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RESEARCH REPORT

Modelling European Credit Spreads

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The interest for credit risk from academics and practitioners is booming. The up till now available literature on this subject, however, concentrates almost uniquely on US markets. While these markets play a major role in the world economy European bond markets are experiencing an ongoing growth and a trend towards maturity. How credit risk behaves in a European context has not been studied. Therefore, Deloitte and Touche took the lead in exploring the properties of European credit spreads. We would like to thank Deloitte & Touche and especially Mr J. Vlaminckx for giving us the opportunity to explore this interesting, new and last but not least important domain of financial research. The cooperation of Artesia-bank, especially Mr. C. Piret, L. Schockaert and S. Praet, made it possible to succeed in our objectives. Not only do we provide a lot of empirical evidence concerning the behaviour of these spreads, moreover we address at least two policy issues. The main theme of our research states that

1. Credit risk and interest rate risk are not independent but are negatively correlated. Risk management systems that fail to recognise these dependencies are doomed to mislead users and do not give the correct signals with respect to the portfolio benefits that can be obtained.

2. Credit risk has to be analysed not only by rating category, it also has to be analysed by maturity bucket. Neglecting the maturity dimension, as the recent BIS proposal does, fails to recognise an easy to capture risk dimension.

We sincerely hope that our research efforts will lead to a better understanding of the credit spread and will be used to enhance credit risk management systems. Of course, the usual disclaimers apply. Any remaining errors are ours and this document only expresses the authors' (current) view and does not necessarily imply a similar view of Deloitte & Touche.

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1. Introduction

In order to be attractive to investors, risky bonds should offer higher yields than comparable risk-free bonds, to compensate them for the probability of losing (part of) their invested funds. Consequently, a risky bond trades at a lower price than a risk free bond (given an identical maturity and coupon rate). The difference between the yield on the risky bond ('risky yield', *YTM*) and the yield of the comparable risk-free bond ('risk-free yield', *i*) is called the credit spread (*sp*).

The spread should at least compensate investors for the expected losses on the risky bond, but –to the extent that investors are risk averse– should also include a risk premium to reward investors for accepting the risk to assume higher than expected losses.

The credit spread may therefore exhibit continuous changes as well as sudden jumps. The jump part is due to credit migration and actual default, whereas continuous changes can be attributed to continuous changes in credit quality and variations in risk premia.

Of course, the analysis above makes abstraction from several market imperfections. Most importantly, it assumes that the risky bond is identical to the risk-free bond, save for its default risk. In practice, government bond markets are larger and more liquid than corporate bond markets. This implies that in addition to the credit spread, investors will need to be rewarded for holding bonds less liquid than government bonds. The spread, *sp*, thus also contains a liquidity premium.[1] Therefore, changes in the measured 'credit' spread, *sp*, may also be due to time-varying liquidity premia. In the theoretical analysis that follows, we will to a large extent ignore the liquidity premium. Also in the empirical analysis the distinction between pure credit spread and liquidity premium will not be made because of the difficulty to disentangle them.

For banks it is important to have a benchmark model enabling the bank to set the credit spread on a loan sufficiently high to earn the bank's target return on the economic capital that has to be set aside for the loan. For bond investors it is necessary to be able to understand how the credit spreads are determined in the market, as this is an important element in the risk-reward analysis. Knowledge of the time series dynamics of credit spreads is also useful when bonds of different credit ratings are actively traded and/or hedged. If the interest rate risk of a risky bond or debt portfolio has to be hedged using government bond based derivatives, traders have to know how the credit spread behaves with respect to interest rate

[1] Other elements may also be embedded in the spread, e.g. call features or other contingent contract specifications; see below.

changes to minimise basis risk. New hedging tools, the so-called credit derivatives, are priced based on the credit spread (e.g. credit spread options). Evidently, the stochastic process the credit spread follows has to be determined. Finally, for regulators, credit spreads reveal basic features of credit risk and the correlation of credit risk with interest rate risk. These features should be recognised in the standard setting activities of regulators.

Given this apparent interest of several market participants in credit spreads, we will focus on this aspect of credit risk in this report. First, we will situate the credit spread in the theoretical pricing models (section 2) and in the available empirical literature (section 3). Several loan-specific (3.1) and common factors (3.2) will be identified that influence the behaviour of the credit spread. Noting that most of the literature has examined bond spreads, section 3.3 reports to what extent the empirical findings concerning bond spreads can be generalised towards loan spreads. Equipped with the literature overview, the remainder of the report concentrates on the study of *European* Credit Spreads. Section 4 will introduce the data used (4.1) and will discuss how we computed the spreads (4.2). Summary statistics are provided in sub-section 4.3. Risk reduction opportunities by diversifying bond portfolios across different maturity buckets and different rating categories will be explored in section 5. This line of research will show that, contrary to the BIS proposal on regulatory capital, neither rating nor maturity may be ignored as risk factors. Section 6 will look for a possible relationship between interest and credit risk. It will be shown that, contrary to what most pricing models assume, interest and credit risk are not independent. We provide evidence of negative correlation between these two risk categories. This finding also has policy implications since it implies that an integrated view on risk management is a necessary condition for maintaining a competitive position in the market place. Although, we do not find very convincing results, section 7 will discuss the extent to which we find mean reversion in the spreads under study. Finally, we conclude with a brief summary and with restating the policy implications of our report.

2. Theoretical Pricing Models

To explain the credit spread one has to take into account not only all the elements having an impact on expected default, but also the risk premium (and its determinants) investors require to assume the risk of higher losses. This is quite complex as risk enters the picture in several ways. The four major sources of credit risk are default risk, credit migration risk, exposure uncertainty risk and recovery risk. ***Default risk*** refers to the fact that it is never certain if and when a firm will default on its obligations. ***Credit migration risk*** captures the changes in credit quality, which will affect the value of the portfolio held. ***Exposure uncertainty risk*** comprises all optionalities implied in loan and bond contracts (e.g. puttable bonds, pre-payment options, …). ***Recovery risk*** concerns the uncertainty about the value of the bond that is faced once the bond defaults.[2] CreditMetrics already provides evidence that the uncertainty on the recovery rates and the exposures can be quite large, so careful modelling these risk sources is presumably important. However, because of the large impact default and credit migrations have on debt value, modelling them appropriately is probably the most crucial element to understand credit risk pricing and thus the credit spread.

Theoretical credit risk models tackle the default risk in different ways. The default mode paradigm allows the bond to reside in only two ‘states’ of the world. Either the debt defaults or it does not. More elaborate models (Mark to market/model mode, MTM-mode) include other states of the world. They recognise a (relatively small) number of different risk categories, or rating classes, and for each category a default probability is modelled. In addition, also the probabilities that ratings change (so-called *migration probabilities*) with the concomitant impact on the bond’s spread are taken into account. In a sense, the theoretically most appealing approach is a limiting case of the latter way of viewing the default process. Instead of designating only a limited number of possible risk categories, in the limit, an entire continuum of categories is allowed. The category, in which a given bond then resides, depends on the fundamental (business) risk the issuing firm assumes. Although this ***structural-form approach*** is more complex and abstract, it has the appeal that it allows to identify the driving forces behind credit risk and thus the credit spread.

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[2] In addition, the credit risk premium required by investors may change through time due to economic circumstances without changes in default or recovery risk. This will also impact credit spreads and thus bond prices. Studies modelling the credit spread thus implicitly capture all three sources of risk.

A pioneering paper in this strand was Merton (1974) in which the firm's total value was modelled as a geometric Brownian motion. If at maturity of the firm's (single) debt instrument, the firm value is less than the face value of the debt, the firm defaults. If it is higher, the debt is simply repaid. Bondholders are thus actually short in a put on the firm's total value, with a strike price equal to the face value of the debt. Using insights from option pricing theory, the value of the risky debt is inferred. The firm's default risk is actually explicitly linked to the variability of the firm's asset value (business risk), the value of the debt issued (leverage ratio) and its maturity.

However, the Merton model contains many flaws. Firstly, it requires inputs related to the value of the firm. These inputs are not always readily available. Secondly, it allows default only at one specific moment, the maturity date of the bond. Thirdly, it assumes independence between interest rates and credit risk. To the extent that changes in interest rates are related to the business cycle and/or the firm's value, this is questionable. The model has therefore been adapted to account for some of these unrealistic assumptions (e.g. Longstaff and Schwartz (1995), see Nandi (1998) and Skora (1998) for non-technical overviews). However, more problematic is the corollary of these models that default is predictable shortly before default. This follows from the assumption that the firm's value follows a continuous process like the geometric Brownian motion in the Merton model. The predictability of default runs against the market observation that even highly rated firms default suddenly.

Some authors have tried to remedy this snag by assuming that the value of the firm does not always follow a continuous ('smooth') path, but from time to time also experiences a (downward) jump leading to immediate default (e.g. Jarrow and Turnbull (1995), Jarrow, Lando and Turnbull (1997), Zhou (1997)). Another possibility is the so-called ***reduced-form approach***. Instead of emphasising the value of the issuing firm, reduced-form models directly focus on the default and/or recovery process. They can also easily be adapted to allow for credit-rating changes. These changes may have an important impact on secondary market prices of bonds, either before the rating change if it is anticipated, or at the moment itself if not. The drawback of these models is that the default and recovery processes are postulated exogenously, which makes it difficult to link default and recovery value to the fundamental characteristics of the bond and issuer. Another drawback of these reduced-form models is that they assume the same default process for each bond within a rating class, whereas in practice different bonds within the same rating class have different credit spreads. Finally, the credit spread should only change when there is a rating migration, which is clearly not reflected in market data.[3]

[3] Extensions allow for credit spread changes even without rating migration, e.g. Lando (1998) on Cox processes.

As tedious or abstract the structural models may be, they still allow us to designate potential determinants of the credit spread. It then remains to be investigated whether, from an empirical point of view, these are valid determinants.

3. Empirical Evidence

A large part of the empirical literature has focused on the determinants of the credit spread. Which firm- and bond-specific characteristics bear an important relation to credit spreads? Besides these cross-sectional differences in credit spreads, recently the literature has started to pay attention to the time-series dynamics of credit spreads. How volatile are credit spreads? Do credit spreads correlate across rating categories? The answers to these questions are of course important for managing risk in bond and loan portfolios that are marked to market. Also, time-series analysis is important to test the statistical process assumptions made by the credit derivative pricing models.

The following cross-sectional factors are reported to have an impact on credit spreads. We divide them into two groups. The first series of factors, summarised in sub section 3.1, are related to the bond or the issuing company. The second group, dealt with in sub-section 3.2, refers to common time-varying determinants.

3.1. Specific factors

3.1.1. Credit rating

As the credit spread compensates the holder of the debt instrument for expected losses, there should be a link between the credit spread and the credit rating class, given the fact that there exist ample evidence that rating categories indeed entail an indication of relative credit risk. Researches have indeed shown that there exists a close relationship between credit rating classes and subsequent default experience. This is mirrored in empirical studies where it is always found that the credit spread widens at an increasing rate as the credit rating worsens. This can for instance be seen in Table 1 taken from Duffee (1998) for US investment grade corporate bonds.

Table 1 US Corporate Bond Yield Spread 1985-95

Maturity	Moody's Rating Class	Average Spread	Standard Deviation	Average Maturity
Short (2-7 yr.)	Aaa	0.67	0.083	3.8
	Aa	0.69	0.083	4.0
	A	0.93	0.107	4.2
	Baa	1.42	0.184	4.4
Medium (7-15 yr.)	Aaa	0.77	0.102	10.1
	Aa	0.71	0.084	9.2
	A	1.01	0.106	9.4
	Baa	1.47	0.153	9.1
Long (15-30 yr.)	Aaa	0.79	0.088	23.9
	Aa	0.91	0.087	21.3
	A	1.18	0.125	21.7
	Baa	1.84	0.177	21.2

Spreads are average spreads (in %) of non-callable and non-puttable corporate bonds relative to US Treasury debt; Standard deviation is for monthly spread changes. Source: Duffee (1998) Table I, Panel D.

However, the standard deviation of individual bonds' credit spreads *within a given rating category* increases as the credit rating worsens. This indicates that not all bonds within the same rating class are assumed to bear the same credit risk. Apparently, the higher cross-sectional standard deviation in the lower rating classes indicates that rating agencies allow for more heterogeneity in these classes.

By re-valuing the debt instrument assuming a transition to a given credit rating class and then taking expectations, the MTM-mode of credit risk management models effectively take this empirical evidence into account. However, the relatively large standard deviations shown in Table 1 should also be taken into account when computing unexpected losses.

3.1.2. Term to maturity

Theoretically, there is a relation between the term to maturity of the bond and its credit spread, which is also known as the ***term structure of credit spreads*** or ***credit spread curve*** (see Merton, 1974; Jarrow, Lando and Turnbull, 1997; Longstaff and Schwartz, 1995; Tychon, 1998). This relationship is not necessarily upward sloping. It can also be downward sloping or humped-shaped. The intuition behind the latter is that highly rated companies can hardly become better rated, but can get down-rated. The reverse applies to less-than-investment-rated companies. The longer the term to maturity, the higher the probability that the credit rating of such a company increases. This explains that the credit spread can be lower for longer maturity bonds. Empirical evidence is available for this phenomenon (Sarig and Warga, 1989; Fons, 1994; see also the references in Van Horne, 1998, 141-2).

However, Helwege and Turner (1997) indicate that the downward sloping credit spread curve might be a consequence of using average credit spreads of bonds in a given credit rating class. A bias would be introduced when using sets of bonds with the same credit rating. As was already mentioned in the previous section, differences in credit risk exist even within identical rating classes. Moreover, the safer firms tend to issue the longer dated bonds.[4] Therefore, the credit spread is underestimated for the longer maturities, such that the downward sloping credit spread curves in fact only follow from using less risky bonds for the longer maturities.

Helwege and Turner correct for this bias by looking at pairs of BB- and B-rated bonds issued by the same company at the same moment, having the same seniority but having different maturities. Differences in credit spread (computed using the primary market offerings) are therefore only due to maturity (and also potentially different call features). In a large majority of cases, these comparisons point towards upward sloping credit spread curves. This does not necessarily imply that the theoretical pricing models are wrong. It may be the case that for the bonds in the sample, the probability of an improvement of credit conditions was insufficiently high (due to low earnings volatility or a too low a debt-to-equity ratio – both are important factors in the theoretical models).

In any case, many other authors also fail to find other than positively sloped credit spread curves. Litterman and Iben (1991) indicate that in their sample the credit spread curve is upward sloping, although they only study BBB or higher rated bonds. Ma, Rao and Peterson (1989) report a positive relation between yield spread and duration[5] and Duffee (1996b) also finds (using investment-grade bonds) that for typical firms the term structure of yield spreads is upward sloping, with a slope which is positively related to the level of the spread. Fons (1994) computes credit spreads using historical default rates and assuming risk-neutrality. Although the credit spreads increase with term to maturity for investment-grade bonds, the credit spread curve for Ba-rated bonds is slightly humped, whereas the credit spread curve for B-rated bonds is negatively sloped. In contrast, Angbazo, Mei and Saunders (1998) find a positive relation between term to maturity and credit spreads on loans for highly leveraged transactions. It is remarkable that even for these highly risky loans no humped or downward sloping curve is found.

[4] This implies that term to maturity and credit risk are not independent. Term to maturity is determined endogenously in the firm's financing decisions. See e.g. Mitchell (1991) and the references cited therein (footnote 2).

[5] Duration is used as it is deemed more appropriate than term to maturity for high-yield bonds because of their high coupon rates. Chance (1990) elaborating Merton's (1974) model finds that risky bonds have a lower duration than riskless bonds with similar term to maturity.

3.1.3. Seniority and collateral

Both the seniority of a bond or loan and the collateral attached as security to it, have an impact on the credit spread because, arguably, both kinds of provisions will increase the recovery rate in case of default. Indeed, Izvorski (1997) finds that for defaulted US bonds debt seniority is one of the most important determinants of the recovery ratio, thus implying a lower yield for senior issues. This is also the case for syndicated bank loans: a study by FITCH IBCA showed that while distressed bank loans recovered 82%, senior subordinated debt of the same issuers recovered 42% and subordinated debt only 39% (Grossman, Brennan and Vento, 1998).

In some papers, however, the reverse relationship is reported: within a rating class security covenants actually *increase* the issue’s yield (e.g. Angbazo, Mei and Saunders (1998) for highly leveraged transaction loans). Roberts and Viscione (1984) explain this anomalous finding by differences in credit risk *within the same rating category*. Relatively risky bonds are more likely to have covenants, which in turn may lead to higher credit ratings for the issue than it would have without covenants. To eliminate this bias Roberts and Viscione (1984) study the yield difference between bonds issued by the same company, with similar features except for seniority/security covenants. In their sample, they do find lower yields for higher security bonds.

3.1.4. Coupon rate

In general, the credit spreads on coupon bonds are not equal to credit spreads on zero-coupon bonds because of either a non-flat term structure or a non-flat credit spread structure. To the extent that the credit-spread curve is upward sloping, higher coupon bonds will have lower credit spreads than lower coupon bonds with the same maturity (Litterman and Iben, 1991). Likewise, if the bond’s duration shortens, e.g. because of an interest rate increase, the credit spread will decrease if the credit spread curve is upward sloping. Therefore, even if there is no relation between the interest rate level and credit spreads of zero coupon bonds, there still might be a relation between the former and the credit spread on coupon bonds.

3.1.5. Other factors

Of course, the spread between a risky and a riskless bond is not only due to credit risk if also other characteristics of the two bonds differ. Callability or other option features may be important to take into account. In efficient markets the value of these options is embedded in the bond’s price and thus in the credit spread. The results in Duffee (1998) clearly indicate that the callability feature can dramatically change spread behaviour. He finds that spreads are negatively related to changes in risk-free rates. However, the relationship is stronger for callable bonds as the call feature's value is obviously related to interest rate level. If rates increase, the calls move further to the out-of-the-money range. This implies that prices of callable risky bonds do not drop as much as those of non-callable bonds, therefore lowering the credit spread stronger for callable bonds.

Also differences in liquidity may be important. To the extent that the riskless reference bond is more liquid than the risky bond, the spread between the two will also include a liquidity premium. When liquidity is measured as the issue's size, many authors find a negative relation between spread and size: the larger the size, the larger the issue's liquidity, the lower the required yield and therefore the spread. Boardman and McEnally (1981) find a negative relation between size and yield for Baa or better-rated US corporate bonds. Also for highly levered transaction loans do Angbazo, Mei and Saunders (1998) find a negative relationship between size and their spread. This corroborated by Shulman, Bayless and Price (1993) who report a significantly negative relation between several spread and liquidity proxies for individual high-yield bonds.

3.2. Common factors

3.2.1. Liquidity effects

Of course, besides the liquidity of a specific issue market-wide 'liquidity events' may also impact credit spreads. Cornell (1992) e.g. reports large abnormal returns on low-grade bonds due to changes in liquidity in the junk bond market. First, the bonds experienced positive abnormal returns (resulting in higher prices and hence in lower spreads) when Drexel Burnham Lambert exponentially increased the issuance of low-grade bonds, and then abnormal negative returns (higher spreads) when the market collapsed after Drexel's default in 1989. This is confirmed by Patel, Evans and Burnett (1998) and the same observation is made by Arak and Corcoran (1996) related to yield spreads on privately placed issues: investment grade issues had lower spreads than expected in late 1989 and early 1990, whereas sub-investment issues yielded less than expected according to economic conditions.

Similarly, after the Russian moratorium in August 1998 credit spreads rose sharply in the international secondary debt markets, at a moment when liquidity dried up, which reinforced the credit spread increase.

Fridson and Jónsson (1995) also find significant relations between the high-yield spread and liquidity proxies. These proxies include the net inflows to high-yield bond mutual funds (negative relation), cash proportion held by these funds (positive), and the three-month moving average price of the high-yield index (positive).

It may be argued that these market-wide changes in spread due to changes in liquidity do not really belong in a report on credit risk. Nevertheless, it is not always clear whether in all liquidity-induced changes credit risk is not involved. It may be the case that due to dramatically altered risk perceptions, credit spreads explode or tighten. At the same time the changes in risk perception may equally impact the volume investors want to trade. The Bank for International Settlements, for instance, links both the sharply increased risk and liquidity premia in the wake of the Russian debt moratorium in 1998 to the drying-up of securities issuance. Both are "… suggestive of a large-scale retrenchment in the supply of risk capital" (BIS, 1999:93). In any case, when the focus of interest is the credit spread (e.g. because of the fact that the pay-off of a credit derivative is related to the credit spread, or because the bond portfolio is marked to market), models should take into account that the level of the credit spread may dramatically wander through time regardless whether this is due to changes in liquidity or changes in risk perception.

3.2.2. Term structure of interest rates

There are strong theoretical arguments to assume that there is a relation between credit spreads and the risk-free interest rate level. First, under the simplifying assumptions that investors are risk-neutral and the recovery rate given default is constant and known, there exist a purely mathematical relation between the two. Consider for simplicity a one period risky bond and assume that the recovery rate given default is zero.[6] If *EDF* denotes the expected default frequency (or the probability of default), market equilibrium implies

$$(1+i) = (1-EDF)\cdot(1+YTM) + EDF\cdot 0\,,$$

where i is the risk-free one period rate and *YTM* the promised yield on the risky debt. This relation implies the following for the credit spread sp:

$$sp \equiv YTM - i = (1+i)\cdot EDF/(1-EDF)\,.$$

As long as *EDF* is a proper constant probability residing between 0 and 1, a positive relation exists between the risk-free rate i and the spread sp.

Of course, if investors are risk-averse, the reaction of the credit spread also depends on the risk premium the spread contains. If the risk premium decreases as the risk-free rate increases, this lowers the positive risk-neutral effect. Also, if the probability of default *EDF* is correlated with the risk-free rate i, the positive relation between the credit spread sp and i may be altered. However, this would require a negative correlation between i and *EDF*.

[6] This analysis can be generalised to a multiperiod coupon bond, with similar qualitative conclusions, see Hurley and Johnson (1996). They also include a non-zero recovery rate.

Second, from many theoretical (structural) models it follows that default-risky instruments may depend upon the risk-free interest rate, if the value of the firm depends on the interest rate (e.g. Longstaff and Schwartz, 1995). Some reduced-form models directly allow for correlation between interest rates and the probability of default, implying a link between credit spreads and interest rates. However, because of tractability, empirical implementation of these models often assumes these two variables to be independent from each other.

The (scarce) empirical evidence as to the relation between interest rates and credit spreads is mixed. Duffee (1998) studies the relation between interest rate variables and credit spreads on non-callable corporate bonds.[7] To this end he regresses monthly changes of credit spreads on changes in the three-month Treasury bill yield and changes in the slope of the term structure, as measured by the difference between the thirty-year constant-maturity Treasury yield and the three-month bill rate. In contrast to the mathematical argument above, Duffee finds significantly negative slope coefficients for both variables.[8] For long maturities, the slopes of both variables are similar, thus cancelling the influence of the three-month bill rate, leaving a negative association with long-term interest rate changes.

Arak and Corcoran (1996) also find a negative relation between yield spreads on privately placed issues and risk-free rates when all variables are measured in levels. The relation is significant for A and Baa-rated paper, at least when influences of other economic variables are taken into account, but not for Ba-rated paper. Fridson and Jónsson (1995), however, report that they did not find any relation between the level of Treasury rates and the spread on high-yield bonds, which are also below-investment grade.

Morris, Neal and Rolph (1998) point to statistical pitfalls in these studies. They argue that when corporate bond yields are cointegrated with Treasury rates, both the regressions in levels and the usual regressions in first differences may lead to false inferences. Using 10-year constant maturity Treasury bonds and Moody's Aaa and Baa seasoned indices over the period January 1960 to December 1997,[9] they find that each of the corporate yield series is cointegrated with Treasury rates. However, in both cases the long-run relationship turns out to be *positive*. When Treasury rates increase by 1% point, Aaa (Baa) rates increase by 1.028 (1.178)% points: this implies that credit spreads *increase*! Using more appropriate first

[7] Duffee also studies established US bond indices which equally include callable bonds and finds that these indices react even more negatively to the term structure variables.
[8] The relation holds regardless of maturity, but becomes stronger the lower the rating class considered (all indices studied are investment grade; the lowest rating class is Moody's Baa). For Aaa-bonds the relation with the short term rate is only significant for short maturities, and not a single coefficient of the term structure variable is significant. The coupon effect (see Section 0) is not sufficiently strong to explain the negative relation.
[9] This is a much longer data period than used in Duffee (1998) which was a period of generally declining interest rates.

difference regressions,[10] however, learns that *in the short-run* the relationship between Treasury rates and corporate spreads is *negative*.

This leaves us with some apparent contradictions. Firstly, although the negative relation seems at odds with the simple mathematical argument, a sufficient condition for consistency is a negative correlation between interest rate risk and default risk, implying a decrease in the probability of default when the interest rate increases. This is actually what follows in the model by Longstaff and Schwartz (1995a). Moreover, their model entails that the higher the value of the company is correlated with changes in interest rates, the stronger the rate sensitivity of the credit spread will be. The Arak and Corcoran (1996) and Fridson and Jónsson (1995) can thus be made consistent with those of Duffee (1998) if below-investment-grade issuers were more negatively correlated with interest rate changes than investment-grade issuers.

Secondly, the cointegration results of Morris, Neal and Rolph (1998) imply that bond yields are non-stationary, which seems hard to explain economically, as this would imply that yields may grow to infinity… Structural breaks in the series under study, which may hamper correct statistical inference of cointegration models, may be an explanation for their results.

3.2.3. Business cycle

According to finance textbooks, credit spreads behave cyclically over time (e.g., Van Horne, 1998). During periods of economic downturn credit spreads are expected to increase, as investors are more concerned with safety. On the other hand, during periods of economic expansion, investors are likely to seek the highest-yielding investments, implying reduced risk premia. Liquidity and marketability aspects might have an additional effect on the cyclical nature of credit spreads: to the extent that investors want to hold more liquid instruments in periods of recession, the spread will increase. Moreover, business conditions are also likely to impact default risk: as debt-service becomes more difficult in periods of economic downturn, the required risk premium may increase.

Arak and Corcoran (1996) find some empirical corroboration of the anticipated credit spread behaviour. They study yield spreads on privately placed issues, both investment-graded (A-rated) and sub-investment graded (Ba-rated) issues. They find that credit spreads are negatively correlated to economic activity as well as to the direction of change: when economic activity is high or expanding credit spreads tend to decrease.

[10] In econometric parlance, an error-correction term must be introduced.

3.3. Bond spreads versus loan spreads

In the previous sections we summarised the empirical evidence according to credit spread behaviour. However, the bulk of the evidence pertains to bond markets. In contrast, many applications focus upon loans. It is therefore important to know to which extent the results available for the bond market carry over to the loan market[11]. Unfortunately, due to a lack of data not much evidence is available. It is only during the last years that some research on this issue has been done, spurred by the fact that secondary markets for loans start to develop and financial institutions realising the importance of this kind of research have started to make data available to researchers. In this section, an overview of published research on credit spreads for loans is given. The general conclusion is that spreads on loans are different from spreads on comparable bonds, but that they do show co-movement to some extent. Therefore, care should be taken when bond market data are applied in risk management tools for loan portfolios.

Arak and Corcoran (1996) use data on privately placed debt yields. They find that these yields do not closely follow yields of comparable-quality public debt issues, although there is more similarity for A-rated paper than for sub-investment grade issues (Ba-rated). Moreover, privately issued lower rated issues have a considerably lower spread compared to their publicly issued counterparts (see Table 2). Both observations are explained by the fact that lower rated private issues include more covenants than similarly rated bonds, which implies lower default losses for the former and therefore a lower spread and less co-movement between the series as the credit risk profile is dramatically changed. They also find that public issue yield spreads are far more volatile than privately placed issue yields.

Table 2 Characteristics of Private–Public Yield Spreads on Intermediate-Term Issues, 1980-1990

Quality of Issues	Mean Spread in bp (Private minus Public)	Standard Deviation
A	+22	28
BBB (Baa)*	0	46
BB (Ba)	-66	63

* 1977-1990; Source: Arak and Corcoran (1996), Exhibit 3.

Similar results are found by Angbazo, Mei and Saunders (1998) who study highly leveraged transaction loans. Spreads on these loans are stickier than spreads on Baa- rated bonds as well as spreads on junk bonds. Nevertheless, the series do show some relation with each other although much less strong than a one-to-one

[11] There is reason to believe that credit risk in private debt portfolios is not entirely similar to credit risk is public debt portfolios. Carey (1998) finds that especially for sub-investment grade issues credit risk for private debt is lower. This is both due to lower default rates and lower losses given default. Carey suggests that this is evidence of private debt being better monitored by lenders.

relation. They estimate that when loan yields increase by 1 percentage point, loan spreads increase by some 30 bp.

Keim and von Kleist (1999) focus on spreads of primary issues of emerging market debt instruments, both bonds and loans. They find that both types of debt instruments react similarly to a number of issue-specific and general items, but that bond spreads are generally double as high as loan spreads with comparable characteristics. However, it is not clear whether this is due to the mere difference between loans and bonds or to the fact that all loans studied have a floating rate whereas all bonds have a fixed interest rate.

4. European Credit Spreads: Data Description and Spread Construction

Nearly all known credit risk management tools use data calibrated to the US situation. Not only default rates, credit migration probabilities and recovery rates pertain to the US, also empirical modelling of credit spreads is to a large extent confined to the US market. Nevertheless, as markets become more global and corporate bond markets develop in other parts of the world, non-US data may be useful to ascertain the robustness of known results. In this section we focus on *European* credit spreads and their empirical characteristics.

4.1. Index data description

We obtained bond index data constructed by Merrill Lynch. Its 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 direct government bond indices also investment grade corporate bond indices were used. The latter are based on publicly traded bonds, issued by companies domiciled in the European Union and excludes convertible securities. Since we want to focus on the behaviour of credit spread through time for different maturity classes and ratings, we will work with the respective sub-indices produced by Merrill Lynch – see Table 3 for the exact indices used.

All these indices are based upon the composite rating of Moody's and Standard & Poors, if the issue is rated by both. If ratings do not coincide, an average rating is used which is 'rounded' downwards. The composition of each index is determined on the last business day of the previous month. During the month, each bond will stay in the index, regardless whether or not the bond is downgraded or upgraded, or whether the maturity does no longer fit the classification. Also when bonds are called during the month, they are not removed from the index until the end of the month. A similar rule holds for changes in the amount outstanding during a month: face values are kept constant and are adjusted at the start of a new month. All issues have a fixed coupon (including step-ups) and a minimum remaining term to maturity of one year.

Table 3 Average Number of Issues

	All Ratings	AAA	AA	A	BBB	Not Rated
All Maturities	***948.01***	***317.28***	***349.92***	***154.71***	***25.46***	***100.64***
1-3 years	***248.22***	93.40	91.72	32.37	7.48	23.25
3-5 years	***262.85***	78.83	106.41	43.76	5.91	27.94
5-7 years	***160.36***	57.98	46.43	31.83	9.58	14.54
7-10 years	***201.11***	54.41	77.97	37.03	2.59	29.10
10-more years	***75.46***	32.52	27.39	9.71	NA	5.84
			Relative Across Ratings			
	All Ratings	AAA	AA	A	BBB	Not Rated
All Maturities	***100.0%***	***33.5%***	***36.9%***	***16.3%***	***2.7%***	***10.6%***
1-3 years	*100.0%*	37.6%	36.9%	13.0%	3.0%	9.4%
3-5 years	*100.0%*	30.0%	40.5%	16.6%	2.2%	10.6%
5-7 years	*100.0%*	36.2%	29.0%	19.8%	6.0%	9.1%
7-10 years	*100.0%*	27.1%	38.8%	18.4%	1.3%	14.5%
10-more years	*100.0%*	43.1%	36.3%	12.9%	NA	7.7%
			Relative Across Maturities			
	All Ratings	AAA	AA	A	BBB	Not Rated
All Maturities	***100.0%***	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*
1-3 years	***26.2%***	29.4%	26.2%	20.9%	29.4%	23.1%
3-5 years	***27.7%***	24.8%	30.4%	28.3%	23.2%	27.8%
5-7 years	***16.9%***	18.3%	13.3%	20.6%	37.6%	14.4%
7-10 years	***21.2%***	17.1%	22.3%	23.9%	10.2%	28.9%
10-more years	***8.0%***	10.2%	7.8%	6.3%	NA	5.8%

Calculations are based upon Merrill Lynch data. Ratings are composite Moody's and Standard and Poors ratings. Maturity buckets include the lower boundary and exclude the upper boundary. Averages are computed from daily data over the period 31 March 1998 through 17 May 1999 (292 observations, except for the '7-10 years BBB' index, where only 271 observations were available). "NA" denotes not available.

Although the bond index data start on 31 December 1995, daily data are only available from 31 March 1998 onwards. This implies that our daily sample, which runs till 17 May 1999, only contains 292 observations per index. In Table 3 we indicate the average number of issues for each maturity bucket and rating class over this sample period. Table 4 shows similar data for the average market value. From these tables, it can be seen that both the number of issues and the total market value of issues indicate that bonds with maturities longer than 10 years are relatively scarce.[12] Moreover, the average maturity (shown together with other characteristics in Table 5) of these bonds range between 10.8 years (A-rated bonds) up to 12.5 years (AAA-rated bonds), implying that more than ten years is effectively not really that long a maturity. Also, BBB-rated bonds are relatively under-represented in the sample (and in the market!). It is important to note that for this rating category the maturity buckets contain very few different issues, which should be kept in mind during the empirical analysis. Also, for BBB-rated bond

[12] Note that there are no BBB-rated bonds in this category. The "not-rated" class is not used in the empirical analysis.

index series the ‘7-10 years’ maturity bucket contained no issues over the period from 31 July 1998 to 28 August 1998.

Table 4 Average Market Value Outstanding

	All Ratings	AAA	AA	A	BBB	Not Rated
All Maturities	***307.1***	***102.1***	***109.2***	***54.3***	***6.9***	***34.7***
1-3 years	***65.4***	22.5	23.1	10.1	1.7	8.0
3-5 years	***74.3***	21.8	30.1	12.8	2.0	7.6
5-7 years	***61.2***	18.8	17.9	15.1	2.6	6.7
7-10 years	***76.7***	23.4	28.7	14.0	0.6	10.0
10-more years	***29.5***	15.4	9.4	2.3	NA	2.4
			Relative Across Ratings			
	All Ratings	AAA	AA	A	BBB	Not Rated
All Maturities	***100.0%***	***33.2%***	***35.6%***	***17.7%***	***2.2%***	***11.3%***
1-3 years	*100.0%*	34.4%	35.3%	15.4%	2.6%	12.2%
3-5 years	*100.0%*	29.3%	40.6%	17.2%	2.7%	10.2%
5-7 years	*100.0%*	30.8%	29.2%	24.7%	4.3%	11.0%
7-10 years	*100.0%*	30.6%	37.4%	18.2%	0.7%	13.1%
10-more years	*100.0%*	52.3%	31.8%	7.9%	NA	8.0%
			Relative Across Maturities			
	All Ratings	AAA	AA	A	BBB	Not Rated
All Maturities	***100.0%***	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*
1-3 years	***21.3%***	22.1%	21.2%	18.6%	24.6%	23.0%
3-5 years	***24.2%***	21.4%	27.6%	23.6%	29.0%	21.8%
5-7 years	***19.9%***	18.5%	16.4%	27.8%	38.6%	19.4%
7-10 years	***25.0%***	23.0%	26.3%	25.7%	8.2%	28.9%
10-more years	***9.6%***	15.1%	8.6%	4.3%	NA	6.8%

Calculations are based upon Merrill Lynch data. Market values are expressed in billions of euro. Ratings are composite Moody’s and Standard and Poors ratings. Maturity buckets include the lower boundary and exclude the upper boundary. Averages are computed from daily data over the period 31 March 1998 through 17 May 1999 (292 observations, except for the ‘7-10 years BBB’ index, where only 271 observations were available). “NA” denotes not available.

From Table 5 no clear pattern can be discerned as to the relation between rating class and average maturity *within maturity baskets*. However, there is a visible difference between the average coupon rates: as could be expected, coupon rates and yields to maturity are generally larger for lower rated bonds. As the ‘coupon effect’ may have an impact on the relation between interest rates and yield spreads, this should be taken into account in the empirical analysis. From the last column, it is clear that the BBB-rated issues are generally somewhat smaller on average than the others, especially in the longer maturity buckets. Also, bond indices with longer maturities contain larger issues on average than the shorter dated issues. This may have an impact on the liquidity premia contained in the bond spread.

Table 5 Average Characteristics for the Merrill Lynch Euro Corporate Bond Indices

		Maturity	Modified Duration	Conven-tional Yield to Maturity	Coupon	Average Market Value per Issue
1-3 years	AAA	2.03	1.85	3.70	6.48	241.1
	AA	1.98	1.80	3.80	6.51	251.8
	A	1.90	1.72	3.90	7.23	314.1
	BBB	1.73	1.57	4.25	7.64	206.3
3-5 years	AAA	3.96	3.44	3.95	5.78	278.4
	AA	3.97	3.41	4.11	6.38	282.6
	A	4.12	3.50	4.26	6.71	292.5
	BBB	3.75	3.17	4.45	7.58	335.6
5-7 years	AAA	5.91	4.86	4.22	6.03	328.3
	AA	5.68	4.65	4.28	6.21	394.1
	A	5.90	4.77	4.48	6.57	476.5
	BBB	5.76	4.60	4.65	7.18	276.5
7-10 years	AAA	8.60	6.58	4.57	5.98	427.1
	AA	8.72	6.65	4.70	5.94	363.7
	A	8.84	6.65	4.90	6.32	368.9
	BBB	8.81	6.56	5.34	6.34	211.3
10+ years	AAA	12.47	8.53	4.76	6.02	475.9
	AA	10.87	7.94	4.84	5.53	347.2
	A	10.84	7.75	5.12	5.92	240.9

Calculations are based upon Merrill Lynch data. Ratings are composite Moody's and Standard and Poors ratings. Maturity buckets include the lower boundary and exclude the upper boundary. Averages are computed from daily data over the period 31 March 1998 through 17 May 1999 (292 observations, except for the '7-10 years BBB' index, where only 271 observations were available). 'Maturity', 'Modified duration' and 'conventional yield to maturity' are equally-weighted averages over all issues. 'Coupon' is a market value-weighted average. 'Average market value per issue' is expressed in billions of euro.

4.2. Credit spread series

Although Merrill Lynch computes option-adjusted spreads, these data are only available since 31 March 1999, which leaves us with far too few observations (31 daily observations) to do any analysis. We therefore had to compute yield spreads in a different way. Because we had no daily data available on individual bond prices, nor the sufficient information on any potential call features of the bonds, we simply computed the spread as the difference between the yield to maturity as reported by Merrill Lynch and a comparable government bond yield. Because of the differences in coupon rates across rating categories, shown in Table 5, we chose to take the yield of a government bond with similar duration rather than similar maturity.

Table 6 Average Characteristics for the Merrill Lynch AAA-rated Euro-Sovereigns Bond Indices

	Number of Issues	Market Value Outstanding	Maturity	Modified Duration	Conventional Yield to Maturity	Coupon
All issues	176.43	1205.7	7.31	5.10	4.00	6.63
1-3 years	57.54	272.0	1.94	1.75	3.52	6.97
3-5 years	45.54	296.2	4.03	3.45	3.77	6.46
5-7 years	27.52	198.0	5.98	4.82	3.98	6.82
7-10 years	28.52	276.9	8.40	6.45	4.24	6.21
10-more years	17.32	162.7	22.10	11.77	4.88	6.88

Calculations are based upon Merrill Lynch data. Maturity buckets include the lower boundary and exclude the upper boundary. Averages are computed from daily data over the period 31 March 1998 through 17 May 1999 (292 observations). 'Maturity', 'Modified duration', 'Conventional yield to maturity' and 'Coupon' are averages over all issues. 'Market value' is in billions of euro.

The government bond yields used were the yields of indices of AAA-rated Euro-sovereigns, also computed by Merrill Lynch. Average characteristics for these bond indices can be found in Table 6. There are fewer government issues than corporate bond issues, but the former are much larger, as evidenced by the average market value outstanding column. Obviously, average yields for government bonds are lower than the corporate bond yields. However, we did not compute spreads by simply subtracting the government bond yield from the bond yields in the corresponding maturity bucket. This would not properly account for potential differences in maturity or coupon rate between the government and corporate bond index. Therefore, for each corporate bond index and each day in our sample we subtracted the yield of the government bond index with the same average (modified) duration as the corporate bond index. Of course, in most cases the average duration of the corporate bond index did not match the average duration of a government bond index. In these cases we took an interpolated government bond yield. This yield was exponentially interpolated from the two adjacent government bond yields. The following example provides more details.

Example: Computing Credit Spreads

To explain the construction of our 'duration adjusted' spread series, we follow the example of the 5-7 year A-rated bond index observation for 17 May 1999. Its modified duration was 4.978, while its yield to maturity was 4.124%. We followed the following steps:

- Obtain duration and yield of adjacent government bond indices:
  3-5 years: duration = 3.406; yield = 3.206%
  5-7 years: duration = 4.990; yield = 3.601%

- Compute the continuously compounded the government bond yields:
  3-5 years: ln(1+3.206%) = 3.156%
  5-7 years: ln(1+3.601%) = 3.538%

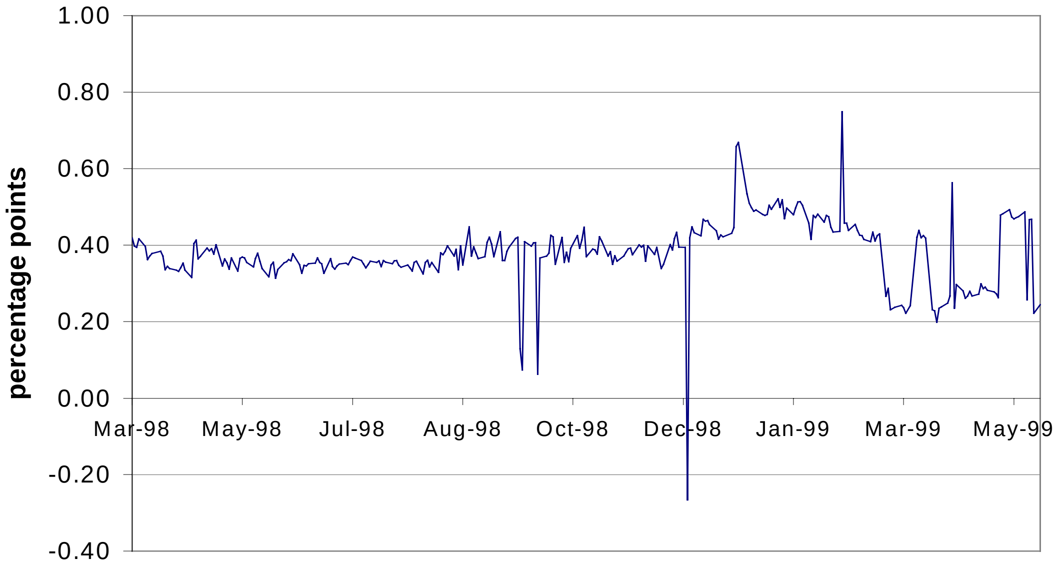
- Linearly interpolate the continuously compounded yields:
  3.156% + (3.538% – 3.156%) $\times$ (4.978 – 3.406) $\div$ (4.990 – 3.406) = 3.535%

- Compute the conventional yield and yield spread:
  conventional yield = exp(3.535%) – 1 = 3.598%
  spread = 4.124% – 3.598% = 0.526%

Unfortunately, the resulting data still contained some problems. For instance, the yield spreads for the 1-3 year A-rated bonds are shown in Figure 1 on page 22. Not only do the series contain some 'spikes', where the spread jumps up or down, simply reverting to its previous level the next day, it also shows a negative spread on 8 December 1999![13] In a communication by Merrill Lynch we were told that the series may contain some errors due to individual bond mispricings. As these errors do no longer exist the next day, series exhibit the jumps or 'reversals' mentioned above. Because lack of individual bond data, we filtered the series in order to correct for these singularities.

[13] Although jumps were detected in a few more series, this is the only negative spread encountered.

Figure 1 Adjusted Credit Spread Series for 1-3 Years A-Rated Bonds



For each series, we computed a ‘reversal indicator’ series. This indicator was obtained by multiplying for each day the change in the spread by the previous day’s spread change. Reversals therefore imply large negative indicator values. We removed the largest ‘reversals’ and replaced the spread by the arithmetic average of the previous and next day’s spreads. Subsequently, the effect of these corrections on the characteristics of the series was examined. We looked at summary statistics of the series, such as average change in spread, its standard deviation and its serial correlation at several lags. If necessary, we repeated the correction procedure by eliminating the next largest reversal until the series characteristics did not change materially. It turned out that only the removal of the single negative spread was sufficient to obtain relatively well-behaved series. As a check, we also removed several other reversals and re-ran the statistical analysis, without obtaining qualitatively different results. Because it is not certain whether the reversals are due to data errors or genuine market behaviour, it was opted to report only results based on the original data set with only the single negative observation removed.

4.3. Summary statistics

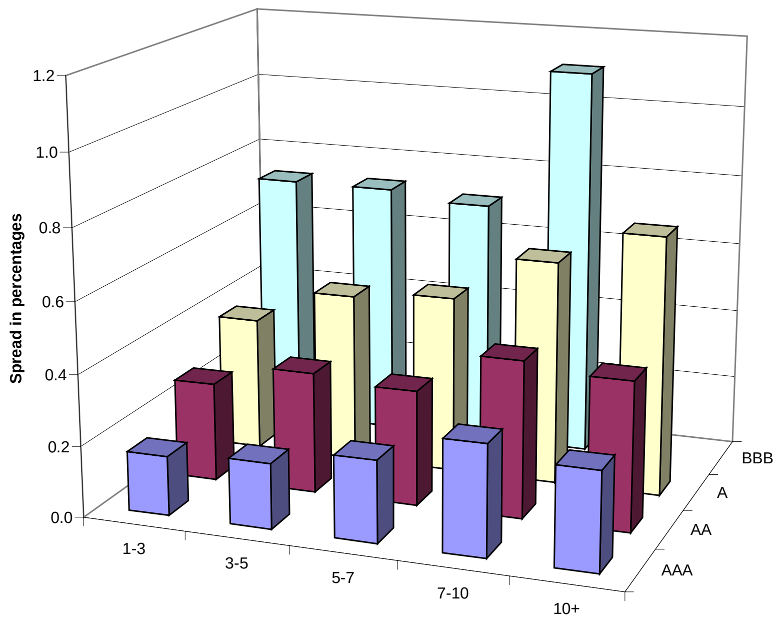
Summary statistics of the series can be found in Table 7. As could have been expected, average spreads increase monotonically the lower the credit rating. This is also summarised in Figure 2. The relation is clearly not linear: the difference between the BBB-rated indices and AA-rated indices is generally much higher than between other adjacent rating classes. Remarkably, the spreads are considerably lower than the spreads reported by Duffee (1998) and given in Table 1. For AAA-rated bonds, our spreads vary between 17 basispoints (bp) and 31 bp, whereas Duffee finds at least 67 bp. The picture is similar for the other rating categories. Of course, our data period is much shorter than Duffee’s and does not overlap with his. Our average spreads do seem consistent with the findings of Pendrosa and Roll (1998) for US investment grade spreads covering the period 1995-1997. Unfortunately, they do not provide an estimate of the average spread on the US market, but the graphs they present, show spread levels similar to our data.

Table 7 Summary Statistics of Yield Spreads

		Average Spread (in %)	Standard Deviation (in %)	First Order Auto-correlation	Second Order Auto-correlation	Third Order Auto-correlation	Ljung-Box Statistic at 20 lags
1-3 years	AAA	0.167	0.056	0.835	0.815	0.812	2876.3
	AA	0.279	0.029	0.853	0.784	0.740	2139.7
	A	0.381	0.080	0.642	0.517	0.481	851.5
	BBB	0.726	0.197	0.947	0.899	0.846	2835.1
3-5 years	AAA	0.184	0.051	0.937	0.915	0.897	4005.8
	AA	0.343	0.070	0.944	0.934	0.920	4804.5
	A	0.481	0.086	0.977	0.970	0.965	5255.1
	BBB	0.726	0.142	0.934	0.918	0.900	3844.1
5-7 years	AAA	0.230	0.048	0.934	0.919	0.898	3750.6
	AA	0.325	0.061	0.924	0.904	0.897	4321.5
	A	0.504	0.083	0.923	0.887	0.847	3442.5
	BBB	0.701	0.120	0.974	0.957	0.943	4375.3
7-10 years	AAA	0.311	0.081	0.975	0.964	0.951	4824.0
	AA	0.443	0.109	0.983	0.975	0.968	5273.6
	A	0.635	0.145	0.988	0.985	0.981	5506.7
	BBB	1.105	0.502	0.984	0.970	0.957	NA
10+ years	AAA	0.276	0.057	0.902	0.879	0.849	3056.4
	AA	0.420	0.095	0.971	0.952	0.943	4980.3
	A	0.733	0.187	0.991	0.987	0.984	5623.1

Calculations are based upon Merrill Lynch data. Yield spreads are spreads relative to government bond yields with similar duration. Ratings are composite Moody's and Standard and Poors ratings. Maturity buckets include the lower boundary and exclude the upper boundary. Statistics are computed from daily data over the period 31 March 1998 through 17 May 1999 (292 observations, except for the '7-10 years BBB' index, where only 271 observations were available). "NA" denotes not available.

Figure 2 Average Credit Spreads by Rating Class and Maturity Bucket



As far as the relation between spread and maturity is concerned, we generally find an upward sloping credit curve, as was also the case for the Duffee (1998) series (and in most of the papers discussed in section 3.1.2). Nevertheless, in some cases the relation is not monotone: see e.g. '10 and more years' bucket for AAA and AA-rated bonds. Perhaps this is due to a liquidity effect, as in Table 5 it is shown that these longer dated issues are somewhat larger than the others. In addition, it may be the case that relatively less credit risky issuers issue longer dated bonds (see section 3.1.2).

Furthermore, we note that, as in Longstaff and Schwartz (1995b), the standard deviation of spreads is also increasing when credit rating deteriorates. No clear relation with maturity can be observed. Finally, we also observe that the first lag autocorrelation coefficient of all spread series is relatively large, and often near 0.95 or higher.[14] We do not present stationarity tests because the reported low power of unit root tests on observation periods as short as this one. In any case, if we accept on economic grounds that the credit spread series are stationary, it is clear from the high autocorrelation coefficients that they revert only slowly to their long-run average.

In Table 8 summary statistics for *changes* in credit spreads are presented. To some extent these are more important in a risk management context, as it is important to understand how credit spreads behave through time. It can be noticed

[14] A notable exception is the autocorrelation coefficient for the '1-3 years A-rated' index. However, remember that this is the series containing some 'odd' reversals, which we chose not the eliminate. Of course, such reversals bias the autocorrelation coefficient away from one.

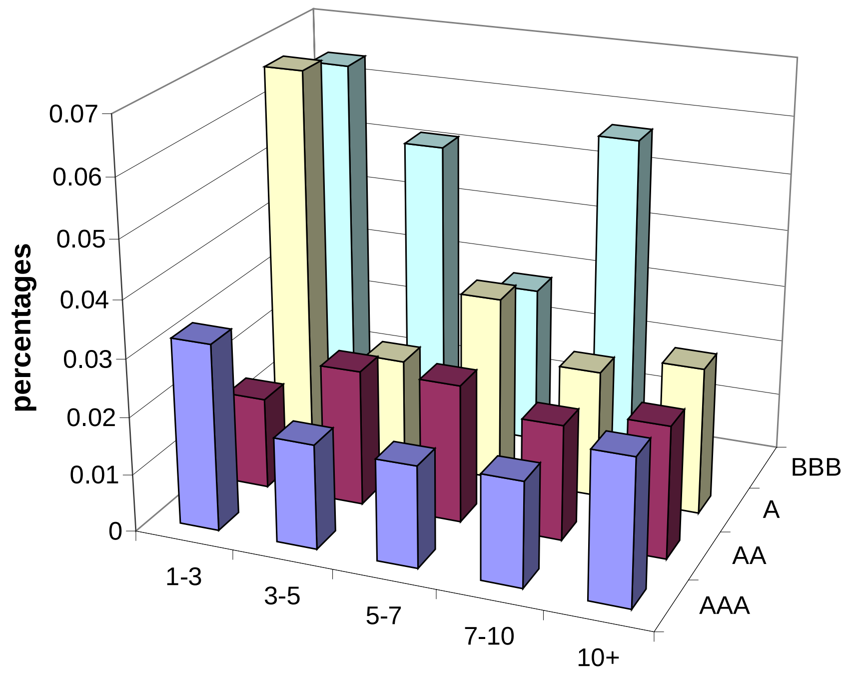
that average changes in spreads are very small and insignificantly different from zero. This could have been expected as they measure the trend of credit spreads over the time period investigated. When we look at the standard deviation of spread changes (also pictured in Figure 3), there is not a clear relation to rating class. This contrasts both with Pedrosa and Roll (1998), who find lower standard deviations for lower rating classes, and with Duffee (1998) or Longstaff and Schwartz (1995b) who find the opposite effect. Looking at the maturity class, we neither have a clear picture, which is consistent with Duffee (1998), but not with Pedrosa and Roll (1998), who find decreasing volatility for longer maturities. The fact that Longstaff and Schwartz (1995b) and Pedrosa and Roll (1998) use logarithmic spread differences whereas Duffee (1998) and this report use simple first differences, is not the cause of the conflicting results: re-computing the standard deviations using logarithmic differences does not alter our results.

Table 8 Summary Statistics of Yield Spread Changes

		Average Spread Change (in bp)	Standard Deviation (in bp)	Skew-ness	Kurtosis	First Order Auto-correlation	Second Order Auto-correlation	Third Order Auto-correlation
1-3 years	AAA	0.028	3.240	-0.829*	33.987*	-0.437*	-0.057	0.075
	AA	-0.020	1.587	0.629*	8.930*	-0.266*	-0.086	-0.109
	A	-0.060	6.758	-0.068	15.808*	-0.331*	-0.105	0.031
	BBB	0.255	6.391	2.966*	44.404*	-0.068	0.040	-0.049
3-5 years	AAA	0.022	1.815	0.101	7.054*	-0.319*	-0.048	-0.100
	AA	0.027	2.360	-0.116	20.612*	-0.412*	0.026	-0.091
	A	0.033	1.861	-0.054	5.778*	-0.359*	-0.026	-0.039
	BBB	0.093	5.131	-0.788*	7.634*	-0.375*	0.009	0.095
5-7 years	AAA	0.011	1.762	-0.363*	6.277*	-0.386*	0.044	-0.048
	AA	0.030	2.402	0.101	16.643*	-0.371*	-0.081	-0.012
	A	0.032	3.239	-0.873*	8.988*	-0.262*	0.015	-0.077
	BBB	0.086	2.766	-0.921*	9.669*	-0.193*	-0.040	-0.049
7-10 years	AAA	0.033	1.820	-0.173	6.622*	-0.283*	0.037	-0.026
	AA	0.047	2.003	-0.449*	10.507*	-0.262*	-0.026	-0.029
	A	0.081	2.217	0.009	6.009*	-0.350*	0.022	-0.035
	BBB	-0.246	5.667	-1.446*	15.208*	-0.200*	0.060	-0.054
10+ years	AAA	0.026	2.534	-1.050*	16.774*	-0.383*	0.035	-0.042
	AA	0.062	2.290	-0.611*	8.582*	-0.171*	-0.182*	-0.023
	A	0.123	2.555	0.329*	5.981*	-0.293*	-0.044	0.054

Calculations are based upon Merrill Lynch data. Yield spreads are spreads relative to government bond yields with similar duration. Ratings are composite Moody's and Standard and Poors ratings. Maturity buckets include the lower boundary and exclude the upper boundary. Statistics are computed from daily data over the period 1 April 1998 through 17 May 1999 (291 observations, except for the '7-10 years BBB' index, where only 271 observations were available). "NA" denotes not available. Asterisks denote autocorrelation, skewness or kurtosis coefficients more than two (asymptotic) standard deviations away from zero.

Figure 3 Standard Deviation of Spread Changes by Credit Rating Class and Maturity Bucket



In Table 8 the first three order autocorrelation coefficients of the spread changes are also shown. Without any exception, all first order coefficients are negative and usually significantly different from zero.[15] This is in contrast to Duffee (1998) who uses monthly data and mostly finds positive autocorrelations. The negative autocorrelation may be a reflection of poor liquidity in the European corporate bond market. By frequently bouncing between the bid and the ask quote, negative autocorrelation may be introduced. Unfortunately, with the data at hand, we cannot investigate this hypothesis. Higher order autocorrelation does hardly seem present in the series.

In any case, from the skewness and kurtosis coefficients in Table 8, it is clear that spread changes are not normally distributed. This is both due to skewness and kurtosis. The skewness coefficients are statistically different from zero, and the kurtosis coefficients are significantly in excess of three, the value a normal distribution would show. Most skewness coefficients are negative. All kurtosis coefficients are significantly higher than three, which implies that the distributions have higher peaks and thicker tails than the normal distribution does. If the latter distribution is used for risk management purposes, this means that more extreme changes would effectively occur than expected. Therefore, value-at-risk measures based upon the normal distribution will be underestimating true risk and capital requirements will be insufficient. Of course, it could be argued that our series contain some degree of error – of which the 'reversals' mentioned above are a

[15] The asymptotic standard deviation of the autocorrelation coefficients is $\sqrt{1/291} = 0.059$.

reflection – which explains skewness and excess kurtosis. Although we cannot completely discard this rationalisation, it seems implausible as we also find these characteristics in the series for which these 'reversals' were removed. To the extent that excess kurtosis is not diversifiable in a portfolio, any risk management model will have to take this non-normal behaviour into account. Whether or not a diversified portfolio of corporate bonds still exhibits these characteristics will be investigated in the next section.

5. Risk Characteristics in a Portfolio Context

In the previous Section the individual characteristics of the spread series were documented. However, from a portfolio point of view it is equally, if not more, important to understand the risk properties of diversified bond portfolios. Although our 'individual' series are already diversified bond portfolios, more diversification may be achieved by combining indices from different rating categories and/or maturity buckets. Indeed, it is highly unlikely that banks or bond investors would only hold loans or bonds from one rating-maturity combination.

5.1. Correlations between bond market segments: a first look

A first indication about the risk reduction possibilities is obtained by computing all pairwise correlation coefficients. It follows that, to a large extent, changes in the different spread series are positively correlated. The average correlation coefficient (out of 171 pairwise correlations) is 0.278 (see Table 9). This is approximately half of what Pendrosa and Roll (1998) found, possibly implying larger risk diversification opportunities in Europe than in the US. In our sample 8 of the correlations are even negative (but not significantly), whereas in the Pendrosa-Roll sample, the minimum correlation coefficient was 0.281.

Table 9 Summary Statistics on Pairwise Correlation Coefficients

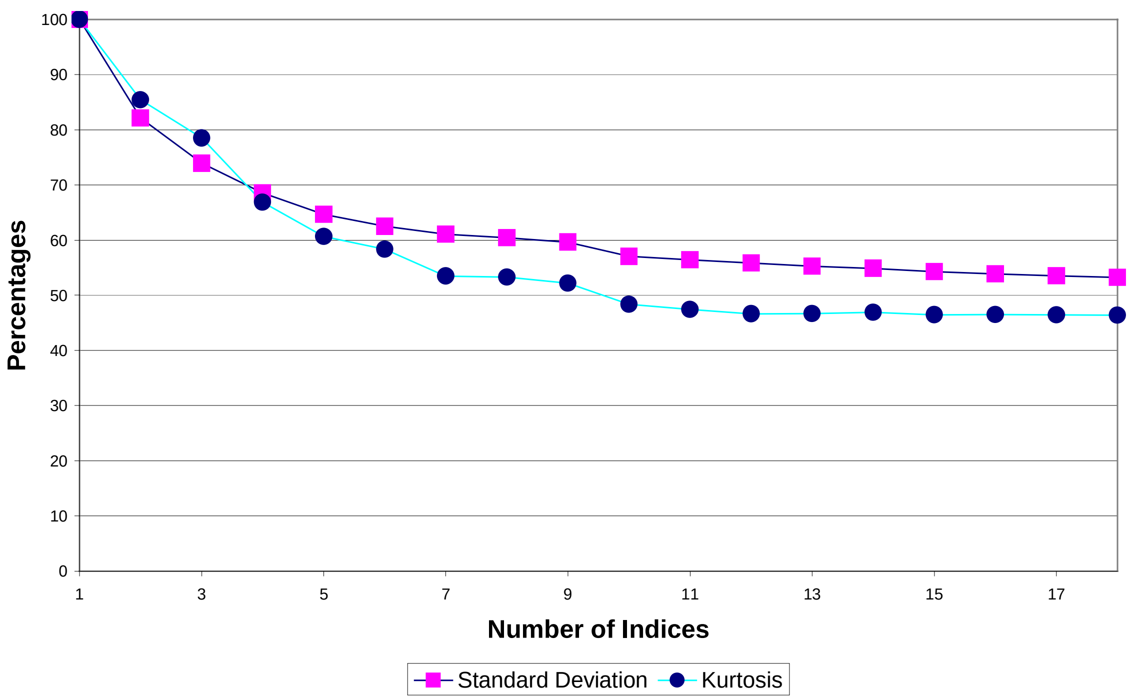
	Average Correlation Coefficient	Minimum Correlation Coefficient	Maximum Correlation Coefficient	Total Number of Correlation Coefficients	Number of Significant Correlation Coefficients
All Coefficients	*0.278*	*-0.101*	*0.740*	*171*	*111*
Within Same Rating Class	0.299	-0.064	0.738	36	32
Within Same Maturity Bucket	0.350	0.003	0.669	27	23
All Other Coefficients	0.253	-0.101	0.740	108	56

Correlation coefficients are Pearson correlations. Significance is a the two-sided 5% level.

5.2. Total risk reduction

To gauge the risk diversification opportunities in the European corporate bond market further, we constructed series of spread changes for simulated equally weighted bond portfolios and then computed standard deviation and kurtosis coefficients for these portfolios. Risk diversification should result in reduced standard deviation and kurtosis. We started by forming portfolios consisting out of two different bond indices. Of course, only $\binom{18}{2} = 153$ different combinations are possible in our data set of 18 bond indices which have observations across the entire time period studied. We therefore computed average risk measures across all these portfolios. We then gradually increased portfolio diversification by allowing investments in ever more different bond indices. Because the number of different portfolio combinations increases rapidly, we randomly formed 250 portfolios for each of the sizes between 3 and 16 indices. Then, for each portfolio size, we computed average risk measures across these 250 portfolios. For portfolios consisting out of 17 assets all 153 combinations were computed. Finally, the maximum naïve diversification possible in our data set is achieved by simply holding the entire market. To be consistent with the other portfolios, an equally weighted portfolio of all indices was used to represent the market.

Figure 4 Risk Measures for Increasingly Diversified Portfolios



In Figure 4 the effect of diversification on the risk measures is graphed. Consistent with the low average correlation coefficient in Table 9, the reduction in the standard deviation is quite important. If we set the average standard deviation of spread changes for individual bonds at 100%, risk can be reduced by approximately 47%. Moreover, risk reduction is relatively fast: increasing portfolio size from single indices to 4 indices already reduces risk (as measured by standard deviation) by nearly a third. Similarly, also kurtosis is halved through diversification. Again relatively small portfolios already achieve lower kurtosis levels. It should be stressed, however, that even when holding the (equally weighted) market portfolio, the kurtosis coefficient is more than 6, which is significantly higher than three. The normal distribution therefore does not seem suitable for portfolio risk modelling. Although not shown in Figure 4, the effect of diversification on skewness is remarkable: the average skewness coefficient is –0.12 for individual bond indices and triples to –0.36 for the equally weighted market portfolio. Again, this is not in accordance to the normal distribution, which is symmetric.

Of course, in the exercise above, diversification was very naïve in the sense that every combination of bond indices was equally likely to be included in our sample. Perhaps more diversification can be obtained by judiciously and selectively diversifying across the rating or maturity dimension. As a first indication, we computed the correlation coefficients within maturity buckets and rating classes (see Table 9). We did not find any particular pattern when we compared correlations within or across rating categories or maturity buckets. The average correlation within identical maturity buckets (0.350) is slightly higher than the average coefficient within identical rating classes (0.299), but not significantly (*t*-statistic of 1.071). Also, approximately the same ratio of significantly positive coefficients is found in both groups. Risk reduction seems to be more worthwhile by combining indices from different rating *and* different maturity buckets: the last row in Table 9 indicates that correlations between such index-pairs are somewhat lower and less often significantly different from zero than for pairs within the same rating class or maturity bucket.

A second indication of the effect of risk reduction characteristics across the rating and maturity dimensions can be found in Table 10. This table reports similar summary statistics as in Table 8 (Summary Statistics of Yield Spread Changes) but now for value weighted aggregate indices. We computed average spreads for the different credit rating classes and maturity buckets. Average series were computed using the outstanding market value of each constituent index as weights.

Table 10 Summary Statistics Aggregate Indices

	Average Spread Change (in bp)	Standard Deviation (in bp)	Skew-ness	Kurtosis	First Order Auto-correlation	Ljung-Box Statistic at 20 lags
	Market Value Weighted Aggregates					
All series	0.035	1.467	-0.376*	6.591*	-0.371*	79.6*
AAA	0.026	1.563	-0.172	6.313*	-0.399*	80.4*
AA	0.028	1.491	-0.313*	6.569*	-0.333*	76.8*
A	0.039	2.059	0.131	7.048*	-0.396*	64.4*
BBB	0.122	2.935	-0.828*	11.129*	-0.201*	35.3*
1-3 years	-0.009	2.207	0.195	10.588*	-0.383*	65.5*
3-5 years	0.037	1.777	0.116	7.028*	-0.367*	67.2*
5-7 years	0.023	1.869	-0.555*	7.120*	-0.346*	78.4*
7-10 years	0.064	1.739	-0.492*	9.335*	-0.269*	53.6*
10+ years	0.051	2.079	-1.076*	12.203*	-0.295*	50.5*

Calculations are based upon Merrill Lynch data. Yield spreads are spreads relative to government bond yields with similar duration. Ratings are composite Moody's and Standard and Poors ratings. Maturity buckets include the lower boundary and exclude the upper boundary. Statistics are computed from daily data over the period 1 April 1998 through 17 May 1999 (291 observations). All aggregates are made up by all relevant individual index' spread series. Asterisks denote autocorrelation, skewness or kurtosis coefficients more than two (asymptotic) standard deviations away from zero. Ljung-Box statistics significant at the 5% level are also denoted by an asterisk.

Again, using the Jarque-Bera test (not shown), the normality hypothesis for the aggregate series can be rejected in every case. This can clearly be seen from the skewness and kurtosis coefficients in Table 10. Many series show significant negative skewness and, more importantly, all series show excess kurtosis. This definitely implies that large "surprises" in the series can hardly be diversified and therefore also show up in the aggregate series.

Although standard deviations and kurtosis of the aggregate spread changes are generally lower than those for the individual series, naïve risk reduction possibilities along both dimensions are limited. Only the aggregate AAA and AA portfolios achieve risk levels (standard deviation and kurtosis coefficient) comparable to the total (value weighted) market portfolio's risk levels. The lower rated portfolios as well as the maturity portfolios consistently remain above these levels. This indicates that the maturity is the first dimension across which diversification strategies should be pursued. The second dimension seems to be credit rating, as borne out in the lower rating categories.

However, the evidence shown in Table 9 and Table 10 is very crude as the aggregate rating and maturity indices are not independent from each other. It was shown in Table 4 that maturity distributions were not identical across rating classes. For instance, the BBB-category contains relatively more bonds in the '5-7 years' range (38.6%) than do the other categories (19.9%). Likewise, rating distributions are not similar across maturity buckets. As an example we notice that more than half of the bonds in the 'more than 10 years' category are AAA-rated (53.2%), whereas in the population AAA-bonds account only for a third (33.2%). Therefore, to understand more about the pure risk driving forces on the corporate bond market we have to disentangle the rating and maturity dimensions more formally. To this end we adopt the methodology introduced by Heston and Rouwenhorst (1994) who used it to separate the country and the industry effect for European stocks.

5.3. Searching for risk dimensions

5.3.1. Methodology

We assume that the change in the spread Δsp_{it} at time *t* of a bond *i* in rating category *r* and maturity bucket *m* can be divided into a general component COM_t, common to all spreads at time *t*, a rating component RAT_{rt}, a maturity component MAT_{mt}, and a unique component ε_{it} :

$$\Delta sp_{it} = COM_t + RAT_{rt} + MAT_{mt} + \varepsilon_{it} ,$$

where *r* = AAA, AA, A, or BBB and *m* = 1-3 years, 3-5 years, 5-7 years, 7-10 years, or more than 10 years, and i belongs rating category *r* and maturity bucket *m*.

Estimates of these components can be obtained by running, for each time period *t*, a cross-sectional regression of Δsp_{it} on a constant, which is an estimate of the general component COM_t and a set of rating and maturity dummies:

$$\Delta sp_{it} = COM_t + \sum_r RAT_{rt} \cdot DUM(i,r) + \sum_m MAT_{mt} \cdot DUM(i,m) , \qquad (*)$$

where *DUM*(*i*,*r*) and (*DUM*(*i*,*m*)) are dummy variables which equal one if bond index *i* is in rating category *r* (maturity bucket *m*) and zero else. The slope coefficients of the dummy variables then provide estimates for the respective rating and maturity components, whereas the regression residuals (omitted in equation (*)) proxy the unique components and the constant term the common component. The regression is first run for the spread changes on 17 May 1999 (the start of our data period), yielding estimates for the components on that day. Subsequently, estimates for the following day were obtained by performing the same regression using next day's spread changes. Repeating this procedure for each trading day, time series for all these components were built. Using the time-series properties of the components, it is possible to indicate the relative importance of rating and maturity factors for determining spread changes.

Obviously, the regression equation cannot be estimated directly, as the regressors are perfectly correlated: each bond always belongs to exactly one rating category and maturity bucket. Thus, the sum of both the rating and the maturity dummies always equal the constant vector. Therefore, two constraints have to be added before estimating the regression equation. Any two linearly independent constraints will do and can generally be written as follows:

$$\sum_r a_{rt} RAT_{rt} = 0$$
$$\sum_m b_{mt} MAT_{mt} = 0$$

where a_{rt} (b_{mt}) are arbitrary weights attached to rating category r (maturity bucket m) at day t.

Following Heston and Rouwenhorst (1994) we choose these weights in such a way that the components obtain an economically intuitive interpretation. In our implementation, a_{rt} denotes the relative market value of bond indices in rating category r (relative to the total market value of all bond indices) at day t.[16] Likewise, b_{mt} is the relative market value of bond indices in maturity bucket m at day t. The constraints therefore simply impose that the (weighted) average maturity and rating components are zero for each day. Each rating or maturity component can thus be interpreted as a deviation from the average rating or maturity component. In addition, if equation (*) is estimated with weighted least squares using the relative market values of all individual bond indices as weights, it follows from the properties of least squares that the (weighted) average unique component is also zero for each day. So, if we sum equation (*) (using relative market weights) across all bond indices, only the constant COM_t remains, which implies that this component can be interpreted as the value-weighted average spread change.

Likewise, if we sum equation (*) across all bond indices in a given rating category r using relative market weights, we would obtain $COM_t + RAT_{rt}$, *if the maturity distribution in rating category r were identical to the maturity distribution in the total market*. To see this, first note that weighted residuals sum to zero within a given rating class, because of the least squares property that residuals are orthogonal to the regressors. Secondly, the weighted sum of maturity effects would also disappear under the condition that the maturity distributions are similar across rating classes. The term RAT_{rt} can therefore be interpreted as a pure rating component in excess of the common component. It is the (weighted) average spread change of bonds in the same rating category. Similar reasoning leads to the conclusion that MAT_{mt} is a pure maturity component. It is the (weighted) average spread change of bonds in the same maturity bucket in excess of the common component, under the assumption that the rating distribution is identical across maturity buckets. Due to the variation in rating and maturity distribution across classes and buckets (see Table 4), the thus defined 'pure' rating and maturity components do not necessarily coincide with the aggregate series in Table 10.

[16] Market values at the beginning of the day were used.

In what follows, we first report how the model fits the data series. Then we present summary statistics on the rating and maturity components. Finally, the contribution of these components to spread risk will be investigated.

5.3.2. Model fit

One drawback that makes our results less powerful than those of Heston and Rouwenhorst, is that we do not have observations of all individual bonds from the Merrill-Lynch universe. We therefore run the regression equation using the 19 rating-maturity indices we do have. This implies that we only have 19 data points to estimate 8 regression coefficients.[17] This lack of degrees of freedom means that the estimation results will contain much more sampling noise. Nevertheless, taken this caveat into account, we still obtain reasonable results. One way to appreciate the appropriateness of the analysis is to compute the time-series correlation between the original indices and the reconstructed series. Based upon the time-series of the common component and the incremental rating and maturity components a proxy of the original series may be constructed. The difference between the two series is the estimate of the unique component:

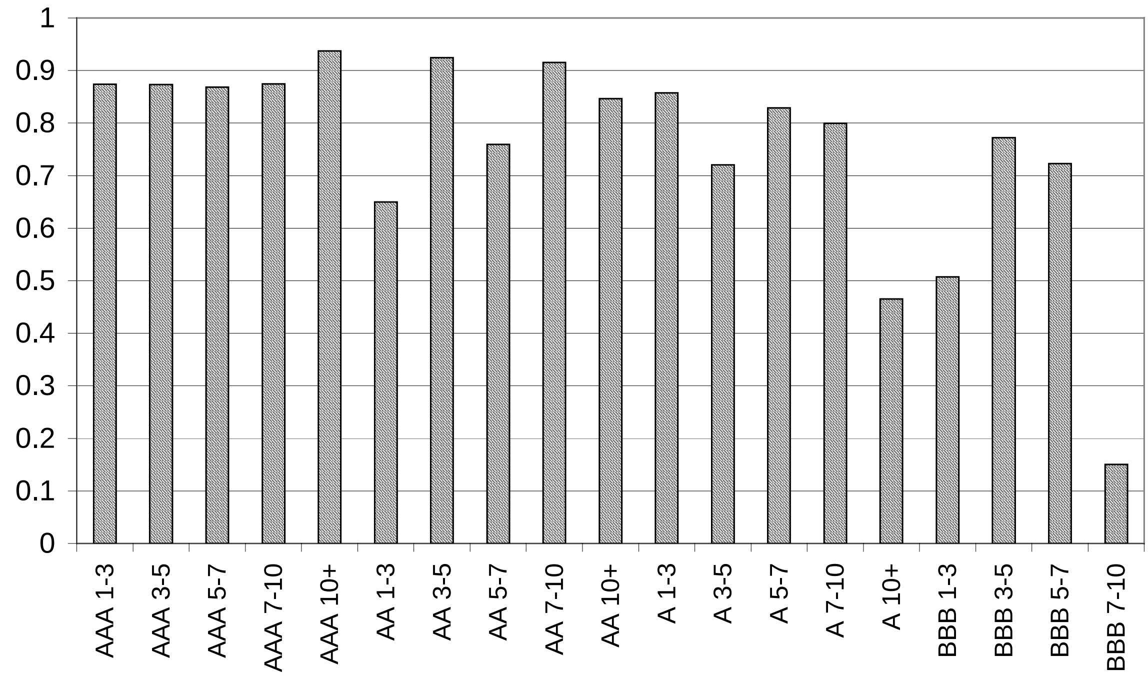
$$\Delta sp_{it}^{proxy} = COM_t + RAT_{rt} + MAT_{mt} ,$$

where estimated values for the components are used, and where i belongs to rating class r and maturity bucket m.

The correlations between the original series and the proxies are graphed in Figure 5. On average, the correlation is 0.755 for the market-weighted series, which implies that more than 55% of spread variation is accounted for by our model. It should be noted that the average is considerably lower than the median (0.829) because of the very low fit for the 'BBB, 7-10 years' bond index and a bad fit for 'A, more than 10 years' and 'BBB, 1-3 years'. Because these indices have very low market value (on average less than 1% of total market value, see Table 4), the fit would be even better if value-weighted averages had been used. Obviously, the correlations with the aggregate series from Table 10 (not shown) are much higher due to the diversification of the unique components. We conclude that our methodology leads to a reasonable fit.

[17] The constant, 4 rating categories and 5 maturity buckets. Two coefficients are eliminated by imposing the two restrictions.

Figure 5 Pearson Correlation Coefficient Between Changes in Spreads and Their Proxies



5.3.3. Characteristics of rating and maturity components

In Table 11 time series summary statistics for the rating and maturity components are given. Recall that averages are not independent across series as their market-value weighted average is zero due to the constraints imposed during estimation. It can be seen that generally spread changes increase with lower rating and longer maturity. More importantly, standard deviations are much more different across rating components than across maturity components: whereas in the latter case the maximum standard deviation is about twice as large as the minimum (0.850 bp versus 1.833), in the former it is five times as large (0.504 bp versus 2.670 bp). Standard deviations increase strongly as the credit quality drops. In contrast, spread variation seems to drop as the maturity lengthens.

Again, all components clearly show excess kurtosis, whereas the negative skewness found in the series is to a large extent due to the common component. Consistent with the summary statistics for the individual series, all components show significant negative serial correlation. Higher order autocorrelations (not shown) are not significantly different from zero.

Table 11 Summary Statistics Rating and Maturity Components

	Average Spread Change (in bp)	Standard Deviation (in bp)	Skew-ness	Kurtosis	First Order Auto-correlation	Ljung-Box Statistic at 20 lags
Common	0.024	1.468	-0.411*	6.510*	-0.380*	83.3*
AAA	-0.003	0.615	-0.260	8.923*	-0.356*	50.6*
AA	-0.003	0.504	0.195	6.475*	-0.331*	54.4*
A	0.006	1.247	0.904*	11.656*	-0.347*	50.8*
BBB	0.062	2.670	-2.072*	19.850*	-0.206*	49.3*
1-3 years	-0.031	1.833	-0.164	11.807*	-0.292*	61.4*
3-5 years	0.003	1.020	-0.235	19.766*	-0.370*	61.0*
5-7 years	0.001	0.989	0.149	7.734*	-0.295*	52.7*
7-10 years	0.023	0.850	0.104	5.124*	-0.204*	34.8*
10+ years	0.027	1.339	-0.709*	7.507*	-0.218*	26.9

Summary statistics are time-series statistics from cross-sectionally estimated coefficients in equation (*). Statistics are computed from daily data over the period 1 April 1998 through 17 May 1999 (291 observations). Asterisks denote autocorrelation, skewness or kurtosis coefficients more than two (asymptotic) standard deviations away from zero. Ljung-Box statistics significant at the 5% level are also denoted by an asterisk.

5.3.4. Identification of risk dimensions

We can also use our estimates to decompose the variance of spread changes of a value-weighted rating or maturity index into pure maturity and rating effects. We have

$$\Delta sp_{rt} = COM_t + RAT_{rt} + \sum_m w_{rmt} \cdot MAT_{mt} ,$$

for each rating class r, and where w_{rmt} denotes the relative value of bucket m in rating class r at day t. The change in spread in rating class r in excess of the common component can therefore be due to the pure rating effect and/or the weighted effect of all maturity components:

$$\Delta sp_{rt} - COM_t = RAT_{rt} + \sum_m w_{rmt} \cdot MAT_{mt} .$$

The variance of excess spread changes in rating class r is therefore due to the variance of the pure rating component, the variance of an average maturity component and possibly a covariance term between the two components:

$$\sigma^2(\Delta sp_r - COM) = \sigma^2(RAT_r) + \sigma^2\left(\sum w_{rm} MAT_m\right) + 2 \cdot \operatorname{cov}\left(RAT_r, \sum w_{rm} MAT_m\right).$$

The first term is the variance of the pure rating component and is listed in the first column of the upper panel of Table 12. The last two terms catch the maturity effects. Their sum is listed in the fourth column of the upper panel in the same table. Both variance components are expressed with respect to the total variance $\sigma^2(\Delta sp_r - COM)$. These are the ratios given in Table 12.

Table 12 Decomposition of spread changes in excess of the common component

	Pure Rating Effect		Average of 5 maturity effects	
	Variance (× 10000) $\sigma^2(RAT_r)$	Ratio relative to index $\frac{\sigma^2(RAT_r)}{\sigma^2(\Delta sp_r - COM)}$	Variance (× 10000) $\sigma^2(\sum w_{rm} MAT_m)$	Ratio relative to index $\frac{\sigma^2(\sum w_{rm} MAT_m)}{\sigma^2(\Delta sp_r - COM)}$
AAA	0.382	1.013	0.008	0.021
AA	0.247	0.976	0.008	0.032
A	1.576	1.017	0.017	0.011
BBB	6.865	0.966	0.203	0.029
Average	*2.267*	*0.993*	*0.059*	*0.023*
	Pure maturity effect		Average of 4 rating effects	
	Variance (× 10000) $\sigma^2(MAT_m)$	Ratio relative to index $\frac{\sigma^2(MAT_m)}{\sigma^2(\Delta sp_m - COM)}$	Variance (× 10000) $\sigma^2(\sum w_{rm} RAT_r)$	Ratio relative to index $\frac{\sigma^2(\sum w_{rm} RAT_r)}{\sigma^2(\Delta sp_m - COM)}$
1-3 years	3.304	0.987	0.004	0.001
3-5 years	1.077	1.039	0.004	0.003
5-7 years	0.946	0.971	0.021	0.021
7-10 years	0.718	0.996	0.005	0.006
10+ years	1.810	1.013	0.052	0.029
Average	*1.571*	*1.001*	*0.017*	*0.012*

The pure rating effect measures the average change in spread of subindices in a given rating class relative to subindices in other rating classes but in the same maturity buckets.

The sum of 5 maturity effects represent the component of the average change in spread that can be attributed to the difference in maturity distribution relative to the total market. For the rating class BBB only 4 maturity effects have been included (no '10 years or more' bonds).

The pure maturity effect measures the average change in spread of subindices in a given maturity bucket relative to subindices in other maturity buckets but in the same rating classes.

The sum of 4 rating effects represent the component of the average change in spread that can be attributed to the difference in rating distribution relative to the total market. For the maturity bucket '10-more years' only 3 rating effects have been included (no BBB bonds).

Likewise, spread changes in maturity bucket *m* in excess of the common component is due to the a pure maturity component and an average rating component:

$$\Delta sp_{mt} - COM_t = MAT_{mt} + \sum_r w_{rmt} \cdot RAT_{rt} \ ,$$

for any maturity bucket *m*. A similar variance decomposition can be made. Numerical results for both variance decompositions are shown in Table 12.

From the first column in Table 12 it can be seen that the variance of the pure rating effects is generally somewhat higher than those of the pure maturity effects. This is due to the effect of the lower rating categories, and especially the BBB-rated bonds. What is more important is that the pure maturity effect is dominant for the maturity buckets: the rating effects are on average responsible for only 1.2% of total variance.[18] The pure rating effect is likewise dominant for the rating indices, but the maturity effects amount to 2.3% of total variance on average. This should not be stressed too much, as this is mostly due to the large maturity effect in the BBB rating class. Given the fact that relatively few issues fall in this category, the equally weighted averages give this class too much weight.

All in all, it seems that both dimensions – rating and maturity – are equally important in European bond credit spreads. Especially in the lower rating categories does the rating dimension show up. Remarkably, as for the maturity effect, this shows up in the short end ('1-3 years') and in the long end ('more than 10 years'). Two risk dimensions is not inconsistent with the empirical results in Duffee (1996b) who estimates the price of credit risk by fitting a reduced form model using individual US corporate bond data. Estimation proceeds in two steps: first, a continuous-time risk-free interest rate process is estimated after which the credit risk process is fitted. Although his estimation results are not totally satisfactory, at least these two factors seem necessary. To the extent that the maturity dimension we found is linked to term structure variables and the rating dimension to the credit risk process, both sets of results are consistent. We would need individual bond data over a substantially longer period, however, to verify this hypothesis.

[18] Note that the sum of the shares of both variance components may be larger than one due to negative covariance between the two.

6. Relation With the Term Structure

In this section we will investigate the relation between the risk-free term structure and credit spreads. This is an important aspect for credit risk management, as many pricing models require independence between credit risk and interest rates. Nevertheless, US evidence as reported in section 3.2.2 shows that this is too strong an assumption.

To study the relationship between credit spreads and the term structure, we follow the approach in Duffee (1998): changes in the credit spread are regressed upon a constant, changes in the short-term risk-free rate and changes in the slope of the term structure:

$$\Delta sp_t = c_0 + c_1 \Delta i_t + c_2 \Delta slope_t$$

These variables are chosen given the vast empirical evidence that two factors explain most of the variation in the risk-free term structure. These factors are often identified as being the level and the slope of the term structure.

To construct proxies for both term structure variables we used the conventional yields of the Merrill Lynch AAA-rated Euro-sovereign bond indices we also used to compute duration adjusted credit spreads. The yield of the 1 to 3 years maturity bucket index was used as the short-term risk-free rate *i*. The difference in yield of the more than 10 years index and the former is our proxy for the slope of the term structure. Of course, this implementation is not unique. We could have used yields for other maturities, but we chose to use the yields at both extreme sides of the term structure. Equivalently, we could have used changes in the long-term yield to measure changes in the level of the term structure. Obviously, as both sets of regressors are linear combinations of each other, they are statistically equivalent. The estimation results can be found in Table 13.

Table 13 Regression Results for the Relation between the Credit Spread and the Term Structure

$$\Delta sp_t = c_0 + c_1 \Delta i_t + c_2 \Delta slope_t$$

		c_0	c_1	c_2	Adjusted R-Squared	Durbin Watson Statistic
1-3 years	AAA	0.000 (-0.354)	-0.129 (-2.249)	0.019 (0.427)	0.7%	2.87
	AA	-0.001 (-2.516)	-0.172 (-5.962)	0.091 (4.329)	14.0%	2.62
	A	-0.002 (-0.779)	-0.260 (-1.707)	-0.020 (-0.169)	0.5%	2.64
	BBB	0.000 (0.013)	-0.503 (-3.079)	0.090 (0.644)	4.8%	2.17
3-5 years	AAA	-0.001 (-1.209)	-0.262 (-5.143)	-0.012 (-0.298)	16.2%	2.56
	AA	-0.001 (-1.188)	-0.321 (-6.029)	-0.092 (-2.096)	15.1%	2.84
	A	-0.001 (-1.223)	-0.288 (-5.704)	-0.066 (-1.625)	19.2%	2.74
	BBB	0.000 (0.103)	-0.267 (-2.602)	-0.147 (-1.652)	2.2%	2.78
5-7 years	AAA	-0.001 (-1.552)	-0.320 (-13.061)	-0.138 (-5.315)	30.6%	2.75
	AA	-0.001 (-0.924)	-0.285 (-10.388)	-0.069 (-1.189)	11.1%	2.67
	A	-0.001 (-0.434)	-0.331 (-7.197)	-0.192 (-3.369)	10.7%	2.51
	BBB	-0.001 (-0.501)	-0.437 (-5.259)	-0.167 (-2.587)	22.1%	2.32

Table 13 Regression Results for the Relation between the Credit Spread and the Term Structure (Continued)

		c_0	c_1	c_2	Adjusted R-Squared	Durbin Watson Statistic
7-10 years	AAA	0.000 (-0.568)	-0.281 (-10.439)	-0.185 (-6.000)	27.8%	2.67
	AA	0.000 (-0.287)	-0.310 (-10.525)	-0.233 (-5.587)	31.2%	2.70
	A	0.000 (0.304)	-0.259 (-6.525)	-0.189 (-5.255)	17.0%	2.74
	BBB	-0.004 (-1.265)	-0.370 (-2.757)	-0.053 (-0.372)	2.4%	2.40
10+ years	AAA	-0.001 (-0.660)	-0.370 (-10.290)	-0.279 (-3.956)	27.7%	2.85
	AA	0.000 (-0.360)	-0.353 (-7.010)	-0.215 (-4.716)	26.2%	2.39
	A	0.001 (0.817)	-0.150 (-2.513)	-0.104 (-2.444)	3.6%	2.63

Calculations are based upon Merrill Lynch data. Δsp_t is the first difference of the yield spread. Yield spreads are spreads relative to government bond yields with similar duration. ΔI_t denotes the first difference in the yield of the '1-3 years' government bond index. $\Delta slope_t$ denotes the first difference in the slope of the term structure of risk-free interest rates. The slope is measured as the difference between the 'more than 10 years' government bond yield and the '1-3 years' government bond yield. Ratings are composite Moody's and Standard and Poors ratings. Maturity classes include lower boundary and excludes upper boundary. Statistics are computed from daily data over the period 1 April 1998 through 17 May 1999 (291 observations, except for the '7-10 years BBB' index, where only 271 observations were available). Figures between parentheses denote t-statistics corrected for heteroscedasticity and autocorrelation using the Newey-West (1987) procedure.

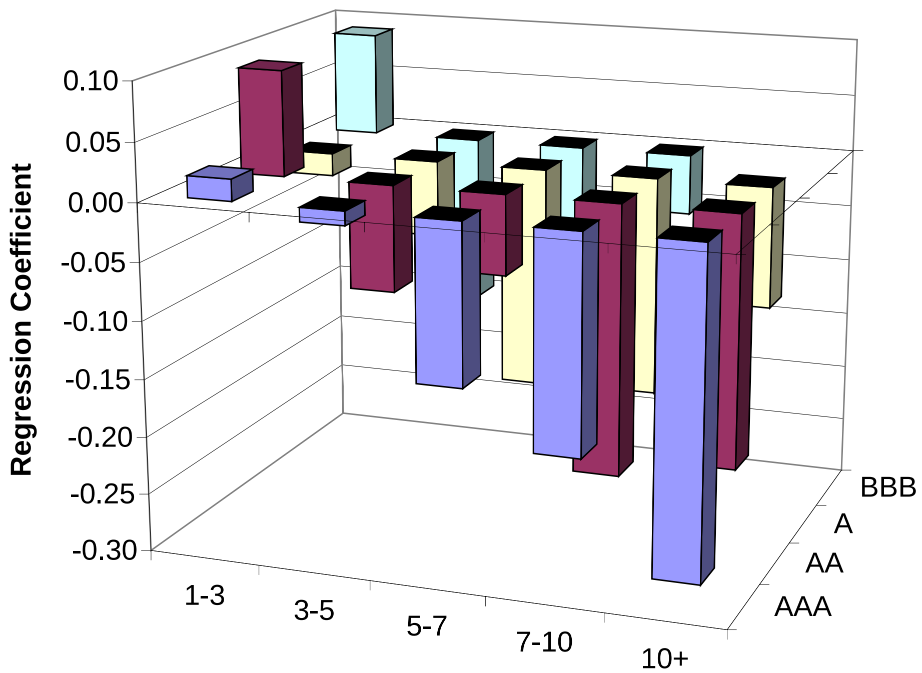
From Table 13 it is clear that for all series there exists a negative relation between changes in the credit spread and changes in the level of the term structure. From a statistical point of view, the relation is significant in all cases but the 'A-rated 1-3 years' bond index where significance is marginal.[19] Also from an economic point of view the relation is important. Most coefficients are in the vicinity of –0.30 (the average coefficient is –0.298). This implies that when risk-free interest rates increase by 1%, credit spreads drop by 30 bp; or in other words that risky rates only increase by 70 bp. Risky bonds are therefore less subject to interest rate risk than comparable government bonds. This is consistent with the theoretical results by Chance (1990) who shows that default-prone zero bonds have a lower duration than comparable risk-free bonds. However, Chance's model also implies that the lower the credit quality of the issuer, the lower the duration will be. Although we do not find strong evidence on this issue, our results are not inconsistent with Chance's model: in three out of four cases the coefficient for BBB-rated bonds is higher in absolute value than for their better rated counterparts.

[19] Remember, this is the most badly behaved series. If we eliminate two more 'reversals' the relation becomes highly significant as well.

In any case, our findings are to some extent comparable to the US results reported in Duffee (1998). There a negative relation is also found, but is somewhat lower in absolute value. This may be due to the fact that our series may also contain callable bonds. It is however remarkable that the monthly results in Duffee carry over to the higher frequency used in this report.

The results for the changes in the slope of the term structure are also comparable to those of Duffee (1998). In our sample, the effect is most visible at the longer maturities. Again, for these series the relation is significantly negative. For the shorter-term bond spreads no firm statistical relation has been found. Duffee also finds less significant effects for shorter term bonds, although it should be stressed that his "short term" bonds have an average maturity of 3.8 to 4.4 years, maturities for which we also find weakly significant estimates. Both for the US and in our sample it appears that information in the long-term risk free rate, captured in the *slope* variable, is less relevant for shorter maturities. The overall negative estimates (average coefficient is –0.103) implies that spreads drop when the term structure slope increases. Generally, the effect is stronger the longer the maturity (see Figure 6), which means that when the slope of the risk-free term structure increases, the credit spread curve will steepen less. Again, there is an off-setting effect between interest rate risk and credit risk.

Figure 6 Coefficient of Changes in the Slope of the Term Structure



One way to appreciate the implications of the relationships between spread changes and term structure changes is by looking at bond returns. It is well-known that bond returns can be proxied by changes in the yield to maturity multiplied by the bond's modified duration *D*:[20]

$$\frac{\Delta P}{P} \approx -D \cdot \Delta YTM \ .$$

As we can decompose the change in the yield to maturity into the change in the risk-free rate *i* and the change in the credit spread *sp*, we can rewrite the return equation as

$$\frac{\Delta P}{P} \approx -D \cdot \Delta i - D \cdot \Delta sp \ .$$

This allows a decomposition of return variance into the variance of risk-free rates, the variance of spread changes and the covariance between these two terms:

$$\sigma^2(return) \approx D^2 \cdot \left(\sigma^2(\Delta i) + \sigma^2(\Delta sp) + 2 \cdot \sigma(\Delta i, \Delta sp)\right).$$

The last two terms arise because the change in spread is stochastic. They can therefore be seen as the contribution of spread changes in return variance. Given the fact that the relationship between spread changes and interest rate changes is negative (see Table 13), the covariance term will be negative, inducing two off-setting effects: the variance of spread changes implies higher return variance, but the negative covariance term reduces return variance. A priori, it is unclear which effect dominates.

As far as *interest rate risk* is concerned, the negative correlation implies that there is not a proportionate relation between interest rate changes and return. If corporate bonds are hedged against interest rate risk using government bond futures, the optimal hedge ratio will be lower than one. This can be seen from the following analysis. The optimal hedge ratio *h* is:

$$h = \frac{\text{cov}(bond\ returns, futures\ returns)}{\text{var}(futures\ returns)} \ .$$

[20] Note that we only focus on price changes, thus ignoring the coupon part in total bond return. As the coupon is fixed and deterministic (save for default risk), it will have a negligible role in return variance.

Applying the duration approximation to returns and assuming the duration of the futures contract is equal to the bond's duration *D*, the optimal hedge ratio is:

$$h = \frac{\operatorname{cov}(-D \cdot \Delta i - D \cdot \Delta sp, -D \cdot \Delta i)}{\operatorname{var}(-D \cdot \Delta i)} = 1 + \frac{\operatorname{cov}(\Delta i, \Delta sp)}{\operatorname{var}(\Delta i)} = 1 + \rho \cdot \frac{\sigma(\Delta sp)}{\sigma(\Delta i)},$$

where ρ denotes the correlation between interest rate changes and spread changes. A negative correlation therefore implies an optimal hedge ratio less than one.

Table 14 illustrates these relationships for the Merrill-Lynch indices. The first two columns show that the duration approximation works relatively well: it accounts for approximately 72% of total return variance on average (median is nearly 77%). The average (median) correlation between total return and approximate return is 0.85 (0.89). The last three columns focus on the variance decomposition. The third column indicates the part of total variance due to risk-free interest rate changes. On average, these changes account for about 105% (median more than 118%) of total return variance. This implies that due to the negative correlation between interest rate changes and spread changes (shown in the fourth column) corporate bonds are on average less risky (in terms of return variation) than default-free bonds with comparable duration. The average figures, however, hide large discrepancies. For some series the spread changes rather than the interest rate changes are to a large extent responsible for the return variance. It is notable that precisely the series for which the fit in Table 13 is worst do not show the beneficial risk diversification in Table 14. Given the dominance of interest rate changes, it follows that if corporate bonds are to be hedged by futures contracts on government bonds, the hedge ratio is less than one: the optimal hedge ratio is 0.731 (0.717) on average (median); see the last column of Table 14.

Table 14 Bond Return Variance Decomposition and Optimal Hedge Ratio

		Ratio return proxy variance to total return variance	Correlation between return proxy variance and total return variance	Proportion of variance due to risk-free interest rate changes $\frac{\sigma^2(\Delta i)}{\sigma^2(\Delta P/P)_{prox}}$	Correlation between risk-free interest rate changes and spread changes	Optimal hedge ratio *h*
		(1)	(2)	(3)	(4)	(5)
1-3 years	AAA	45.3%	0.664	52.0%	-0.127	0.861
	AA	29.4%	0.610	105.4%	-0.320	0.826
	A	103.8%	0.835	47.3%	-0.054	0.940
	BBB	55.1%	0.747	17.5%	-0.236	0.430
3-5 years	AAA	58.9%	0.819	137.4%	-0.522	0.741
	AA	63.9%	0.836	126.8%	-0.486	0.686
	A	56.3%	0.826	147.6%	-0.573	0.716
	BBB	80.5%	0.862	39.2%	-0.173	0.752
5-7 years	AAA	71.4%	0.917	156.0%	-0.622	0.717
	AA	76.7%	0.918	114.8%	-0.415	0.741
	A	84.8%	0.909	94.0%	-0.379	0.683
	BBB	71.0%	0.887	124.6%	-0.499	0.637
7-10 years	AAA	77.9%	0.949	141.0%	-0.552	0.760
	AA	78.7%	0.954	150.1%	-0.587	0.717
	A	87.1%	0.942	118.6%	-0.413	0.781
	BBB	55.5%	0.564	42.5%	-0.218	0.695
10-more years	AAA	87.3%	0.966	152.4%	-0.587	0.643
	AA	85.2%	0.957	138.6%	-0.528	0.712
	A	90.9%	0.947	91.1%	-0.231	0.857
Average		71.6%	0.848	105.1%	-0.396	0.731
Median		76.7%	0.887	118.6%	-0.415	0.717

Calculations are based upon Merrill Lynch data. Ratings are composite Moody's and Standard and Poors ratings. Maturity buckets include the lower boundary and exclude the upper boundary. Statistics are computed from daily data over the period 1 April 1998 through 17 May 1999 (291 observations, except for the '7-10 years BBB' index, where only 271 observations were available). The return proxy is based on $\Delta P/P_{prox} = -D \cdot \Delta i - D \cdot \Delta sp$, where i denotes the risk-free rate, sp the credit spread and D modified duration.

7. Mean Reversion

The summary statistics for spread changes shown in Table 8 as well as the Durbin-Watson statistics in Table 13 show that the series contain significant negative first order serial correlation. This may be an indication of some kind of mean reversion: the tendency of spreads to return to some long-term value after deviations from this value. This idea is very common in term structure models where it is often assumed that the risk-free short-term interest rates reverts to its long-term average.[21]

Longstaff and Schwartz (1995b) introduced the mean-reversion hypothesis in the credit spread literature. They developed a pricing model for credit spread options assuming that the spread followed a mean-reverting process, like risk-free rates did in Vasicek (1977). They also obtained some empirical corroboration for this model using monthly data on credit spreads for Moody's utility and industrial US bond indices over the period April 1977–December 1992. In this section, we will investigate whether daily European credit spreads also show the same behaviour over a much shorter time period.

To this end we will perform the following regression:

$$\Delta sp_t = a + b \cdot sp_{t-1} + e_t ,$$

where e_t is the regression error. In this representation, the slope coefficient b is assumed to be negative if mean-reversion is present. Its absolute value indicates the rate by which credit spreads are pulled to their long-term value $-a/b$. Estimation results are shown in Table 15.

[21] Examples include Vasicek (1977) and Cox, Ingersoll and Ross (1985).

Table 15 Mean-Reversion Regression Results

$$\Delta sp_t = a + b \cdot sp_{t-1} + e_t$$

		a	*b*	Adjusted R-Squared	Durbin Watson Statistic	Implied Long-Term Value –*a*/*b*
1-3 years	AAA	0.028 (2.567)	-0.164 (-2.589)	7.8%	2.64	0.171
	AA	0.040 (4.908)	-0.145 (-4.971)	6.8%	2.35	0.276
	A	0.135 (4.288)	-0.355 (-4.252)	17.2%	2.23	0.380
	BBB	0.033 (2.966)	-0.042 (-2.801)	1.3%	2.08	0.786
3-5 years	AAA	0.012 (3.359)	-0.066 (-3.524)	3.1%	2.53	0.182
	AA	0.021 (2.768)	-0.059 (-2.787)	2.8%	2.74	0.356
	A	0.012 (3.044)	-0.025 (-2.937)	1.0%	2.67	0.480
	BBB	0.049 (3.620)	-0.066 (-3.518)	3.0%	2.66	0.742
5-7 years	AAA	0.016 (3.637)	-0.067 (-3.665)	3.1%	2.65	0.239
	AA	0.025 (2.992)	-0.077 (-3.003)	3.6%	2.63	0.325
	A	0.040 (3.105)	-0.078 (-2.981)	3.6%	2.42	0.513
	BBB	0.020 (2.507)	-0.027 (-2.427)	1.1%	2.35	0.741

Table 15 Mean-Reversion Regression Results (continued)

		a	*b*	Adjusted R-Squared	Durbin Watson Statistic	Implied Long-Term Value $-a/b$
7-10 years	AAA	0.009 (3.087)	-0.028 (-2.874)	1.2%	2.52	0.321
	AA	0.009 (2.971)	-0.020 (-2.723)	0.8%	2.49	0.450
	A	0.010 (2.865)	-0.015 (-2.710)	0.6%	2.67	0.667
	BBB	0.005 (1.070)	-0.007 (-1.073)	0.0%	2.40	0.714
10- more years	AAA	0.028 (2.860)	-0.100 (-2.795)	4.8%	2.63	0.280
	AA	0.014 (3.341)	-0.031 (-3.115)	1.4%	2.29	0.452
	A	0.008 (2.142)	-0.010 (-1.992)	0.1%	2.57	0.800

Calculations are based upon Merrill Lynch data. sp_t is the yield spread in percentage points. Yield spreads are spreads relative to government bond yields with similar duration. Ratings are composite Moody's and Standard and Poors ratings. Maturity classes include lower boundary and excludes upper boundary. Statistics are computed from daily data over the period 1 April 1998 through 17 May 1999 (291 observations, except for the '7-10 years BBB' index, where only 271 observations were available). Figures between parentheses denote *t*-statistics corrected for heteroscedasticity and autocorrelation using the Newey-West (1987) procedure.

Despite the fact that we study only a short time period, the regression results are encouraging. Firstly, nearly all estimated regression coefficients are statistically significant at the 5% level (an exception is the index 'BBB, 7-10 years'). Also, all the slope coefficients are negative, which implies mean-reversion. Second, the estimated implied long-run spread levels to which spreads should eventually revert (shown in the last column of Table 15) are very comparable to the reported average spreads in Table 7. The long-term levels are also internally consistent in the sense that lower rating classes have higher long-term spread levels than better rated classes in comparable maturity buckets.

Nevertheless, some caveats are in order. First, the regression does hardly fit the observations: for most indices the proportion of variance explained does not reach 5%. This means that besides the mean-reversion effect the noise term is dominant. Of course, this may be due to the fact that we study only a limited time period, which makes it difficult to recognise a slowly mean-reverting effect. However, the adjusted determination coefficients reported by Longstaff and Schwartz (1995b) are similar to ours despite the fact that they study more than 15 years of data. Second, given that our data period may be very specific, the estimated long-term spread levels may not be representative in future periods. Therefore, if pricing models such as the one proposed by Longstaff and Schwartz (1995b) are used care should be taken when parameter values are inferred from regression estimates as in our Table 15.

8. Conclusions and Policy Recommendations

Credit risk comprises default risk as well as credit migration risk. Especially the latter requires a good understanding of the price of credit risk. Analysing credit spreads provides answers to a lot of questions related to pricing, hedging and risk management.

In this report the spread between the yield to maturity on a risky bond and the yield to maturity on a risk free bond is examined. We are aware that this spread is not a pure credit spread but also captures a time-varying liquidity premium. Unfortunately, at present, especially the data necessary to disentangle the effects are not available.

The spreads we examined were European credit spreads. Doing this, we filled the void that existed because virtually all published research studies US spreads. Moreover, the EMU Broad Market Indices of Merrill Lynch provided us with benchmarks split up per rating and maturity categories. Four investment grade rating categories (AAA, AA, A and BBB) were studied together with five maturity buckets (1-3, 3-5, 5-7, 7-10 and 10+ years). At the time the research was carried out, daily data were available from March 31, 1998 till May 17, 1999. We documented a refined spread calculation based on duration matching between the risky and the risk free bonds. This was especially necessary because the average modified duration of corporate and government bonds within the same maturity bucket was not the same. Most clearly this can be seen in the long-end segment. The (modified) duration of 10+ years corporate bonds ranged from 7.75 to 8.53 whereas government bonds typically have a much longer duration of approximately 12.

The spreads we report are relatively low (17 to 31 bp for AAA bonds and 70 to 110 bp for BBB bonds) but seem similar to US evidence over the same sample period. As theory suggests, higher spreads are being charged for lower rated bonds but the extra spread charged increases fast in credit quality becomes lower. Bonds with a longer term to maturity also have higher spreads than short term bonds.

The changes in spread average close to zero ranging from –0.25 to 0.25 bp over the 19 indices studied. On statistical grounds, these average spread changes are not statistically significantly different from zero. Moreover, spreads do seem to revert to a long term level. If spreads at a certain moment are above this level, they will tend to become lower. On the other hand, if spreads are exceptionally low, they will be driven upwards towards the long term level again. During our sample period, this reversion has occurred rather fast.

From a manager's point of view, risk should not be studied based on single assets but on the portfolio as a whole. The extent to which diversification holds, depends on the correlation we find between the assets. In general, the lower the correlations, the more diversification benefits can be pursued. For the European credit spreads, we find lower correlations (on average 28%) than those reported for the US market. Moreover, we even find negative correlations that from a diversification viewpoint are the most desirable. We show that by combining indices with different ratings and/or maturities, almost 50% of the total risk can be diversified. In order to achieve this result, diversification needs to be developed along both the maturity and the rating dimension. A rather sophisticated econometric analysis showed that both dimensions are equally important in European bond credit spreads. This finding is important since the BIS tends to focus only on the rating dimension. The maturity dimension, however, is equally important but does not show up in the BIS proposals. Moreover, the maturity dimension is much easier to apply than the (always more or less subjective) rating dimension.

Credit risk and interest rate risk have been treated as largely independent sources of risk. Pricing models conveniently assume independence to maintain a minimum tractability of the models. Practitioners, not withstanding some notable exceptions, tend to separate the management of market and credit risk in separate divisions. Our research showed that there is a clear relationship between the spreads and the term structure of risk-free interest rates. If risk-free interest rates rise, risky yields increase too but not proportionally. If risk-free interest rates increase by 1%, risky rates increase by only 70 bp. This implies that the credit spread drops if risk-free interest rates increase. If the term structure (difference between long and short term risk-free interest rates) becomes steeper, spreads also drop on average. Hedging activities are clearly affected by these findings. Spreads enable us to calculate optimal hedge ratios for cross-hedging activities whereby a portfolio of corporate bonds is hedged with a future on government bonds. Thanks to the negative correlation between spread changes and risk-free interest changes, a smaller number of futures will do compared to a naïve hedge. Moreover, this finding also illustrates that market risk and credit risk should be unified in a single risk management framework. A challenging job for the future.

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