On the Pricing of Credit Risk in Eurocurrency Market

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Abstract

Most of previous studies on credit risk have been focused on corporate bond markets. This paper focuses on whether the credit risk is priced in the Eurocurrency market. The empirical test relies on a multivariate GARCH (1,1)-in-mean version of the ICAPM model to describe the joint stochastic process of three state variables: world market risk, interest rate risk, and credit risk, during the period January 1986 to December 2002. The paper documents a negative, significant, and time-varying systematic credit risk premium.

I. Introduction

The corporate bond and risk management literature have over the last years clearly emphasized the benefits and limits of credit risk diversification for corporate bond portfolios (see Crouhy, Galai and Mark (2001) or Jarrow and Turnbull (2000) for a survey). However, our understanding of the credit risk structure is limited and empirical work that aims at characterizing credit risk structure of interest rate in well-established capital markets such as the Eurocurrency market is still lacking. This study attempts to fill the gap by empirically characterizing the time-variation of the credit risk premium in the Eurocurrency market. Eurocurrency deposits as corporate liabilities have finite lives and pre-specified terminal value. Therefore, Eurocurrency deposits involve two types of risk: interest rate risk and credit risk. These two types of risk and their interactions are fundamental determinants of the valuation of Eurocurrency deposits and their derivatives. This study attempts to establish whether credit risk is priced in the Eurocurrency deposit rates. In particular, a conditional version of Merton's (1973) intertemporal CAPM is used to pursue this objective. For that purpose, I introduce the TED spread, which is the yield spread of three-month futures contracts for U.S. Treasuries and three-month contracts for Eurodollars having identical expiration months, as a state variable in addition to an interest rate risk state variable in a multivariate GARCH (1,1)- in-mean (MGARCH-M) return generating model in order to examine whether systematic credit risk is indeed priced in the Eurocurrency deposit rates. The empirical results show that the credit risk premium is negative, significant and time -varying.

The paper is organized as follows. The next section motivates the use of stochastic discount factor (SDF) model. The econometric model - MGARCH-M is described in Section III. Section IV discussed the data used. The empirical results are reported in Section V. Some concluding remarks are reserved for Section VI.

II. The Theoretical Motivation: Stochastic Discount Factor (SDF)

We know that the first-order condition of any consumer-investor's portfolio optimization problem can be written as:

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$$E[M_t R_{j,t} \mid \Omega_{t-1}] = 1, \ \forall j = 1 \cdots\cdots N \tag{1}$$

where M_t is the known as a stochastic discount factor, an intertemporal marginal rate of substitution, or pricing kernel; $R_{j,t}$ is the gross return of asset j at time t and Ω_{t-1} is market information known at time $t-1$. Essentially equation (1) is the first-order condition of any consumer-investor's portfolio optimization problem, and it says that the expected present value of future payoffs, $R_{j,t}$, discounted at M_t from investing \$1 in asset j today should be equal to \$1. In other words, M_t satisfying equation (1) is a valid stochastic discount factor which ensures that there is no arbitrage opportunity when market is complete and in equilibrium. Without specifying the form of M_t, equation (1) has little empirical content since it is easy to find some random variable M_t for which the equation holds. Thus, it is the specific form of M_t implied by an asset-pricing model that gives equation (1) further empirical content (e.g., Ferson (1995)). Suppose M_t and $R_{j,t}$ have the following factor representations:

$$M_t = \alpha_0 + \sum_{k=1}^{K} \beta_k F_{k,t} + u_t \tag{2}$$

$$r_{j,t} = \alpha_j + \sum_{k=1}^{K} \beta_{jk} F_{k,t} + \varepsilon_{j,t} \quad \forall j = 1 \cdots\cdots N \tag{3}$$

where $r_{j,t} = R_{j,t} - R_{0,t}$ is the raw returns of asset j in excess of the risk-free rate, $R_{0,t}$, at time t, $E[u_t F_{k,t} \mid \Omega_{t-1}] = E[u_t \mid \Omega_{t-1}] = E[\varepsilon_{j,t} F_{k,t} \mid \Omega_{t-1}] = E[\varepsilon_{j,t} \mid \Omega_{t-1}] = 0 \ \forall j,k$; $F_{k,t}s$ are common risk factors which capture systematic risk affecting all assets $r_{j,t}$ including M_t; β_{jk} are the associated time-invariant factor loadings which measure the sensitivities of the asset to the common risk factors, while u_t is an innovation and $\varepsilon_{j,t}$ are idiosyncratic terms which reflect unsystematic risk. The risk-free rate, $R_{0,t-1}$, must also satisfy equation (1).

$$E[M_t R_{0,t-1} \mid \Omega_{t-1}] = 1 \tag{4}$$

Subtract Eq.(4) from Eq.(1), we obtain

$$E[M_t r_{j,t} \mid \Omega_{t-1}] = 0 \quad \forall j = 1 \cdots\cdots N \tag{5}$$

Apply the definition of covariance to equation (5), obtaining:

$$E[r_{j,t} \mid \Omega_{t-1}] = \frac{Cov(r_{j,t}; -M_t \mid \Omega_{t-1})}{E[M_t \mid \Omega_{t-1}]} \quad \forall j = 1 \cdots\cdots N \tag{6}$$

Substitute equation (2) into equation (6):

$$E[r_{j,t} \mid \Omega_{t-1}] = \sum_{k=1}^{K} \frac{-\beta_{jk}}{E[M_t \mid \Omega_{t-1}]} Cov(r_{j,t}, F_{k,t} \mid \Omega_{t-1}) = \sum_{k=1}^{K} \lambda_{k,t-1} Cov(r_{j,t}; F_{k,t} \mid \Omega_{t-1}) \tag{7}$$

where $\lambda_{k,t-1}$ is the time-varying price of factor risk. Equation (7) is a general conditional multi-factor asset-pricing model derived from the intertemporal consumption-investment optimization problem. In empirical test, the SDF is projected onto three risk factors: the world market risk, interest rate risk, and credit risk. I can now rewrite the conditional multi-factor asset-pricing model in equation (7) as

$$r_{j,t} = \lambda_{MKT.t-1} Cov(r_{j,t}, r_{MKT,t} \mid \Omega_{t-1}) + \lambda_{INT,t-1} Cov(r_{j,t}; r_{INT,t} \mid \Omega_{t-1}) + \lambda_{TED,t-1} Cov(r_{j,t}; r_{TED,t} \mid \Omega_{t-1}) + \varepsilon_{j,t} \tag{8}$$

where "MKT", "INT", and "TED" denote world market, interest rate, and credit risks, respectively. In modeling the stochastic evolution of interest rate and credit risk factors, I assume that they are mean-reverting as suggested by Longstaff and Schwartz (1995) and Duffee (1999). Based on these empirical facts, I define the interest rate factor (INT), and credit risk factor (TED) as follows:

$$INT_t = \beta_0 + \beta_1 INT_{t-1} + \varepsilon_{INT,t} \tag{9}$$

$$TED_t = \gamma_0 + \gamma_1 TED_{t-1} + \varepsilon_{TED,t} \tag{10}$$

III. Econometric Methodology

The conditional ICAPM in equation (8) has to hold for every asset, including the market portfolio. However, the model does not impose any restrictions on the dynamics of the conditional second moments. Given the computational difficulties in estimating a larger system of asset returns, parsimony becomes an important factor in choosing different parameterizations. In this paper, a parsimonious GARCH process originally proposed by Ding and Engle (1994) is modified to accommodate the GARCH-in-mean effect. Specifically, the dynamic process for the conditional variance-covariance matrix of asset returns is specified as:

$$H_t = H_0 * (\iota\iota' - aa' - bb') + aa' * \varepsilon_{t-1}\varepsilon_{t-1}' + bb' * H_{t-1} \tag{11}$$

where H_t is $(N+3)\times(N+3)$ time-varying variance-covariance matrix of asset returns and risk factors. $N+3$ is the number of equations where the first N equations are those for the Eurocurrency deposits, the $(N+1)^{th}$ equation is for the interest rate risk factor; the $(N+2)^{th}$ equation is for the credit risk factor, and the $(N+3)^{th}$ equation is for the world market risk factor. H_0 is the unconditional variance-covariance matrix of innovations, ε_t. ι is a $(N+3)\times 1$ vector of ones, a and b are $(N+3)\times 1$ vectors of unknown parameters, and * denotes element by element matrix product. The H_0 is unobservable and has to be estimated. As suggested by De Santis and Gerard (1997, 1998), it can be consistently estimated using iterative procedure. In particular, H_0 is set equal to the sample covariance matrix of the excess return in the first iteration, and then it is updated using the covariance matrix of the estimated residual at the end of each iteration. Under the assumption of conditional normality, the log-likelihood to be maximized can be written as:

$$\ln L(\theta) = -\frac{TN}{2}\ln 2\pi - \frac{1}{2}\sum_{t=1}^{T}\ln|H_t(\theta)| - \frac{1}{2}\sum \varepsilon_t(\theta)'\, H_t(\theta)^{-1}\varepsilon_t(\theta) \tag{12}$$

where θ is the vector of unknown parameters in the model and T is the number of observations over time. Since the normality assumption is often violated in financial time series, a quasi-maximum likelihood estimation (QML) proposed by Bollerselv and Wooldridge (1992) which allows inference in the presence of departures from conditional normality is used. Under standard regularity conditions, the QML estimator is consistent and asymptotically normal and statistical inferences can be carried out by computing robust Wald statistics. The QML estimates can be obtained by maximizing equation (12), and calculating a robust estimate of the covariance of the parameter estimates using the matrix of second derivatives and the average of the period-by-period outer products of the gradient. Optimization is performed using the Broyden, Fletcher, Goldfarb and Shanno (BFGS) algorithm, and the robust variance-covariance matrix of the estimated parameters is computed from the last BFGS iteration.

IV. Data and Summary Statistics

The sample consists of weekly data on four Eurocurrency deposit rates and spot exchange rates: deutsche mark (DM), Japanese (JP), U.K. pound (UK), and Swiss franc (SW). Three risk factors are a world market risk measured as the log first difference of Datastream world total return index (dividend included) in excess of the 7-day Eurodollar deposit rate (MKT), an interest rate risk measured as the yield difference between 10-year Treasury constant maturity rate and 7-day Eurodollar rate (INT), and a credit risk proxied by the TED spread (TED). The 7-day Eurodollar deposit rate is used as risk-free rate to compute the excess world equity returns, and the four Eurocurrency deposits. Excess world equity return is calculated as $\ln(\frac{p_{t+1}}{p_t}) - \frac{1}{52}\ln(1+i_t^{us\$})$ where p_t is the Datastream world total return index at time t; $i_t^{US\$}$ is annualized 7-day Eurodollar rate. Excess Eurocurrency return is calculated as $\frac{1}{52}\ln(1+i_t^*) + \ln(\frac{s_{t+1}}{s_t}) - \frac{1}{52}\ln(1+i_t^{US\$})$ where s_t is the spot exchange rate at time t expressed as U.S. dollar price of one unit of foreign currency; i_t^* is the annualized 7-day Eurocurrency deposit rate known at time t. The instruments used to model the dynamic of three risk prices include a dividend yield on Datastream world total return index in excess of the 7-day Eurodollar deposit rate (DIV), a change in the implied volatility index (VIX) from Chicago Board Option's Exchange, which provides an objective, observable, and dynamic measure of stock uncertainty, and a constant ($CONSTANT$). All the data are extracted from Datastream and cover the period from January 1, 1986 through December 22, 2002, which is a 887-data-point series. However, this paper works with rates of return and use the first difference of information variables, and finally all the instruments are used with a one-week lag, relative to the excess return series; that leaves 885 observations expanding from January 17, 1986 to December 27, 2002. All the data are extracted from Datastream.

Table 1 presents summary statistics of the continuously compounded excess world equity returns and Eurocurrency returns. As can be seen from Panel A, among the four Eurocurrency returns, UK has the highest mean return (0.056%) and JP has the lowest mean return (0.007%). As for the risk factors, TED has the highest mean return (0.567%), and MKT registers the lowest mean return (0.068%). Table 1 also reports Bera-Jarque and Ljung-Box statistics. In all cases, the Bera-Jarque test statistic strongly rejects the hypothesis of normally distributed returns. The Ljung-Box test statistics, which is defined as: $LB(k) = T(T+2)\sum_{j=1}^{k}\frac{\rho_j^2}{T-j}$ where ρ_j is the j^{th} lag autocorrelation, k is the number of autocorrelations, and T is the sample size (See Ljung and Box (1978)), for raw returns, $LB(24)$, is not significant for any of the Eurocurrency returns, implying that the

Eurocurrency market is weak-form efficient. For squared returns, $LB^2(24)$ is significant at least at the 5% level for in all cases, indicating strong nonlinear dependencies in those returns. This is consistent with the volatility clustering observed in most financial asset returns: Large (small) changes in prices tend to be followed by large (small) changes of either sign. The GARCH models used in this study are well known to capture this property. The unconditional correlation coefficients reported in the bottom half of Table 1 show that all Eurocurrency returns are positively correlated with all three factor returns except SW which is negatively correlated with TED.

V. Empirical Evidence

Many empirical studies have shown that the prices of risk are time varying. (e.g., Harvey (1991), Dumas and Solnik (1995), De Santis and Gerard (1997, 1998), Tai (1999, 2001), and among others.) This time-varying price of risk is economically appealing in the sense that investors use all available information to form their expectations about future economic performance, and when the information changes over time, they will adjust their expectations and thus their expected risk premia when holding different risky assets. The dynamics of prices of risk are chosen according to the theoretical international asset pricing model developed by Adler and Dumas (1983). In their model, the price of world market risk is a weighted average of the coefficients of risk aversion of all national investors. Since the weights measure the relative wealth of each country and if all investors are risk averse, the world price of market risk should be positive. Thus, similar to Bekaert and Harvey (1995) and De Santis and Gerard (1997,1998) an exponential function is used to model the dynamic of $\lambda_{MKT,t-1}$ and for the dynamics of $\lambda_{INT,t-1}$ and $\lambda_{TED,t-1}$, a linear specification is adopted because the model does not restrict the prices of interest rate and credit risks to be positive.

$$\lambda_{MKT,t-1} = \exp(\varphi'_{MKT} z_{t-1}) \tag{13}$$

$$\lambda_{INT,t-1} = \varphi'_{INT} z_{t-1} \tag{14}$$

$$\lambda_{TED,t-1} = \varphi'_{TED} z_{t-1} \tag{15}$$

where $z_{m,t-1} = \{CONSTANT, DIV, VIX\}$

is vector of information variables observed at the end of time $t-1$ and φ's are time-invariant vectors of weights. Table 2 contains the estimation results for equation (8). The parameter estimates for both the conditional mean and variance processes are reported in Panel A. Summary statistics concerning the risk premia and diagnostic test statistics for the standardized residuals are shown in Panel B. Finally, the hypothesis tests regarding the prices of risk and the predictability of information variables are presented in Panel C. The results are very encouraging. For example, the joint null hypothesis of zero prices of market, interest rate, and credit risks is strong rejected by the Wald test statistic with a p-value of zero. The joint null hypothesis of constant prices of three risks is also significantly rejected with a p-value of zero. Next, the null hypothesis of constant price of factor risk is tested individually, and the Wald test statistic rejects the null at 1% level for INT and TED, suggesting that not only are interest rate and credit risks priced in the Eurocurrency market, but also they are time-varying. The two information variables selected to predict the dynamics of the risk prices are all significant, which are confirmed by the Wald test statistics. The strong predictability of VIX found here shed a new light on the usefulness of implied volatility index in predicting the dynamics of risk prices since VIX has not been used in testing conditional asset-pricing model.

Next, consider the parameter estimates for the conditional variance process. As can be seen in the table, the elements in the vectors a and b are statistically significant at 1% for all return series, suggesting strong GARCH effect in both Eurocurrency and world equity markets.

Panel B reports some diagnostic tests performed on the standardized residuals and the standardized residuals squared for the purpose of assessing the adequacy of the model. Most of the Bera-Jarque test statistics for the standardized residuals are lower than the corresponding statistics for the original return series. However, the hypothesis of normality is still rejected for all cases but DM. Such evidence against normality validates the use of robust standard errors computed from using the quasi-maximum likelihood method of Bollerslev and Wooldridge (1992). I also compute the Ljung-Box portmanteau statistics to test the null hypothesis of zero autocorrelation up to 24 lags in both the standardized residuals and the standardized residuals squared. The results in Panel B indicate that the MGARCH(1,1)-M specification used in this study performs quite well in capturing the dynamics of the conditional first and second moments with few exceptions.

One advantage of modeling the conditional second moments via MGARCH approach is that it enables one to recover some interesting statistics such as conditional volatility, and, more importantly, the size of different risk premia. These interesting statistics will not be available if one leaves the condition second moments unspecified such as the pricing kernel approach employed by Dumas (1993), Dumas and Solnik (1995), and Tai (1999).[2] Panel B of Table 2 reports those statistics. For example, the predicted weekly average risk premium for Eurocurrency return is –0.0004% for DM, 0.0221% for JP, -0.0058% for UK, and -0.01% for SW. All these risk premia are basically dominated by the market risk premia; however, the credit risk premium is still an important component risk premium in Eurocurrency market because the annualized credit risk premia range from negative 52 basis points for DM to negative 64 basis points for SW. These statistics suggest the importance of modeling the time-varying credit risk premium in the Eurocurrency market.

VI. Summary and Concluding Remarks

Most of previous studies on credit risk have been focused on corporate bond markets. This paper focuses on whether the credit risk is priced in the Eurocurrency market. The empirical test relies on a multivariate GARCH (1,1) - in- mean version of the ICAPM model to describe the joint stochastic process of three state variables: world market risk, interest rate risk, and credit risk, during the period January 1986 to December 2002. The paper documents a negative, significant, and time-varying systematic credit risk premium.

[2] See the comments provided by Campbell Harvey in Dumas (1993).

Table 1
Summary statistics of Eurocurrency and risk factor returns [a]

	DM	*JP*	*UK*	*SW*	*INT*	*TED*	*MKT*
Mean (%)	0.023	0.007	0.056	0.015	1.188	0.567	0.068
Std. Dev. (%)	1.520	1.673	1.372	1.682	1.245	0.321	1.979
Minimum (%)	-5.244	-6.174	-10.095	-6.775	-3.652	0.088	-13.755
Maximum (%)	5.144	14.500	5.005	6.023	3.721	1.624	7.608
$B-J$	13.145**	1852.35**	518.58**	23.851**	12.783**	101.166**	768.406
$LB(24)$	19.922	29.481	26.101	17.987	15107.40**	13612.64**	31.679**
$LB^2(24)$	90.914**	65.445**	41.605*	42.253*	15230.11**	12987.74**	45.836**
	DM	*JP*	*UK*	*SW*	*INT*	*TED*	*MKT*
DM	1						
JP	0.505	1					
UK	0.701	0.363	1				
SW	0.928	0.521	0.666	1			
INT	0.025	0.064	0.000	0.018	1		
TED	0.006	0.032	0.013	-0.007	-0.426	1	
MKT	0.135	0.238	0.150	0.062	-0.014	0.010	1

[a] (i) The statistics are based on weekly data from 01/17/1986 to 12/27/2002 (885 observations). The excess Eurocurrency returns are deutsche mark (DM), Japanese (JP), U.K. pound (UK), and Swiss franc (SW). Three risk factors are a world market risk measured as the log first difference of Datastream world total return index (dividend included) in excess of the 7-day Eurodollar deposit rate (MKT), an interest rate risk measured as the yield difference between 10-year Treasury constant maturity rate and 7-day Eurodollar rate (INT), and a credit risk proxied by the TED spread (TED). The 7-day Eurodollar deposit rate is used as risk-free rate to compute the excess world equity returns, and the four Eurocurrency deposits. (ii) The Bera-Jarque ($B-J$) tests normality based on both skewness and excess kurtosis and is distributed χ^2 with two degrees of freedom. (iii) $LB(24)$ and $LB^2(24)$ denote the Ljung-Box test statistics for up to the 24th order autocorrelation of the raw and squared returns, respectively. (iv) * and ** denote statistical significance at the 5% and 1% level, respectively.

Table 2: ICAPM with time-varying risk prices [a]

Panel A: Parameter estimates

Conditional mean process
world prices of market, interest rate, and credit risks

	CONSTANT	*DIV*	*VIX*
φ_{MKT}	1.683	0.382	-0.672
	(0.667)*	(0.550)	(2.715)
φ_{INT}	888.159	813.791	326.920
	(242.401)**	(162.298)**	(606.315)
φ_{TED}	-132.570	-112.896	-291.583
	(25.353)**	(26.887)**	(103.458)**

Conditional variance process

	DM	*JP*	*UK*	*SW*	*INT*	*TED*	*MKT*
a	0.187	0.225	0.183	0.191	0.362	0.352	0.180
	(0.016)**	(0.030)**	(0.024)**	(0.017)**	(0.001)**	(0.011)**	(0.030)**
b	0.965	0.963	0.959	0.962	0.929	0.934	0.978
	(0.007)**	(0.011)**	(0.013)**	(0.007)**	(0.000)**	(0.004)**	(0.008)**

Panel B: Summary statistics and residual diagnostics

Summary statistics

	DM	*JP*	*UK*	*SW*	*INT*	*TED*	*MKT*
Predicted total risk premium (%)	0.0004	0.0221	0.0058	-0.0100	1.1727	0.5660	0.1173
Market risk premium (%)	0.0174	0.0322	0.0169	0.0091			0.1600
Interest risk premium (%)	-0.0070	-0.0212	0.0006	-0.0067			0.0034
Credit risk premium (%)	-0.0100	0.0111	-0.0117	-0.0124			-0.0472
Prices of factor risk					289.733	-49.707	411.628
Conditional volatility (%)	1.5087	1.6315	1.3618	1.6725	0.4187	0.0920	1.9298
Residual diagnostics							
$B-J$	4.929	513.09**	3613.77**	556.35**	297310**	733.66**	918.65**
$LB(24)$	16.171	26.910	16.246	18.926	46.048**	32.090	31.885
$LB^2(24)$	37.134*	12.304	12.582	9.868	3.251	100.32**	13.747

Table 2 (continued)

Panel C: Hypothesis tests concerning prices of risks and the predictability of instruments			
Null Hypothesis	**Wald**	**d.f.**	**P-Value**
1. Are the prices of interest rate, credit and market risks equal to zero? $H0: \varphi_{INT}^{Z} = \varphi_{TED}^{Z} = \varphi_{MKT}^{Z} = 0; Z = \{CONSTANT, DIV, VIX\}$	1597.33	9	0.000
2. Are the prices of interest rate, credit and market risks constant? $H0: \varphi_{INT}^{Z} = \varphi_{TED}^{Z} = \varphi_{MKT}^{Z} = 0; Z = \{DIV, VIX\}$	60.476	6	0.000
3. Are the prices of interest rate risk equal to zero? $H0: \varphi_{INT}^{Z} = 0; Z = \{CONSTANT, DIV, VIX\}$	28.936	3	0.000
4. Are the prices of interest rate risk constant? $H0: \varphi_{INT}^{Z} = 0; Z = \{DIV, VIX\}$	25.145	2	0.000
5. Is the price of credit risk equal to zero? $H0: \varphi_{TED}^{Z} = 0; Z = \{CONSTANT, DIV, VIX\}$	46.907	3	0.000
6. Is the price of credit risk constant? $H0: \varphi_{TED}^{Z} = 0; Z = \{DIV, VIX\}$	30.776	2	0.000
7. Is the price of market risk equal to zero? $H0: \varphi_{MKT}^{Z} = 0; Z = \{CONSTANT, DIV, VIX\}$	9.496	3	0.023
8. Is the price of market risk constant? $H0: \varphi_{MKT}^{Z} = 0; Z = \{DIV, VIX\}$	0.488	2	0.783
9. Is there any predictability from the excess dividend yield? $H0: \varphi_{INT}^{Z} = \varphi_{TED}^{Z} = \varphi_{MKT}^{Z} = 0; Z = \{DIV\}$	31.958	3	0.000
10. Is there any predictability from implied volatility? $H0: \varphi_{INT}^{Z} = \varphi_{TED}^{Z} = \varphi_{MKT}^{Z} = 0; Z = \{VIX\}$	8.228	3	0.041

[a] Returns: $r_{j,t} = \lambda_{INT,t-1} h_{jINT,t} + \lambda_{TED,t-1} h_{jTED,t} + \lambda_{MKT,t-1} h_{jMKT,t} + \varepsilon_{j,t}$

$j = DM, JP, UK, SW, MKT$

$INT_t = \beta_0 + \beta_1 INT_{t-1} + \varepsilon_{INT,t}$

$TED_t = \gamma_0 + \gamma_1 TED_{t-1} + \varepsilon_{TED,t}$

$\boldsymbol{\varepsilon}_t \mid \Omega_{t-1} \sim N(0, H_t)$

where $\lambda_{TED,t-1} = \varphi_{TED}' z_{t-1}$; $\lambda_{INT,t-1} = \varphi_{INT}' z_{t-1}$; $\lambda_{MKT,t-1} = \exp(\varphi_{MKT}' z_{t-1})$;

$Z_{t-1} = \{CONSTANT, DIV, VIX\}$

GARCH: $H_t = H_0 * (\iota\iota' - aa' - bb') + aa' * \varepsilon_{t-1}\varepsilon_{t-1}' + bb' * H_{t-1}$

Standard errors are given in parentheses. $LB(24)$ and $LB^2(24)$ are the Ljung-Box test statistics of order 24 for serial correlation in the standardized residuals and standardized residuals squared. * and ** denote statistical significance at the 5% and 1% level, respectively.

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