Macroeconomic Determinants of the Term Structure of Corporate Spreads

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Abstract

We investigate the macroeconomic determinants of corporate spreads using a no-arbitrage technique. Structural shocks are identified by a New-Keynesian model. Treasury bonds are priced in an affine model with time-varying risk premia. Corporate bonds are priced in a reduced-form credit risk model where default risk depends on macroeconomic state variables. Using U.S. data, we find that the monetary policy shock contributes to more than 50% the corporate spread variations at different forecasting horizons. Its contribution, in general, declines with credit classes. In contrast, the aggregate supply and demand shocks contribut more to the spread variations in low credit classes than in high credit classes. In addition, they in general contribute more for longer forecasting horizons.

JEL codes: E43, E44, G12

Bank Classifications: Debt management, Financial markets, Interest rates.

1 Introduction

This paper investigates the macroeconomic determinants of corporate spreads. We introduce an empirical new-Keynesian model to study the dynamics of macroeconomic variables and identify structural shocks. Then we incorporate the macro variables as state factors in an affine term structure model and a reduced-form credit risk model derived under no-arbitrage conditions. This setting enables us to study the joint dynamics of the macroeconomic variables and both treasury and corporate yields. We can also assess the contribution of macroeconomic shocks to the variance of corporate spreads. We implement the macro-finance modeling strategy developed in Ang and Piazzesi (2003) with U.S. macro, treasury, and corporate data. Variance decomposition results show that the monetary policy shock contributes to a majority of the variance in corporate spreads at different forecasting horizons. Its explanatory power in general declines with credit ratings. In addition, the contribution of the aggregate supply and aggregate demand shocks to the variance in corporate spreads generally increases with bond maturities and forecasting horizons.

Default risk affects all corporate bonds. Therefore, the valuation of risky debt is central to theoretical and empirical work in corporate finance. There are two main approaches to pricing the risk of default. The structural approach, pioneered by Black and Scholes (1973) and Merton (1974), takes as given the dynamics of the asset value of the issuing company, and prices corporate bonds as contingent claims on the asset. Much of the literature following this approach defines default as occurring when the firm's asset value falls below a pre-specified threshold (Kim, Ramaswamy, and Sundaresan (1993), Leland (1994), Longstaff and Schwartz (1995) and Collin-Dufresne and Goldstein (2001)). This approach has been applied in Merton (1977), Cooper and Mello (1991), and many other studies. The attractive feature of these models is that they explain the default time of a company in terms of firm-specific variables, so called "microeconomic" variables. However, one common assumption of these models is that the evolution of firm value follows a diffusion process. Since a diffusion process does not allow a sudden drop in firm value, the probability that a firm defaults in the near term is negligible. Therefore, these models generate near-zero credit spreads for short-term debt, which is strongly rejected by empirical evidence (Jones, Mason, and Rosenfeld (1984)). Alternatively, Zhou (2001) obtains positive short-term credit spreads by modeling the asset value as a jump-diffusion process. He is able to match the size of the credit spreads on corporate bonds and generate various shapes of yield spread curves and marginal default rate curves. However, the absence of an analytical solution for defaultable bonds makes it difficult to estimate and test his model. In addition, implementing the structural approach faces significant practical difficulties due to the lack of observable data on a firm's value.

Another approach, the reduced-form approach first introduced by Jarrow and Turnbull (1995), proposes an exogenous model for the default process and allows for the possibility of default in the immediate future. This framework has been expanded by Madan and Unal (1998, 2000), Duffee (1999), and Duffie and Singleton (1999). A major advantage of this approach is that it generates realistic short-term credit spreads. In addition, the reduced form models have flexibility in specifying the sources of default. This study applies the reduced-form approach to investigate the effects of macroeconomic variables on corporate spreads.

Investigating the cyclical variations in the risk spread between corporate bonds with different credit ratings, Jaffee (1975) regresses the yield spread between bonds with different credit ratings on some macroeconomic variables, and finds that these macroeconomic variables can explain a large proportion of the cyclical variation. Wilson (1997) studies the relationship between average default rates and the state of the economy using a logit model in which the default probability of a firm is assumed to depend on current macroeconomic variables. He concludes that the business cycle is related to a firm's default risk. Collin-Dufresne, Goldstein, and Martin (2001) investigate the determinants of credit spread changes including both firm-specific variables and macro-economic variables in their regression and find that these variables have very low explanatory power. Their results suggest that "the credit spread changes are mainly driven by local supply/demand shocks that are independent of the credit-risk factors and standard proxies for liquidity".

However, there are several disadvantages to using such regression models to study the corporate bond yield spreads. First, one can only study the effects of macroeconomic variables on those yield spreads of bonds with maturities that are included in the model. The regression models do not describe how yield spreads of bonds with maturities not included may respond to the changes in the macroeconomic variables. Second, the regression models do not impose the requirement that the movement of the various included corporate bond yield spreads provide no-arbitrage opportunities.

Recently, several empirical studies (Janosi, Jarrow, and Yildirim (2000), Bakshi, Madan, and Zhang (2001)) take advantage of the tractability and flexibility in the reduced-form models to estimate default risk. Janosi, Jarrow, and Yildirim (2000) estimate a reduced-form credit risk model that incorporates both liquidity risk and default risk with individual corporate data. Their findings support the existence of a non-zero liquidity premium and negative correlation between the default risk and interest rate risk. Bakshi, Madan, and Zhang (2001) estimate and test several empirical credit risk models that incorporate economy-wide and firm-specific distress factors with individual corporate data. They find that firm-specific distress factors play a role in explaining defaultable corporate bond yields. A number of empirical studies have shown that interest rate risk is one of the most important factors that affect the default risk of a corporate bond. Duffee (1998) shows the existence of a negative relationship between treasury yields and corporate bond yield spreads. Bakshi, Madan, and Zhang (2001) find that interest rate risk captures the first-order effect of default. Once interest rate risk is taken into consideration, the pricing performance of the model is marginally improved by including other firm-specific variables. Other empirical studies (Altman (1968, 1975), Wilson (1997), and Collin-Dufresne, Goldstein, and Martin (2001)) find that default premia vary with business conditions. Because the predictive power of the term structure on future economic activities is limited (Estrella and Hardovelis (1991, 1997), Harvey (1998), Ang, Piazzesi, and Wei (2002), and Philippe Mueller (2008)), one might expect an improvement in the pricing performance of credit risk models by incorporating macroeconomic variables associated with the business cycle into the model. This study intends to show that the systematic default risk associated with corporate bonds are driven by other factors beside the interest rate.

We propose an empirical new-Keynesian model to describe the dynamics of macro variables. The macroeconomic model comprises an aggregate supply (AS) equation, an aggregate demand (AD) equation, and a forward looking monetary policy rule (e.g. Clarida, Galí, and Gertler (1999), and Cho and Moreno (2006)). Then we construct an affine term structure model using a factor representation for the stochastic discount factor (SDF), coupled with a reduced-form credit risk model. The SDF is driven by macroeconomic shocks. In the credit risk model, the mean-loss function depends on macroeconomic variables. In this framework, we can investigate the impact of macroeconomic shocks on the term structure of corporate spreads.

We estimate the model with monthly U.S. data from 1994 to 2006 using the maximum likelihood estimation technique. Our main findings are as follows. First, the monetary policy shock is the dominant factor in explaining the dynamics of corporate spreads. The monetary policy shock accounts for more than 70%, 60%, and 50% of the spread variance at the 1-year, 5-year and 10-year forecasting horizon respectively. Its explanatory power in general declines with credit ratings.

Second, at the 1-year forecasting horizon, the aggregate supply and aggregate demand shocks contribute to less than 30% of the spread variance across the credit ratings and business sectors. They contribute up to 48% of the spread variance at the 10-year forecasting horizon. Their contributions in general increase as credit ratings decline. This demonstrates the importance of the aggregate supply and aggregate demand shocks in understanding corporate spreads, specially for low credit rating bonds.

This paper contributes to several branches of the literature. The first is the empirical studies of the dynamics of macro variables and corporate spreads (e.g. Altman (1968, 1975), Jaffee (1975), Wilson (1997), and Collin-Dufresne, Goldstein, and Martin (2001)). In contrast to these empirical studies, we are able to explain the dynamics of the whole term structure of corporate spreads, not just spreads with selected maturities in a regression. In addition, the implied movements of seleted spreads in relation to each other may not rule out arbitrage opportunities in those studies, whereas the dynamics of both default-free and defaultable yield curves is derived under the no-arbitrage assumption in this paper. The second part of the literature is the work that incorporates observable macroeconomic variables in term structure models[1]. This paper is a natural extension of the literature from the treasury bond sector to the corporate bond sector. Our framework allows us to study the impact of macroeconomic shocks on both treasury and corporate yield curves. Finally, this paper is related to recent theoretical work in the credit risk literature incorporating business cycle in structural models[2]. These studies find that it is important to construct structural models, which incorporate comovements of risk premia, default probability, default loss, and business cycle, to explain observed corporate spreads. We investigate the macroeconomic determinants of corporate spreads

[1]These works include Ang and Piazzesi (2003), An, Dong, and Piazzesi (2005), Bakaert, Cho, and Moreno (2005), Bikbov and Chernov (2005), Diebold, Rudebusch, and Arouba (2005), Duffee (2005), Gallmeyer, Hollifield, and Zin (2005), Garcia and Luger (2006), Hördahl, Tristani, and Vestin (2004), and Wu (2002) among others.

[2]See Chen, Collin-Dufresne, and Goldstein (2006), and Chen (2007) among others.

in a reduced-form model, and our findings are consistent with those theoretical models.

This paper is similar to Amato and Luisi (2004) and Wu and Zhang (2005), which studies the role of macro variables in explaining corporate spreads in reduced-form models. While they use unrestricted VAR(1) processes to model the joint dynamics of the macroeconomic variables, we use an empirical New-Keynesian model to identify the macroeconomic shocks. The New-Keynesian model is built on the rational behavior of consumers and firms, and it allows interactions among interest rate, inflation and real activity. In their studies, inflation and real activity are assumed to be independent to monetary policy shocks. In addition, we use transaction prices instead of quoted prices on corporate bonds in the estimation, because stale quoted prices associated with corporate bonds (Sarig and Warga (1989)) might induce a pseudo-relationship between corporate spreads and macroeconomic variables.

The rest of the paper is organized as follows. Section 2 outlines the model and describes how to price treasury and corporate bonds under no-arbitrage conditions. Section 3 discusses the data and the estimation technique. Section 4 presents findings, and Section 5 concludes.

2 The Model

Consider an economy with the time horizon $\left[0, \overline{T}\right]$. The economy is assumed to be frictionless with no arbitrage opportunities. The set of tradable securities includes zero-coupon treasury (default-free) bonds and zero-coupon corporate (defaultable) bonds of all maturities. The treasury bond pays a sure dollar at maturity T, for $0 \leq T \leq \overline{T}$, with time t price $p(t, T)$. A particular firm issues a risky bond that promises to pay a dollar at maturity T, with time price $v(t, T)$. The bond is risky because if the firm goes bankrupt prior to time T, the promised one dollar may not be paid. Most default models use a stopping time to characterize default time. The structural approach literature (Merton (1974), Kim, Ramaswamy, and Sundaresan (1993), Longstaff and Schwartz (1995) and Collin-Dufresne and Goldstein (2001)) defines default as occurring at a predictable time when the firm value reaches a default boundary. The reduced-form approach literature (Jarrow and Turnbull (1995), Madan and Unal (1998), and Duffie and Singleton (1999)) describes default as occurring at a time that is not predictable and allows for the possibility of instantaneous default. This paper employs the reduced-form approach to define default. Let Γ represent the first time the firm defaults. Default time is a random variable. Let

$$N(t) = 1_{\{\Gamma \leq t\}} = \left\{ \begin{array}{ll} 1 & \text{if } \Gamma \leq t \\ 0 & \text{otherwise} \end{array} \right\}.$$

The random variable $N(t)$ is a point process indicating whether or not default occurred prior to time t. Let $h(t)$ represent its intensity process. The time intensity process, $h(t)\Delta$, gives the approximate probability of default for this firm over the interval $[t, t+\Delta]$.

Following Duffie and Singleton (1999), we assume that if default occurs, the bondholder will receive a fractional recovery, $(1 - L(t))$, of the market value of the bond just prior to default. In other words, the bond is worth only a fraction of its pre-default value when default occurs.

Under the assumption of no arbitrage, standard arbitrage pricing theory (Duffie and Singleton (2000)) implies that there exists an equivalent risk-neutral measure Q such that the values of default-free and risky zero-coupon bonds are martingales, implying

$$
\begin{aligned}
p(t,T) &= E_t^Q\left[\exp\left(-\int_t^T r(t)dt\right)\right], \\
v(t,T) &= E_t^Q\left[\exp\left(-\int_t^T \left(r(t)+h(t)L(t)\right)dt\right)\right],
\end{aligned}
$$

where $r(t)$ is the instantaneous interest rate.

2.1 Macro Model

To identify structural macro shocks and their relationship with the short-term interest rate, we propose an empirical discrete-time macro model inspired by the new-Keynesian macroeconomic literature (Clarida, Galí, and Gertler (1999)). In these models, an economy is represented by a core structure consisting of an aggregate supply equation (a Phillips curve), an aggregate demand equation (an IS/AD equation), and a monetary policy rule for setting a short-term interest rate (the policy instrument). These models imply a dynamic system among inflation, real activity, and the short-term interest rate.

In the economy, we assume that the macroeconomic fundamentals are captured by a set of state variables $(\pi_t,\ g_t,\ r_t)$, where π_t is inflation, g_t is real activity, and r_t is the short-term interest rate. The evolution of the state variables is described by the following model (e.g. Cho and Moreno (2006)),

$$
\begin{aligned}
\pi_t &= \alpha_\pi E_t\pi_{t+1} + (1-\alpha_\pi)\,\pi_{t-1} + \alpha_g g_t + \varepsilon_{\pi t}, && (1) \\
g_t &= \beta_g E_t g_{t+1} + \left(1-\beta_g\right) g_{t-1} + \beta_r\left(r_t - E_t\pi_{t+1}\right) + \varepsilon_{gt}, && (2) \\
r_t &= (1-\rho)(\gamma_\pi E_t\pi_{t+1} + \gamma_y g_t) + \rho r_{t-1} + \varepsilon_{rt}. && (3)
\end{aligned}
$$

The aggregate supply (AS) equation (1) describes the supply side of the economy. It links inflation to expected future inflation and the real marginal cost with an assumption that real activity is proportional to the marginal cost. In the presence of price stickiness, higher expected inflation will lead to higher prices today. The aggregate demand (AD) equation (2) postulates that current real activity depends on lagged and expected real activity and on the real interest rate. Higher expected real activity leads to higher consumption today, and higher consumption today raises the current aggregate demand. Equation (3) represents a monetary policy rule (MP) where the monetary authority sets the short-term interest rate according to Clarida, Galí, and Gertler (2000). The monetary policy rule has the form of a forward-looking Taylor rule that allows some degree of monetary policy inertia captured by the smoothing parameter ρ. The lagged interest rate captures the well known tendency of the monetary authority towards smoothing interest rates. The monetary authority systematically reacts to the expected future inflation and to real activity. The above three equations are usually appropriate to describe yearly or quarterly data. Since we will use monthly data in estimation, we modify the equations to describe monthly data using an approach similar to Rudebush (2002). The equations we will estimate are

$$\pi_t = \frac{\alpha_\pi}{3}\sum_{i=1}^{3} E_t\pi_{t+i} + (1-\alpha_\pi)\sum_{i=1}^{3}\delta_{\pi i}\pi_{t-i} + \alpha_g g_t + \varepsilon_{\pi t}, \quad (4)$$

$$g_t = \frac{\beta_g}{3}\sum_{i=1}^{3} E_t g_{t+i} + \left(1-\beta_g\right)\sum_{i=1}^{3}\zeta_{gi}g_{t-i} + \beta_r\left(r_t - E_t\pi_{t+3}\right) + \varepsilon_{gt}, \quad (5)$$

$$r_t = (1-\rho)(\gamma_\pi E_t\pi_{t+3} + \gamma_y g_t) + \rho r_{t-1} + \varepsilon_{rt}, \quad (6)$$

where all variables now are expressed at the monthly frequency. In the estimation, we impose $\sum_{i=1}^{3}\delta_{\pi i} = 1$, a version of the natural rate hypothesis.

To solve the model, we can write it in general form

$$A \begin{bmatrix} E_t X_{1,t+1} \\ X_{2,t+1} \end{bmatrix} = B \begin{bmatrix} X_{1,t} \\ X_{2,t} \end{bmatrix} + G\epsilon_t,$$

where $A = \begin{bmatrix} A_{11} & 0 \\ 0 & I \end{bmatrix}$, $B = \begin{bmatrix} B_{11} & B_{12} \\ B_{21} & B_{22} \end{bmatrix}$, and $G = \begin{bmatrix} G_1 \\ G_2 \end{bmatrix}$. $X_{1,t}$ and $X_{2,t}$ are vectors of non_predetermined endogenous variables and predetermined variables, respectively[3]. The coefficients of matrices A, B and G are defined by equations (4) to (6). A solution to the rational expectation model based on the Schur decomposition can be obtained numerically by standard methods (e.g. McCallum (1998), and Klein (2000)). The solution can be written as the following reduced form,

$$X_{2,t+1} = \Phi X_{2,t} + \Sigma \varepsilon_t. \tag{7}$$

The reduced form macro dynamics are essentially a VAR process with non-linear restrictions on its parameter matrices.

The system (7) expresses the short-term interest rate as a linear function of the state vector $X_{2,t+1}$, which follows a first-order Gaussian VAR. More precisely, we can express the short-term interest rate as

$$r_t = \delta_1^{\mathrm{T}} X_{2,t+1},$$

where $\delta_1 = [0, 0, 1, 0, 0, 0, 0]^{\mathrm{T}}$.

2.2 Pricing Kernel

In the discrete-time setting, the recursive price formula for a zero-coupon treasury bond can be written as

[3]In the model, $X_{1,t} = (E_t\pi_{t+1}, E_t g_{t+1}, E_t\pi_{t+2}, E_t g_{t+2}, E_t\pi_{t+3}, E_t g_{t+3}, \pi_t, g_t, r_t)$, and $X_{2,t} = (\pi_{t-1}, g_{t-1},, r_{t-1}, \pi_{t-2}, g_{t-2}, \pi_{t-3}, g_{t-3})$

$$p_t = E_t^Q \left[\exp\left(-r_t\right) \cdot p_{t+1} \right], \tag{8}$$

and the recursive price formula for a zero-coupon corporate bond can be written approximately[4] as

$$v_t \approx E_t^Q \left[\exp\left(-r_t - h_t L_t\right) \cdot v_{t+1} \right], \tag{9}$$

where r_t is the one-period risk-free interest rate, h_t is the one-period intensity function, L_t is the loss rate, and the expectation is taken under the risk-neutral measure Q. The Radon-Nikodym derivative is denoted by ξ_{t+1}, which converts the risk-neutral measure to the physical measure. For any $t+1$ random variable Z_{t+1} we have that $E_t^Q\left(Z_{t+1}\right) = E_t\left(Z_{t+1}\xi_{t+1}\right)/\xi_t$. In the standard affine term structure setting, ξ_{t+1} is assumed to follow the log-normal process:

$$\xi_{t+1} = \xi_t \exp\left(-\frac{1}{2}\lambda_t^{\mathrm{T}}\lambda_t - \lambda_t^{\mathrm{T}}\varepsilon_{t+1}\right),$$

where λ_t is the market price of risk associated with the source of uncertainty, ε_{t+1}, in the economy. The market price of risk is assumed to be proportional to the factor volatilities in standard affine term structure models (Dai and Singleton (2000)), which implies a constant risk premium in our Gaussian setting. However, recent empirical studies (e.g. Duffee (2002), and Dai and Singleton (2002)) have highlighted the benefits in allowing for a more flexible specification of the market price of risk. We follow their approach and specify λ_t as a linear function of $X_{2,t+1}$

$$\lambda_t = \lambda_0 + \lambda_1 X_{2,t+1}, \tag{10}$$

[4] The exact recrusive price formula for a zero coupon corporate bond is shown in Duffie and Singleton (1999) as $v_t = E_t^Q\left[(1-h_tL_t)\exp(-r_t)v_{t+1}\right]$.It can be shown that $(1-h_tL_t)\exp(-r_t) \approx \exp(-r_t - h_tL_t)$ using the approximation of $\exp c$, for small c, given by $1+c$.

where λ_0 is a 7×1 vector, and λ_1 is a 7×7 matrix. This specification allows for a time-varying risk premium and relates it to the fundamentals of the economy. It should be pointed out that, in a micro-founded framework, the market price of risk depends on consumer preferences rather than being imposed exogenously. However, this empirically motivated specification gives us the flexibility to match yield dynamics.

The number of parameters in λ_t is very large. We impose zeros for some parameters to avoid over-fitting. Specifically, we assume that only current state variables are priced, and that the parameters corresponding to lagged state variables and their cross-terms are zeros. Thus, we parameterize the market prices of risk as

$$\lambda_t = \begin{pmatrix} \lambda_{01} \\ \lambda_{02} \\ \lambda_{03} \\ 0_{4\times 1} \end{pmatrix} + \begin{pmatrix} \lambda_{11} & \lambda_{12} & \lambda_{13} & \\ \lambda_{21} & \lambda_{22} & \lambda_{23} & 0_{3\times 4} \\ \lambda_{31} & \lambda_{32} & \lambda_{33} & \\ & 0_{4\times 3} & & 0_{4\times 4} \end{pmatrix} X_{2,t+1}.$$

Define m_{t+1} as the nominal pricing kernel for treasury and corporate bonds,

$$m_{t+1} = \exp\left(-r_t - \frac{1}{2}\lambda_t^{\mathrm{T}}\lambda_t - \lambda_t^{\mathrm{T}}\varepsilon_{t+1}\right). \tag{11}$$

2.3 Treasury Bond Yields

The pricing kernel m_{t+1} prices all zero-coupon treasury bonds in the economy from the recursive relation:

$$E_t\left(m_{t+1}p_{t+1}^{(n-1)}\right) = p_t^{(n)},$$

where $p_t^{(n)}$ is the price of an n-period zero-coupon treasury bond at time t.

Using the above equation recursively, we can compute the yield of an n-period zero-coupon treasury bond as

$$y_t^{(n)} = a_n + b_n^{\mathrm{T}} X_{2,t+1}. \tag{12}$$

The coefficients a_n and $b_n$are given by $a_n = -A_n/n$ and $b_n = -B_n/n$, where A_n and B_n follow the difference equations:

$$\begin{aligned} A_{n+1} &= A_n - B_n^{\mathrm{T}} \left(\Sigma\lambda_0\right) + \frac{1}{2} B_n^{\mathrm{T}} \Sigma\Sigma^{\mathrm{T}} B_n, \\ B_{n+1}^{\mathrm{T}} &= B_n^{\mathrm{T}} \left(\Phi - \Sigma\lambda_1\right) - \delta_1^{\mathrm{T}}, \end{aligned}$$

with $A_1 = 0$ and $B_1^{\mathrm{T}} = -\delta_1^{\mathrm{T}}$.

The expressions of a_n and b_n in equation (12) show that λ_0 controls the level of long yields relative to short yields and λ_1 controls the time-varying component of long yields related to the state variables.

2.4 Corporate Bond Yields

The reduced-form approach in the credit risk literature provides great flexibility to model default risk through the specification of the intensity function. Lando (1998) illustrates how to model default risk by a Cox process which allows for dependence of the default risk on state variables of the economy. A number of empirical studies (Altman (1968), Altman and Kishore (1996), and Wilson (1997)) have found that both the default probability of a firm and the fractional loss rate when the default occurs depend on the overall business climate, and are time varying. This study does not intend to separately identify the impacts of the state of the economy on the default probability and the fractional loss rate. Instead, it tries to estimate the mean-loss rate process which incorporates the information of both the default risk and the fractional loss rate. In this paper, we assume that the mean-loss rate, $h_t L_t$, is a linear function of the current state variables, the short-term interest rate r_t, the inflation π_t, and the real activity g_t,

$$h_t L_t = \eta_0 + \eta_r r_t + \eta_\pi \pi_t + \eta_g g_t = \eta_0 + \eta_1 X_{2,t+1}. \tag{13}$$

The mean-loss rate per unit of time is assumed to be an affine function of the state variables. This implies that a negative mean-loss rate ($h_t L_t < 0$) is possible. Nevertheless, this simple assumption allows for a closed-form price formula for the corporate bonds.

Given the specification of the mean-loss function, zero-coupon corporate bonds in the economy are priced from the following recursive relation:

$$E_t \left(m_{t+1} \exp\left(-h_t L_t\right) v_{t+1}^{(n-1)} \right) = v_t^{(n)},$$

where $v_t^{(n)}$ is the price of an n-period zero-coupon corporate bond at time t.

Following the same technique used to price treasury bonds, we can compute the yield of an n-period zero-coupon corporate bond as

$$\widetilde{y}_t^{(n)} = \widetilde{a}_n + \widetilde{b}_n^{\mathrm{T}} X_{2,t+1}. \tag{14}$$

The coefficients $\widetilde{a}_n$ and $\widetilde{b}_n$ are given by $\widetilde{a}_n = -\widetilde{A}_n/n$ and $\widetilde{b}_n = -\widetilde{B}_n/n$, where $\widetilde{A}_n$ and $\widetilde{B}_n$ follow the difference equations:

$$\begin{aligned}
\widetilde{A}_{n+1} &= \widetilde{A}_n - \widetilde{B}_n^{\mathrm{T}} \left(\Sigma\lambda_0\right) - \eta_0 + \frac{1}{2}\widetilde{B}_n^{\mathrm{T}} \Sigma\Sigma^{\mathrm{T}} \widetilde{B}_n, \\
\widetilde{B}_{n+1}^{\mathrm{T}} &= \widetilde{B}_n^{\mathrm{T}} \left(\Phi - \Sigma\lambda_1\right) - \delta_1^{\mathrm{T}} - \eta_1^{\mathrm{T}},
\end{aligned}$$

with $\widetilde{A}_1 = -\ \eta_0$ and $\widetilde{B}_1^{\mathrm{T}} = -\delta_1^{\mathrm{T}} - \eta_1^{\mathrm{T}}$.

2.5 Corporate Spreads

The yields of zero-coupon treasury and corporate bonds are linear functions of the state variables $X_{2,t+1}$ from equation (12) and (14). Thus, the corporate-treasury yield spreads are also linear functions of the state variables $X_{2,t+1}$,

$$spd_t^{(n)} = \widetilde{y}_t^{(n)} - y_t^{(n)} = \widetilde{a}_n - a_n + \left(\widetilde{b}_n^{\mathrm{T}} - b_n^{\mathrm{T}}\right) X_{2,t+1}. \tag{15}$$

Note that η_0 measures the corporate spread for one-period, given that macroeconomic variables are at their long-run means. Unlike many structural models which predict near zero short-term corporate spreads, the reduced-form approach can generate positive short-term spreads.

Given our setup, treasury yields, corporate yields, and corporate_treasury spreads are all in affine form. Despite time-varying risk premia, our system is still Gaussian, and impulse responses, variance decompositions and other techniques can be easily implemented.

3 Data and Econometric Methodology

We estimate the model with monthly U.S. data on macroeconomic variables, treasury and corporate yields. The sample period is from 1994:01 to 2006:12. Two macroeconomic variables are constructed to capture the cyclical behaviour of the economy. The first macroeconomic variable is an inflation measure based on the core consumer price index (CPI). The inflation rate is measured as the annualized quarterly growth rate of the CPI. The second macroeconomic factor is a real activity measure based on the industrial production index (IP). The real activity growth rate is measured as the annualized quarterly growth rate of IP. The quarterly growth rates are calculated as the difference in logs of the index at month t and $t+3$. These variables are commonly used in the business cycle literature. The consumer price index is usually treated as a lagging-indicator of business cycles and the industrial production index as a leading-indicator of business cycles. The U.S. Federal Fund rate is used to measure the short-term interest rate. The macroeconomic series are taken from the St. Louis FED economic database.

The treasury data used in this study are continuously compounded zero-coupon yields constructed by Gurkaynak, Sack, and Wright (2006) at the Federal Reserve Board. The yield curves are constructed based on U.S. treasury notes and bonds excluding "on-the-run" and "just-off-the-run" issues. In this study, we use bond yields of maturities $3, 6, 12, 24, 36, 60, 84, 120, 180, 240$ and 360 months. Bond yields are sampled at the end of a month. All yields are at annualized rates. The monthly observations on the macroeconomic variables and selected yields are plotted in Panel A and B of Figure 1, respectively. Inflation is relatively stable during the sample period, reflecting Fed's ability to control it. Real activity is relatively more volatile. Short yields are more volatile than long yields, which have downward trends during the sample period. Table 1 summarizes the mean, standard deviation, and autocorrelations of the macroeconomic variables and the treasury yields. The table shows that the average yield curve is upward sloping. The standard deviations of yields generally decrease with maturity, and yields are highly autocorrelated.

Our corporate data come from the Mergent Fixed Income Securities Database (FISD), which is a comprehensive database of publicly-offered U.S. bonds. FISD provides details on debt issues and the issuers, as well as transactions by insurance companies. This database contains monthly price, accrued interest, and return data on corporate and government bonds. According to the Flow of Funds accounts published by the Federal Reserve, insurance companies hold about one-third of outstanding corporate bonds. Thus, FISD should adequately represent the corporate bond transactions. Instead of using individual corporate data, for which the default risk may depend on firm-specific variables, we construct a data set that aggregates companies with a given credit rating and in a particular business sector. Using these aggregate data, we hope to capture the common factors that affect the default risk. Implicitly, I assume that credit classifications are accurate in the sense that at any moment of time they accurately separate bonds into different risk categories. However, I do not assume that the risk associated with each credit rating remains constant over the business cycle. In fact, the purpose of this paper is to demonstrate that the cyclical variations in the risk associated with each credit rating can be attributed to some common macroeconomic variables.

We restrict our sample to fixed-rate U.S. dollar bonds in two business sectors, the industrial and financial sectors. We exclude bonds that are callable, puttable, convertable, and sinking funds. We also exclude issues with asset-backed and credit-enhancement features. We only consider investment-grade bonds with average Standard and Poor's and Moody's ratings above BBB(Baa), since insurance companies often limit their purchase of non-investment-grade bonds. In addition, we exclude all AAA bonds and bonds with maturities less than 1 year since previous studies (Elton *et al.* (2001), and Campbell and Taksler (2003)) have found that data for these issues appear problematic. Therefore, the credit ratings of bonds used in this study are AA(Aa), A(A), and BBB(Baa). Finally, we eliminate bonds where the price data is problematic. This involves estimating the zero-coupon yield curve for each credit class and business sector, and examining the data on bonds that had unusually high pricing errors when priced using the spot curve. Following Elton *et al.* (2001), we adopt the Nelson and Siegel (1987) procedure to estimate the zero-coupon yield curve every month for each sector and credit class. We filter out bonds with pricing errors larger than 5$. We repeat the above described process until all bond pricing errors are smaller than 5$. In the end, we construct 906 corporate zero-coupon yield curves (156 months $\times$ 2 sectors $\times$ 3 credit classes) over the sample period of January 1994 to December 2006. We use corporate yields with maturities $2, 5, 7, 10, 15, 20, 25$, and 30 years in the estimation. The summary statistics of the average corporate bond yield spreads for each sector and credit class are presented in Table 2. Panel C of Figure 1 plots the 10-year corporate spreads for credit class AA, A and BBB in the industrial sector.

Corporate yield spreads depend on the dynamics of macroeconomic variables, the market price of risk and the mean-loss rate. We employ the maximum likelihood technique to estimate the parameters in the macro model, the market price of risk and the mean-loss rate process for all risk classes formed by the intersection of credit class and business sector. Note that the estimated market price of risk reflects the risk premium required by investors of holding not only long-term treasury bonds but also corporate bonds. A heteroskedasticity and autocorrelation consistent covariance matrix estimator (Newey and West (1987)) for the parameter estimates is calculated.

The likelihood function is calculated based on the reduced form macro equation (7), the treasury yield formula in equation (12) and corporate yield formula in equation(14). White noise measurement errors are added to treasury and corporate formulas to construct the likelihood function. We estimate parameters in the macro dynamics, the market price of risk and mean-loss rate by maximizing the log-likelihood function.

4 Empirical Results

In this section we present our empirical findings. First we present the parameter estimates in the macro model, and discuss the impulse response functions of macro variables to structural shocks. We then present the estimates of the market price of risk and the mean-loss rate. Finally, we use variance decompositions to investigate the contributions of the structural shocks to corporate-treasury spreads.

4.1 Macroeconomic Model

4.1.1 Parameter Estimates

The parameter estimates of the empirical New-Keynesian macro model are shown in Table 3. The asymptotic standard errors are obtained based on a 3-lag Newey and West (1987) consistent covariance estimator. Our estimation yields a unique stationary solution.

The first row of Table 3 shows the parameter estimates of the Phillips curves. The Phillips curve parameter estimate has the expected sign, but is not statistically significant. This reflects the weak link between real activity and inflation in the sample period. The finding is consistent with the previous studies. The forward-looking parameter in the aggregate supply equation, α_π, is indistinguishable from 0.5, implying that agents put similar weights on expected and past inflation. The estimate of $\alpha_\pi = 0.52$ is higher than the estimates provided by some previous researchers. For example, Fuhrer (1997) obtains estimates for α_π of between 0.02 and 0.20, with a variety of measures of the output gap. However, our estimate is closer to those using a direct measure of expectations from surveys. Clark *et al*. (1996) obtains an estimate of about 0.40 using the Michigan survey expectations. A recent study by Cho and Moreno (2006) obtains an estimate of 0.56 for α_π, very close to our estimate.

The second row shows the parameter estimates for the aggregate demand equation. The estimate of the forward-looking parameter, β_g, is 0.39, implying that agents put more weight on past real activity than expected. The estimate is lower than 0.49 obtained by Cho and Moreno (2006), possibly due to different sample periods. The real interest rate parameter estimate has the right sign, but is not statistically significant.

The third row shows the parameter estimates in the monetary policy rule equation. The short rate loads positively on inflation and real activity with coefficients of 1.61, and

0.05 respectively. The results suggests that the Federal Reserve Board responds strongly to shocks which could increase expected future inflation. A 1 percent increase in expected inflation leads to a 1.61 percent increase in the short rate. The interest rate smoothing parameter estimate is 0.91, reflecting the well known interest rate smoothing behaviour by the Fed. These estimates are consistent with ones found by Clarida, Galí, and Gertler (1999) amd Cho and Moreno (2006).

4.1.2 Impulse Responses of Macro Variables

Figure 2 shows the impulse response functions of the macro variables to a one standard deviation increase in each of the structural shocks. The units for the responses are in basis points (bps). The impulse response calculation is based on the estimated reduced-form model (7).

A positive aggregate supply shock can be interpreted as a sudden increase in wages and thus the price level. It pushes up inflation by almost 50 bps. Inflation then returns slowly to its equilibrium level. The initial response of real activity is almost zero. The Fed responds aggressively by raising the short-term interest rate. Fed's response makes the real activity decrease for a long period of time.

A positive aggregate demand shock increases real activity. The response of inflation to the aggregate demand shock is positive and close to zero due to the insignificant Phillips curve parameter. The Fed does not respond initially, and then starts to raise the short-term interest rate slowly because of the inflationary pressure.

A positive monetary policy shock reduces real activity because it raises the real interest rate and reduces aggregate demand. The monetary shock also reduces inflation, but the impact is very small and close to zero. Finally, the monetary policy shock has a persistent effect on the short-term interest rate, given the smoothing behaviour of the Fed.

4.2 Market Prices of Risk

We report the estimates of the market prices of risk in Table 4. The market price of risk is estimated with both treasury and corporate yields. It should reflect the risk premia required to hold treasury and corporate bonds. The market price of risk coefficients corresponding to inflation, real activity, and the short-term interest rate are highly significant, implying that the observable macro variables drive the time-variation in risk premia embedded in treasury and corporate yields.

4.3 Mean-Loss Rate

Moody's reports that both the default rates and the loss rates for corporate bonds exhibit pronounced cyclical components. Default rates and loss rates tend to be higher during recessions, when interest rates are typically below their long-run means. In addition, as pointed out by Longstaff and Schwartz (1995), the static effect of a higher spot rate is to increase the risk-neutral drift of the firm value process. They presume a negative correlation between the spot rate and firm values. Previous empirical studies (Duffee (1998), Janosi, Jarrow, and Yildirim (2000), and Bakshi, Madan, and Zhang (2001)) have also found a negative relationship between short-term interest rates and corporate spreads. Therefore, the sign for the short-term interest rate in the mean-loss function is expected to be negative.

The CPI index is usually treated as a lagging-indicator of business cycles. A high inflation rate usually indicates the final phase of the business cycles. Although the specific timing of the change in default risk is difficult to set, it appears in many cases that the financial position of firms begins to deteriorate in the final phase of the boom. In addition, high inflation increases the economic uncertainty, and thus increases the default risk. Furthermore, Moody's data show that the loss rate is high in recessions.

One would expect that the loss rate starts to rise at the end of economic expansions. So the sign for the inflation factor in the mean-loss function is expected to be positive. The IP index is usually treated as a leading-indicator of business cycles. A rise in the IP index indicates an improvement in the overall economic environment, which should bring investment opportunities for companies. Thus a rise in the IP index should increase the value of the firm and decrease the default risk. In addition, a rise in the IP index usually indicates the beginning of a new round of business expansion, and so that the loss rate is expected to fall. Therefore, the sign for the real activity factor in the mean-loss function is expected to be negative.

Table 5 reports the parameter estimates in the mean-loss functions for all risk classes formed by the intersection of credit rating and business sector. The estimation results support these predictions. The estimates for η_r are negative and statistically significant across risk classes and business sectors. In addition, within each business sector, the estimated η_r for low credit rating bonds in general are larger in absolute magnitude than those for high credit rating bonds, suggesting that the mean-loss rates of low quality bonds are more sensitive to the level of the interest rate than that of high quality bonds.

The estimates for η_π are all positive and statistically significant across credit classes and business sectors. The estimates for η_g are negative and generally statistically significant. The results strongly support the assumption that high inflation increases the mean-loss rate, but the support for the assumption that high real activity reduces the mean-loss rate is not as strong.

The estimated values of η_π and η_g are in general of a larger magnitude for low credit rating bonds than those for high credit rating bonds. The results suggest that the default probability of the low credit rating bonds is more sensitive to changes in the overall business climate than that of high credit rating bonds.

The results also show that the fit of the non-linear regressions is quite high for high credit rating bonds across business sectors with a R^2 of 0.91 or higher for AA bonds. The R^2 in general is smaller for the low credit rating bonds. Intuitively, high credit rating bonds are traded more like treasury bonds, so the macro factors that drive the short-term interest rate process can explain the majority of the price variations for the high credit rating bonds. For the low credit rating bonds, although the macroeconomic factors still affects the mean-loss rate, it seems that the macroeconomic risk is not the only source.

Investigating the in-sample pricing errors, I find that the pricing performance of our model in general declines with credit ratings. The average pricing errors are larger for low credit rating bonds than those for high credit rating bonds. For example, the average pricing error is 20 basis points for AA bonds and 43 basis points for BBB bonds in the financial sector. The results are consistent with the conclusion that the yields of low credit rating bonds are more likely affected by factors in addition to macroeconomic factors.

4.4 Variance Decompositions of Corporate Spreads

From the corporate yield spread equation (15), the state variables $X_{2,t+1}$ explains all corporate spreads dynamics. To understand the role of each variable in $X_{2,t+1}$, we compute the variance decomposition from the model.

Table 6 reports the variance decompositions of corporate spreads for maturities of 5 years, 10 years, and 20 years at forecast horizons of 1 year, 5 years, and 10 years. At the 1-year forecast horizon, the monetary policy shock explains more than 70% of the variance in corporate spreads across maturities, credit classes and business sectors. However, its contribution in general declines with credit rating. At the 5-year horizon, the monetary policy shock is still the dominate factor in explaining over 60% of variance in corporate spreads. Nevertheless, the aggregate supply and aggregate demand shocks each contribute over 15% of the spread variance. Their contributions in general increase as credit rating declinines. At the 10-year horizon, the monetary policy shock still explains more than 50% of spread variance. However, the aggregate supply and aggregate demand shocks together contribute at least 36% and 44% of the spread variance in BBB bonds in the financial sector and the industrial sector, respectively.

5 Conclusion

This paper identifies structural macroeconomic shocks in a New-Keyesian model, and investigates the contributions of those structural shocks to the variation in corporate spreads. We find that the monetary policy shock is the dominant factor in explaining the variation in corporate spreads at different forecasting horizons. Its explainatory power in general declines with credit ratings. On the contrary, the aggregate supply and demand shocks contribute relatively more to spread variance in lower credit classes. In addition, their contributions in general increase with forecasting horizons.

This paper exploits information from macro variables, such as inflation, real activity, and the short-term interest rate, to explain default dynamics in corporate bonds. It does not consider the downgrade risk associated with holding corporate bonds. Nevertheless, incorporating macro variables into no-arbitrage reduced-form credit risk models helps understand the underlying macro fundamentals that drive the dynamics in corporate spreads.

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