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A No-Arbitrage Analysis of Macroeconomic Determinants of the Credit Spread Term Structure

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From a large array of economic and financial data series, this paper identifies three fundamental risk dimensions underlying an economy: inflation, real output growth, and financial market volatility. Furthermore, through a no-arbitrage model, the paper links the dynamics and market pricing of the three risk dimensions to the term structure of U.S. Treasury yields and corporate bond credit spreads. Model estimation shows that positive inflation shocks increase Treasury yields and widen credit spreads on corporate bonds across all maturities and credit-rating classes. Positive real output growth shocks also increase Treasury yields, but they suppress the credit spreads at low credit-rating classes, thus generating negative correlations between interest rates and credit spreads. The financial market volatility factor has a small and transient effect on the Treasury yield curve, but it exerts a strongly positive and persistent effect on the credit spread term structure. The paper provides a robust and internally consistent method for extracting systematic economic information from a large array of noisy observations and establishing how different risk dimensions of the fundamental economy interact with interest rate and credit risk.

Key words: credit spreads; term structure; interest rates; macroeconomic factors; inflation; real output growth; financial market volatility; dynamic factor model; no-arbitrage model
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1. Introduction

In this paper, we propose an internally consistent approach to quantifying the linkages between the dynamics and market prices of the systematic macroeconomic risks and the term structure of interest rates and credit spreads. First, from a large array of economic and financial data series, we identify three fundamental risk dimensions underlying an economy: inflation, real output growth, and financial market volatility. In practice, many macroeconomic numbers and financial market variables are available. Each variable contains some information but also a tremendous amount of noise about the state of the macroeconomy. Focusing merely on one or a few of these variables is inefficient, but incorporating all of them as state variables into a formal model of credit spreads is unrealistic. Through a dynamic factor structure, we succinctly summarize the information content in many noisy series.

Second, we propose flexible specifications on how these dynamic macroeconomic factors are priced and how the instantaneous interest rates and credit spreads respond to these economic factors. Given these specifications, we use no-arbitrage arguments, as in Duffie and Singleton (1999) and Duffie et al. (2003), to derive the whole term structures of interest rates and credit spreads as functions of these dynamic macroeconomic factors. This way, we are able to make an internally consistent analysis of the impacts of a large number of macroeconomic and financial variables on the interest rates and credit spreads across the whole spectrum of maturities. Furthermore, the estimation not only shows how the variables affect the term structure but also reveals the reasons behind it. In particular, model estimation illustrates how different risk dimensions in the macroeconomy vary over time and how market investors price these risks differently. The macroeconomic risk dynamics and their pricing jointly determine the dynamics and the term structure of interest rates and credit spreads.

Our estimation shows that positive inflation shocks increase Treasury yields and credit spreads across all maturities and credit-rating classes. The effects on Treasury yields are the strongest. The effects on credit spreads are weaker and become increasingly so at lower credit ratings. Positive shocks on real output growth also increase Treasury yields, more so at short than at long maturities. The effects on credit spreads are slightly positive for high credit ratings but become negative, and increasingly so as the credit rating declines. Thus, a positive shock to the real side of the economy increases the benchmark interest rate level and flattens an otherwise upward-sloping yield curve but narrows the credit spread, particularly at low credit-rating classes. When the variation of the real output growth dominates the economy, its opposite effects on interest rates and credit spreads generate negative correlations between the two. Finally, the volatility factor has a small positive effect on the Treasury yield curve, but the effect becomes strongly positive and persistent on the term structure of credit spreads.

In this paper, we identify three fundamental risk dimensions underlying an economy from a large array of economic and financial data series, and we link the dynamics and market pricing of the three risk dimensions to the term structure of interest rates and credit spreads. Many studies in the literature incorporate economic variables to explain interest rates and credit spreads, but few analyze the relation at a fundamental level such as this. For example, several studies use regressions to analyze the determinants of credit spreads, and some economic variables are often included in these regressions (e.g., Altman et al. 2005, Bevan and Garzarelli 2000, Carey 1998, Collin-Dufresne et al. 2001, Elton et al. 2001, Frye 2000, Pedrosa and Roll 1998). However, the regression results often depend on the specific choices of the explanatory variables as well as on the choices of the maturity and credit rating of the credit spreads used as the dependent variable. More important, without a serious classification of the economic risk dimensions and a fundamental model to link the economic risk dynamics and market prices to asset pricing, the economic meanings and underlying driving forces of the regression coefficients are unclear. The coefficients can only be interpreted within the context of the specific regression. In contrast, by estimating our no-arbitrage model and identifying the dynamics and market pricing of the economic risks, we learn the impacts of the economic risks on the interest rates and credit spreads, not only at the observed maturities but also across the whole term structure. Furthermore, combining the instantaneous loading coefficients with the estimated risk dynamics reveals not only the contemporaneous effects but also the multi-period impulse responses of the macroeconomic risk factors.

Also related to our work are studies that use either reduced-form or structural models to summarize the variation on the term structure of interest rates and credit spreads (Bakshi et al. 2006, Bangia et al. 2002, Collin-Dufresne et al. 2003, Delianedis and Geske 2001, Duffee 1999, Duffie and Singleton 1997, Eom et al. 2004, Huang and Huang 2003, Jones et al. 1984, Longstaff et al. 2005, Longstaff and Schwartz 1995, Nickell et al. 2000). These studies can link the factor dynamics and their market pricing to the whole term structure of interest rates and credit spreads; however, many of these studies rely on latent factors derived directly from the yield curve and credit spread term structure. The economic meanings of these latent factors are unclear. In the few studies that try to incorporate economic variables, often only a small number of observable variables are included for tractability reasons. Other valuable economic variables are conspicuously left out.

Most recently, a growing literature starts to recognize the importance of incorporating economic risk factors into no-arbitrage term structure models (e.g., Ang and Piazzesi 2003, Ang et al. 2004, Bekaert et al. 2005, Bikbov and Chernov 2006, Buraschi and Jiltsov 2005, Diebold et al. 2006, Duffee 2006, Gallmeyer et al. 2005, Hördahl et al. 2006, Lu and Wu 2004, Rudebusch and Wu 2008, Wachter 2006). These studies find that using a no-arbitrage framework not only makes the estimation results more interpretable, but also often produces significantly different and more stable results than those from regressions. These findings serve in part as our motivation for using the no-arbitrage framework to study the macroeconomic determinants of the credit spreads. In addition, the dynamic factor structure embedded in the no-arbitrage framework also enables us to extract the systematic macroeconomic risk information from the large array of noisy macroeconomic and financial data series.

The rest of this paper is organized as follows. Section 2 describes the procedure for extracting the dynamic macroeconomic factors. Section 3 presents a no-arbitrage model that links the dynamic macroeconomic factors to the whole term structure of Treasury and corporate bond yields. Section 4 describes the construction of Treasury and corporate yields and our estimation strategy. Section 5 discusses the estimation results and examines the relation between credit spreads across different maturities and rating classes and the extracted macroeconomic factors. Section 6 concludes the paper.

2. Extracting Dynamic Economic Factors

A large array of economic and financial data series is available, yet many contain similar information mingled with a significant portion of noise from either measurement errors or idiosyncratic movements. We use a dynamic factor model to summarize the information and suppress the noise in many observed macroeconomic and financial series.

2.1. Estimating Dynamic Factor Models with Maximum Likelihood and the Kalman Filter

To apply a dynamic factor model, we first decompose the aggregate economy into three broad dimensions: (1) the nominal side of the economy, (2) the real side of the economy, and (3) the volatility of the financial market. Macroeconomists often decompose the economy into the nominal and real sides and argue that shocks to the two sides of the macroeconomy should be separated and treated differently. In addition to these two dimensions, we also incorporate a financial market volatility dimension to capture the compound effect of economywide business risk and financial leverage, both of which affect corporate bond valuation (Merton 1974).

We describe the economy by fixing a filtered probability space $\{\Omega, \mathcal{F}, \mathbb{P}, (\mathcal{F}_t)_{t\geq 0}\}$, under which a vector Markov process $X \in \mathbb{R}^3$ governs the three systematic risk dimensions of the macroeconomy. We specify the dynamics of X through the following stochastic differential equation:

$$dX_t = -\kappa X_t\, dt + dW_t, \tag{1}$$

where W_t denotes a standard Brownian motion vector and κ controls the mean-reverting speed of the process. We standardize X to have zero long-run mean and identity instantaneous covariance matrix. We also constrain κ to be a lower triangular matrix. In discrete time notation, X_t follows a VAR(1) process, where the autoregressive matrix is given by $\Phi = \exp(-\kappa \Delta t)$, with Δt denoting the discrete time interval. The continuous time setup in (1) facilitates our Treasury and corporate bond pricing in the subsequent sections.

We use $y \in \mathbb{R}^N$ to denote a set of macroeconomic and financial data series, where the dimension N can be much larger than the dimension of the state of the economy, $N \gg 3$. We summarize the systematic movements in the N data series through the three dynamic factors via the following linear factor structure:

$$y_t = HX_t + e_t, \qquad \mathcal{R}^y = \mathbb{E}[e_t e_t^\top]. \tag{2}$$

If we regard the factor dynamics in (1) as the state-propagation equation and their relations with the data series in (2) as the measurement equation, we can use the classic Kalman filter to infer the systematic states of the economy from the observed data series. If we use $\bar{y}_t, \bar{A}_t$ to denote the time-$(t-1)$ forecasts of time-t values of the measurement series and their covariance matrix obtained from the Kalman filter, we can define the log likelihood function by assuming that the forecasting errors on the observed time series are normally distributed:

$$l_t(\Theta) = -\tfrac{1}{2}\log|\bar{A}_t| - \tfrac{1}{2}\big((y_t - \bar{y}_t)^\top (\bar{A}_t)^{-1}(y_t - \bar{y}_t)\big). \tag{3}$$

We estimate the model parameters by maximizing the sum of the log likelihood values.

2.2. Data Description

Our estimation is based on 13 monthly or quarterly macroeconomic and financial series from January 1988 to June 2004. The 13 series include seven inflation-related series, four output-related series, and two financial market volatility indexes constructed from stock index options. The seven inflation-related series are the consumer price index (CPI), the core CPI, the producer price index (PPI), the core PPI, the personal consumption expenditure (PCE) deflator, the core PCE deflator, and the gross domestic production (GDP) deflator. The GDP deflator is available at a quarterly frequency. All other variables are available at a monthly frequency. We first convert the price indexes into year-over-year percentage changes and then standardize each series by subtracting the sample mean and dividing the series by the sample standard deviation.

The CPI measures the average change in the prices of a basket of goods and services bought by a typical urban household. The PPI measures the change in the selling prices received by domestic producers for all finished goods. The PCE deflator measures the average change in the prices of a basket of goods and services purchased by the typical consumer. Their respective core measures exclude food and energy, the prices of which tend to be highly volatile. The GDP deflator measures the average change in the prices of all goods and services produced by the domestic economy. We do not take a stance on which of the seven series provides the most accurate and timely measure of inflationary pressure. Instead, we include them all in our estimation and extract one common factor that captures the systematic movements.

The data set includes four output and employment series: the real GDP, industrial production, nonfarm payrolls, and the real PCE. The real GDP is available at a quarterly frequency. The other three series are available at a monthly frequency, but the data on real PCE start at a later date in January 1991. The real GDP growth is the broadest measure of the output growth. Industrial production measures the production of goods. Although less comprehensive, it is more timely because the industrial production numbers are released monthly, whereas the GDP numbers are released quarterly. Nonfarm payrolls measure the number of employees on firms' payrolls. Farms are excluded because of their seasonal nature, which can skew total employment figures. This number is a key indicator of the employment scenario of the economy, one that has far-reaching implications for both inflation and output growth. On the demand side of the economy, we include real personal consumption expenditure, which often registers changes in the state of the economy before changes in production. We first convert the four series into year-over-year growth rates and then standardize them before we extract the real growth factor.

To extract a financial market volatility factor, we include two volatility indexes: the VXO index computed from options on the S&P 100 index, and the VIX volatility index computed from options on the S&P 500 index. The VXO measures the one-month at-the-money Black and Scholes (1973) implied volatility on the S&P 100 index options, and the VIX is a specific portfolio of option prices that approximate the one-month variance swap rate on the S&P 500 index (Carr and Wu 2006). Both series are available daily from the Chicago Board of Options Exchange, but the VIX series starts at a later date in January 1990. The two series show a large amount of short-term variations. To reduce noise, we compute the yearly moving average of the daily volatility series. Then we sample the moving averages at the end of each month and extract the volatility factor in monthly frequency. We first take logs on the two series and then standardize them before we extract the volatility factor.

To improve identification and to enhance the economic interpretation of the factors, we put structural constraints on the factor-loading matrix. We constrain the first factor to have positive loadings on the seven inflation series and the nonfarm payroll series and zero loadings on all other series. This factor summarizes the inflation pressure in the economy. We constrain the second factor to have nonzero loadings only on real GDP, industrial production, nonfarm payroll, and the real component of the personal consumption expenditure. Thus, this factor summarizes the real part of the macroeconomy, which we label the real output factor. Finally, we constrain the third factor to have nonzero loadings only on the two financial market volatility indexes, making it a financial market volatility factor. We estimate the dynamic factors in monthly frequency. For data that are available quarterly or at a later date, our estimation method readily accommodates missing data.

2.3. Time-Series Dynamics of the Macroeconomic Factors

Table 1 reports the estimates and the absolute values of the t-statistics (in parentheses) of parameters (H) that link each observed data series to the three economic factors. The last column reports the predicted variation (PV) of the factors on each series, defined as one minus the ratio of the forecasting error variance over the variance of the original series. The predicted variation measures the predictive performance of the three dynamic factors on each of the 13 series. It also reflects the relative informativeness of the 13 series about the underlying economic factors.

Table 1 Extracting Systematic Dynamic Factors from Macroeconomic and Financial Data

Series	H_1		H_2		H_3		PV
CPI	0.439	(6.45)	—	—	—	—	0.891
Core CPI	0.415	(4.06)	—	—	—	—	0.841
PPI	0.316	(2.92)	—	—	—	—	0.424
Core PPI	0.403	(7.45)	—	—	—	—	0.767
PCE deflator	0.454	(8.47)	—	—	—	—	0.949
Core PCE deflator	0.424	(4.44)	—	—	—	—	0.857
GDP deflator	0.437	(7.81)	—	—	—	—	0.929
Real GDP	—	—	0.277	(5.67)	—	—	0.571
Industrial production	—	—	0.299	(8.43)	—	—	0.641
Nonfarm payrolls	0.169	(4.50)	0.379	(10.7)	—	—	0.988
Real PCE	—	—	0.228	(6.89)	—	—	0.449
VXO	—	—	—	—	0.391	(14.0)	0.987
VIX	—	—	—	—	0.379	(13.6)	0.974

Notes. The parameters are estimated with the maximum likelihood method and Kalman filtering using macroeconomic and financial data series. The macroeconomic data are from the Federal Reserve Board. The volatility series are from the Chicago Board of Options Exchange. The sample period covers January 1988–June 2004.

Among the seven inflation variables, the highest predicted variation comes from the PCE deflator, a finding that supports the Federal Reserve Board's emphasis on this measure as a more reliable gauge of inflation pressure. The lowest predicted variation comes from the PPI, an indication that this series is the least informative about inflation pressure. Nevertheless, the loading estimates on all seven series are statistically significant and positive, suggesting that all seven series contain useful information about the state of inflation. Hence, it is appropriate to use them all instead of picking one over another.

The nonfarm payrolls number is a key indicator of the employment scenario of the economy, and it has far-reaching implications for both inflation and output growth. Hence, we allow the inflation factor to have a nonzero loading on the nonfarm payrolls series. The loading estimates are smaller than those on the seven inflation variables, but the high t-statistics suggest that this loading estimate is strongly significant and that nonfarm payrolls are indeed informative about the inflation pressure of the economy.

Among the four output and employment series, nonfarm payrolls also have the highest loading and highest t-statistics on the second factor. Furthermore, the predicted variation is the highest among all 11 macroeconomic series. Thus, it is the most informative about the macroeconomy. Again, however, all four series have significantly positive loadings on the real output factor. Hence, they are all informative about the real side of the economy.

The predicted variations are high for both volatility indexes. The loading estimates on the two series are also similar, suggesting that the two indexes move closely together.

Table 2 Time-Series Dynamics of the Economic Factors

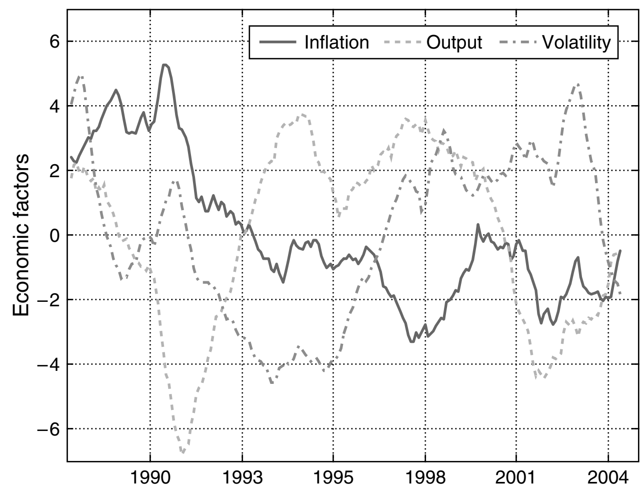
Dynamic factors (X)	κ in: $dX = -\kappa X dt + dW$		
Inflation	0.1139 (0.62)	0 —	0 —
Real output	0.4891 (2.71)	0.2007 (1.58)	0 —
Volatility	0.1484 (1.00)	−0.1790 (1.42)	0.0625 (0.49)

Notes. Entries report the parameter estimates and the absolute values of the t-statistics (in parentheses) on time-series dynamics of the three economic factors. The dynamics are estimated with the maximum likelihood method and Kalman filtering using 13 macroeconomic and financial data series. The macroeconomic data are from the Federal Reserve Board. The volatility series are downloaded from Bloomberg. The data are monthly and cover January 1988–June 2004.

Table 2 reports the parameter estimates for κ, which control the dynamics of the three economic factors. Given the lower triangular structure, the ranking of the three factors determines their dependence structure. We let inflation be the first factor. Thus, the prediction of this factor depends only on its own past value. The small estimate for the first diagonal element of κ at 0.1139 reflects the high persistence of inflation. The second factor is real output, the conditional mean of which depends on the lagged values of both the inflation factor and the output factor itself. The off-diagonal term 0.4891 indicates that past values of the inflation factor predict negatively on the changes in the real output. Thus, the two macroeconomic factors show negative cross-correlation. The third factor is the volatility factor, which responds negatively to inflation but positively to output. The small diagonal value suggests that the volatility factor is also highly persistent because of our moving average smoothing.

Given the parameter estimates, the Kalman filter generates the updated values of the three dynamic factors from the 13 observed series. Figure 1 plots the time series of the three extracted economic factors. The solid line depicts the inflation factor, the dashed line depicts the real output growth factor, and the dash-dotted line depicts the financial market volatility factor. The inflation factor had a spike in early 1991 that coincided with the spike in inflation pressure caused by energy shocks during the first Gulf War. The inflationary pressure quickly receded and stayed low for the rest of the sample period. The dashed line for the real output growth shows two periods of sharp slowdown and one period of prolonged high output growth. The volatility factor started high in the late 1980s but stayed low between 1992 and 1997. The volatility factor increased in late 1997 after the Asian crisis and, after that, the Russian default and the ensuing hedge fund crisis. Volatility went up again around late 2002 and early 2003 after a series of corporate scandals.

Figure 1 Time Series of Extracted Economic Factors



3. A No-Arbitrage Dynamic Term Structure Model

We propose a dynamic term structure model that uses no-arbitrage arguments to link the dynamic economic factors extracted in the previous section to the whole term structure of interest rates on Treasury bonds and credit spreads on corporate bonds.

3.1. Market Prices of Factor Risks and Risk-Neutral Factor Dynamics

To price Treasury and corporate bonds based on the dynamic factors extracted in the previous section, we need to specify how market participants price risks in the dynamic factors. We consider a flexible specification, under which the market prices can vary with the economic risk levels:

$$\gamma(X_t) = \gamma_0 + \gamma_1 X_t. \tag{4}$$

Under this specification, we can derive the factor dynamics under the risk-neutral measure $\mathbb{Q}$,

$$dX_t = \kappa^{\mathbb{Q}}(\theta^{\mathbb{Q}} - X_t)\,dt + dW_t^{\mathbb{Q}}, \tag{5}$$

with $\kappa^{\mathbb{Q}}\theta^{\mathbb{Q}} = -\gamma_0$ and $\kappa^{\mathbb{Q}} = \kappa + \gamma_1$. We also constrain γ_1 and hence $\kappa^{\mathbb{Q}}$ to be a lower triangular matrix.

3.2. Term Structure of Treasury Yields

To price Treasury bonds, we assume that the instantaneous Treasury interest rate is affine in the three dynamic factors:

$$r_t = r(X_t) + \varepsilon_t^r, \quad r(X_t) = a_r + b_r^{\top} X_t, \tag{6}$$

where ε_t^r denotes movements in the instantaneous interest rate that are not explained by the three dynamic factors. By design, X_t and $r(X_t)$ are orthogonal to ε_t^r.

We can write the time-t value of a zero-coupon Treasury bond with time to maturity τ as

$$\begin{aligned} B(t,\tau) &= \mathbb{E}_t^{\mathbb{Q}}\left[\exp\left(-\int_t^{t+\tau} r(X_s)\,ds\right)\right] \\ &\quad\cdot \mathbb{E}_t^{\mathbb{Q}}\left[\exp\left(-\int_t^{t+\tau} \varepsilon_s^r\,ds\right)\right] \\ &= B(X_t,\tau)E(t,\tau), \end{aligned} \tag{7}$$

where $\mathbb{E}_t^{\mathbb{Q}}[\cdot]$ denotes the expectation operator under measure $\mathbb{Q}$ conditional on time-t filtration $\mathcal{F}_t$. The multiplicative decomposition follows from the orthogonality assumption between X and ε^r. We leave the dynamics of ε_t^r unspecified and regard $E(t,\tau)$ as an error term on the bond price that is not explained by the three macroeconomic factors.

Based on the specifications of the factor dynamics X_t, market prices $\gamma(X_t)$, and the instantaneous interest rate function $r(X_t)$, we can derive $B(X_t,\tau)$ as an exponential affine function of the economic factors

$$B(X_t,\tau) = \exp(-a(\tau) - b(\tau)^\top X_t), \tag{8}$$

where the coefficients $[a(\tau), b(\tau)]$ are solutions to the following ordinary differential equations:

$$\begin{aligned} a'(\tau) &= a_r - b(\tau)^\top \gamma_0 - b(\tau)^\top b(\tau)/2, \\ b'(\tau) &= b_r - (\kappa^{\mathbb{Q}})^\top b(\tau), \end{aligned} \tag{9}$$

subject to the boundary conditions $a(0) = 0$ and $b(0) = 0$. Thus, the continuously compounded spot rates are affine functions of the three economic factors,

$$R(X_t,\tau) \equiv -\frac{\ln B(X_t,\tau)}{\tau} = \left[\frac{a(\tau)}{\tau}\right] + \left[\frac{b(\tau)}{\tau}\right]^\top X_t. \tag{10}$$

The observed spot rate, $R(t,\tau)$, can be written as

$$R(t,\tau) = R(X_t,\tau) + e(t,\tau), \tag{11}$$

where $e(t,\tau) \equiv -\ln E(t,\tau)/\tau$ denotes the portion of the spot rate that is not explained by the three economic factors. In our estimation, we treat $e(t,\tau)$ as the measurement error.

3.3. Term Structure of Corporate Yields and Credit Spreads

Duffie and Singleton (1999) and Duffie et al. (2003) show that one can value defaultable bonds analogously by adjusting the risk-free discounting with an instantaneous credit spread. Specifically, the time-t value of a zero-coupon defaultable bond with time to maturity τ can be written as

$$D(t,\tau) = \mathbb{E}_t^{\mathbb{Q}}\left[\exp\left(-\int_t^{t+\tau} (r_u + s_u)\,du\right)\right], \tag{12}$$

where s_t denotes the instantaneous loss-adjusted default spread. To price corporate bonds at a certain credit-rating class (or industry sector) i, we assume that the instantaneous credit spread for that rating class is an affine function of the three economic factors,

$$s_t^i = s^i(X_t) + \varepsilon_t^i, \qquad s^i(X_t) = a_i + b_i^\top X_t, \tag{13}$$

where ε_t^i denotes the portion of the spread that is not explained by the three economic factors.

Then we can show analogously that the fair value of the zero-coupon bond in the ith credit-rating class is also exponential affine in the three dynamic economic factors:

$$\begin{aligned} &D_i(t,\tau) = D_i(X_t,\tau)E_{ir}(t,\tau), \quad \text{with} \\ &D_i(X_t,\tau) = \exp(-a_i(\tau) - b_i(\tau)^\top X_t), \end{aligned} \tag{14}$$

where $E_{ir}(t,\tau)$ is the error term induced by the unexplained movements in both the Treasury interest and the credit spread, and the coefficients $[a_i(\tau), b_i(\tau)]$ are solutions to the ordinary differential equations:

$$\begin{aligned} a_i'(\tau) &= (a_r + a_i) - b_i(\tau)^\top \gamma_0 - b_i(\tau)^\top b_i(\tau)/2, \\ b_i'(\tau) &= (b_r + b_i) - (\kappa^{\mathbb{Q}})^\top b_i(\tau), \end{aligned} \tag{15}$$

subject to the boundary conditions $a_i(0) = 0$ and $b_i(0) = 0$.

The continuously compounded spot rate on the defaultable bond is again affine in the economic factors,

$$R_i(X_t,\tau) \equiv -\frac{\ln D_i(X_t,\tau)}{\tau} = \left[\frac{a_i(\tau)}{\tau}\right] + \left[\frac{b_i(\tau)}{\tau}\right]^\top X_t. \tag{16}$$

The observed spot rate on the defaultable bond can be written as

$$R_i(t,\tau) \equiv -\frac{\ln D_i(t,\tau)}{\tau} = R_i(X_t,\tau) + e_{ir}(t,\tau), \tag{17}$$

with $e_{ir}(t,\tau) \equiv -\ln E_{ir}(t,\tau)/\tau$.

We define the credit spread on the corporate bond as the difference between the spot rate on the defaultable corporate bond and the corresponding spot rate on the Treasury:

$$\begin{aligned} S_i(t,\tau) &\equiv R_i(t,\tau) - R(t,\tau) \\ &= \left[\frac{a_i(\tau) - a(\tau)}{\tau}\right] + \left[\frac{b_i(\tau) - b(\tau)}{\tau}\right]^\top X_t + e_i(t,\tau), \end{aligned} \tag{18}$$

with $e_i(t,\tau) = e_{ir}(t,\tau) - e(t,\tau)$. Thus, we use no-arbitrage arguments to link the credit spreads across all maturities at a certain credit-rating class to the dynamic economic factors. The linkages are determined by the factor dynamics, the market prices of factor risks, and the instantaneous interest rate and credit spread as functions of these factors. The model provides economic insights into the determinants of the Treasury yields and corporate bond credit spreads.

In this paper, we follow traditional practice and define credit spreads by using the corresponding Treasury yields as the risk-free benchmark. Recently, mainly concerned by potential liquidity squeezes in the Treasury market, both academics and practitioners have been proposing alternatives, such as eurodollar swap rates, to replace the Treasury as the benchmark. It has become an industry standard to use the swap rates as benchmarks in pricing credit derivatives such as credit default swaps. The swap rates are based on interbank lending rates, which include a credit component reflecting the AA rating of the banks involved. Hence, the swap rates are not really default risk free. Nevertheless, because they are over-the-counter contracts, they are less subject to the liquidity squeezes that the U.S. Treasuries have experienced (Liu et al. 2006). Feldhütter and Lando (2005) show that the "true" risk-free rate is somewhere between the Treasury rate and the swap rate. We choose the Treasury rate mainly because of data availability. We need to construct a long sample to analyze the impacts of economic variations, but the swap rate data became reliable across the whole spectrum of maturities only after the early 1990s.

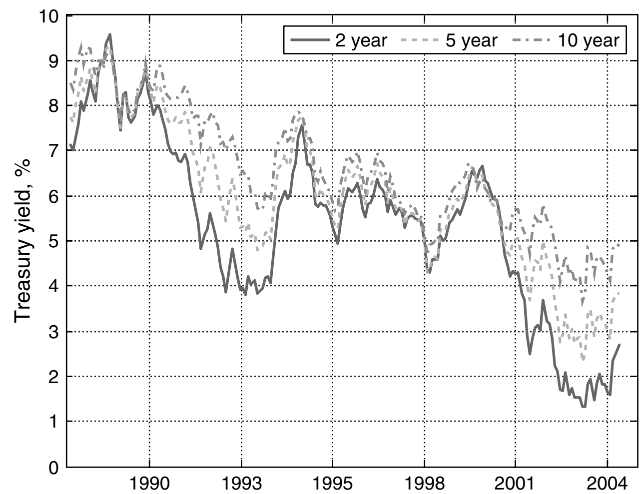
4. Linking Economic Factors to Treasury Yields and Credit Spreads

The Treasury yields data are monthly continuously compounded spot rates obtained from the Federal Reserve Board, which extracts the rates from the Treasury notes and bond prices according to the procedure proposed by Svensson (1995). The spot rates are available at 12 maturities: 3 months, 6 months, and every year from 1 to 10 years. We use the same sample period as for the economic factors.

Figure 2 plots the time series of the Treasury yields at three selected maturities: 2 (solid line), 5 (dashed line), and 10 years (dash-dotted line). During the 15-year sample period, the long-term rate showed a downward trend, largely matching the downward trend in the time series of the inflation factor in Figure 1. The plot also reveals two periods of low short-term interest rates with steeply upward-sloping term structures around 1993 and 2003. Each incidence follows the trough of the real output factor in Figure 1. The Treasury term structures are relatively flat in the late 1980s and the late 1990s.

We construct continuously compounded spot rates for corporate bonds in each of the four rating classes (AA, A, BBB, and BB). Credit spread is calculated as the difference between the spot rate at each rating class and the maturity-matched Treasury rate.

Figure 2 **Time Series of Treasury Yields at Selected Maturities**



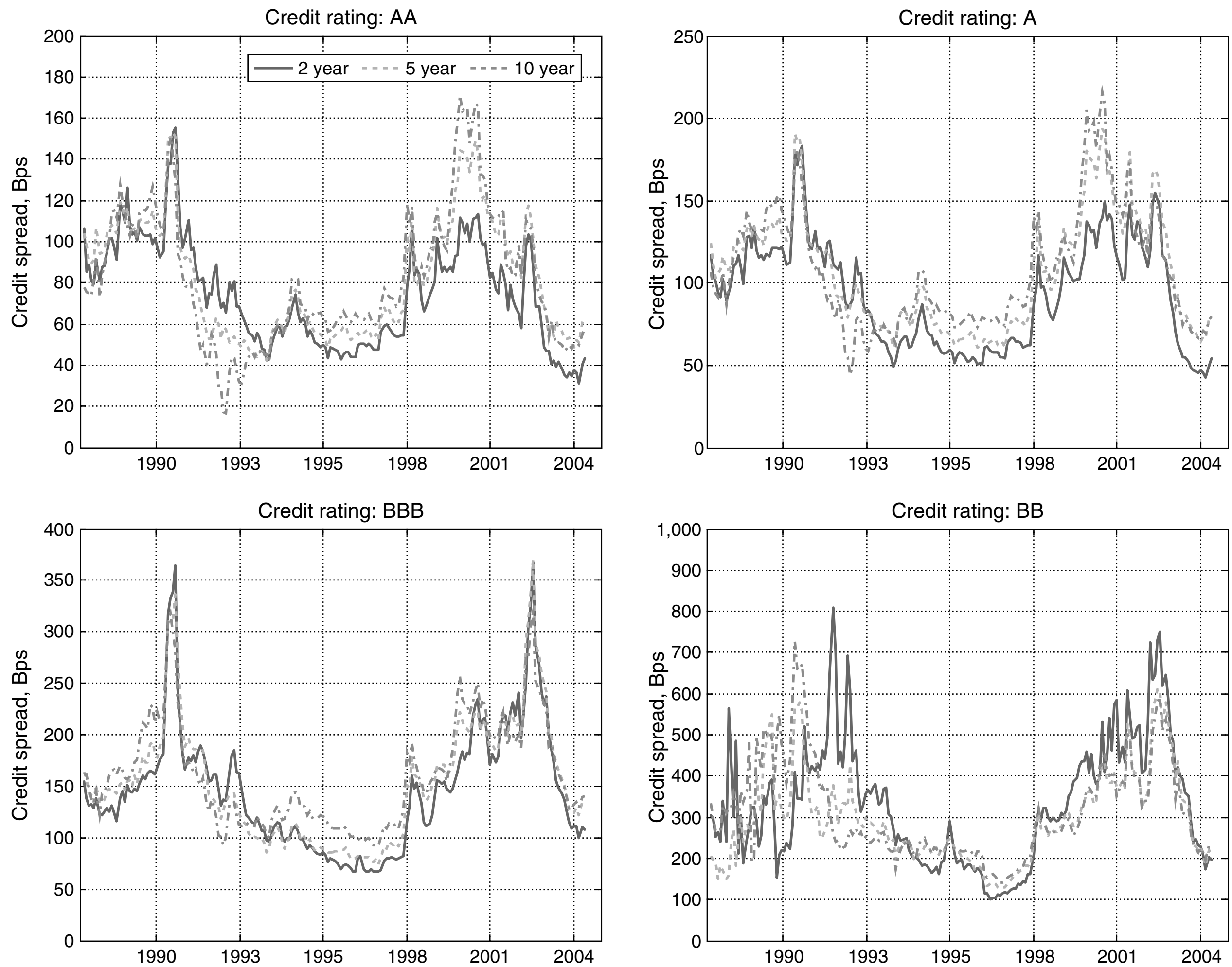
The maturity for the credit spread goes from 1 to 10 years every year. To construct the spot rates, we estimate the Nelson and Siegel (1987) model on month-end prices of corporate bonds that are either in the Merrill Lynch U.S. Corporate Master Index or the Merrill Lynch U.S. High-Yield Index. The estimation selects senior unsecured bonds with valid price quotes, with maturities between 1 and 35 years, with a fixed coupon schedule, but without option features. The resulting bond sample has 337,990 bond-month observations.

Figure 3 plots the time series of credit spreads in basis points (Bps) at three selected maturities (2, 5, and 10 years) and the four credit-rating classes. The spreads increase as the rating declines. Aside from the magnitude difference, the time series show strong common movements. Across all rating classes, we observe two common periods of high spreads, corresponding to the two recessions in our sample period.

To estimate the no-arbitrage linkages between the economic factors and the Treasury yields and corporate bond credit spreads, we cast the dynamic term structure model into a state-space form, extract the distributions of the states at each date by using the Kalman filter, and estimate the model parameters using the maximum likelihood method, assuming normal forecasting errors on the observed data series.

The statistical dynamics of the three economic factors have already been estimated in the previous sections using the 13 macroeconomic and financial time series. The estimates are reported in Table 2. We take these parameter estimates as given and estimate the remaining parameters that determine the no-arbitrage links using data from each market. First, we estimate the market prices of factor risks and the Treasury instantaneous interest rate function using the 12 Treasury spot rate series. Based on this estimation, we determine the impact of the economic factors on the

Figure 3 Time Series of Credit Spreads on Corporate Bonds at Selected Maturities and Different Rating Classes



Treasury yield curve. Then, we reestimate the market prices of factor risks, and we also estimate the instantaneous credit spread function at each credit-rating class using the 10 credit spread series in that rating class. We repeat this estimation procedure for each credit-rating class. The procedure generates a set of estimates on the market prices of risks for each market. Market efficiency dictates that different markets should price the same risk the same way. Hence, the different sets of parameter estimates obtained from different markets should be close. Large deviations suggest market segmentation, data issues, or model misspecification.

5. Macroeconomic Determinants of Treasury and Defaultable Term Structures

By estimating the dynamic term structure models, we quantify the impact of each economic factor on the term structure of Treasury yields and credit spreads at different credit-rating classes. Furthermore, we link these impacts to the underlying factor dynamics and market prices of factor risks.

5.1. Market Prices of Economic Risks

Table 3 reports the estimates and t-statistics of the model parameters that determine the market prices of economic risks. Each panel reports a set of estimates from one market. The estimates on γ_0 measure the constant portion of the market price. The difference between the estimates on $\kappa^{\mathbb{Q}}$ and that on κ in Table 2 determines the proportional component of the market price: $\gamma_1 = \kappa^{\mathbb{Q}} - \kappa$.

Given the parameter estimates and the extracted economic factors, we can compute the market price of the economic risk factors, $\gamma(X_t) = \gamma_0 + \gamma_1 X_t$, and study how they vary over time and how they co-move with the economic factors. We find that the market prices estimated from the five markets are largely consistent with one another, with some variations that we attribute to measurement error, market segmentation, or both. The left panel of Figure 4 plots the time series of the average market prices on each of the

Table 3 Market Prices of Economic Risk

γ_0	$\kappa^{\mathbb{Q}}$					
Treasury yield						
0.0115 (0.08)	0.0117 (0.13)	0	—	0	—	
−1.7951 (2.32)	0.3328 (0.66)	0.3481 (9.22)		0	—	
3.5003 (1.42)	−0.9021 (0.54)	−0.1689 (0.63)		0.7241 (12.5)		
Credit rating group: AA						
−1.2959 (10.56)	0.1038 (9.16)	—	—	—	—	
−1.5492 (4.55)	−0.0464 (0.49)	0.4035 (5.20)		—	—	
7.9824 (20.38)	−0.0720 (0.51)	−0.3207 (1.89)		0.0959 (10.11)		
Credit rating group: A						
−0.2805 (0.19)	0.0877 (0.09)	—	—	—	—	
−1.9276 (0.57)	0.0683 (0.03)	0.3890 (1.89)		—	—	
2.9054 (0.17)	−0.2062 (0.02)	−0.1850 (0.42)		0.1636 (7.55)		
Credit rating group: BBB						
−0.4496 (0.42)	0.0495 (0.11)	—	—	—	—	
−2.5961 (1.08)	0.1104 (0.06)	1.5610 (0.89)		—	—	
3.0067 (0.41)	−0.0113 (0.00)	−1.3348 (0.69)		0.1651 (5.50)		
Credit rating group: BB						
−0.9907 (0.69)	0.0054 (0.32)	—	—	—	—	
−0.8301 (0.13)	1.0995 (0.56)	0.2557 (0.33)		—	—	
3.6565 (0.63)	−0.6077 (0.71)	0.0180 (0.05)		0.0178 (0.42)		

Notes. Entries report the parameter estimates and absolute magnitudes of the t-statistics (in parentheses) on market prices of economic factor risks that, in conjunction with the time-series dynamics in Table 2, determine the risk-neutral factor dynamics. The parameters are estimated from Treasury yields and corporate credit spreads at each credit-rating class. γ_0 denotes the constant component of the market price of the factor risks, which determines the constant component of the risk-neutral drift of the factors. $\kappa^{\mathbb{Q}} = \kappa + \gamma_1$ defines the mean-reverting property of the dynamic factors under the risk-neutral measure, with γ_1 denoting the proportional component of the market prices. The parameters are estimated with maximum likelihood methods, using Treasury yields and corporate bond credit spreads, respectively. The data are monthly, cover January 1988–June 2004, and are obtained from the Federal Reserve Board and Merrill Lynch.

three economic factors. The market price of inflation risk is negative, with its absolute magnitude larger (more negative) at higher inflation periods than at lower inflation periods.[1] As the inflation trends down during our sample, the market price of inflation risk also becomes less negative. The market price of real output growth is also negative, but it varies positively with the real growth level. The market prices are the most negative during the two recessions but become less negative during the high growth period. Finally, the volatility factor shows a positive market price that increases with the risk factor level.

Table 4 reports the coefficient estimates on the instantaneous interest rate function of the Treasury bonds and the instantaneous credit spread function on each rating class for the corporate bonds. The intercept estimate on the Treasury rate measures the long-run mean of the instantaneous Treasury interest rate, which is estimated at 4.86%. The intercept estimates on the corporate bonds measure the fixed component of the instantaneous spread induced by credit risk. The estimates increase as the rating declines. As expected, the compensation for credit risk increases as the probability of default increases.

The loading coefficient (b) estimates on Treasury rates measure the contemporaneous response of the short Treasury rate to unit shocks on the three economic factors. The estimates for the three elements are all positive and strongly significant, suggesting that inflation, output, and financial market volatility all have positive impacts on the short-term Treasury rate. If we combine the loading coefficients with the market price estimates on the three economic factors, we can compute the risk premium on the short rate induced by the three economic factors, $\gamma(r_t) = b_r^\top \gamma(X_t)$. The right panel of Figure 4 plots the time series of the interest rate risk premium. The risk premium is the most negative in the early 1990s, reflecting the combined effect of high inflation and low real output growth during this period. The financial market volatility is also high during this period, but its impact on the Treasury interest rate is smaller compared to the impacts from inflation and real output growth. In contrast, the interest rate risk premium is the highest around 1998, as a result of low inflation, high real growth, and high financial market volatility.

The bond-pricing literature has long recognized that the interest rate risk premium is on average negative. This negative risk premium leads to an upward-sloping mean term structure (Backus et al. 1998, 2001; Duffee 2002). In this paper, we identify three macroeconomic risk dimensions that exert different impacts on the interest rate term structure. We show that the interest rate risk premium becomes more negative and hence the term structure becomes more steeply upward sloping when the inflation is high, real output growth is low, and financial market volatility is low. But the risk premium can become positive and the term structure flat when the inflation is low, the real output growth is high, and the financial market volatility is high, as in the late 1990s.

5.2. Macroeconomic Determinants of Treasury Yield Term Structure

Equation (9) illustrates how the short rate function (a_r, b_r) interacts with the risk-neutral factor dynamics $(\gamma_0, \kappa^{\mathbb{Q}})$ to determine both the mean term structure of Treasury yields, as measured by $a(\tau)/\tau$, and the factor loadings across the term structure, as measured by $b(\tau)/\tau$. Figure 5 plots the mean term structure in the left panel and loadings of the three factors in the right panel. The upward-sloping mean term structure in the left panel is consistent with data observation. The three lines in the right panel show the contemporaneous response of the Treasury yield curve to unit shocks on the three economic factors. The solid line

[1] For graphical clarity, we magnify the market price of inflation risk (solid line) by a scale of 10.

Table 4 The Instantaneous Default-Free Interest Rate and Credit Spread Functions

Ratings	Treasury	AA	A	BBB	BB
Intercepts (a)	0.0486 (56.3)	0.0053 (7.42)	0.0063 (4.23)	0.0100 (1.91)	0.0345 (2.98)
Factor loadings (b)					
Inflation	0.0107 (18.1)	0.0011 (4.88)	0.0011 (1.25)	0.0007 (0.23)	−0.0008 (0.41)
Real output	0.0073 (23.8)	0.0002 (1.20)	−0.0001 (0.50)	0.0012 (0.29)	−0.0052 (5.86)
Volatility	0.0025 (31.1)	−0.0006 (10.9)	−0.0002 (2.29)	0.0002 (1.34)	−0.0005 (1.77)

Notes. Entries report the parameter estimates and absolute magnitudes of the t-statistics (in parentheses) on the instantaneous default-free interest rate function and the instantaneous credit spread function under different rating classes. The parameters a are the corresponding intercepts, and the parameters b are the corresponding loading vectors on the three factors. The parameters are estimated with the maximum likelihood methods and Kalman filter, using corporate bond yield spreads over the corresponding Treasury yield at maturities from 1 to 10 years. The data are monthly, cover January 1988–June 2004, and are obtained from the Federal Reserve Board and Merrill Lynch.

denotes the response to the inflation factor, which is positive and the strongest among the three lines. Furthermore, because of the high risk-neutral persistence of the inflation factor, the response to the inflation factor persists as the maturity increases.

The dashed line denotes the impact of the real output growth factor, which is also positive but smaller in magnitude. Furthermore, because of the lower risk-neutral persistence of this real output growth factor, the impact dissipates faster as maturity increases. For a unit shock to the real output factor, the response of the 1-year Treasury rate is about twice as much as that of the 10-year Treasury rate. Finally, the dash-dotted line captures the impact of the financial market volatility factor, which is positive but small in magnitude. Its impact also declines quickly with increasing maturities.

Taken together, our results suggest that the variation of the long-term rate is largely determined by the inflation rate, whereas the short-term rate varies with both inflation and real output growth. This result explains why the long-term rate has been trending down, as does the inflation factor. It also sheds light on the recent "Greenspan conundrum" (Rudebusch et al. 2006): in 2004 and 2005, the long-term rate stayed low despite consecutive raises on the short-term rate by the Federal Reserve Board in response to increasing economic strength. Our analysis suggests that only when the short rate hike is induced by inflation pressure does the long-term rate increase with it. Short rate increase induced by real output growth does not lead to parallel increases on the long end of the yield curve.

5.3. Macroeconomic Determinants of Credit Spread Term Structure

The loading coefficients (b_i) on the instantaneous credit spread interact with the risk-neutral factor dynamics $\kappa^{\mathbb{Q}}$ to determine how shocks in the three macroeconomic factors impact the term structure of corporate bond yields and hence the credit spreads. For each credit-rating class, Figure 6 plots the three elements of $(b_i(\tau) - b(\tau))/\tau$, which measure the contemporaneous responses of the credit spread term structure to unit shocks on the three economic factors. Each panel in Figure 6 corresponds to one rating class, and each line corresponds to the response of the credit spread term structure to one of the three economic factors.

Figure 4 Time-Varying Market Prices of Economic Risks

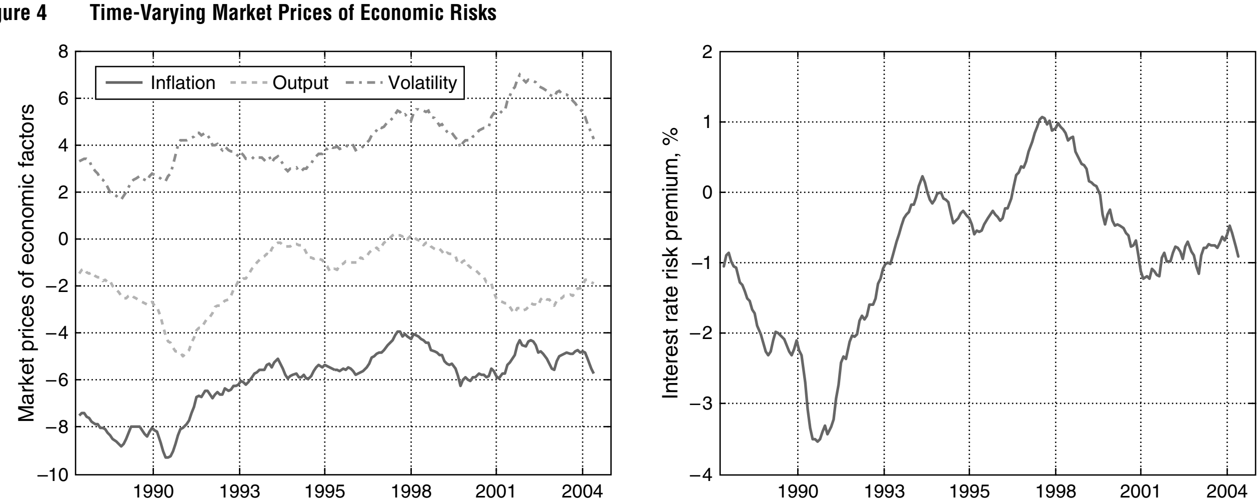
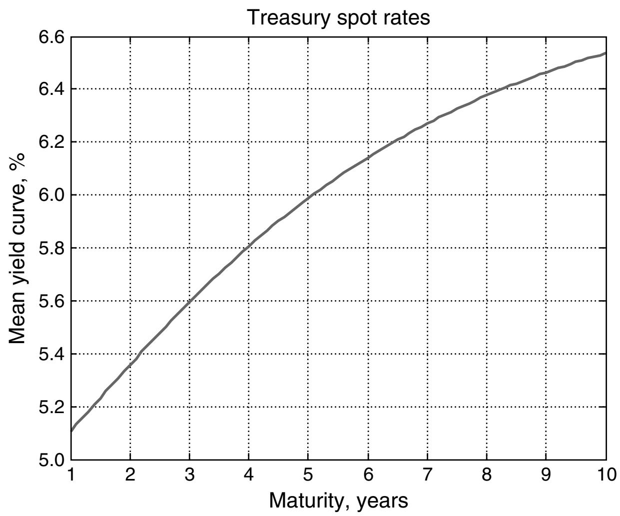


Figure 5 Mean Treasury Yield Curve and Factor Loadings



The solid line in each panel denotes the response of the credit spread term structures to the inflation factor. The responses are positive at most rating classes and are persistent across maturities. The positive responses suggest that increasing inflation not only increases the Treasury rate across all maturities but also widens the credit spreads on corporate bonds.

The dashed line in each panel shows the response of the credit spread term structure to the real output growth factor. The responses are slightly positive for AA credit spreads, but they become negative for the A rating class and much more so for the BBB and BB credit-rating classes. Furthermore, the negative responses are larger at short maturities than at long maturities. Thus, while a positive output shock increases the interest rate level and flattens an otherwise upward-sloping yield curve, it reduces the pricing and risk of corporate default and narrows the credit spread, particularly at low rating classes and short maturities.

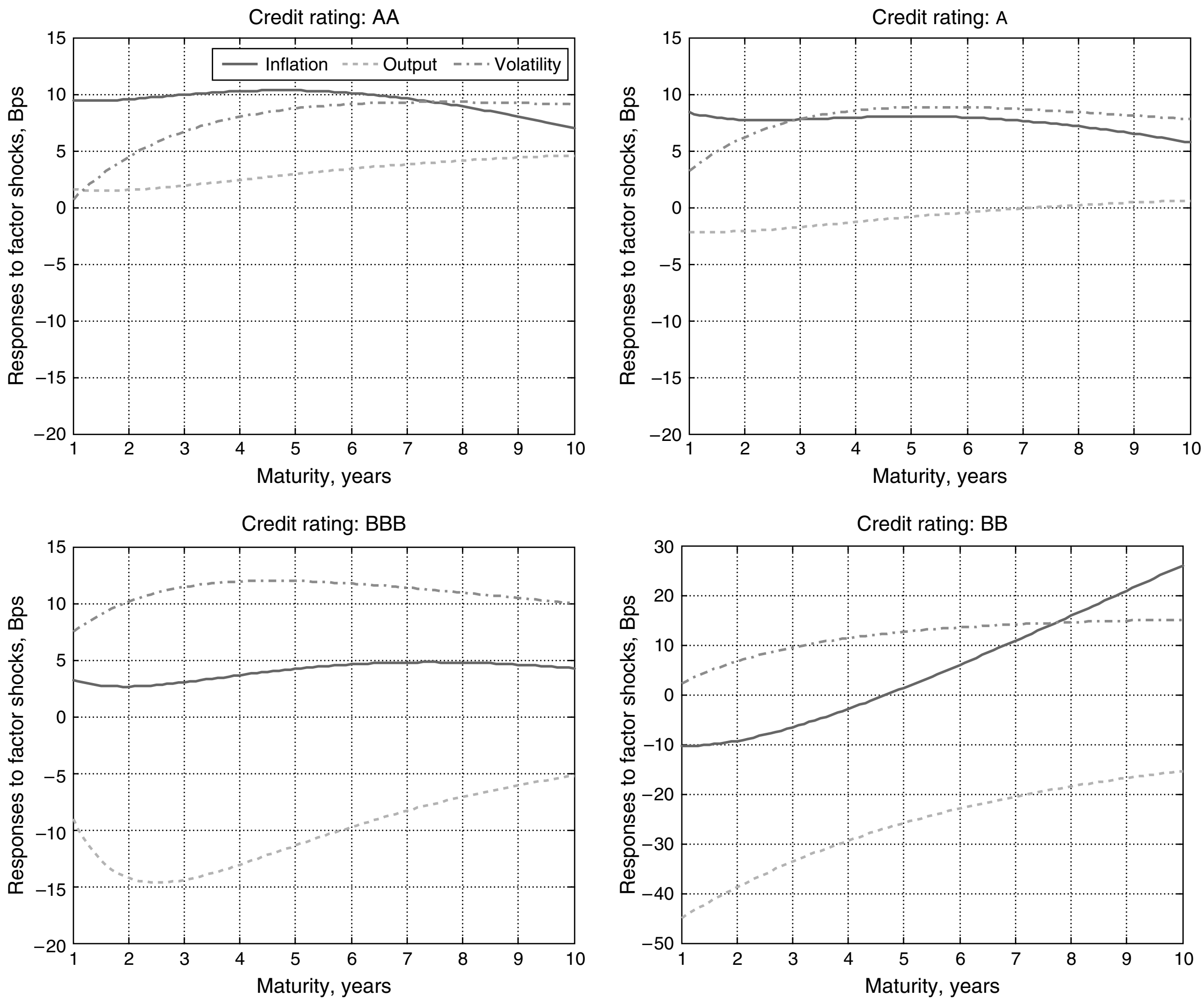
The dash-dotted line in each panel plots the response of the credit spreads to the financial market volatility factor. The responses are positive for all rating classes and become increasingly so with declining credit ratings. In all cases, the responses increase with maturities, a finding consistent with the high risk-neutral persistence for this volatility factor estimated from the corporate bond market. Therefore, whereas the Treasury yields are dominated by macroeconomic forces, the financial market volatility plays an important role in the credit spreads, particularly at low rating classes and long maturities.

The literature has often identified a negative relation between credit spreads and the short-term interest rate (Duffee 1998). Our economic analysis suggests that this negative relation is mainly induced by their opposite responses to the real output growth: although the short-term interest rate increases with real output growth, the credit spread narrows with it. Our analysis also shows that the relation between the interest rate and credit spread is not always negative. At times when the real output growth is relatively stable but the inflation and financial market volatility are strongly time varying, interest rates and credit spreads can co-move positively as they respond to inflation and volatility in the same way. Thus, when modeling the co-movements between interest rates and credit spreads, it is important to condition the co-movements on the underlying economic factors. A direct loading of credit spread on the instantaneous interest rate (e.g., Feldhütter and Lando 2005 and Frühwirth et al. 2006) is an oversimplification that ignores the actual driving forces behind the interest rate movements.

5.4. Regression Analysis versus No-Arbitrage Modeling

We estimate the linkages between the economic factors and the term structure of interest rates and credit spreads via a dynamic term structure model that guarantees no arbitrage. Compared to direct regression analysis, our approach offers several advantages. First, our dynamic term structure model implies a linear relation between the Treasury yields and credit spreads on the one hand and the economic factors on the other. The model relates the linear coefficients to the economic factor dynamics and market prices and hence enables us to understand the reasons behind the estimated linkages. Second, through the no-arbitrage constraints, yields and credits across all maturities are estimated within one system. The estimates are less affected by the measurement errors associated with each individual series. Third, given

Figure 6 Contemporaneous Response of the Credit Spread Term Structure to Unit Shocks on the Economic Factors



the structural estimates, we can learn not only the contemporaneous impacts but also the multiperiod impulse response of the economic factors on the interest rates and credit spreads at any observed or unobserved maturities. In contrast, the regression approach only generates the contemporaneous response estimates at a given maturity, with no obvious ways to extrapolate to other maturities and time periods.

Table 5 reports the coefficient estimates and R-squares from directly regressing Treasury yields and corporate bond credit spreads on the three economic factors. For comparison, the last row of each panel also reports the R-squares from the dynamic term structure model estimation, which can be regarded as a constrained linear regression. Comparing the regression slope coefficients to the estimated response functions from the dynamic term structure model in Figures 5 and 6, we find that the regression results are largely consistent with the term structure model results, with some small deviations. The coefficient estimates on inflation are mostly positive. The coefficient estimates on the real output growth are slightly positive under the AA rating class but become increasingly negative as the credit rating declines. The coefficient estimates on the volatility factor are positive and increasingly so at lower rating classes. Comparing the R-squares from the unconstrained regression and our dynamic factor model, we observe that using the dynamic term structure model does not give up much on the explanatory power, but it gains on economic interpretation and internal consistency across maturities.

5.5. Residual Analysis

In this paper, we extract three fundamental risk dimensions from the macroeconomy: the nominal and real sides of the economy and the volatility of the financial market. We analyze how the dynamics and market pricing of the three macroeconomic risk dimensions influence the term structure of Treasury yields and corporate bond credit spreads. The literature has also identified many other factors that affect

Table 5 Regression Estimates on the Response Functions

Maturity	1	2	3	4	5	6	7	8	9	10
					Regressing Treasury yields on economic factors					
Intercept	5.08	5.39	5.63	5.83	6.00	6.15	6.27	6.39	6.49	6.58
Inflation	0.83	0.79	0.74	0.71	0.68	0.66	0.64	0.62	0.60	0.58
Output	0.48	0.42	0.35	0.30	0.26	0.22	0.19	0.17	0.16	0.14
Volatility	0.08	0.04	0.01	−0.01	−0.02	−0.03	−0.04	−0.04	−0.05	−0.05
R^2	0.79	0.78	0.78	0.78	0.79	0.79	0.79	0.79	0.79	0.79
R_d^2	0.72	0.71	0.70	0.70	0.70	0.71	0.71	0.71	0.71	0.71
					Regressing AA credit spreads on economic factors					
Intercept	0.75	0.75	0.77	0.80	0.82	0.83	0.84	0.84	0.83	0.82
Inflation	0.09	0.08	0.08	0.07	0.07	0.06	0.06	0.06	0.06	0.06
Output	0.02	0.00	−0.00	0.00	0.01	0.01	0.02	0.02	0.03	0.03
Volatility	0.02	0.04	0.05	0.06	0.07	0.07	0.07	0.07	0.07	0.07
R^2	0.47	0.57	0.58	0.55	0.52	0.48	0.45	0.42	0.39	0.38
R_d^2	0.44	0.54	0.53	0.48	0.43	0.39	0.37	0.36	0.35	0.35
					Regressing A credit spreads on economic factors					
Intercept	0.89	0.94	0.99	1.04	1.07	1.09	1.10	1.09	1.09	1.08
Inflation	0.07	0.07	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05
Output	−0.01	−0.04	−0.04	−0.03	−0.02	−0.02	−0.01	−0.00	−0.00	0.00
Volatility	0.04	0.05	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07
R^2	0.43	0.55	0.54	0.51	0.48	0.44	0.41	0.39	0.36	0.34
R_d^2	0.41	0.53	0.51	0.48	0.44	0.41	0.39	0.37	0.35	0.34
					Regressing BBB credit spreads on economic factors					
Intercept	1.52	1.47	1.48	1.51	1.54	1.56	1.58	1.60	1.61	1.61
Inflation	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.05
Output	−0.09	−0.13	−0.13	−0.12	−0.11	−0.10	−0.09	−0.08	−0.07	−0.06
Volatility	0.06	0.08	0.10	0.11	0.11	0.11	0.11	0.11	0.10	0.10
R^2	0.40	0.60	0.65	0.66	0.65	0.63	0.60	0.56	0.52	0.49
R_d^2	0.39	0.58	0.64	0.66	0.65	0.63	0.59	0.56	0.52	0.49
					Regressing BB credit spreads on economic factors					
Intercept	3.83	3.32	3.08	2.98	2.97	2.99	3.03	3.07	3.10	3.13
Inflation	−0.05	−0.08	−0.06	−0.02	0.02	0.07	0.11	0.15	0.18	0.21
Output	−0.41	−0.35	−0.30	−0.26	−0.23	−0.22	−0.21	−0.20	−0.19	−0.19
Volatility	0.18	0.11	0.09	0.09	0.10	0.11	0.12	0.14	0.15	0.16
R^2	0.36	0.48	0.50	0.48	0.47	0.49	0.52	0.55	0.59	0.61
R_d^2	0.33	0.47	0.49	0.46	0.46	0.48	0.52	0.55	0.58	0.60

Notes. Entries report the coefficient estimates and R-squares (R^2) from regressing Treasury yields and credit spreads on the three economic factors. For comparison, in the last row of each panel, we also report the R-squares (R_d^2) from the dynamic term structure model estimation, which can be regarded as a constrained linear regression.

the Treasury yields and credit spreads. For example, the Treasury market has been found to contain a liquidity component that lowers the Treasury yield when the Treasury supply declines during eras of budget surplus (Feldhütter and Lando 2005, Jordan and Jordan 1997, Longstaff et al. 2005). Bikbov and Chernov (2006) and Dai and Philippon (2004) find that fiscal policy variables help explain the Treasury term structure. Credit spreads have also been found to contain compensations for expected default losses, possible tax effects, and liquidity costs (e.g., Collin-Dufresne et al. 2001, Elton et al. 2001). Furthermore, the classic model of Merton (1974) suggests that the credit spreads on the bonds of a firm depend on the firm's characteristics, such as its financial leverage. These liquidity, tax, and idiosyncratic factors constitute the measurement errors ($e(t,\tau)$ and $e_{ir}(t,\tau)$) on Treasury yields and credit spreads in our estimation. The R-squares (R_d^2) reported in Table 5 from our dynamic term structure model suggest that these remaining factors account for 30% of the variation in Treasury yields and 50%–60% of the variation in credit spreads.

In this section, we analyze the behavior of the residuals and explore their determinants. First, we find that for each market, the residuals at different maturities share high cross-correlations, averaging between 0.65 for the BB market and 0.92 for the Treasury market. The high correlations imply that a significant portion of the residuals are driven by some common factors outside the three macroeconomic factors that we have identified. We also find that one principal component from the 10 residuals at each market explains over 90% of the variation in the Treasury, A, and BBB markets, about 88% of the variation in the AA market, and 59% of the variation in the BB market.

To understand the common movements in the residuals, we consider two variables. The first is the U.S. budget deficit (DEF) as a percentage of the GDP, which we use as a measure for the fiscal policy following the studies from Bikbov and Chernov (2006) and Dai and Philippon (2004). The second is a financial leverage measure that we construct synthetically from five observed series. The first series is the debt-to-net-worth ratio, where debt includes all credit market instruments such as commercial paper, municipal securities, corporate bonds, bank loans, and other loans and mortgages. Net worth is defined as total assets minus total liabilities. Total assets include financial assets and tangible assets at their market value or replacement costs. Total liabilities include debt as defined above plus trade payable, tax payable, and other miscellaneous liabilities.

The second series is also a debt-to-net-worth ratio, except that tangible assets are valued at their book value rather than their replacement cost. The third series is the debt-to-equity ratio, where debt is defined as above and equity denotes the total market value of equities. The fourth series is the financial-gap-to-nominal-GDP ratio, where financial gap is defined as capital expenditure less the sum of U.S. internal funds and inventory valuation adjustment. The last series is the ratio of net change in corporate bonds to nominal GDP. Previous studies (e.g., Bevan and Garzarelli 2000) have used all five measures to proxy different aspects of the aggregate financial leverage. The two debt-to-net-worth ratios and the debt-to-equity ratio measure the leverage as in the Merton (1974) model. The financial gap measures the shortfall in internally generated funds and is hence a flow measure. So is the ratio of change in debt to GDP. Without a consensus on which one is the best proxy, we consolidate the five measures into one common factor similar to what we have done on the three economic risk factors. The loadings of the extracted financial leverage factor on the five series are −0.2553, 0.3580, 0.4424, −0.2206, and −0.1595, respectively.

Similar to the findings in Bikbov and Chernov (2006) and Dai and Philippon (2004), the Treasury yields are positively correlated with the DEF, with an average correlation of 0.24. This positive correlation can come from interactions between monetary and fiscal policies (Cochrane 2001, Sargent and Wallace 1981), liquidity squeezes caused by the variation in Treasury issuance as a result of increased or decreased budget deficit, or both. We find that credit spreads across all rating classes are negatively correlated with the DEF, although corporate bond yields are positively correlated with the DEF. Therefore, an increasing DEF increases the Treasury yields more than it increases the corporate bond yield, consistent with the liquidity squeeze story: the Treasury debt issuance declines during eras of budget surplus, and the reduced supply of Treasury securities imposes a liquidity squeeze on the Treasury market that increases the Treasury price and lowers the Treasury yield.

We also find that both Treasury yields and credit spreads are positively correlated with the financial leverage factor. The correlation averages around 0.56 for Treasury yields and 0.23 for credit spreads. The positive correlation is consistent with the traditional story that increasing financial leverages increases the volatility and the financing cost of the market.

However, when we measure the correlation between the residual principal component and the DEF and financial leverage factor, the signs are largely switched. The residuals from both Treasury yields and credit spreads become negatively correlated with both budget deficit and the financial leverage factor. When we regress the principal component of the residuals on the two additional factors, the R-squares from the regressions are low, ranging from 5% to 23%. Thus, similar to the findings in Collin-Dufresne et al. (2001), the remaining movements in the Treasury yields and credit spreads cannot be fully explained by fiscal policy or financial leverage.

6. Conclusion

We use a dynamic factor model to summarize the information in many observed macroeconomic and financial data series and to provide a no-arbitrage link between the dynamic economic factors and the term structure of Treasury yields and credit spreads of corporate bonds at different credit-rating classes and industry sectors. By estimating the model, we quantify the impacts of many macroeconomic and financial series on the whole term structure of Treasury yields and credit spreads. We also learn the fundamental reasons behind the impacts through the estimated factor dynamics and market prices of economic risks.

We find that positive inflation shocks increase Treasury yields and credit spreads across all maturities and credit-rating classes. The impacts on Treasury yields are the strongest. The effects on credit spreads are smaller and decline with lower credit ratings. Positive shocks on real output growth also increase Treasury yields, more so at short maturities than at long maturities. The effects on credit spreads are positive for high credit-rating classes but become negative and increasingly so as we move to lower credit-rating classes. The financial market volatility factor has small and transient effects on the Treasury yield curve but strongly positive and persistent impacts on the credit spreads across the whole term structure.

This paper focuses on the aggregate behavior of credit spreads and their relations to the aggregate macroeconomic conditions. For future research, it is also important to understand how credit spreads in a specific firm vary with firm-specific characteristics such as firm-level volatility and financial leverage. A firm-level analysis can potentially explain the remaining variations in the credit spreads. Furthermore, while aggregate studies such as ours reveal how the financial market prices credit risk overall and how the market pricing varies with macroeconomic conditions, a firm-level study provides insights into how firm-level decisions (on financial and operating leverages) and business characteristics influence the default probability and loss given default, and hence the credit rating. An important line for future research is to integrate aggregate macroeconomic pricing factors with firm-level risk characteristics into one model framework so that bonds from all firms can be priced in one consistent framework.

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References

Altman, E. I., B. Brady, A. Resti, A. Sironi. 2005. The link between default and recovery rates: Theory, empirical evidence and implications. *J. Bus.* **78** 2203–2228.

Ang, A., M. Piazzesi. 2003. A no-arbitrage vector autoregression of term structure dynamics with macroeconomic and latent variables. *J. Monetary Econom.* **50** 745–787.

Ang, A., S. Dong, M. Piazzesi. 2004. No-arbitrage Taylor rules. Working paper, Columbia University, New York.

Backus, D., S. Foresi, C. Telmer. 1998. Discrete-time models of bond pricing. Working paper, New York University, New York.

Backus, D., S. Foresi, A. Mozumdar, L. Wu. 2001. Predictable changes in yields and forward rates. *J. Financial Econom.* **59** 281–311.

Bakshi, G., D. Madan, F. Zhang. 2006. Investigating the role of systematic and firm-specific factors in default risk: Lessons from empirically evaluating credit risk models. *J. Bus.* **79** 1955–1987.

Bangia, A., F. X. Diebold, A. Kronimus, C. Schagen, T. Schuermann. 2002. Ratings migration and the business cycle, with application to credit portfolio stress testing. *J. Banking Finance* **26** 445–474.

Bekaert, G., S. Cho, A. Moreno. 2005. New-Keynesian macroeconomics and the term structure. Working paper, Columbia University, New York.

Bevan, A., F. Garzarelli. 2000. Corporate bond spreads and the business cycle: Introducing GS-spread. *J. Fixed Income* **9** 8–18.

Bikbov, R., M. Chernov. 2006. No-arbitrage macroeconomic determinants of the yield curve. Working paper, Columbia University, New York.

Black, F., M. Scholes. 1973. The pricing of options and corporate liabilities. *J. Political Econom.* **81** 637–654.

Buraschi, A., A. Jiltsov. 2005. Inflation risk premia and the expectation hypothesis. *J. Financial Econom.* **75** 429–490.

Carey, M. 1998. Credit risk in private debt portfolios. *J. Finance* **53** 1363–1387.

Carr, P., L. Wu. 2006. A tale of two indices. *J. Derivatives* **13** 13–39.

Cochrane, J. H. 2001. Long-term debt and optimal policy in the fiscal theory of the price level. *Econometrica* **69** 69–116.

Collin-Dufresne, P., R. S. Goldstein, J. Helwege. 2003. Is credit event risk priced? Modeling contagion via the updating of beliefs. Working paper, Washington University, St. Louis.

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

Dai, Q., T. Philippon. 2004. Fiscal policy and the term structure of interest rates. Working paper, New York University, New York.

Delianedis, G., R. Geske. 2001. The components of corporate credit spreads: Default, recovery, tax, jumps, liquidity, and market factors. Working paper, University of California–Los Angeles, Los Angeles.

Diebold, F. X., G. D. Rudebusch, S. B. Arouba. 2006. The macroeconomy and the yield curve: A dynamic latent factor approach. *J. Econometrics* **131** 309–338.

Duffee, G. 1999. Estimating the price of default risk. *Rev. Financial Stud.* **12** 197–226.

Duffee, G. R. 1998. The relation between Treasury yields and corporate bond yield spreads. *J. Finance* **53** 2225–2241.

Duffee, G. R. 2002. Term premia and interest rate forecasts in affine models. *J. Finance* **57** 405–443.

Duffee, G. R. 2006. Term structure estimation without using latent factors. *J. Financial Econom.* **79** 507–536.

Duffie, D., K. Singleton. 1997. An econometric model of the term structure of interest rate swap yields. *J. Finance* **52** 1287–1322.

Duffie, D., K. Singleton. 1999. Modeling term structure of defaultable bonds. *Rev. Financial Stud.* **12** 687–720.

Duffie, D., L. H. Pedersen, K. Singleton. 2003. Modeling sovereign yield spreads: A case study of Russian debt. *J. Finance* **58** 119–160.

Elton, E. J., M. J. Gruber, D. Agrawal, C. Mann. 2001. Explaining the rate spread on corporate bonds. *J. Finance* **56** 247–277.

Eom, Y. H., J. Helwege, J.-Z. Huang. 2004. Structural models of corporate bond pricing: An empirical analysis. *Rev. Financial Stud.* **17** 499–544.

Feldhütter, P., D. Lando. 2005. Decomposing swap spreads. Working paper, Copenhagen Business School, Copenhagen, Denmark.

Frühwirth, M., P. Schneider, L. Sögner. 2006. The risk microstructure of corporate bonds: A Bayesian analysis. Working paper, Harvard University, Cambridge, MA.

Frye, J. 2000. Depressing recoveries. *Risk* (October) 108–111.

Gallmeyer, M., B. Hollifield, S. Zin. 2005. Taylor rules, McCallum rules, and the term structure of interest rates. *J. Monetary Econom.* **52** 921–950.

Hördahl, P., O. Tristanoi, D. Vestin. 2006. A joint econometric model of macroeconomic and term structure dynamics. *J. Econometrics* **131** 405–444.

Huang, J.-Z., M. Huang. 2003. How much of the corporate-Treasury yield spread is due to credit risk? Working paper, Pennsylvania State University, University Park.

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

Jordan, B. D., S. D. Jordan. 1997. Special repo specials: An empirical analysis. *J. Finance* **52** 2051–2072.

Liu, J., F. A. Longstaff, R. E. Mandell. 2006. The market price of credit risk: An empirical analysis of interest rate swap spreads. *J. Bus.* **79** 2337–2360.

Longstaff, F. A., E. S. Schwartz. 1995. A simple approach to valuing risky fixed and floating rate debt. *J. Finance* **50** 789–819.

Longstaff, F. A., S. Mithal, E. Neis. 2005. Corporate yield spreads: Default risk or liquidity? New evidence from the credit-default swap market. *J. Finance* **60** 2213–2253.

Lu, B., L. Wu. 2004. Systematic macroeconomic movements and the term structure of interest rates. Working paper, Baruch College, City University of New York, New York.

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

Nelson, C. R., A. F. Siegel. 1987. Parsimonious modeling of yield curves. *J. Bus.* **60** 473–489.

Nickell, P., W. Perraudin, S. Varotto. 2000. Stability of rating transitions. *J. Banking Finance* **24** 203–227.

Pedrosa, M., R. Roll. 1998. Systematic risk in corporate bond yields. *J. Fixed Income* **8** 7–26.

Rudebusch, G. D., T. Wu. 2008. A macro-finance model of the term structure, monetary policy, and the economy. *Econom J.* Forthcoming.

Rudebusch, G. D., E. T. Swanson, T. Wu. 2006. The bond yield "conundrum" from a macro-finance perspective. *Monetary Econom. Stud.* **24** 83–128.

Sargent, T. J., N. Wallace. 1981. Some unpleasant monetarist arithmetic. *Federal Reserve Bank of Minneapolis Quart. Rev.* **5** 1–17.

Svensson, L. E. O. 1995. Estimating forward interest rates with the extended Nelson & Siegel method. *Quart. Rev. Sveriges Riksbank* **3** 13–26.

Wachter, J. A. 2006. A consumption-based model of the term structure of interest rates. *J. Financial Econom.* **79** 365–399.