The Effects of Default Correlation on Corporate Bond Credit Spreads

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Abstract

The tendency for firms' defaults to cluster is a widely accepted phenomenon in corporate bond and credit derivatives markets. In this paper, I analyse the relationship between systematic default correlation and corporate bond credit spreads. I show that credit spreads are positively related to CDO market implied default correlation and that this holds using either a model implied measure of default correlation or the spread between a CDO's equity and super-senior tranches. Using monthly data spanning January 2004 to September 2008, I show that a one basis point decrease in the CDO tranche spread-of-spreads translates into a 0.91 basis point increase in 5-year credit spreads and a 0.94 basis point increase in 10-year credit spreads; this after controlling for the risk-free term structure of interest rates, equity market returns and volatility, and firm effects. In addition, I perform principal component analysis on the regression residuals and find little evidence of a missing systematic factor.

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I. Introduction

The tendency for firms' defaults to cluster is a widely accepted phenomenon in corporate bond and credit derivatives markets. The general observation is that regardless of the state of the economy there is some average number of firms that default each period, and intermittently there are sharp increases in the number of defaults. These spikes, or default clusters, are not persistent and the number of defaults readily reverts to the pre-cluster average.[1] Modelling this phenomenon plays a prominent role in bond risk management and in the valuation of credit derivatives, such as collateralized debt obligations (CDOs), and it is this phenomenon that is typically modelled by a default correlation parameter. The objective of this paper is to examine the relationship between this phenomenon and the cross-sectional variation of corporate bond credit spreads.

I show that corporate bond credit spreads are increasing in default correlation, as implied from the collateralized debt obligation market. This relationship holds for both a model implied measure of default correlation and a CDO tranche spread-of-spreads proxy of default correlation. Specifically, using monthly data spanning January 2004 to September 2008, I empirically show that a one basis point decrease in the CDO tranche spread-of-spreads translates into a 0.91 basis point increase in 5-year credit spreads and a 0.94 basis point increase in 10-year credit spreads; this after controlling for the risk-free term structure of interest rates, equity market returns and volatility, and firm effects. The CDO tranche spread-of-spreads is the difference between the equity tranche spread (highest default risk) and the super-senoir tranche spread (lowest default risk). I demonstrate that it is decreasing in default correlation. Further to showing that corporate bond credit spreads are increasing in default correlation, I use principal component analysis to show that my

[1] A clear example of this is presented by Das, Duffie, Kapadia, and Saita (2007) where they plot the aggregate number of firm defaults by month from 1976 to 2004; their Figure 2 shows that intermittently there are periods where a month with relative few defaults (2 or 3) is followed by a series of months with twice this number of defaults and then again periods with few defaults.

decomposition residuals do not contain a missing systematic factor. This result adds to the growing body of literature that argues against the Collin-Dufresne, Goldstein, and Martin (2001) claim that there is a missing systematic credit spread factor.

Prevailing research that considers factor decomposition of credit spreads predominantly focuses on firm specific characteristics and/or systematic macroeconomic variables. Generally, firm specific factors include firm leverage, equity returns, equity volatility (either historical or option implied), option implied volatility smiles, bond liquidity, and credit ratings, while typical systematic factors are the level and slope of the term structure of interest rates and the historic returns and volatility of the equity market (see, for example, Ericsson, Jacobs, and Oviedo (2009), Cremers, Driessen, Maenhout, and Weinbaum (2008), Chen, Lesmond, and Wei (2007), and Campbell and Taksler (2003) and their related literature). Duffie, Eckner, Horel, and Saita (2009) show that an unobserved covariate is a factor in predicting real-world default clustering; this combined with the often cited finding of Collin-Dufresne, Goldstein, and Martin (2001) that a missing systematic factor is required to fully explain the variation of credit spread changes, suggests that beyond the current systematic factors, credit spreads contain an additional factor that characterizes default clustering.

A major difficulty in proposing and estimating a novel systematic factor for credit spread decomposition is the lack of unique financial markets that can be used to measure such a factor. The growth of the credit derivatives market, the CDO market in particular, however, fills this void. CDOs are credit derivatives whose pay-offs are contingent on the rate at which defaults accumulate within a standardized portfolio of bonds. As outlined below, this default rate is directly related to default correlation. Expectations regarding future default correlation are integral in determining CDO prices.

Implying default correlation from CDO market spreads is akin to implying equity volatility from equity options. This alone distinguishes it from commonly used systematic factors.

In being a market implied rate it updates as readily as the market updates default risk expectations, and moreover, it is a forward looking measure of default correlation. A CDO market implied measure of default correlation is able to characterize default clustering that is driven by either an unobserved covariate or firm-to-firm contagion; this however may be considered a limitation as it does not differentiate between these two mechanisms. The use of a credit derivatives implied factor in credit spread decomposition parallels the approach used in Cremers, Driessen, Maenhout, and Weinbaum (2008) and Cremers, Driessen, and Maenhout (2008) where information in equity options is used to help explain the cross-sectional variation of credit spreads and the high average level of credit spreads, respectively. This paper distinguishes itself from this related literature as credit derivatives, whose prices are directly dependant on expectations regarding future default correlation, are used to imply a systematic default risk factor.

There exists a limited amount of research that shows a link between market implied default correlation and credit spreads. Cremers, Driessen, and Maenhout (2008) and Driessen (2005) are representative examples; the former incorporates systematic risk in a structural model using equity and equity index options, and the latter calibrates a reduce-form model of default that includes a latent systematic factor. Building on this literature this paper is the first to empirically show a direct relationship between CDO market implied default correlation and corporate bond credit spreads.

The outline of the paper is as follows. In Section 2 related literature and default correlation are discussed and the model used to imply default correlation is developed. Section 3 outlines the data used and describes how firm specific credit spread term-structures are estimated. Following this, Section 4 presents the result showing the positive relationship between credit spreads and default correlation and also the residual analysis that indicates that there is no missing systematic factor. The paper concludes in Section 5.

II. Modelling Default Correlation

A. Related Literature

Existing literature has explored at least two possible mechanisms that can result in default clustering. The first is systematic. It is caused by common factors that affect all firms, such as the level of the risk-free interest rate. The second is contagion. This occurs when the default of one firm causes default in other firms. Contagion has at least two possible channels, one is directly through firm-to-firm business relationships, and the other is through investors as they observe unexpected credit events and then, in turn, update their beliefs regarding default risk. The first form of contagion can be thought of in terms of the correlation of firm specific factors, such as firm-to-firm credit chains, wherein the default of one firm translates into a rise in the conditional probability of default of firms that it does direct and/or indirect business with. Alternatively, when investors update their beliefs it is other firms' market prices of default risk that can be thought of as increasing.

Looking at default rates directly, Lucas (1995) estimates the historic default correlations between firms and presents his finds across credit rating groups. Lucas notes that default correlation is low amongst high credit quality firms, and that although it is generally increasing in time there are instances (mostly in lower credit ratings) where it increases and then decreases. The reported default correlations, however, do not disentangle default due to systematic risk or default due to contagion. Das, Freed, Geng, and Kapadia (2006), Akhavein, Kocagil, and Neugebauer (2005), and de Servigny and Renault (2002) consider the correlations between proxies for firms' asset volatility and leverage as they related to actual defaults, and although they are able to characterise the average level of default correlation between firms they are not able to directly account for the clustering phenomenon.

Duffie, Saita, and Wang (2007) consider the estimation of firms' default probabilities, under the doubly-stochastic formulation of default times, and they provided evidence that default rates are partly determined by systematic covariates. Das, Duffie, Kapadia, and Saita (2007) also provide empirical evidence that systematic default factors play a role in modelling real-world default rates and default clustering, but their results also indicate that an additional mechanism, such as an unobserved systematic covariate, or "frailty", is required to fully account for historic default rates. Considering the notion of frailty correlated defaults, Duffie, Eckner, Horel, and Saita (2009) estimate real-world default rates with a model that accounts for an unobservable systematic factor. Their model allows for two possible default correlation channels. The first is through future correlation between the model factors, and the second is the uncertainty in the conditional distribution of the unobserved frailty factors, where the conditioning set includes historic defaults and factor observations.

Support for the second channel of default clustering, contagion, is predominantly driven by theory. Giesecke and Weber (2006) and Giesecke and Weber (2004) present models that capture default correlation through business channels. Battiston, Delli Gatti, Gallegati, Greenwald, and Stiglitz (2007) consider a network economy model where defaults can cascade through firms' trade credits. An example of this would be the default of a manufacturing firm cascading and resulting in the default of one or more of its suppliers. Collin-Dufresne, Goldstein, and Helwege (2003) provide a model where contagion occurs when an unexpected jump-to-default results in investors updating their beliefs and this translates into market-wide jumps-to-default. Also considering default correlation of this type are Giesecke (2004) and Jarrow and Yu (2001).

Default correlation due to counterparty risk is empirically studied by Jorion and Zhang (2009) where empirical evidence is provided that a creditor's default risk rises as bankruptcies occur. This type of contagion is consistent with "bad contagion" as defined by Jorion and Zhang (2007) where they argued that contagion can be bad or good; good contagion being such that it has a positive "competition effect" whereby the default of a competitor can increase surviving firm's market share, and thus lower a firm's default risk.

Using the reduced-form framework[2] Driessen (2005) presents a model that has a common stochastic factor that drives a component of firm credit spreads. The factor is described as a latent factor that is a common component of expected excess corporate bond spreads. Although it is not directly specified as a default correlation factor, it is compared to the Collin-Dufresne, Goldstein, and Helwege (2003) model where firm specific jump-to-default can result in market-wide jumps-to-default. Driessen offers that this common factor may capture some of the features of this jump-to-default contagion.

Cremers, Driessen, and Maenhout (2008) use a structural model of default with the firms' values following jump-diffusion processes. The structural model incorporates firm specific jumps and correlation through either the Wiener processes or through a systematic jump process. Their model is calibrated such that the Wiener processes are assumed to be homogenous across firms and correspond to the average equity return correlation. The parameters for the systematic jumps, which is modelled as a double-exponetial process, are calibrated to S&P 500 Index option prices and option returns. It follows that incorporating systematic jumps can account for more of the average level of credit spreads than previous studies.

Driessen (2005) and Cremers, Driessen, and Maenhout (2008) are representative of the limited amount of research that shows a link between market implied default correlation and credit spreads. In particular, the calibration of default correlation, as it pertains to firm credit spreads, tends to be done via the equity and/or equity options markets. To

[2]The reduced-form frame work models assume that a firm's default is a random event that occurs with some instantaneous default intensity that defines, conditional on no prior default, the probability of default over a short time interval. Affine instantaneous risk-free rate models are a common starting point with default risk incorporated by using a stochastic process to define the instantaneous credit spread and where default correlation is modelled by a stochastic process that is common to all firms. Duffie and Singleton (1999) discuss this approach in detail.

date, a direct link between CDO market implied default correlation and corporate bond credit spreads has yet to be shown. This gap in the literature is what this paper specifically addresses.

B. CDO Implied Default Correlation

The credit derivatives market provides a venue where a risk-neutral measure of default clustering can be estimated. This is possible because there are liquidly traded products in the credit derivatives market, such as standardized collateralized debt obligations (CDOs)[3], whose payoffs are contingent on how defaults accumulate in a reference portfolio of bonds. In order to price and hedge these products a model of risk-neutral default correlation is required. This makes characterizing default correlation the quantitative backbone of the CDO market. I use CDOs to imply an aggregate level forward-looking measure of default correlation and I consider two different measures. The first measure is the standard deviation of a CDO implied hazard rate density. The valuation of CDOs within the implied hazard rate density framework is discussed in Bobey (2007), and the positive relationship between the implied hazard rate density standard deviation with default correlation is shown in Bobey (2008). The second measure looks at the spread between a CDO's equity tranche and its super-senior tranche. As I demonstrate below, this spread is decreasing in default correlation, and it is this property that I exploit as a my second measure of default correlation.

Understanding how default correlation can be implied from the CDO market requires an outline of the structure of a CDO. A CDO is a credit derivative whose underlying is a portfolio of reference bonds and whose payoffs, over a predetermined time frame, are contingent on defaults occurring within the reference portfolio. The percent of portfolio

[3] The CDO market is an over-the-counter derivatives market where standardized and bespoke products trade. It is important to point out that the CDOs used in this paper are not directly associated with the sub- prime mortgage market that underwent financial distress in the latter half of 2007 and early 2008.

default losses are divided into tranches. The tranches are then ranked according to the probability of a tranche incurring its maximum allowable cumulative loss. The riskiest tranche, called the equity tranche, has the highest probability of incurring its maximum allowable number of defaults while the least risky tranche, called the super-senior tranche, has the lowest probability.[4]

A tranche buyer pays a spread, which is a percent of a tranche's notional outstanding, to the seller who makes pay outs, equal to the loss-given-default, as defaults occur within the tranche. The tranche spread can be thought of as insurance against default. To see this consider a one-year CDO whose reference portfolio contains a very large number of homogenous bonds each with a one-year probability of default of 1% and a loss-given-default of 100% of principal. The CDO's structure can be idealized by one "index" and five tranche contracts.

The index contract is for protecting all of the defaults in the portfolio. The expected loss-given-default over one year is 1% of the portfolio's principal. It follows that, when the discount rate is zero, the risk-neutral cost to insure against this expected loss is equal to 1% of the portfolio's principal. The index is essentially a credit default swap on the entire reference portfolio.

The remaining five contracts represent the tranches that divide the portfolio losses. The first tranche absorbs the first 3% of losses, and the second, third, fourth, and fifth tranches absorb 3–7%, 7–10%, 10–15%, and 15-100% of losses, respectively.[5] The first tranche is the

[4] CDOs can be classified as being cash or synthetic. In a cash-CDO there is an actual portfolio of bonds or reference cash flows whereas a synthetic CDO's reference portfolio is essentially a portfolio of credit default swaps. Cash CDOs generate an income and pay distributions, or coupons, where as synthetic CDOs do not. Further, cash CDOs have triggers that, when reached, result in the underlying portfolio being partially liquidated to pay the holders of the super-senior tranche a portion of their principal.

[5] The upper and lower cut-offs, or attachment points, are motivated by an actual CDO: the CDX. With exception to the super-senior tranche, all other attachment points are taken directly from the CDX. The CDX super- senior attachment is actually 15–30%. Using 30% as the upper cut-off does not change the underlying intuition of the example. Also, although a 30–100% tranche exists it is not actively quoted or traded.

most junior tranche and the fifth is the most senior tranche. As the recovery rate is zero, holding all five of the tranche contracts simultaneously provides the same level of default protection that holding the index does. Thus, the total cost to insure all five tranches together is the same as insuring the index.

In order to value the tranches individually, something about the tendency for firms' defaults to cluster must be known or assumed. For example, if default clustering is perfect (all firms default simultaneously), then in 99% of the years no firms default and the cost of insurance for all tranches is zero. In 1% of the years, all firms default and all five of the tranches lose 100% of their principal. The fair price to insure against tranche defaults, when expressed as a percent of the tranches' notional outstanding, is the same for all five tranches.

Alternatively, if firms' defaults are perfectly independent then, for a 1% one-year probability of default the expected number of defaults is 1% of the portfolio. The expected loss is then 1% of the portfolio principal or 1/3 of the 0–3% and the fair value of the insurance reflects this loss. The cost to insure against defaults for the remaining tranches is zero. In order for the next tranche to absorb defaults, the expected portfolio loss needs to exceed 3%, and so forth for the more senior tranches.

This idealized example highlights that the relative costs to insure the tranches are determined by how firms' defaults cluster. It immediately follows that pricing CDOs requires a model that characterizes default correlation. Moreover, if given a model and a set of market spreads risk-neutral default correlation can be implied from the market. Further, this model is the first demonstration that the spread-of-spreads between the riskiest and safest tranches in decreasing in default correlation. In the latter case, defaults were perfectly independent and the spread-of-spreads was no-zero, while in the former case defaults were perfectly correlated and the spread-of-spreads was zero (as all tranche prices were the same).

How default correlation is implied from a CDO can be shown explicitly by considering a reference portfolio of N firms with the credit quality of the i^{th} firm characterized by a standard normally distributed factor C_i that is composed of two uncorrelated components, an idiosyncratic factor, F_i, and a systematic factor, M. Both factors are assumed standard normally distributed. This leads to the following factor representation

$$C_i = a_i M + \sqrt{1 - a_i^2} F_i, \quad a_i \in [-1, +1], \tag{1}$$

for some constant a_i. The credit quality of firms i and j are correlated through C_i and C_j only through a_i and a_j. This pairwise correlation is $a_i a_j$. This set-up represents one-factor Gaussian correlation and is commonly referred to as the one-factor Gaussian copula model.

To relate the credit quality of each firm to default times, denote firm i's default time as τ_i, and let $Q_i(t)$ be the risk- neutral probability of default by time t on $[0, t]$. A correlation structure for the default times can be obtained by matching the percentiles of C_i and τ_i by setting

$$\text{Prob}(C_i < C) = \text{Prob}(\tau_i < t).$$

where C is defined as

$$C = \Phi^{-1} \left[Q_i \left(t \right) \right], \tag{2}$$

for time t and standard cumulative normal distribution Φ. The correlation structure for the default times follows by considering (1) and taking the conditional probability

$$\text{Prob}(C_i < C \mid M) = \Phi \left[\frac{C - a_i M}{\sqrt{1 - a_i^2}} \right], \tag{3}$$

which, with (2), leads to

$$\text{Prob}(\tau_i < t \mid M) = \Phi \left[\frac{\Phi^{-1} \left[Q_i \left(t \right) \right] - a_i M}{\sqrt{1 - a_i^2}} \right] \tag{4}$$

If it is assumed that firms are homogenous in the sense that the Q_i's and a_i's are the same, so all pair wise correlation is $a^2 = \rho$, then the correlation structure of default times is defined by

$$\text{(5)} \qquad \text{Prob}(\tau_i < t \mid M) = \Phi\left[\frac{\Phi^{-1}\left[Q\left(t\right)\right] - \sqrt{\rho}M}{\sqrt{1-\rho}}\right], \quad \rho \in [0,1].$$

This model of default correlation is the one that is most commonly used to price CDOs. Features of the model that are appealing is that conditional on M the default times are independent and that $\text{Prob}(\tau_i < t \mid M) = Q(t \mid M)$ with the unconditional probability of default always $Q(t)$.

The model can be used to value the payment leg and the default leg cash flows of a CDO's tranches. The payment leg cash flows are a series of payments that are a percent of the tranche's notional outstanding. They are made periodically, usually quarterly, by the tranche buyer until maturity or the notional outstanding of the tranche is zero. The default leg cash flows are the payoffs made by the seller of the tranche at the times of default. The expected present value of both of these cash flow legs is a function of the expected times of default given by (5). In the absence of arbitrage the expected present values of the cash flow legs are equal, and are represented by

$$\text{(6)} \qquad \mathbb{E}\left[V^{DL}\right] = s\mathbb{E}\left[V^{PL}\right],$$

where the present value of the payment and default legs are denoted as V^{DL} and V^{PL}, respectively, and s is an annual spread that is paid periodically.[6] By characterizing the default times using (5) the CDO tranches are valued by taking expectations over the density of M. Details of how to calculate the cash flows are contained in Bobey (2008), among others.

[6]Some tranches, usually the equity tranches, are quoted as an upfront spread with a fixed annual spread. In these instances the upfront spread is the difference between the expected present value of the default leg and the product of the expected present value of the payment leg and the annual spread.

A set of hypothetical 5-year maturity CDO tranche spreads is listed in Table 1. They are calculated using (5) and assume that ρ is the same for all of the tranches. The table indicates that the most junior tranche spreads, column (1), are decreasing in tranche correlation, the two most senior tranche spreads, columns (4) and (5), are increasing in tranche correlation, and the two mezzanine tranche spreads, columns (2) and (3), are non-linear in tranche correlation. In addition, column (7) shows that the CDO tranche spread-of-spreads between the equity and super-senior tranche is decreasing in default correlation.

Table 1 also reports the five implied tranche correlations that match the model spreads to January 29, 2004 CDX market spreads. It is clear that the implied ρ's are not consistent across the CDOs structure as they have a "smile" relationship. This is a well know failing of the one-factor Gaussian copula model.

An alternative to the one-factor Gaussian copula model is motivated by the observation that M is a time-constant random variable which represents the systematic credit environment for the life of a contract. When integrating over M, to get the unconditional expectations in (6), the model is implicitly assigning probabilities to different possible future systematic credit environments.

Assigning probabilities to possible future credit environments can also be achieved by assuming default is a random event that occurs with some default rate λ. It follows that the M-conditional cumulative probability of default at time t can be expressed as

$$Q(t \mid M) = 1 - e^{-\lambda_M t}, \tag{7}$$

where λ_M is the default rate conditional on M. This representation indicates that conditioning on M is equivalent to specifying a set of possible conditional default rates. A distribution of possible default rates can be defined directly and the expectations in (6) can be taken over this distribution. This approach was first proposed by Hull and White (2006).

When a set of possible default rates is assumed, calibrating the model spreads to market spreads yields the entire distribution of possible default rates. The result is a market implied default rate density, or implied hazard rate density. Hull and White (2006) refer to this as the implied copula model. They show how to estimate the density non- parametrically while Bobey (2007) shows how the calibration can be done parametrically, under the assumption that the predetermined distribution of the hazard rates can be either a mixture of 2 or 3 Weibull densities.

The relationship between M and λ_M indicates that an implied hazard rate density fully captures the correlation between default times. To draw this out more fully recall the idealized example used to describe the structure of a CDO. In that example each bond has a one-year probability of default of 1%; this is a one-year default rate and can be thought of as the average default rate. The implied copula approach allows us to choose K possible default rates, λ_k for $k = 1, \ldots, K$, and assign a probability p_k of observing λ_k, so long as the expected value is equal to the average default rate and the sum of the probabilities equals one. The p_k's are directly estimated when the model is calibrated to market spreads.

By incorporating different default rates we have that in p_k % of the years λ_k % of the firms default. Different p_k's represent the probability of observing different levels of default clustering. Large (small) values of λ_k imply high (low) degrees of default clustering. It follows that as the distribution of the λ_k's becomes more dispersed the greater the probability of default clustering.

An increase in the dispersion of the implied hazard rate density is consistent with the increase in dispersion of $Q(t)$ when ρ increases. Figure 1 shows this relationship for hypothetical CDO spreads that are calculated with $\rho = 0.03$ and $\rho = 0.30$. The implied default rate density for the CDX on January 29 2004 is also presented. The densities' standard deviations are reported in Table 1, columns (8) and (9). For this idealized example the 2- and 3-Weibull densities' have similar standard deviations, in general this not the case.

This is supported by the results discussed in Bobey (2008) where it is shown that the dispersion of the implied hazard rate density, as measured by its standard deviation, increases as firms' default correlation increases. This is shown by assuming firms' hazard rates follow jump-diffusion processes that are correlated through their Wiener processes, systematic jumps, or both. Further, it is reported that the standard deviation of the implied hazard rate density has time variation that is independent of the level and slope of the risk-free term structure, VIX volatility index, one-year S&P 500 historic returns, and the spread between the 3-month Eurodollar rate and the 3-month T-Bill rate. Bobey (2008) concludes that the implied hazard rate density standard deviation is increasing in default correlation and contains information regarding systematic default risk that is not captured by previously considered systematic factors.

C. Linking CDO Implied Default Correlation and Bond Credit Spreads

Consider the model above that characterized the credit quality of N firms. Equation (1) represents the credit quality of the i^{th} firm as a linear combination of an idiosyncratic factor, F_i, and a systematic factor, M, where pairwise correlation is is given by $a_i a_j$, for firms i and j, and under the assumption of homogeneous pairwise correlation $a_i a_j = a^2 = \rho$. By assuming homogenous pairwise correlation ρ can be thought of as a systematic factor, as it is common to all firms, but it is important to note that its origin is heterogeneous pairwise correlation.

For easy of exposition, consider a defaultable zero-coupon discount bond that pays \$1 at maturity t and that has an expected recovery rate of R. If we assume that this bond issuer's credit quality is defined as above the M-conditional cumulative probability of default at maturity can be modelled as $Q(t \mid M) = \text{Prob}(\tau_i < t \mid M)$, as given in equation (5). It follows that the M-conditional price of the bond, B_M, is given as

$$B_M = e^{-rt} \left[1 - Q(t \mid M)(1 - R) \right],$$

where r is the risk-free rate. The M-conditional yield to maturity can be represented as $y_M = r + z_M$, where z_M is the conditional spread over the risk-free rate. It follows that the conditional price of the bond can be represented as

$$e^{-(r+z_M)t} = e^{-rt} \left[1 - Q(t \mid M)(1 - R) \right],$$

and it follows that

$$z_M = -\frac{1}{t} \ln \left[1 - Q(t \mid M)(1 - R) \right].$$

The unconditional bond price is attained by integrating B_M over the distribution of M, and the unconditional credit spread follows directly. This representation shows that the framework used to price the tranches of a CDO can also be used to price the defaultable bond and in doing so demonstrates a theoretical link between the valuation of a firm's default risk as it pertains to both a CDO and a its risky bond. Further, it is evident that a firm's credit spread, z, is a function of the homogeneous pairwise correlation parameter ρ. The approach I use is to imply a systematic measure of default correlation from the the CDO market and then empirically test its relationship to credit spreads. The standard deviation of the implied hazard rate density and the CDO spread-of-spreads are the two measures of default correlation that I consider.

I hypothesize that default correlation is a measure of systematic default risk and is a component of bond credit spreads; when systematic default correlating is above average, firms' default risks are expected to be above average and it is anticipated that credit spreads will also be above average. The empirical prediction is that: *Credits spreads are positively related to CDO market implied default correlation.*

III. Description of Data

The primary data set is an unbalance panel of bond level observations, of which there are 24,516 bond-month observations for 179 unique firms and 2906 unique bonds spanning 57 months. The second data set, which is a subset of the bond-level data set, is an unbalance panel of firm level fixed-maturity bonds where 5 and 10-year maturities are considered, of which there are 3661 firm-month observations for 179 unique firms. The 5 and 10-year fixed-maturities are treated separately. The primary difference between these two sets of data is that in the primary data set the panel is at the bond level, and so a firm can be observed multiple times for a given observation day, whereas in the fixed-maturity data sets the panel is at the firm level, and so a firm can be observed only once for a given observation day. Below I outline the data that the panels are comprised of.

A. CDO Implied Default Correlation

The standard deviation of the CDO implied hazard rate density is estimated for spreads quoted at the close of the penultimate trading day each month spanning January 2004 to September 2008; both the 2-Weibull and 3-Weibull models are considered. If there was no CDO quote on the penultimate trading day, the next most recent set of historic quotes was used. As discussed above, the calibration of the implied hazard rate density model to market spreads follows Bobey (2007). The CDO tranche spread-of-spread is calculated as the difference between the equity tranche spread and the super-senior tranche spread. Summary statistics of the these measures are provided in Table 4. The historic CDO spreads where compiled from three sources: a GFI data set was used up to the end of 2004 and Reuters 3000Xtra for the remaining data with Bloomberg being used to cross check spreads or fill missing data points.

B. Firm Specific Spot Credit Spreads

I estimate credit spreads by constructing *firm specific* zero-coupon spot credit curves for each observation month. The construction of firm specific term structures as a means of estimating credit spreads is both novel and necessary for my empirical estimation. It was chosen as it address the following three issues. Firstly, using zero-coupon credit spreads is one way to remove potential coupon effects in the regression. Secondly, the primary data set is a bond level unbalance panel of credit spreads. Using firm specific term structures of credit spreads allows me to construct a subset of data at the firm level using fixed maturity credit spreads. By testing my hypothesis on this subset of data I address the potential issue of a small number of firms that have a large number of bonds driving my results. Thirdly, using firm specific term structures allows the construction of two different sets of principal component factors. As discussed in detail below, I test for the presence of a missing systematic factor using principal component factors which are estimated (i) by pooling all of the firm specific term structures using a set of fixed maturity bonds and (ii) by average across firms on a given observation month for a fixed maturity.

All bond data is from the TRACE database. For each trade the clean price, bond-yield, bond coupon rate, settlement value in millions of dollars, and time stamp are recorded. On the last trading day of each month, spanning January 2004 to September 2008, all firms that have at least four different bonds traded, each with a time-to-maturity between 1.5- and 15.25-years, are kept and the price, coupon rate, and previous day's mean settlement value are recorded. This set of data is then filtered by matching the firms with the firm characteristics described in Table 2. A total of 3631 spot credit curves are estimated and then used to generate 24,516 bond specific credit spreads. There are 2906 unique bonds in the data set and 179 unique firms.

With a set of at least four bonds per firm, firm specific zero-coupon spot credit spread curves are estimated using the Nelson-Siegel parameterization. The risk-free spot curve is bootstrapped from LIBOR-Swap rates and the credit spread is measured as the difference between the zero-coupon firm specific yield curve and the LIBOR-Swap spot curve.[7] This is outlined below using the following notation

$P_{cl}(t, c, T)$	: time t clean *market price* of a T-year bond with coupon c,
$P_M(t, c, T)$	: time t clean *model price* of a T-year bond with coupon c,
$a(t)$	: time t accrued interest,
r_t	: t-year instantaneous zero-coupon risk-free spot rate,
s_t	: t-year instantaneous zero-coupon spot credit spread (Nelson-Siegel parameterized),
$y_t = r_t + s_t$	: t-year instantaneous zero-coupon spot yield.

The time t model price, per \$100, of a semi-annual coupon bond, with cash-flow times $\{t_1, t_2, \ldots, T\}$ and a spot yield curve defined by the set $\{y_t : t \in \{t_1, t_2, \ldots, T\}\}$, is given by

$$P_M(c, y_t, t) = \frac{c}{2} \sum_{i=t_1}^{T} e^{-y_i i} + e^{-y_T T} - a(t). \tag{8}$$

Using the Nelson-Siegel method each $\{s_t\}$ is parameterized through four parameters: (b_0, b_1, b_2, b_3). The shape of each spot credit curve is given by

$$s(t) = b_0 + \frac{(b_1 + b_2)}{t/b_3}\left(1 - e^{-\frac{t}{b_3}}\right) - b_2 e^{-\frac{t}{b_3}}, \quad b_0 \geq 0,\ b_0 + b_1 \geq 0, \tag{9}$$

with initial and terminal conditions $h(0) = b_0 + b_1$ and $h(\infty) = b_0$, respectively. The model prices are calibrated to the market prices by minimizing the sum-of-squared model errors,

[7] The LIBOR-swap rates were chosen over the Constant Maturity Treasury rates for the following reasons. Duffee (1996) presents strong arguments in favour of using the market convention for bench-mark risk-free rates and not Treasury rates. Hull, Predescu, and White (2004) indicate the risk-free rate that is implied between a firm's credit default swap spreads and its bond spread is closer to LIBOR-swap rates than the Treasury rates. Reason often cited as to why the Treasury rate is not the risk-free rate also include: (i) preferential tax treatment, (ii) financial institutions hold Treasuries for regulator capital, and (iii) the amount of capital required to support Treasury investments is less than that required for high credit quality corporate bonds.

for bonds $k = 1, \ldots, N$, as

$$(10) \qquad \min_{b_0, b_1, b_2, b_3} \sum_{k=1}^{N} \left[P_M \left(c_k, t, T_k \right) - P_{cl} \left(c_k, t, T_k \right) \right]^2 .$$

This defines the entire spot spread curve, between maturities T_1 and T_N, for firm i on day t. It follows that the j^{th} bond's credit spread is $s(T_j)$.

Summary statistics for the credit spreads are reported in Table 3. A breakdown is given for the full data set, column (1), and by credit rating, columns (2)-(7). For all observations the mean credit spread is 91.35 basis points and the mean 5-year and 10-year credit spreads are 92.21 and 116.50 basis points, respectively. The mean bond settlement value (on the previous day) is \$389 K; the mean time-to-maturity is 5.51-years; and the mean coupon rate is 5.74%. The mean and median credit spreads are increasing by credit group as are the mean bond settlement value and time-to-maturity. In terms of observations, the AA credit rating group represents the largest number of bond level and firm level observations.

C. Control Variables

In addition to introducing default correlation as a systematic factor, I include control variables that existing literature has shown help explain credit spread variation. All of the control variables are measured on the penultimate trading day of each month; the result is that each of the control variables is lagged one-day from the observation day. A list of all the variables, how they are estimated, and the predicted sign of their regression coefficients can be found in Table 2. Summary statistics for the firm and bond specific factors are given in Table 3 and summary statistics for the systematic factors are given in Table 4.

I include the following firm specific factors: firm leverage, equity option implied volatility, firm equity excess returns, and equity option implied volatility smile. At the bond level time-to-maturity is included. Liquidity is also controlled for at the bond and at the firm level. At the bond level the mean settlement value of a bond is used while at the firm level the mean settlement value of all of the bonds used to construct the firm specific term structure of credit spreads are used. The additional systematic control variables that are used include: the level and slope of the risk-free rate, S&P 500 returns, and VIX volatility index.

There is extensive empirical support for the use of these factors as control variables. Among this are Ericsson, Jacobs, and Oviedo (2009), Cremers, Driessen, Maenhout, and Weinbaum (2008), Cremers, Driessen, and Maenhout (2008), Avramov, Jostova, and Philipov (2007), Chen, Lesmond, and Wei (2007), Bedendo, Cathcart, and El-Jahel (2007), Papageorgiou and Skinner (2006), Ericsson and Renault (2006), Blanco, Brenna, and Marsh (2005), Van Landschoot (2004), Hull, Nelken, and White (2004), Campbell and Taksler (2003), Collin-Dufresne, Goldstein, and Martin (2001), Lesmond, Ogden, and Trzcinka (1999), Duffee (1998), Fons (1994) and Sarig and Warga (1989).

IV. Empirical Analysis

This paper is concerned with decomposing the cross-sectional variation of credit spreads and as such I perform my empirical analysis on credit spread levels. This approach follows Ericsson, Jacobs, and Oviedo (2009), Cremers, Driessen, Maenhout, and Weinbaum (2008), and Campbell and Taksler (2003). Cremers, Driessen, Maenhout, and Weinbaum (2008) point out that specification of the empirical test in levels is appropriate as there is little econometric evidence that credit spreads are non-stationary, and further, that using credit spread changes focuses the analysis specifically on the time variation of credit spreads.

The primary unbalance panel regression that I use is for the credit spread at time t of bond j issued by firm i

$$
\begin{aligned}
(11)\quad s_{ijt} = \alpha_i &+ \beta_1 \left(\textit{Default Correlation}\right)_t + \beta_2 \left(\textit{Firm lev}\right)_{it} + \beta_3 \left(\textit{Implied vol}\right)_{it} \\
&+ \beta_5 \left(\textit{Implied smile}\right)_{it} + \beta_6 \left(\textit{Excess rtn}\right)_{it} + \beta_7 \left(\textit{Bond liq}\right)_{jt} + \beta_8 \left(\textit{Time-to-mat.}\right)_{jt} \\
&+ \beta_9 \left(\textit{Level}\right)_t + \beta_{10} \left(\textit{Slope}\right)_t + \beta_{11} \left(\textit{S\&P500 rtn}\right)_t + \beta_{12} \left(\textit{VIX}\right)_t + \varepsilon_{jt},
\end{aligned}
$$

with month dummies, firm fixed effects, $\varepsilon_{jt} = \eta_{jt} + \rho_j \varepsilon_{j,t-1}$, and where *Default Correlation* is either the implied hazard rate standard deviation or the CDO spread-of-spreads. In addition to correcting for bond level serial correlation, the model standard errors are corrected for bond level heteroskedasticity. The only differences in the empirical tests that are performed on the fixed-maturity data sets is that their standard errors are corrected for firm level heteroskedasticity and serial correlation. The estimation follows the Prais-Winsten estimation methodology.

A. Relationship Between Default Correlation and Bond Level Credit Spreads

The estimation results using the full bond level unbalanced panel are reported in Table 5. Four different estimation cases are reported: (i) benchmark regressions without a default correlation measure, columns (1) and (2), (ii) regressions using the 2-Weibull model implied standard deviation, columns (3) and (4), (iii), regressions using the 3-Weibull implied standard deviation, columns (5) and (6), and (iv) regressions using the CDO spread-of-spreads, columns (7) and (8). In each case results without and with firm fixed effects are report in the odd and even columns, respectively.

In terms of the factor of interest there is strong evidence that bond credit spreads are positively related to default correlation. This result holds for both of the model implied measures and for the CDO spread-of-spreads measure. Considering column (8), a one basis point fall in the CDO spread-of-spreads translates into a 0.84 basis point increase in bond credit spreads. This is an economically significant result as it implies that there is almost a one-to-one pass through of relative changes in the CDO spreads to bond level credit spreads, even after control for bond, firm, and additional systematic factors.[8]

Comparing the 2- and 3-Weibull models, the 3-Weibull model has greater economic significance. Considering Table 1, doubling the homogenous Gaussian correlation from 0.10 to 0.20 represents an increase in the 3-Weibull implied hazard rate standard deviation of 0.0092 (a 0.23 observation standard deviation change) and translates into a 7.28 basis point increase in bond credit spreads. Equivalent the 0.0044 (a 0.30 observation standard deviation change) increase in the 2-Weibull implied hazard rate standard deviation translates into a 5.88 basis point increase in credit spreads. Comparatively, the equity super-senior tranche spread fell 12.91 basis points and this translates into roughly a 10.85 basis point increase in bond credit spreads.

The results reported in Table 5 also indicate that the model specification is able to explain a substantial amount of the cross-sectional variation of the bond level credit spreads. With out firm fixed effects the regression report R^2s of 0.59 or 0.60. The inclusion of firm fixed effects increases the R^2s to 0.73. The addition of the default correlation measure does not present a significant increase in the explanatory power of the model specification.

Considering the additional control variables, the regression results closely match results reported in existing literature and the signs of the coefficients are broadly in line with prediction. Comparing the estimation without a default correlation measure with those regressions that include a default correlation measure it is evident that the coefficients for the firm and bond level control variables generally have the same sign, significance and magnitude. Regarding the systematic factors there are deviations from the expected

[8] A one basis point fall in the spread-of-spreads represents a reasonable change in the spreads, particularly during times of financial distress. For the full sample period the average month on change in the CDO spread-of-spreads was -0.7 basis points and for the trailing 12-months from September 2008 it was -3 basis points.

results.

One such deviation is the sign on the VIX. For all of the results reported in Table 5 the relationship between bond credit spreads and the VIX is negative. This is a very puzzling result as it implies that credit spreads are decreasing in equity market volatility and it is difficult to justify. Cremers, Driessen, Maenhout, and Weinbaum (2008) report a similar result in their analysis however they also report varying degrees of significance depending on their estimation specification. Further, the inclusion of a measure of default correlation lowers the economic significance of the S&P 500 returns, but increases the economic significance of the VIX, see columns (2), (4), (6), and (8).

For the 2-Weibull model, column (4), the level of the risk-free rate is insignificant and the slope is only weakly significant and with the wrong sign. These are unexpected results. This suggests that 2-Weibull mode and the level of risk-free rate could be co-linear; of the default correlation measures the 2-Weibull model has the highest correlation with the level of the risk-free rate, see Table 4. That the slope has the wrong sign is more difficult to justify. It is possible that as the 2-Weibull model is the least volatile of the default correlation measures it drowns out the level and slope factors and carries the average level of credit spreads over time that these two factors would otherwise explain.

B. Relationship Between Default Correlation and Firm Level Fixed-Maturity Credit Spreads

The firm level regressions are performed by estimating fixed-maturity credit spreads from the firm specific term structure of credit spreads for each firm-month observation. Two fixed maturities are considered: 5- and 10-year. The results for the firm level regressions are reported in Table 6. As with the results that used bond-month observations four different cases are considered for both the 5- and 10-year maturities, however only regressions with firm fixed effects are reported.

The estimates at the firm level provide further evidence that credit spreads are positively related to default correlation. For all three of the measure of default correlation the estimates reported have strong statistical significance and the predicted signs. Further, comparing the coefficients for the 5-year and the 10-year regressions indicate that the relationship between default correlation is statistically the same for each maturity. For example, comparing columns (3) and (4), the coefficients for *Implied Std-M2* are within each others one-standard error confidence interval; similar conclusions follow for the 3-Weibull and the CDO spread-of-spreads models.

Regarding economic significance, a one basis point fall in the CDO spread-of-spreads translates into a 0.91 basis point rise in 5-year credit spreads and a 0.94 basis point rise in 10-year credit spreads. Both of these suggest a similar level of pass through of relative changes in CDO spreads as reported for the bond level regressions. Adopting the comparison made for the bond level regressions, a 0.0092 change in the 3-Weibull implied hazard rate standard deviation translates into a 9.33 and 8.17 basis point increase in 5- and 10-year credit spreads, respectively. For the 2-Weibull model, the equivalent change translates into a 7.99 and 7.29 basis point increase in 5- and 10-year credit spreads, respectively. Lastly, for an equivalent change in the CDO spread-of-spreads of -12.91 basis point, 5- and 10-year credit spreads increase 11.95 and 12.13 basis points, respectively.

Results for the firm control variables are inline with existing literature and the results reported at the bond level in Table 5. One difference is that for the firm level fixed-maturity regressions, *Implied smile* is not significant. The significance of the systematic factors, however, differs from the results reported for the bond level regressions. The benchmark regressions in columns (1) and (2) suggest that, without a default correlation factor, the risk-free rate level, S&P 500 returns, and the VIX are systematic factors for 5-year credit spreads while only the risk-free rate level and S&P 500 returns are systematic factors for 10-year credit spreads. This observation hold for each of the regression cases that include their respective measure of default correlation, with two exceptions. For the model implied default correlation the S&P 500 returns are the only significant systematic factor, beyond default correlation.

In terms of the model's ability in explaining the cross-sectional variation of fixed-maturity credit spreads, the reported R^2s are comparable to those reported in the bond level regressions. Roughly 66% of the 5-year credit spread cross-sectional variation is explained and approximately 71% of the 10-year credit spread cross sectional variation is explained. Further, as was highlighted previously, the firm level fixed-maturity regressions provide a robustness check for the bond level regressions. As the bond level data is an unbalanced panel at the bond level, firms have multiple bonds on an observation day. Since the number of bonds that a firm may have on a given day is limited only by a lower bound of four bonds, there is potential for a small number of firms with a very large number of bonds driving the results. The generation of the firm level fixed maturity data sets resolves this particular issue. Given that the firm level results are consistent with the bond level results, I conclude that the bond level results are not being driven by a small number of firms that have a large number of bonds trading on each observation month.

C. Credit Rating Breakdown at the Bond and Fixed-Maturity Firm Levels

The summary statics in Table 3 show that of the 24,516 bond-month observations, 12,107 are for A-rated firms, and likewise, of the 3631 total firm-months 1801 are for A-rated firms. To ensure that this particular credit rating group is not driving the results I run the bond level regression reported in Table 5 columns (4), (6) and (8) and fixed-maturity firm level regressions reported in Table 6 columns (3) to (8) by credit rating group. To further motivate this analysis there is existing empirical evidence that credit ratings can help explain credit spread levels; for example Cremers, Driessen, Maenhout, and Weinbaum (2008) and Campbell and Taksler (2003) demonstrate this, with the latter suggesting that credit ratings are more able to explain credit spread cross-sectional variation than select accounting variables are. The regression results by credit rating are reported in Table 7 for the bond level data and in Table 8 for the 5- and 10-year firm level data.[9]

Beginning with the bond level results, Tables 7 reports that across credit rating groups and for each of the three measures of default correlation that credit spreads are positively related to CDO market implied default correlation. The signs on both the 2-Weibull and the 3-Weibull implied hazard rate standard deviation coefficients are positive and significant, with the exception to the 2-Weibull A-rating and B-rating regressions. Consistent with our predictions, the CDO spread-of-spreads regression report negative and significant coefficients across all credit rating groups. For the 5-year firm level regressions both the estimated coefficients are statistically significant from the AAA to the BB credit rating group for all three of the measure of default correlation; there is no statistical significance found in the B credit rating group. Considering the 10-year fixed-maturity results, statistical significance of default correlation coefficients is present for all three CDO market implied measure within the AAA-BBB credit rating range.

The lack of statistical significance of the B credit rating group for the 5-year firm level regressions may due to at least one of the following. Firstly, this credit rating group has the smallest sample size, 124 firm-months. This essentially translates into an average of 2 firms per observation month and so there may not be enough variation within the 5-year B group to measure significant results; likewise, the fact that the coefficients are the opposite sign as predicted could be due to the small sample. Secondly, the CDO spreads that are used to imply the default correlation measures are for a 5-year CDO whose underlying reference portfolio contains only investment grade, BBB or higher, bonds. If follows that for the lower credit rated bonds, a investment grade based default correlation measure may not be sufficiently large or variable to explain non-investment grade bond credit spreads. Turning

[9]All of the regressions included the same control variables as those used in Tables 5 and 6. For ease of exposition only the default correlation coefficient estimates, the t-statistics, the R^2s and observation count have been report. Complete estimation results are available upon request.

to the lack of significance of the BB and B credit rating groups for the 10-year firm level regressions, the explanations for the 5-year firm level regressions carry through; although for the 10-year BB group small sample bias is less a potential issue as the AAA group has fewer observations. An additional explanation for the lack of significance of the BB and B is that the maturity of the CDO that is used to imply default correlation is 5-years. It follows that 5-year investment grade based default correlation is not meaningfully related to 10-year non-investment grade credit spreads.

For the bond level regressions, there is an interesting relationship between the level of credit spread sensitivity to default correlation and credit rating groups reported in Table 7. It is evident for all three of the default correlation measures that the level of credit spread sensitivity to default correlation is non-linear in credit rating, roughly displaying a U-shape. The 2-Weibull model's sensitivity falls from the AAA rating group to the A rating group and then increase to the BB rating group (while ignoring the B rating regression due to insignificance). Similarly, for the 3-Weibull model coefficient's magnitude falls from the AAA to AA group where it is arguably flat for the AA a A rating and then it rises through to the B credit rating group. The relationship for the CDO spread-of-spreads measure initial rises from the AAA to the AA rating and then it falls for the A rating and the steadily increases peaking at the B credit rating group. Considering the firm level regressions, similar patterns are observed for the 5-year credit spreads in the AAA to BB credit rating range and for the 10-year credit spreads within the AAA-BBB credit rating range.

Credit rating classifications are often interpreted as pooling firms with similar leverage, asset volatility, earnings growth, and so forth together. The above results are interesting as they suggest additional firm characteristics may affect how sensitive credit spreads are to systematic measure of default correlation. Such characteristics could include firm diversity, size, and the particular business they operate in. This notion is consistent, for example, with the results reported by Jorion and Zhang (2009) where they demonstrate that creditors default risk rises as bankruptcy occur; in their case a specific firm characteristic, being a creditor, effects firms' credit risks in a specific and predicatble way.

Of the firm specific factors reported in Table 3 mean leverage across credit rating groups reports a similar non-linear patterns as those reported in Tables 5 and 6. Firm leverage is lowest for the A rated credit group as leverage falls from AAA to A and the rises from A to B. This suggests that firms sensitivity to default correlation is increasing leverage. At the bond level, the time-to-maturity falls from the AAA to the AA credit rating groups and then increases through to the BB group. This would suggest that bond specific credit spreads' sensitivity to default correlation are increasing in time-to-maturity. To my knowledge there is no clear empirical evidence that supports either of the these claims and only limited theoretical evidence. The non-linear relationship between firm characteristics and systematic default correlation posses an interesting direction for further investigation.

D. Principal Component Analysis of the Regression Residuals

Collin-Dufresne, Goldstein, and Martin (2001) present an often sighted result that even after controlling firm and systematic factors, the residuals of the cross-sectional variation of credit spread changes contain a missing common factor. The principal component analysis that they perform has become a benchmark test for credit spread analysis. Supporting this find is the residual analysis performed Blanco, Brenna, and Marsh (2005). However, since the initial finding there is a growing bond of empirical research that refutes the case for a missing systematic factor. Examples include Ericsson, Jacobs, and Oviedo (2009), Cremers, Driessen, Maenhout, and Weinbaum (2008), and Avramov, Jostova, and Philipov (2007). I test the residuals of the bond level regressions reported in Table 5 as follows.

For each firm-month term structure of credit spreads I estimate fixed maturity credit spreads at the 2.5, 5, 7.5, 10 and 12.5 year points. Doing so creates an unbalanced panel of 3631 firm-months with five constant credit spread maturities. Keeping this data set pooled I then estimate the principal components of these credit spreads. As reported in Table 9 column (1) Panel A the first PCA explains 86% of the credit spread variation, the second PCA explains an additional 11% of the variation, and the third PCA explains an additional 2%; the first three PCAs explain a cumulative 99.87% of the firm level credit spread variation.[10] These PCAs are then used to construct a set of firm-month PCA factors that are matched by firm and observation month to the bond level data.

I construct another set of PCA factors from the firm level data by taking the above unbalanced firm-month data that is used to create the first set of PCAs and average the credit spreads across all firms for a fixed observation month and fixed maturity. This collapse the data into a timeseries with 57 observation months and five fixed-maturity credit spreads. The PCAs of this data are then estimated, and I report the cumulative percent of variation explained by the first three PCAs in Table 9 column (2) Panel A. The first PCA explains 99% of the average credit spread variation and the percent explain incrementally increase such that the third PCA explains a cumulative 99.99% of the average credit spread variation.[11] Using these three PCAs a set of observation month factors are generated and matched to the bond level data (by observation month).

The first set of PCA factors are PCAs whose covariance matrix measures variation between a single firm's credit spreads and also the variation between the credit spreads of different firms across different maturity points. This is due to the pooling of all of the firm-month credit spreads and assuming independence of the firm-month observations. By pooling a degree of within firm and between firm variation is accounted for in the three PCA factors. In contrast, by averaging across all credit spreads for a given observation month

[10]The eigenvectors for the PCAs are: PCA-1 (0.412, 0.46, 0.48, 0.46, 0.42), PCA-2 (0.62, 0.36, -0.01, -0.36, -0.60), PCA-3 (0.64, -0.44, -0.46, -0.04, 0.42). Which can be interpreted as level, slope, and curvature factors.

[11]The eigenvectors for the PCAs are: PCA-1 (0.44, 0.45, 0.45, 0.45, 0.45), PCA-2 (0.73, 0.22, -0.08, -0.34, -0.54), PCA-3 (0.49, -0.54, -0.45, -0.0, 0.52).

and fixed maturity the PCA's covariance matrix represents the variation of the average credit spread across maturities. By doing this within firm and between firm variation is removed. As such the second set of PCA factors can be considered as purely systematic.

To benchmark the explanatory power of the PCA factors, the bond level credit spreads are regressed on the PCA factors, with month dummies and firm fixed effects included for consistency with the even column regressions in Table 5. The regression results are reported in Table 9 Panel B. Column (1) contains the PCA coefficient estimates using the first set of PCA factors. The estimation indicates that bond level credit spreads are increase in PCA level and slope and decreasing curvature. Further, this regression reports an R^2 of 87%, which is larger than the R^2s report in Table 5. The regression using the second set of PCA factors is reported in column (2). For these regressions only the first and third factors, representing the slope and curvature, are statistically significant. This regression has an R^2 of 62%. This is substantially smaller than the R^2s reported in comparable regressions of Table 5. However it should be highlighted that firm specific variation is only accounted for by the firm fixed effects and this suggests that the first three PCAs of the average firm credit spreads are able to explain a significant amount of bond level credit spread cross-sectional variation.

Testing for a missing systematic factor is performed by taking the residuals from Table 5 columns (2), (4), (6), (8) and individually regressing them on the two sets of PCA factors. Two other regression residuals are also included. The first are the residuals for a bond level model that includes only the firm and bond control variables, and the second is a similar regression that includes only the systematic control variables. Table 9 Panel C reports the R^2s for each of the twelve regressions.

In column (1) the R^2s for regressions with the first set of PCA factors are reported. Comparing the residuals for the regression with firm and bond control variables against the regression with only systematic control variables, it is evident that the idiosyncratic factors explain more of the cross-sectional variation in credit spreads than the systematic factors do. This follows as the lower R^2 for the regression with only firm and bond control variables indicates a smaller amount of the unexplained credit spread variation is explained by the PCAs. For the residuals from Table 5 the R^2s are all around 17%, which is modestly smaller than the regression specified with only firm and bond control variables. These R^2s indicate that the PCA factors explain a limited amount of the unexplained variation in credit spreads. As such this supports the argument against a missing common factor.

Considering the second set of PCA factors that are estimated from average credit spreads, Table 9 Panel C column (2), the reported regression R^2s are very small. The firm bond only regression has the largest R^2 at 2.5%. For the model specifications in Table 5 all of the R^2s in Table 9 Panel C are less than 1%. These results strongly indicate that the unexplained credit spread variation is essentially independent to systematic PCA factors and this further supports the argument against a missing common factor.

Although the reported R^2 for the both sets of regressions support the argument against a missing systematic factor, the firm credit spread based PCAs are large than those reported for the PCAs estimated from average credit spreads. This can be explained by recalling that the covariance matrix used to construct the first set of PCA factors allows for within firm and between firm variation in credit spreads across fixed maturities. In light of this, these PCAs explain a maximal amount of firm-time cross-sectional variation. It follows that these PCAs may be accounting for unobservable firm level variation, beyond firm fixed effects, that the Table 5 model specifications are unable to account for. That the R^2s in Table 5 are around 73% and the main results of the paper are robust to bond and firm level model specification provide stronger evidence against the model missing a firm specific factor than this residual analysis suggesting a possible missing firm specific factor.

V. Conclusion

In this paper, I study the relationship between corporate bond credit spreads and CDO market implied default correlation. Two measures of default correlation are considered. One is a model implied measure where the model is the implied hazard rate density model and the other is the CDO spread-of-spreads. For the CDO spread-of-spreads the difference between the riskiest tranche and the safest tranche are used. I outline how the standard deviation of the implied hazard rate density is increasing in default correlation and I demonstrate that the CDO spread-of-spreads is decreasing in default correlation.

Regressing credit spreads on default correlation, while controlling for firm, bond and additional systematic factors, I show that credit spreads are positively related to CDO market implied default correlation. This results is shown to be robust to regressions using unbalance bond level data and unbalance firm level data using 5 and 10-year fixed maturity credit spreads. Specifically, I show that a one basis point fall in the CDO spread-of-spreads translates into a 0.91 basis point and 0.94 basis point increase in 5 and 10-year credit spreads, respectively.

Using principal component analysis I test my regression residuals for a missing systematic factor. I do this using two different sets of PCA factors. One set allows for within and between firm credit spread variation across maturities, while the other accounts for average credit spread variation across maturities. In both instances I find little evidence of a missing common factor. This results adds to the growing body of literature that supports the argument against standard credit spread decomposition containing a missing systematic factor. Further, my residual analysis suggests that it are the firm and bond control variables that explain most of the cross-sectional variation of the credit spreads.

My analysis also considers a set of regressions broken out by credit rating group. Bond level regression by credit rating also show that default correlation and credit spreads are positively related across all credit rating groups. At the firm level, however, this relationship broad holds only for investment grade credit rating groups. The credit rating break down also reveals an interesting non-linear relationship between the sensitivity of credit spreads to default correlation and credit rating groups. I report that the AAA, AA, BBB, BB, and B groups tend to more sensitive to default correlation than the A credit rating group; the estimated parameters roughly form a U-shape (which is inverted for the CDO spread-of-spreads measure). Within my data set mean and median firm leverage across credit rating groups have similar patterns. This suggests an avenue for future research testing whether firm characteristics such as size, segment diversity or business sector can influence how sensitive credit spreads are to default correlation.

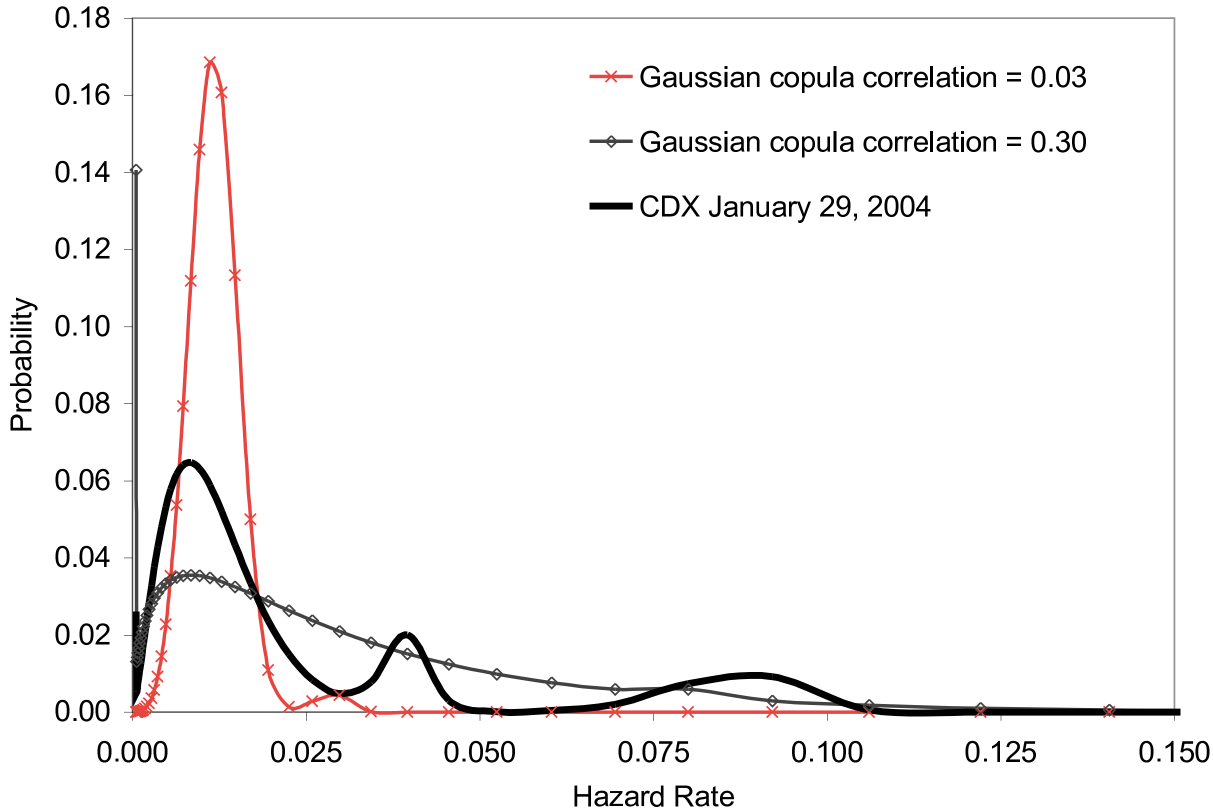

Figure 1: Sample Implied Hazard Rate Densities for Hypothetical CDO and CDX Market Spreads

The implied hazard rate densities are calibrated to the CDO spreads listed in Table 1. For the one-factor Gaussian copula models the spreads are hypothetical spreads valued assuming homogenous correlation of $\rho = 0.03$ and $\rho = 0.30$. Market spreads are for the CDX on January 29, 2004 density.

Table 1: Model CDO Spreads, Gaussian copula Correlations, and Implied Hazard Rate Density Dispersion

The CDO models use the following parameters: 125 firms, 5-year maturity, 4% risk-free rate, 45% recovery rate, and default rate of 1.04% (equivalent to a one-year cumulative probability of default of 1.03%). The default rate corresponds to the average default rate implied from the market Index spread. The "Implied tranche correlations" for January 29, 2004 are calculated by individually calibrating each tranche to a one-factor Gaussian copula model. The CDO spread-of-spreads is the differences between the equity tranche (0-3%) and the super-senior tranche (15-30%), reported in column (7). For each set of spreads a 2-Weibull, column (8), and a 3-Weibull, column (9) implied hazard rate density is also estimated. The hypothetical CDO spreads are calculated assuming that all of the tranches have the same default correlation ρ.

	CDO tranches						CDO spread-of-spreads	Implied hazard rate density	
	(1) 0–3%	(2) 3–7%	(3) 7–10%	(4) 10–15%	(5) 15–30%	(6) Index	(7) Eq-Snr	(8) M2	(9) M3
CDX NORTH AMERICAN INVESTMENT GRADE CDO FOR JANUARY 29, 2004									
Market spread	40.250	318.500	107.500	53.500	14.500	57.500	25.750	0.0144	0.0132
Implied tranche correlation	0.184	0.084	0.183	0.247	0.314				
HYPOTHETICAL CDOS VALUED ASSUMING HOMOGENOUS ONE-FACTOR GAUSSIAN COPULA CORRELATION									
ρ	Tranche Spreads (bps)					Index	Eq-Snr	M2	M3
0.03	56.999	237.297	5.557	0.089	0.000	57.500	56.999	0.0039	0.0040
0.10	48.356	334.121	50.752	7.374	0.172	57.500	48.183	0.0077	0.0086
0.20	38.838	386.156	117.505	37.271	3.569	57.500	35.269	0.0121	0.0178
0.30	30.876	397.946	162.324	71.115	12.831	57.500	18.044	0.0168	0.0204
0.50	17.287	371.868	202.411	126.114	41.545	57.500	-24.258	0.0300	0.0272
0.70	4.786	323.862	195.547	141.517	76.000	57.500	-71.214	0.0486	0.0337

Table 2: Variable Definitions

A bond specific (bond-month) observation corresponds to the last trade of the month for each bond considered. Bond characteristics, trade prices, and settlement values are from TRACE. The risk-free spot curve is bootstrapped from LIBOR-Swap rates provided by the Federal Reserve. Options data is from OptionMetrics. Equity and market returns are from CRSP. Firm balance sheet and credit rating data is from COMPUSTAT. Quarterly balance sheet data is used and, upon announcement, is held constant for each observation month until the next quarterly announcement.

Variable	Predicted Sign	Description
Zero-coupon Spot Credit Spreads		
Bond Level		The zero-coupon spot spreads at a bond's time-to-maturity
Firm Level Fixed Maturity		
5-year		5-year zero-coupon spot spread for each firm
10-year		10-year zero-coupon spot spread for each firm
Default Correlation Measure from the Credit Derivative Market:		
Implied Std	$+$	The standard deviation of the implied hazard rate density estimated from the DJ CDX 5-year CDO and Index using both a 2- and 3-Weibull implied hazard rate density model
EqSsnr	$-$	The spread between the equity and super senior tranches of the DJ CDX 5-year CDO
Firm and Bond Specific Explanatory Variables:		
Firm lev	$+$	Firm leverage = Total Debt / (Market Capital+Total Debt)
Implied vol	$+$	Implied volatility for 30 day at-the-money equity options
Implied smile	$-$	The slope of the equity option implied volatility smile for 30 day at-the-money options
Excess rtn	$-$	Firm's annualized 120-day historic mean daily excess return over the CRSP value weighted market portfolio
Bond liq	$-$	Mean settlement value, \$M, for all intra-day bond trades on the day preceding a bond's trading day
Firm liq	$-$	Mean settlement value, \$M, for all intra-day bond trades on the day preceding a firm's trading day
Time-to-mat	$+/-$	Time to maturity in years for each bond
Equity Market and Term Structure Explanatory Variables:		
S&P500 returns	$-$	1-year historic index returns
Level	$-$	1-year LIBOR-swap zero-rate
Slope	$-$	10-year LIBOR-swap rate minus the 1-year LIBOR-swap zero-rate
VIX	$+$	Volatility index of the near term S&P500 futures options

Table 3: Summary Statistics

The "ALL" column includes all of the credit spreads. All characteristics except the credit spreads, time-to-maturity and the coupon rate are recorded at the close of the penultimate trading day of each observation month.

	(1) ALL	(2) AAA	(3) AA	(4) A	(5) BBB	(6) BB	(7) B
FIRM CHARACTERISTICS							
Mean firm level credit spreads by maturity							
5-year	92.206	20.628	35.818	44.396	113.316	279.131	557.272
10-year	116.504	53.668	57.949	72.838	141.626	283.900	539.181
Median firm level credit spreads by maturity							
5-year	27.781	8.095	10.349	16.316	60.624	215.977	395.944
10-year	60.448	44.427	31.869	41.689	96.155	244.383	462.469
Firm leverage							
Mean	0.452	0.552	0.480	0.416	0.431	0.532	0.720
Median	0.419	0.515	0.505	0.369	0.394	0.524	0.733
Std	0.262	0.283	0.292	0.264	0.218	0.198	0.208
Implied volatlity (of at-the-money 30-day equity option)							
Mean	0.278	0.204	0.249	0.249	0.297	0.392	0.515
Median	0.226	0.194	0.192	0.212	0.253	0.334	0.415
Std	0.190	0.085	0.167	0.166	0.171	0.237	0.346
Excess return (annualized 120-day historic daily mean)							
Mean	-0.084	-0.067	-0.117	-0.052	-0.096	-0.180	-0.142
Median	-0.032	-0.048	-0.082	-0.021	-0.033	-0.045	-0.018
Std	0.439	0.214	0.442	0.357	0.482	0.694	0.607
Implied volatility smile (slope of at-the-money 30-day equity option)							
Mean	-0.010	-0.007	-0.009	-0.009	-0.010	-0.013	-0.035
Median	-0.006	-0.005	-0.008	-0.006	-0.006	-0.006	-0.024
Std	0.029	0.013	0.016	0.020	0.022	0.050	0.090
Mean Bond Settlement Value by Firm ($M)							
Mean	0.436	0.234	0.327	0.363	0.700	0.496	0.338
Median	0.281	0.183	0.248	0.237	0.446	0.426	0.295
Std	0.508	0.202	0.304	0.403	0.767	0.405	0.244
BOND CHARACTERISTICS							
Credit spreads (basis points)							
Mean	91.347	27.057	46.740	57.722	139.569	298.032	522.850
Median	30.233	10.918	16.747	22.692	81.718	256.917	429.085
Std	174.338	42.275	71.515	139.002	182.182	214.121	337.086
Mean bond settlement value by Bond ($M)							
Mean	0.389	0.257	0.335	0.346	0.659	0.470	0.304
Median	0.080	0.061	0.080	0.065	0.128	0.257	0.136
Std	0.766	0.540	0.655	0.715	1.123	0.642	0.349
Time-to-maturity (years)							
Mean	5.510	5.746	5.308	5.472	5.611	5.946	5.921
Median	4.921	4.899	4.729	4.841	5.137	5.552	5.375
Std	2.897	3.392	2.770	2.902	2.756	2.855	3.271
Coupon rate by bond (percent)							
Mean	5.736	5.024	5.409	5.572	6.229	7.090	7.557
Median	5.625	5.000	5.300	5.500	6.200	7.000	7.250
Std	1.332	1.302	1.137	1.225	1.247	1.013	1.620
OBSERVATION SUMMARY							
Bond-Months	24517	1431	5415	12107	3575	1290	699
Unique Bonds	2906						
Firm-Months	3631	119	531	1801	787	269	124
Unique Firms	179						

Table 4: Systematic Factor Summary Statistics

The following are the summary statistics for the systematic factors. There are total of 57 monthly observations spanning January 2004 to September 2008, where the data is recorded from the penultimate trading day of each month. The 2-Weibull model uses two Weibull mixing densities, column (1), the 3-Weibull model, column (2), uses three Weibull mixing densities to represent the implied hazard rate density. The equity super-senior spread, column (3), is the difference between the spreads of the riskiest and the safest CDX tranches, in basis points. The level of the risk-free rate, Level, is the 1-year LIBOR rate, in basis points; the slope of the risk-free rate, *Slope*, is the 10-year 1-year spread, in basis points; the *S&P500 rtn* is the 120-day historic daily excess return rate; *VIX* is the volatility index of the near term S&P500 futures options.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Implied Std						
	M2	*M3*	*EqSsnr*	*Level*	*Slope*	*S&P500 rtn*	*VIX*
Panel A Systematic Factor Summary Statistics							
Mean	0.0145	0.0392	17.547	392.61	99.89	0.0723	0.1623
Median	0.0111	0.0298	23.575	414.02	50.89	0.0869	0.1483
Std	0.0093	0.0259	19.233	126.50	106.53	0.1062	0.0598
Min	0.0057	0.0109	-42.000	134.63	-23.04	-0.3220	0.1052
Max	0.0419	0.1032	36.875	566.95	327.41	0.3129	0.4672
Serial Corr	0.833	0.918	0.859	0.980	0.981	0.895	0.615
Panel B Systematic Factor Cross-Correlation Matrix							
Implied Std-M2	1.000						
Implied Std-M3	0.913	1.000					
EqSsnr	-0.866	-0.887	1.000				
Level	-0.439	-0.323	0.288	1.000			
Slope	0.343	0.214	-0.206	-0.963	1.000		
S&P500 rtn	-0.572	-0.788	0.701	0.022	0.101	1.000	
VIX	0.619	0.725	-0.605	-0.295	0.233	-0.612	1.000

Table 5: Relationship Between Default Correlation and Bond Level Credit Spreads

This table reports the bond level unbalanced panel results of regressing monthly corporate bond spreads on measures of default correlation, while also including idiosyncratic and systematic control variables. Each regression has month dummies. The odd numbered columns, (1)-(3)-(5)-(7), have no firm fixed effects while the even number columns, (2)-(4)-(6)-(8), have firm fixed effects. The 2-Weibull models use two Weibull mixing densities, columns (3)-(4), the 3-Weibull models, columns (5)-(6), use three Weibull mixing densities to represent the implied hazard rate density. The equity super-senior spread, columns (7)-(8), is the difference between the spreads of the riskiest and the safest CDX tranches. The measure of default correlation, *Implied std*, is the standard deviation of the implied hazard rate density. The t-statistics are corrected for bond level heteroskedasticity and autocorrelation; significance as: * for $p < 0.10$, ** for $p < 0.05$, and *** for $p < 0.01$.

	No Factor of Interest		2-Weibull Implied Density		3-Weibull Implied Density		Equity Super-Senior Spread	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Implied Std-M2			1768.84***	1336.26***				
			(14.11)	(12.57)				
Implied Std-M3					1068.52***	791.07***		
					(17.41)	(15.31)		
EqSsnr							-1.02***	-0.84***
							(-16.32)	(-15.71)
Firm lev	53.43***	44.17***	53.18***	34.36**	53.82***	37.41**	53.98***	36.28**
	(12.95)	(2.76)	(13.15)	(2.16)	(13.35)	(2.33)	(13.34)	(2.27)
Implied vol	502.48***	422.76***	504.83***	426.50***	507.01***	429.41***	498.69***	420.13***
	(25.20)	(31.13)	(25.45)	(31.28)	(25.55)	(31.47)	(25.20)	(30.75)
Implied smile	-499.95***	-184.29***	-515.87***	-196.18***	-513.28***	-192.70***	-525.22***	-205.13***
	(-7.65)	(-3.76)	(-7.90)	(-4.01)	(-7.89)	(-3.95)	(-8.05)	(-4.20)
Excess rtn	-48.33***	-47.52***	-43.18***	-43.97***	-42.24***	-43.28***	-44.93***	-45.25***
	(-11.19)	(-15.94)	(-10.04)	(-14.62)	(-9.79)	(-14.32)	(-10.51)	(-15.10)
Bond liq	1.24	-1.07	1.19	-0.96	1.11	-0.95	1.23	-0.93
	(1.54)	(-1.42)	(1.49)	(-1.28)	(1.38)	(-1.28)	(1.54)	(-1.24)
Time-to-mat	3.46***	3.30***	3.32***	3.12***	3.21***	3.07***	3.26***	3.10***
	(12.07)	(13.08)	(11.66)	(12.25)	(11.29)	(12.00)	(11.46)	(12.20)
Level	-0.09***	-0.11***	0.02	-0.02	0.01	-0.03*	-0.10***	-0.12***
	(-4.04)	(-5.82)	(1.02)	(-1.17)	(0.50)	(-1.71)	(-4.86)	(-6.49)
Slope	-0.06**	-0.01	0.01	0.04*	-0.01	0.02	-0.13***	-0.07***
	(-2.34)	(-0.64)	(0.36)	(1.83)	(-0.55)	(1.05)	(-5.02)	(-3.10)
S&P500 rtn	-188.65***	-197.06***	-140.54***	-166.31***	-45.78***	-97.81***	-71.22***	-105.36***
	(-15.77)	(-22.44)	(-11.68)	(-18.42)	(-3.21)	(-9.02)	(-5.65)	(-10.64)
VIX	-300.70***	-157.19***	-332.32***	-184.81***	-372.84***	-216.42***	-298.00***	-155.19***
	(-9.67)	(-7.57)	(-10.63)	(-8.73)	(-11.80)	(-10.09)	(-9.64)	(-7.46)
R^2	0.5940	0.7336	0.5991	0.7362	0.6016	0.7374	0.6003	0.7374
Observations	24516	24516	24516	24516	24516	24516	24516	24516
No Bonds	2906	2906	2906	2906	2906	2906	2906	2906
No Firms	179	179	179	179	179	179	179	179
Firm Effects		Yes		Yes		Yes		Yes

Table 6: Relationship Between Default Correlation and Firm Level 5-year and 10-year Credit Spreads

This table reports the firm level unbalanced panel results of regressing monthly 5-year and 10-year corporate bond spreads on measures of default correlation, while also including idiosyncratic and systematic control variables. Each regression has month dummies and firm fixed effects. The odd numbered columns, (1)-(3)-(5)-(7), are for 5-year credit spreads while the even number columns, (2)-(4)-(6)-(8), are for 10-year credit spreads. The 2-Weibull models use two Weibull mixing densities, columns (3)-(4), the 3-Weibull models, columns (5)-(6), use three Weibull mixing densities to represent the implied hazard rate density. The equity super-senior spread, columns (7)-(8), is the difference between the spreads of the riskiest and the safest CDX tranches. The measure of default correlation, *Implied std*, is the standard deviation of the implied hazard rate density. The t-statistics are corrected for firm level heteroskedasticity and autocorrelation; significance as: * for $p < 0.10$, ** for $p < 0.05$, and *** for $p < 0.01$.

	No Factor of Interest		2-Weibull Implied Density		3-Weibull Implied Density		Equity Super-Senior Spread	
	5-year (1)	10-year (2)	5-year (3)	10-year (4)	5-year (5)	10-year (6)	5-year (7)	10-year (8)
Implied Std-M2			1816.21***	1655.88***				
			(6.71)	(7.50)				
Implied Std-M3					1014.40***	888.16***		
					(7.65)	(8.33)		
EqSsnr							-0.91***	-0.94***
							(-6.72)	(-8.46)
Firm lev	163.24***	117.26***	176.34***	132.45***	183.20***	140.53***	174.86***	135.17***
	(3.10)	(3.24)	(3.33)	(3.64)	(3.44)	(3.84)	(3.29)	(3.75)
Implied vol	366.91***	248.21***	372.29***	252.43***	374.07***	253.74***	366.06***	246.45***
	(10.76)	(10.38)	(10.86)	(10.49)	(10.90)	(10.55)	(10.75)	(10.33)
Implied smile	233.27	-13.28	216.96	-35.44	219.37	-32.81	217.66	-39.75
	(1.44)	(-0.09)	(1.33)	(-0.25)	(1.35)	(-0.23)	(1.34)	(-0.28)
Excess rtn	-41.11***	-39.99***	-37.29***	-35.16***	-36.83***	-34.47***	-39.88***	-37.05***
	(-4.24)	(-5.88)	(-3.79)	(-5.20)	(-3.75)	(-5.04)	(-4.06)	(-5.46)
Firm liq	-3.13	-5.47*	-2.45	-5.01*	-2.44	-5.06*	-2.54	-4.94*
	(-0.81)	(-1.95)	(-0.63)	(-1.80)	(-0.63)	(-1.82)	(-0.66)	(-1.78)
Level	-0.25***	-0.14***	-0.13*	-0.03	-0.16**	-0.06	-0.26***	-0.15***
	(-3.58)	(-2.67)	(-1.83)	(-0.55)	(-2.15)	(-0.99)	(-3.75)	(-2.83)
Slope	-0.12	-0.06	-0.05	0.01	-0.08	-0.02	-0.18**	-0.12*
	(-1.43)	(-0.88)	(-0.55)	(0.22)	(-0.95)	(-0.29)	(-2.17)	(-1.84)
S&P500 rtn	-218.36***	-219.32***	-179.08***	-174.59***	-100.03***	-105.07***	-125.10***	-109.34***
	(-7.52)	(-10.25)	(-5.76)	(-7.73)	(-2.78)	(-4.02)	(-3.55)	(-4.25)
VIX	-123.98**	48.38	-145.80**	12.88	-183.51***	-22.06	-115.66*	45.80
	(-2.08)	(1.09)	(-2.44)	(0.28)	(-3.07)	(-0.48)	(-1.93)	(1.02)
R^2	0.6600	0.7035	0.6661	0.7074	0.6676	0.7090	0.6653	0.7091
Observations	3631	3631	3631	3631	3631	3631	3631	3631
No Firms	179	179	179	179	179	179	179	179

Table 7: Relationship Between Default Correlation and Bond Level Credit Spreads by Credit Rating

This table reports the bond level unbalanced panel results by S&P credit rating of regressing monthly corporate bond spreads on measures of default correlation, while also including idiosyncratic and systematic control variables. Each regression has month dummies and firm fixed effects. The control variables include: *Firm lev*, *Implied vol*, *Excess rtn*, *Bond liq*, *Level*, *Slope*, *S&P500 rtn*, and *VIX*; they have been suppressed for exposition. The measure of default correlation, *Implied std*, is the standard deviation of the implied hazard rate density. The 2-Weibull models use two Weibull mixing densities, the 3-Weibull models use three Weibull mixing densities to represent the implied hazard rate density, and the equity super-senior spread is the difference between the spreads of the riskiest and the safest CDX tranches. The t-statistics are corrected for bond level heteroskedasticity and autocorrelation; significance as: * for $p < 0.10$, ** for $p < 0.05$, and *** for $p < 0.01$.

	AAA (1)	AA (2)	A (3)	BBB (4)	BB (5)	B (6)
Implied Std-M2	639.15***	307.51***	162.12	1824.86***	5359.73***	2024.86
	(3.50)	(3.26)	(0.98)	(7.68)	(10.81)	(1.35)
R^2	0.7587	0.8115	0.7113	0.8046	0.8447	0.8121
Implied Std-M3	429.20***	234.02***	238.56***	1017.90***	2692.31***	3183.72***
	(4.95)	(5.11)	(2.90)	(8.36)	(10.58)	(4.19)
R^2	0.7617	0.8124	0.7115	0.8059	0.8429	0.8189
EqSsnr	-0.23**	-0.46***	-0.36***	-1.37***	-1.66***	-3.34***
	(-2.25)	(-11.37)	(-4.56)	(-11.74)	(-6.36)	(-4.89)
R^2	0.7559	0.8175	0.7118	0.8091	0.8325	0.8191
Observations	1431	5414	12107	3575	1290	699
No Bonds	238	593	1452	654	277	164

Table 8: Relationship Between Default Correlation and Firm Level 5-year and 10-year Credit Spreads by Credit Rating

This table reports the firm level unbalanced panel results by S&P credit rating of regressing monthly 5-year and 10-year corporate bond spreads on measures of default correlation, while also including idiosyncratic and systematic control variables. Each regression has month dummies and firm fixed effects. The control variates are the same as those reported in the previous table, they have been suppressed for exposition. The measure of default correlation, *Implied std*, is the standard deviation of the implied hazard rate density. The 2-Weibull models use two Weibull mixing densities, the 3-Weibull models use three Weibull mixing densities to represent the implied hazard rate density, and the equity super-senior spread is the difference between the spreads of the riskiest and the safest CDX tranches. The t-statistics are corrected for firm level heteroskedasticity and autocorrelation; significance as: * for $p < 0.10$, ** for $p < 0.05$, and *** for $p < 0.01$.

	5-year Credit Spreads						10-year Credit Spreads					
	AAA	AA	A	BBB	BB	B	AAA	AA	A	BBB	BB	B
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Implied Std-M2	1125.12***	735.61***	778.77**	1882.69***	5581.94***	-6320.25	1707.45***	716.82**	1929.40***	1160.98***	1027.64	-1909.47
	(3.53)	(2.82)	(1.98)	(4.15)	(4.58)	(-1.09)	(4.62)	(2.14)	(4.94)	(2.90)	(0.94)	(-0.53)
R^2	0.8542	0.8285	0.7597	0.8608	0.8219	0.6663	0.8461	0.7336	0.7000	0.7875	0.7638	0.7489
Implied Std-M3	683.61***	333.20***	527.40***	1064.27***	3159.86***	-1923.95	929.74***	333.99**	1137.31***	521.81**	658.56	166.85
	(4.52)	(2.66)	(2.87)	(4.51)	(4.87)	(-0.69)	(4.86)	(2.03)	(6.07)	(2.58)	(1.11)	(0.10)
R^2	0.8622	0.8283	0.7609	0.8620	0.8196	0.6640	0.8511	0.7333	0.7022	0.7879	0.7633	0.7494
EqSsnr	-0.57***	-0.53***	-0.56***	-1.13***	-2.14***	0.96	-0.78***	-0.47***	-1.21***	-0.89***	0.18	-0.06
	(-3.28)	(-4.73)	(-3.08)	(-4.91)	(-3.08)	(0.35)	(-3.91)	(-3.21)	(-6.41)	(-4.01)	(0.27)	(-0.03)
R2	0.8475	0.8335	0.7612	0.8617	0.8096	0.6633	0.8338	0.7359	0.7036	0.7906	0.7713	0.7490
Observations	119	531	1801	787	269	124	119	531	1801	787	269	124
No Firms	60	182	513	255	93	57	60	182	513	255	93	57

Table 9: Residual Principal Component Analysis

The "Firm Credit Spread PCAs", column (1), are PCAs that are estimated by pooling all of the firm level term-structure of credit spreads; the "Average Credit Spreads PCAs", column (2), are the PCAs that are estimated by averaging across firms the fixed maturity credit spreads for a given observation month. The fixed maturities include 2.5, 5, 7.5, 10, and 12.5-years. Panel A reports the cumulative percent of credit spread variation explained by the first three principal components. In Panel B the bond level unbalanced panel regressions are the credit spreads on the respective PCAs and include month dummies and firm fixed effects. Panel C reports the R^2s for regressing the residuals of the bond level unbalanced panel regressions on the respective PCAs. For Panel B the model are: *Firm-Bond Level Controls* considers only the firm and bond control variates; *Systematic Controls* considers only the systematic factors excluding the default correlation factor; *Benchmark* considers all of the firm, bond, and systematic factors excluding the default correlation factor; the remain regressions augment the *Benchmark* with the particular default correlation factor of interest; all of the regressions include month dummies and firm fixed effects. The t-statistics are corrected for bond level heteroskedasticity and autocorrelation; significance as: * for $p < 0.10$, ** for $p < 0.05$, and *** for $p < 0.01$.

	(1) Firm Credit Spread PCAs	(2) Average Credit Spread PCAs
Panel A Cumulative Percent Explained by the First Three PCAs		
PCA 1	0.8605	0.9914
PCA 2	0.9763	0.9979
PCA 3	0.9987	0.9999
Panel B Bond Level Credit Spreads Regressed on the First Three PCAs		
PCA 1	79.98***	38.97***
	(75.17)	(72.60)
PCA 2	25.45***	-2.12
	(7.80)	(-0.48)
PCA 3	-60.15***	-93.55***
	(-14.06)	(-11.07)
R^2	0.8739	0.6182
Observations	24517	24517
Panel C Bond Level Unbalance Panel Regression Residuals Regressed on the First Three PCAs		
Model	R^2	R^2
Firm-Bond Level Controls	0.1880	0.0253
Systematic Controls	0.2991	0.0107
Benchmark	0.1776	0.0061
Implied M2-Std	0.1745	0.0037
Implied M3-Std	0.1737	0.0036
EqSsnr	0.1740	0.0037

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