.7%	39.6%	35.1%
Coupon	94.2%	69.6%	32.7%	33.6%
Liquidity	40%	43.5%	23.5%	49.3%

Note: Within each rating category the sample is split into (1) plus and minus-rated bonds, (2) high and low coupon bonds and (3) liquid and less liquid bonds. Panel A presents the average and the standard deviation of the yield errors within subsamples of each rating category. Panel B presents the t-test for equality of the means.

Table 4: Average Credit Spreads for Different Ratings and Time to Maturity

	Years to maturity								
	2 y	3 y	4 y	5 y	6 y	7 y	8 y	9 y	10 y
AAA	20.8	17.0	16.9	18.3	20.2	22.0	23.6	24.9	26.0
	[2.6]	[3.4]	[5.2]	[6.7]	[8.0]	[9.0]	[9.8]	[10.4]	[11.0]
AA+	23.3	22.6	24.4	27.2	30.1	32.8	35.1	37.1	38.6
	[4.1]	[4.3]	[5.9]	[7.7]	[9.2]	[10.2]	[10.9]	[11.4]	[11.6]
AA	27.7	27.0	28.8	31.6	34.5	37.2	39.5	41.5	43.0
	[3.6]	[4.8]	[6.8]	[8.6]	[10.1]	[11.3]	[12.1]	[12.6]	[12.9]
AA-	37.8	37.1	38.9	41.7	44.6	47.3	49.6	51.6	53.1
	[5.9]	[8.5]	[10.6]	[12.4]	[13.8]	[14.9]	[15.7]	[16.2]	[16.6]
A+	38.1	41.6	46.2	50.9	55.2	59.0	62.3	65.1	67.5
	[6.3]	[9.9]	[12.9]	[15.1]	[16.8]	[18.1]	[19.0]	[19.8]	[20.4]
A+	53.9	57.4	62.1	66.8	71.1	74.9	78.1	81.0	83.4
	[12.4]	[17.6]	[20.7]	[22.8]	[24.3]	[25.4]	[26.2]	[26.9]	[27.4]
A-	77.1	80.6	85.2	89.9	94.2	98.0	101.3	104.1	106.5
	[26.9]	[32.0]	[34.9]	[36.7]	[38.0]	[38.8]	[39.5]	[40.0]	[40.5]
BBB+	102.7	104.1	109.9	117.8	126.6	135.7	144.8	153.9	162.9
	[24.1]	[27.0]	[30.1]	[31.2]	[31.0]	[30.4]	[29.8]	[29.9]	[31.1]
BBB and	152.8	154.2	160.1	167.9	176.7	185.8	195.0	204.1	213.0
BBB-	[33.9]	[38.6]	[42.0]	[43.1]	[42.9]	[42.2]	[41.6]	[41.3]	[41.9]

Note: This table presents the averages and the standard deviations (between brackets) of credit spreads for different (sub)rating categories and time to maturity.

Table 5: Average Absolute Yield Errors

Panel A: Average absolute errors: NS versus extended NS model				
			t-test	
	mean	stdev	value	prob
AAA	8.9	2.4	3.93	0.00
AAA (ext model)	8.0	2.3		
AA	11.1	1.7	4.38	0.00
AA (ext. model)	10.5	1.5		
A	18.0	8.7	2.72	0.01
A (ext. model)	16.1	7.8		
BBB	51.8	27.2	2.1	0.04
BBB (ext. model)	45.0	25.2		

Panel B: Average absolut errors of the extended NS model				
	AAA	AA	A	BBB
$\leq$ 2 years	8.1	9.8	16.2	67.1
$\leq$ 3 years	8.8	9.9	17.0	45.2
$\leq$ 4 years	9.1	10.3	15.5	49.5
$\leq$ 5 years	9.6	9.4	15.4	45.8
$\leq$ 6 years	7.4	10.1	16.6	38.4
$\leq$ 7 years	6.5	11.8	17.4	38.8
$\leq$ 8 years	5.9	13.8	15.1	54.3
$\leq$ 9 years	7.8	11.0	15.1	47.2
$\leq$ 10 years	5.9	10.3	15.5	33.1
$>$ 10 years	5.5	10.5	13.7	-

Panel C: % of yield outside a 95% confidence interval (hit ratio)				
	AAA	AA	A	BBB
NS model	2.36	2.12	2.85	2.87
above	0.88	1.49	2.62	2.52
below	1.47	0.63	0.23	0.26
Extended NS model	1.22	1.04	0.98	0.56
above	0.50	0.61	0.86	0.56
below	0.72	0.44	0.13	0.00

Note: Panel A presents the average absolute yield errors (AAE_{yield}) and the standard deviations of the NS and the extended NS model. The results of the t-test of equality of means are presented in column 3 and 4. Panel B presents the AAE_{yield} for different maturity ranges. Panel C presents the percentage of bonds that have a yield outside (above and/or below) a 95% confidence interval around the estimated term structure.

Table 6: Transition Matrices for the Fitted Yield Errors

Panel A: Results of the orignal NS model

		Unconditional Frecuency (ε_t)	Conditional Frequency ($\varepsilon_{t+1}\|\varepsilon_t$) $\varepsilon_{t+1} < 0$	$\varepsilon_{t+1} = 0$	$\varepsilon_{t+1} > 0$
AAA	$\varepsilon_t < 0$	33.7	87.0	5.4	7.6
	$\varepsilon_t = 0$	29.2	5.9	85.0	9.1
	$\varepsilon_t > 0$	37.1	7.1	7.0	85.9
AA	$\varepsilon_t < 0$	43.9	89.8	4.4	5.8
	$\varepsilon_t = 0$	24.2	7.7	86.6	5.7
	$\varepsilon_t > 0$	31.9	7.7	4.4	87.9
A	$\varepsilon_t < 0$	50.4	93.9	2.6	3.5
	$\varepsilon_t = 0$	13.7	10.3	81.5	8.2
	$\varepsilon_t > 0$	36.0	4.6	3.3	92.1
BBB	$\varepsilon_t < 0$	60.3	96.7	2.1	1.2
	$\varepsilon_t = 0$	7.1	20.7	64.2	15.1
	$\varepsilon_t > 0$	32.5	2.0	3.7	94.4

Panel B: Results of the extended NS model

		Unconditional Frecuency (ε_t)	Conditional frequency ($\varepsilon_{t+1}\|\varepsilon_t$) $\varepsilon_{t+1} < 0$	$\varepsilon_{t+1} = 0$	$\varepsilon_{t+1} > 0$
AAA	$\varepsilon_t < 0$	31.6	85.6	6.0	8.3
	$\varepsilon_t = 0$	32.6	5.8	86.0	8.2
	$\varepsilon_t > 0$	35.8	7.5	7.7	84.8
AA	$\varepsilon_t < 0$	41.3	89.2	5.1	5.7
	$\varepsilon_t = 0$	26.0	7.9	86.0	6.1
	$\varepsilon_t > 0$	32.7	7.1	5.1	87.8
A	$\varepsilon_t < 0$	51.7	93.0	3.2	3.8
	$\varepsilon_t = 0$	15.1	11.1	78.9	9.9
	$\varepsilon_t > 0$	33.2	5.7	4.6	89.6
BBB	$\varepsilon_t < 0$	54.0	92.8	3.4	3.8
	$\varepsilon_t = 0$	9.3	24.1	54.9	21.0
	$\varepsilon_t > 0$	36.6	5.1	6.0	88.8

Note: The underlying data are the fitted yield errors from the Nelson-Siegel model (panel A) and the extended NS model (panel B). For each rating category, fitted yield errors are classified in three groups (pos., zero, neg.) at time t and t+1. The percentages of yield errors in a certain category (unconditional frequency) are presented in column 3. The percentages of yield errors in a category at time t+1 conditional on the classification at time t (conditional frequency) are presented in column 4 to 6 in panel B.

Table 7: Forecasting Performance of the NS and the extended NS model

Panel A: NS model				
	Original	Forecasts		
		1 week ahead	2 weeks ahead	1 month ahead
AAA	8.8	11.8	14.4	18.8
	2.4	4.5	6.5	9.7
AA	11.0	13.7	16.0	20.0
	1.7	3.9	5.7	8.8
A	18.2	20.0	21.8	24.7
	8.7	9.0	9.4	10.7
BBB	52.7	53.3	53.9	55.2
	27.1	27.1	27.1	27.3

Panel B: Extended NS model				
	Original	Forecasts		
		1 week ahead	2 weeks ahead	1 month ahead
AAA	8.0	11.1	13.8	18.2
	2.3	4.6	6.6	9.8
AA	10.4	13.1	15.5	19.5
	1.5	3.9	5.8	9.0
A	16.2	18.2	20.1	23.2
	7.8	8.2	8.7	10.4
BBB	45.0	47.1	48.1	50.0
	25.2	25.1	25.2	25.4

Note: This table presents the average absolute yield errors of (1) the original model, (2) one-week ahead forecasts, (3) two weeks ahead forecasts and (4) one month ahead forecasts of the spot rates.

Table 8: Regression results for different (sub)rating categories of bonds with a maturity ranging from 2 to 10 years

$$\triangle CR_{t,j} = \beta_o + \beta_{\triangle i_3} \triangle i_{3,t} + \beta_{\triangle slope} \triangle i_{slope,t} + \beta_m R^m_{t-1,j} + \beta_{\triangle IV} \triangle IV_t + \beta_{\triangle Liq} \triangle Liq_{t,j} + \beta_{lag} \triangle CR_{t-1,j} + \nu_{t,j}$$

CR is the credit spread, i_3 and i_{slope} are the level and the slope of the default-free term structure, R^m is a weighted average of the DJ Euro Stoxx financials and industrials, IV is the implied volatility on the DJ Euro Stoxx and Liq is the average bid-ask spread. j stands for (sub)rating category. Finally, the model also includes a lagged dependent variable. Newey-West standard errors are given between brackets.

Panel A: AAA rated bonds

	2 y	3 y	4 y	5 y	6 y	7 y	8 y	9 y	10 y
β_o	-0.04	-0.01	0.00	0.01	0.01	0.02	0.03	0.04	0.05
	[0.69]	[0.91]	[1.00]	[0.95]	[0.91]	[0.86]	[0.79]	[0.73]	[0.69]
$\beta_{\triangle i_3}$	**-3.24**	**-5.85**	**-6.95**	**-6.97**	**-6.22**	**-4.97**	-3.38	-1.56	0.38
	[0.05]	[0.00]	[0.00]	[0.00]	[0.00]	[0.01]	[0.06]	[0.40]	[0.85]
$\beta_{\triangle slope}$	**-4.00**	**-7.12**	**-8.83**	**-9.26**	**-8.79**	**-7.86**	**-6.72**	**-5.52**	**-4.30**
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
β_m	**-0.06**	-0.06	**-0.07**	**-0.07**	**-0.08**	**-0.09**	**-0.09**	**-0.10**	**-0.12**
	[0.03]	[0.07]	[0.04]	[0.01]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
$\beta_{\triangle IV}$	0.06	0.03	0.03	0.04	0.06	**0.07**	**0.09**	**0.10**	**0.11**
	[0.08]	[0.45]	[0.48]	[0.27]	[0.08]	[0.01]	[0.00]	[0.00]	[0.00]
$\beta_{\triangle liq}$	0.38	0.29	0.33	0.33	0.27	0.17	0.06	-0.04	-0.13
	[0.24]	[0.41]	[0.35]	[0.30]	[0.34]	[0.54]	[0.85]	[0.91]	[0.76]
β_{lag}	**-0.39**	**-0.30**	**-0.20**	-0.11	-0.05	-0.03	-0.04	-0.08	**-0.14**
	[0.00]	[0.00]	[0.00]	[0.09]	[0.39]	[0.62]	[0.50]	[0.22]	[0.05]
$\overline{R}^2$	21.3%	23.9%	27.7%	29.1%	27.3%	23.6%	19.3%	15.6%	13.1%

Panel B: AA plus rating category

	2 y	3 y	4 y	5 y	6 y	7 y	8 y	9 y	10 y
β_o	-0.02	0.02	0.04	0.06	0.06	0.06	0.06	0.06	0.06
	[0.86]	[0.84]	[0.64]	[0.55]	[0.52]	[0.53]	[0.55]	[0.58]	[0.63]
$\beta_{\triangle i_3}$	**-6.10**	**-7.01**	**-6.47**	**-5.49**	**-4.44**	-3.43	-2.47	-1.55	-0.65
	[0.03]	[0.01]	[0.01]	[0.01]	[0.04]	[0.11]	[0.25]	[0.49]	[0.78]
$\beta_{\triangle slope}$	**-5.67**	**-6.51**	**-7.16**	**-7.26**	**-6.88**	**-6.20**	**-5.36**	**-4.47**	**-3.55**
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.01]
β_m	-0.06	**-0.08**	**-0.10**	**-0.11**	**-0.13**	**-0.15**	**-0.16**	**-0.18**	**-0.20**
	[0.13]	[0.05]	[0.01]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
$\beta_{\triangle IV}$	**0.08**	**0.09**	**0.10**	**0.12**	**0.13**	**0.13**	**0.13**	**0.13**	**0.12**
	[0.04]	[0.02]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
$\beta_{\triangle liq}$	-0.05	0.04	0.19	0.31	0.38	**0.40**	**0.41**	**0.40**	**0.40**
	[0.82]	[0.83]	[0.35]	[0.15]	[0.07]	[0.03]	[0.01]	[0.01]	[0.05]
β_{lag}	**-0.38**	**-0.35**	**-0.26**	**-0.16**	-0.09	-0.05	-0.03	-0.04	-0.08
	[0.00]	[0.00]	[0.00]	[0.01]	[0.15]	[0.44]	[0.62]	[0.50]	[0.25]
$\overline{R}^2$	24.5%	27.7%	29.3%	30.8%	31.1%	29.8%	26.9%	22.6%	18.1%

Note: Panel A and B present the regression results for the AAA and AA plus (sub)rating categories. The analysis covers the period January 1998 until December 2002.

Panel C: AA flat rating category									
	2 y	3 y	4 y	5 y	6 y	7 y	8 y	9 y	10 y
β_o	-0.01	0.02	0.05	0.06	0.06	0.06	0.06	0.06	0.06
	[0.89]	[0.82]	[0.63]	[0.54]	[0.51]	[0.52]	[0.53]	[0.56]	[0.60]
$\beta_{\triangle i_3}$	**-6.64**	**-7.26**	**-6.34**	**-5.03**	**-3.77**	-2.67	-1.71	-0.87	-0.08
	[0.01]	[0.00]	[0.00]	[0.00]	[0.01]	[0.07]	[0.27]	[0.61]	[0.97]
$\beta_{\triangle slope}$	**-5.69**	**-6.50**	**-6.99**	**-6.90**	**-6.36**	**-5.57**	**-4.70**	**-3.84**	**-3.01**
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.02]
β_m	-0.05	-0.07	**-0.08**	**-0.10**	**-0.11**	**-0.13**	**-0.15**	**-0.17**	**-0.19**
	[0.22]	[0.11]	[0.02]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
$\beta_{\triangle IV}$	0.06	0.07	**0.09**	**0.11**	**0.12**	**0.13**	**0.13**	**0.12**	**0.11**
	[0.12]	[0.11]	[0.02]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
$\beta_{\triangle liq}$	0.21	0.34	0.34	0.27	0.17	0.09	0.04	0.04	0.09
	[0.56]	[0.33]	[0.26]	[0.30]	[0.47]	[0.71]	[0.88]	[0.89]	[0.77]
β_{lag}	**-0.38**	**-0.33**	**-0.23**	-0.11	-0.02	0.04	0.06	0.04	-0.02
	[0.00]	[0.00]	[0.00]	[0.09]	[0.75]	[0.53]	[0.30]	[0.53]	[0.76]
$\overline{R}^2$	22.8%	23.8%	23.7%	24.7%	25.7%	25.6%	23.5%	19.2%	14.5%

Panel D: AA minus rating category									
	2 y	3 y	4 y	5 y	6 y	7 y	8 y	9 y	10 y
β_o	0.02	0.06	0.08	0.10	0.11	0.11	0.11	0.11	0.11
	[0.90]	[0.69]	[0.55]	[0.46]	[0.42]	[0.41]	[0.41]	[0.43]	[0.46]
$\beta_{\triangle i_3}$	**-5.90**	**-6.64**	**-5.77**	**-4.50**	-3.24	-2.10	-1.07	-0.15	0.69
	[0.04]	[0.03]	[0.03]	[0.05]	[0.12]	[0.32]	[0.63]	[0.95]	[0.80]
$\beta_{\triangle slope}$	**-5.05**	**-5.86**	**-6.38**	**-6.39**	**-5.97**	**-5.28**	**-4.43**	**-3.52**	-2.58
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.02]	[0.12]
β_m	-0.07	-0.09	**-0.11**	**-0.13**	**-0.15**	**-0.17**	**-0.18**	**-0.20**	**-0.21**
	[0.13]	[0.06]	[0.01]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
$\beta_{\triangle IV}$	0.07	0.07	0.09	**0.11**	**0.13**	**0.13**	**0.13**	**0.13**	**0.12**
	[0.13]	[0.16]	[0.06]	[0.01]	[0.00]	[0.00]	[0.00]	[0.00]	[0.01]
$\beta_{\triangle liq}$	0.12	0.17	-0.02	-0.24	-0.42	-0.54	-0.59	-0.60	-0.57
	[0.83]	[0.78]	[0.97]	[0.63]	[0.38]	[0.27]	[0.24]	[0.26]	[0.33]
β_{lag}	**-0.34**	**-0.31**	**-0.24**	**-0.17**	-0.12	-0.08	-0.06	-0.06	-0.08
	[0.00]	[0.00]	[0.00]	[0.01]	[0.08]	[0.24]	[0.37]	[0.36]	[0.22]
$\overline{R}^2$	16.1%	16.0%	15.0%	14.8%	14.8%	14.5%	13.6%	12.2%	10.6%

Note: This table presents the regression results for the AA flat and AA minus subrating categories. The dependent variables are the credit spread changes on AA flat rated bonds (panel C) and AA minus rated bonds (panel D). The analysis covers the period January 1998 until December 2002.

Panel E: A plus rated bonds									
	2 y	3 y	4 y	5 y	6 y	7 y	8 y	9 y	10 y
β_o	0.04	0.12	0.16	0.18	0.18	0.18	0.18	0.19	0.20
	[0.74]	[0.43]	[0.37]	[0.37]	[0.37]	[0.37]	[0.35]	[0.34]	[0.35]
$\beta_{\triangle i_3}$	-3.12	-4.12	-5.36	-5.61	-5.13	-4.16	-2.89	-1.55	-0.36
	[0.25]	[0.20]	[0.12]	[0.11]	[0.14]	[0.22]	[0.38]	[0.63]	[0.92]
$\beta_{\triangle slope}$	-2.20	-4.24	**-6.90**	**-8.32**	**-8.47**	**-7.77**	**-6.59**	**-5.25**	**-3.89**
	[0.33]	[0.12]	[0.02]	[0.00]	[0.00]	[0.00]	[0.01]	[0.04]	[0.14]
β_m	-0.14	-0.13	-0.13	-0.14	-0.16	**-0.18**	**-0.22**	**-0.26**	**-0.31**
	[0.01]	[0.04]	[0.08]	[0.09]	[0.06]	[0.02]	[0.00]	[0.00]	[0.00]
$\beta_{\triangle IV}$	**0.12**	**0.17**	**0.18**	**0.18**	**0.18**	**0.18**	**0.19**	**0.20**	**0.20**
	[0.02]	[0.01]	[0.01]	[0.01]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
$\beta_{\triangle liq}$	0.61	-0.68	-1.32	-1.48	-1.37	-1.14	-0.88	-0.60	-0.27
	[0.35]	[0.32]	[0.10]	[0.08]	[0.10]	[0.16]	[0.26]	[0.45]	[0.76]
β_{lag}	-0.07	-0.18	**-0.21**	**-0.17**	-0.11	-0.06	-0.03	-0.04	-0.09
	[0.26]	[0.06]	[0.01]	[0.04]	[0.17]	[0.48]	[0.76]	[0.70]	[0.25]
$\overline{R}^2$	5.1%	10.3%	14.3%	14.1%	13.1%	13.1%	14.4%	15.7%	15.7%

Panel F: A flat rated bonds									
	2 y	3 y	4 y	5 y	6 y	7 y	8 y	9 y	10 y
β_o	0.06	0.10	0.12	0.13	0.14	0.15	0.16	0.18	0.20
	[0.76]	[0.67]	[0.63]	[0.60]	[0.57]	[0.53]	[0.48]	[0.43]	[0.40]
$\beta_{\triangle i_3}$	-6.35	-7.12	-8.55	-9.07	-8.75	-7.84	-6.59	-5.19	-3.83
	[0.19]	[0.17]	[0.12]	[0.10]	[0.11]	[0.14]	[0.21]	[0.32]	[0.46]
$\beta_{\triangle slope}$	**-4.07**	**-5.79**	**-8.27**	**-9.71**	**-9.99**	**-9.44**	**-8.40**	**-7.12**	-5.75
	[0.03]	[0.03]	[0.01]	[0.00]	[0.00]	[0.01]	[0.02]	[0.04]	[0.09]
β_m	**-0.19**	-0.16	-0.15	-0.16	-0.18	**-0.22**	**-0.26**	**-0.31**	**-0.36**
	[0.02]	[0.09]	[0.13]	[0.12]	[0.06]	[0.02]	[0.00]	[0.00]	[0.00]
$\beta_{\triangle IV}$	0.14	**0.19**	**0.20**	**0.20**	**0.19**	**0.19**	**0.20**	**0.21**	**0.22**
	[0.06]	[0.04]	[0.04]	[0.03]	[0.03]	[0.01]	[0.00]	[0.00]	[0.00]
$\beta_{\triangle liq}$	0.67	1.06	1.52	1.77	1.83	**1.73**	1.51	1.24	0.95
	[0.49]	[0.30]	[0.15]	[0.09]	[0.06]	[0.05]	[0.06]	[0.11]	[0.23]
β_{lag}	0.00	-0.04	-0.07	-0.07	-0.05	-0.03	-0.02	-0.04	-0.07
	[0.97]	[0.64]	[0.38]	[0.42]	[0.59]	[0.75]	[0.82]	[0.73]	[0.43]
$\overline{R}^2$	4.9%	6.5%	9.3%	11.1%	12.0%	12.8%	13.8%	14.4%	14.1%

Note: This table presents the regression results for the A plus and A flat subrating categories. The dependent variables are the credit spread changes on A plus rated bonds (panel E) and A flat rated bonds (panel F). The analysis covers the period January 1998 until December 2002.

Panel G: A minus rated bonds									
	2 y	3 y	4 y	5 y	6 y	7 y	8 y	9 y	10 y
β_o	0.23	0.29	0.32	0.33	0.34	0.35	0.35	0.36	0.38
	[0.41]	[0.35]	[0.33]	[0.31]	[0.30]	[0.29]	[0.27]	[0.26]	[0.26]
$\beta_{\triangle i_3}$	-9.60	-10.6	-12.3	-12.8	-12.5	-11.5	-10.12	-8.64	-7.18
	[0.12]	[0.11]	[0.09]	[0.08]	[0.10]	[0.12]	[0.17]	[0.23]	[0.32]
$\beta_{\triangle slope}$	-4.87	-6.68	**-9.32**	**-10.9**	**-11.2**	**-10.6**	-9.48	-8.03	-6.45
	[0.18]	[0.07]	[0.02]	[0.02]	[0.02]	[0.03]	[0.06]	[0.11]	[0.20]
β_m	**-0.30**	**-0.28**	**-0.28**	**-0.30**	**-0.32**	**-0.35**	**-0.38**	**-0.42**	**-0.47**
	[0.01]	[0.02]	[0.03]	[0.02]	[0.01]	[0.00]	[0.00]	[0.00]	[0.00]
$\beta_{\triangle IV}$	**0.24**	**0.30**	**0.31**	**0.30**	**0.30**	**0.30**	**0.30**	**0.31**	**0.32**
	[0.03]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.00]	[0.00]	[0.00]
$\beta_{\triangle liq}$	-0.62	-0.41	-0.02	0.15	0.15	0.05	-0.13	-0.34	-0.56
	[0.61]	[0.73]	[0.98]	[0.89]	[0.88]	[0.96]	[0.88]	[0.69]	[0.51]
β_{lag}	0.04	-0.03	-0.07	-0.08	-0.06	-0.04	-0.03	-0.02	-0.02
	[0.71]	[0.81]	[0.46]	[0.43]	[0.53]	[0.68]	[0.82]	[0.89]	[0.83]
$\overline{R}^2$	8.1%	8.9%	10.4%	11.3%	11.6%	12.0%	12.7%	13.5%	13.7%

Panel H: BBB rated bonds									
	2 y	3 y	4 y	5 y	6 y	7 y	8 y	9 y	10 y
β_o	-	0.22	0.07	-0.03	-0.11	-0.19	-0.28	-0.37	-0.33
		[0.67]	[0.87]	[0.96]	[0.86]	[0.78]	[0.72]	[0.69]	[0.75]
$\beta_{\triangle i_3}$	-	**-10.8**	**-17.2**	**-21.0**	-23.0	-24.3	-25.5	-27.1	-27.2
		[0.14]	[0.01]	[0.02]	[0.06]	[0.09]	[0.13]	[0.17]	[0.24]
$\beta_{\triangle slope}$	-	-11.07	**-13.9**	**-18.4**	**-23.3**	**-28.2**	**-32.9**	**-37.5**	**-42.4**
		[0.08]	[0.05]	[0.02]	[0.02]	[0.01]	[0.01]	[0.02]	[0.02]
β_m	-	**-0.74**	**-0.70**	**-0.72**	**-0.80**	**-0.91**	**-1.03**	**-1.15**	**-1.13**
		[0.00]	[0.00]	[0.00]	[0.00]	[0.01]	[0.01]	[0.02]	[0.02]
$\beta_{\triangle IV}$	-	0.26	0.28	**0.40**	**0.58**	**0.78**	**1.01**	**1.23**	**1.45**
		[0.11]	[0.10]	[0.02]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
$\beta_{\triangle liq}$	-	**3.48**	3.38	**4.55**	**6.06**	**7.50**	**8.76**	**9.80**	**10.7**
		[0.05]	[0.06]	[0.03]	[0.01]	[0.00]	[0.00]	[0.00]	[0.00]
β_{lag}	-	-0.05	0.09	0.07	0.01	-0.04	-0.08	-0.11	-0.09
		[0.63]	[0.34]	[0.41]	[0.88]	[0.65]	[0.36]	[0.20]	[0.14]
$\overline{R}^2$	-	14.7%	19.6%	24.2%	28.6%	32.4%	34.7%	35.2%	33.7%

Note: This table presents the regression results for the A minus and BBB rating category. The dependent variables are the credit spread changes on A minus rated bonds (panel G) and BBB rated bonds (panel H). The analysis covers the period January 1998 until December 2002. Due to unavailability of enough BBB rated bonds from the start, Panel H starts from June 2000.