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A Study of the Financial Stress Using Credit Spreads*

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In this study, we identify cointegration relationship between corporate bond and Treasury Bond yields. Since there exists nonlinear pressure to return to long-run equilibrium level, TVECM (threshold VECM) is employed. The estimation results are used to evaluate the financial stress embedded in the bond markets. According to the empirical analysis, we could find that Korean financial market is generally stabilized since 2012, when the impact of the U.S. financial crisis has been extinguished, but firms with relatively low credit ratings face a considerably high level of financial stress even after the crisis.

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1. INTRODUCTION

According to the theory of law of one price, a good must sell for the same price in all locations. Otherwise, there is a chance for profit through arbitrage. But the prices can be different when the benefit of arbitrage is limited due to factors such as transaction costs, constraints, and risks. In other words, profit generation through arbitrage is possible only if the price difference of the goods traded in both markets is significant and exceeds the costs associated with the arbitrage transaction. Recently, the diversification and the efficiency by the development of information technology is likely to limit the opportunity of arbitrage. For instance, highly-rated bond market, where information is very efficiently circulated, have low transaction costs and constraints, and hence the value of bond is accurately evaluated.

The difference in the yields between two financial assets is called a credit spread. The magnitude of the spread reflects the relative risk between the two assets. Since Merton (1974), researchs have been actively conducted to identify the determinants of bond prices and credit spreads. In particular, studies such as Duffee (1998), Leland and Toft (1996), and Longstaff and Schwartz (1995) suggest a hypothesis that credit spreads are inversely related to government bond yields, which are considered safe assets. This hypothesis was endorsed by the majority of economists before the U.S. financial crisis in 2008. However, the relevance of the theory has drastically declined because the high uncertainty during the crisis resulted in a synchronized increase of government bond yield and the credit spread. It is the case in Korea as well as in the U.S..[1)]

Assuming a highly-rated corporate bond and Treasury Bond are strong substitutes, it is very likely that there is a stable spread between the yields of the two financial assets. In this case, it is general to utilize the vector error correction model (VECM), assuming that there is a long-run equilibrium

[1)] Figure 1 - figure 3 present the credit spreads between highly-rated corporate bonds (Grade AAA, AA^{-}, and A^{+}) and Treasury Bond in Korea. In 2008 and 2009, the credit spread and Treasury Bond yields increase at the same time.

between the two returns. This approach is based on the assumption that even if the difference in returns between the two financial assets expands in the short term, it will linearly and immediately return to the equilibrium level through arbitrage transactions or policy intervention. However, if the pressure to return to the equilibrium depends on the level of credit spread, then linear VECM is unlikely to account for the movements of bond yields. Suppose that when a credit spread deviates from the equilibrium level, it takes adjustment costs to return to the equilibrium. In this case, if the size of the departure is not large enough, then the possibility of the adjustment is low because the benefits of the adjustment could be less than the costs. On the other hand, if the size of the departure exceeds a certain threshold, adjustment for returning to the equilibrium is likely to be active. The aim of this study is to test for asymmetric adjustment to equilibrium spread using the threshold VECM. Therefore, we first examine the cointegration relationship between the corporate bond and the Treasury Bond yields, and then check the relevance of a linear VECM for those variables. When we find that there is non-linearity in the pressure for returning to the equilibrium, TVECM (Threshold VECM) is utilized. Moreover, if we find that there exists an asymmetry, we may infer the magnitude of financial stress using the estimation results.

Since introduced by Balke and Fomby (1997), TVECM is widely used in studies to model the nonlinear adjustment process to the long-term equilibrium. For example, Lo and Zivot (2001) use the 41 commodities traded in 29 U.S. cities to assess the law of one price, and conclude that the threshold cointegration relationship appears in markets mainly for tradable goods. The purchasing power parity is frequently examined utilizing TVECM. Bec, Salem, and Carrasco (2004) show that the threshold VECM is more suitable using the European time series of exchange rates. Gouveia and Rodrigues (2004) find that non-linear model can be applied to eight pairs of currencies using time series of 14 countries. According to Heimonen (2006), analysis using data from Sweden and Finland suggests that there is non-linearity in the exchange rate adjustment, which implies the operation of a target zone exchange rate system in those countries. Threshold cointegration is applied to other macroeconomic issues. Million (2004) concludes that the coefficients of policy reaction function of the Fed change with the deviation from inflation target. Jawadi, Million, and Arouri (2009) estimate TVECM using the data of six Latin American countries and the United States to show that the stock markets of Mexico and Chile have a significant coincidence with the U.S. stock market, and adjustments occur when the stock index exceeds a certain threshold.

The development of corporate bond market in Korea was limited until 2000.[2)] Also, until the onset of the U.S. financial crisis, the movements of bond yields did not deviate much from the conventional theory such as Duffee (1998). Therefore, threshold VECM was not considered to account for credit spread in Korean bond market. There are some studies which focus on the credit spread in Korea: Jie and Park (2002) examine predictive power of short and long term yield spread and credit spread on Korean business cycle. They find that the short and long term yield spread provides useful information for predicting economic fluctuations while credit spread does not. Cho and Lee (2005) conclude that credit spreads are affected by macroeconomic conditions and expected default probability, and have long-term co-movement with return on risk-free assets. Seo and Kim (2003) estimate linear VECM with corporate bond and Treasury Bond yields. The empirical analysis indicates that the long-run equilibrium relationship between the Treasury Bond and corporate bond yields is stable during the foreign exchange crisis in 1997. Those studies are based on the assumption that the adjustment process of credit spread is linear. Therefore, it is worthwhile to examine the relevance of TVECM to account for the dynamics of Korean financial market. If threshold cointegration is identified, then we can infer the financial stress utilizing the threshold values of credit spread.

For the empirical analysis, we use three-year Treasury Bond and three-year corporate bond yields. Yields on grade AAA, AA^-, and A^+ corporate bonds

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[2)] In 1997, when the foreign exchange crisis occurred, 85% of corporate bond was issued as guaranteed bonds, so that the credit spread did not provide sufficient information on the issuer's credit risk.

are selected because those assets can be regarded as substitutes of Treasury Bond, which is assumed to be a safe asset.[3)] The empirical results are summarized as follows: First, there exist unit roots in the yields of all the bonds used in the analysis. Cointegration rank test results imply that there is a long run equilibrium relation between the yields, and hence VECM or TVECM could be applied. Second, it is concluded that TVECM is more appropriate model because the null hypothesis of linear VECM is consistently rejected by Hansen and Seo (2002) test and Tsay (1998) test. Finally, we could measure the financial stress utilizing the TVECM estimation results. The analysis imply that Korean financial market has generally been stabilized after 2012 when the impact of the U.S. financial crisis has been extinguished. However, the results with credit spread of grade A^+ corporate bond suggests that firms with relatively low credit rating has been under considerable financial stress since the end of 2014.

This paper is organized as follows: Section 2 briefs the methodology used for empirical analysis. In section 3, empirical results such as basic statistics of data, unit root test, cointegration rank test, and TVECM estimation result are summarized. Utilizing the estimated threshold values, financial stress is evaluated. Concluding remarks are presented in section 4.

2. THRESHOLD MODEL OF CREDIT SPREAD

Let us consider two financial assets which are substitutes. In this case, the spread of the two financial asset returns is unlikely to exceed a certain level for a long time because of the pressure to return to the equilibrium level through the intervention of financial authorities or arbitrage transactions. Thus, if there is a cointegration relationship between the two returns, a vector error correction model (VECM) can be set up, which uses this relationship as

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3) Grade BBB^+ or BBB^- corporate bonds are classfied as lowly-rated bonds. Because we need to consider the long-run relationship between coroprate bond and Tresaury Bond, grade AAA, AA^-, and A^+ bonds, which are highly-rated bonds and likely to be sutstitutes of Treasury bond, are used for the analysis.

an error correction term. Specifically, suppose that the two bond yields are denoted by (2×1) vector y_t, then the linear VECM with p lags can be represented as:

$$\Delta y_t = c + \phi s_t + A_1 \Delta y_{t-1} + \cdots + A_p \Delta y_{t-p} + \varepsilon_t, \quad (1)$$

where (2×1) vector ϕ on the error correction term $s_t \left(= y_{1,t} - \beta y_{2,t}\right)$ denotes the pressure to return to the equilibrium level as the credit spread increases. Parameter β implies the cointegration relation between the two yields. In linear VECM, the pressure to return to the equilibrium is expressed as a linear function of the error correction term.[4] However, it is possible that the pressure to return to the equilibrium changes nonlinearly depending on the size of the credit spread. If the credit spread has a nonlinear effect on the pressure, then linear VECM is not appropriate for the analysis. To understand the reason, suppose that adjustment costs are required to return to the long-run equilibrium level when the credit spread deviates from the equilibrium. In this case, if the size of the departure is not large, the possibility of adjustment is low because the benefits are less than the costs. On the other hand, if the size of the departure exceeds a certain threshold, adjustment for returning to the equilibrium is likely to be active. If this nonlinearity is found to exist, then VECM becomes inappropriate to account for the dynamic fluctuations of the two yields.

If linear VECM is rejected, then we can assume threshold VECM that the values of the coefficients change according to the level of credit spread. Assuming a generalized model with M regime, the equation (1) can be rewritten as TVECM as follows:

$$\Delta y_t = \sum_{i=1}^{M} \Xi^{(i)} X_t 1(\gamma_{i-1} < s_{t-1} \le \gamma_i) + \varepsilon_t, \quad (2)$$

[4] Some suggest that estimating the model with subsamples (before 2007 and after 2009) because there could have been a structural break after the financial crisis. I did not follow those suggestions since the cointegration relations are stable over the whole sample period.

where $X_t \equiv \left[1,\ s_{t-1},\ \Delta y'_{t-1},\ \cdots,\ \Delta y'_{t-p}\right]'$ and $\Xi^{(i)} \equiv \left[c^{(i)},\ \phi^{(i)},\ A_1^{(i)},\ \cdots,\ A_p^{(i)}\right]$ denote the vectors of explanatory variables and coefficients in *i*th regime, respectively. Threshold values are represented by $\{\gamma_0,\ \cdots,\ \gamma_M\}$ where $\gamma_0 = -\infty$ and $\gamma_M = \infty$. Function $1(\cdot)$ is the indicator function which is 1 when the condition in the parentheses is satisfied and 0 otherwise. When $M = 1$, the model boils down to linear VECM. If the threshold is known, $\Xi^{(i)}$ can be estimated by the least squares method. However, if the threshold is to be estimated, the least squares method cannot be used because the indicator function is nonlinear. Therefore, concentrated least squares method based on grid search is used as an alternative.[5)]

To test the null hypothesis of linear VECM, we utilize Hansen and Seo (2002) approach, which provides a heteroskedastic consistent LM test statistic. In addition, test proposed by Tsay (1998) is applied to check the results are consistent.

3. EMPIRICAL ANALYSIS

3.1. Data

The data used in the empirical analysis are summarized in table 1. We assume that three-year Treasury Bond (*TB*) is risk-free asset. As risky assets, grade AAA, AA^-, and A^+ three-year corporate bonds are considered

Table 1 Data

(unit: %)

Variable	Remarks
TB	Treasury Bond (3 Year) Yields
AAA	Grade AAA Corporate Bond (3 Year, Non-Guaranteed) Yields
AA	Grade AA^- Corporate Bond (3 Year, Non-Guaranteed) Yields
AP	Grade A^+ Corporate Bond (3 Year, Non-Guaranteed) Yields

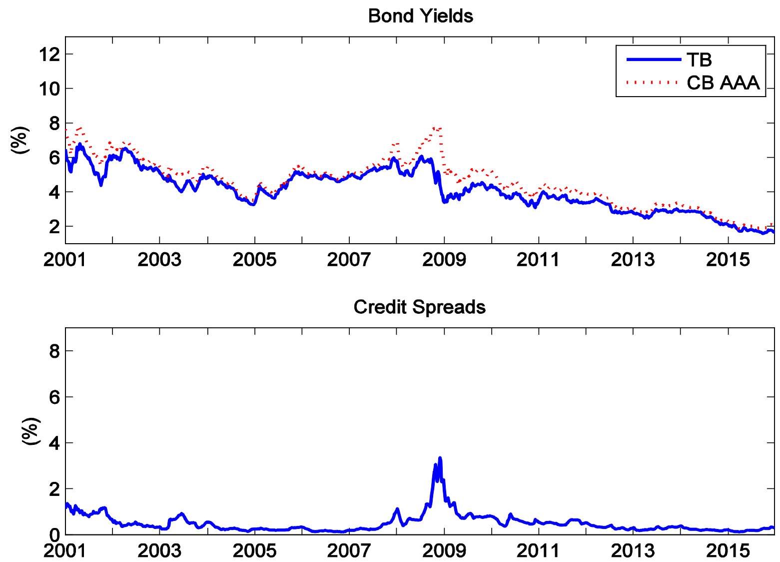
Note: Data is obtained from Bloomberg Professional Service.

[5)] A detailed explanation of this technique is found in Hansen and Seo (2002).

(each bond is represented by variable names of *AAA*, *AA*, and *AP*, respectively). Those three assets are chosen because they are highly-rated corporate bonds and hence are likely to be substitutes of Treasury Bond. The sample period is from 2001 to 2015 when the daily yields of the bonds are available. The frequency of the data is weekly by averaging the daily figures over a week.[6)] The sample size of the weekly data is 783.

Figure 1 - figure 3 show the movements of credit spreads between Treasury Bond and corporate bond yields by grade. According to figure 1, grade AAA corporate bond yields are very similar to Treasury Bond yields, and credit spreads are not large, indicating that the two assets are strong substitutes.[7)] However, the fact that grade AAA corporate bond yields always exceed Treasury Bond yields during the sample period implies the risk inherent in corporate bonds. On the other hand, the magnitude of the credit spread has

Figure 1 Bond Yields and Credit Spread (TB vs. AAA)



6) We could not use daily data because there are dates when only grade AA⁻ bonds are traded.
7) The fact that the estimated cointegration coefficient β has a value close to 1 also suggests a considerable substitute relationship between the two assets.

Figure 2 Bond Yields and Credit Spread (TB vs. AA⁻)

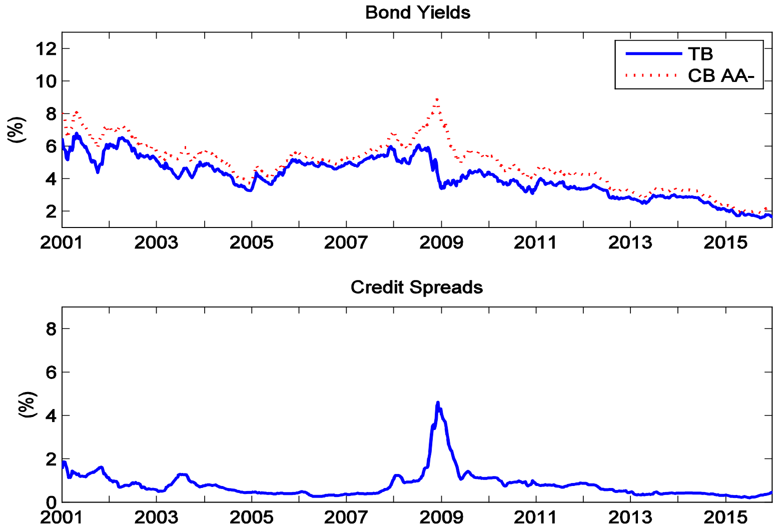
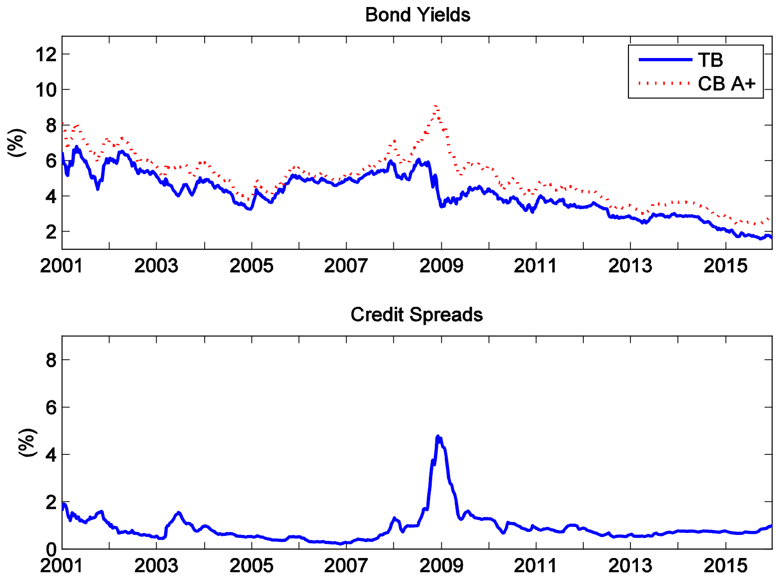


Figure 3 Bond Yields and Credit Spread (TB vs. A⁺)



increased significantly during 2008 and 2009, indicating that the financial crisis in U.S. has had a stong impact on Korean financial market. The credit spreads of grade AA^- and grade A^+ corporate bond yields are relatively higher than grade AAA corporate bond yields in figure 2 and figure 3, which indicates the higher risk premium on those assets. In particular, the credit spreads of the two corporate bonds exceed 400 basis points during the financial crisis period, suggesting that firms with lower credit ratings should have had greater difficulties in borrowing money.[8)]

In table 2, basic statistics of credit spreads are presented by period. The table shows the mean of each credit spread, interquartile range (IQR), and autocorrelation coefficient, over the periods of pre-crisis (Panel A), during the crisis (Panel B), post-crisis (Panel C), and the whole period (Panel D).[9)] The

Table 2 Statistics of Credit Spreads

Statistic	*AAA−TB*	*AA−TB*	*AP−TB*
Panel A: 2001/01/03 - 2007/06/27			
Mean	0.4279	0.7088	0.7192
IQR	0.3158	0.5054	0.5537
AC(1)	0.9793	0.9853	0.9835
Panel B: 2007/07/04 - 2009/06/24			
Mean	1.0342	1.5979	1.7420
IQR	0.7710	1.1905	1.6020
AC(1)	0.9653	0.9863	0.9872
Panel C: 2009/07/01 - 2015/12/30			
Mean	0.3962	0.6241	0.8151
IQR	0.2980	0.4463	0.1962
AC(1)	0.9840	0.9899	0.9804
Panel D: 2001/01/03 - 2015/12/30			
Mean	0.4947	0.7901	0.8967
IQR	0.4030	0.5367	0.4495
AC(1)	0.9833	0.9938	0.9940

Note: IQR and AC(1) represent interquartile range and first order autocorrelation coefficients, respectively.

8) After the global financial crisis, commercial banks have become more cautious about corporate lending due to the stronger prudential regulation. Therefore, firms with relatively lower ratings had to increase bond issuances, resulting in the higher yields on those bonds.

9) IQR is a statistic that measures the degree of variance, defined as the difference between the upper 25 percent quartile minus the lower 25 percent quartile.

mean of credit spread suggests the following facts: First, as we have already seen in figure 1 - figure 3, we can find that the credit spread increases as bond issuer's credit rating declines. Second, during the financial crisis, there is a significant rise (more than 100 basis points) in the credit spreads. Third, credit spreads of grade AAA and grade AA^- corporate bonds during the post-crisis period are lower than before the crisis, while that of corporate bonds with grade A^+ are higher than before the crisis. This implies that firms with relatively lower credit ratings have more constraints in funding after the financial crisis. The volatility of credit spreads based on IQR changes over the periods. As credit rating declines, IQR increases during the pre-crisis and financial crisis periods, but the credit spreads of grade A^+ corporate bonds are the least volatile during the post-crisis periods. We can understand that the firms with relatively low credit rating have consistently had tough time in funding since after the financial crisis. The first autocorrelation coefficient is over 0.96 over all the periods, which is related to the fact that there is a very strong inertia in the movement of credit spreads.[10)]

3.2. Unit Root Tests

We start with testing whether the yield data contains unit root or not. Table 3 and table 4 show the ADF test statistics and their critical values which are based on the test regressions with a time trend and a drift term.[11)] The test regression equation for Panel A is as follows:

$$\Delta y_t = \beta_1 + \beta_2 t + \pi y_{t-1} + \sum_{j=1}^{k} \gamma_j \Delta y_{t-j} + u_t. \quad (3)$$

In the table, τ_3, ϕ_2, and ϕ_3 represent *t*-statistic for $H_0 : \pi = 0,$ likelihood ratio statistics for $H_0 : \beta_1 = \beta_2 = 0,$ and for $H_0 : \beta_2 = \pi = 0,$

10) Due to the presence of such strong inertia, the lag lengths in VECM and TVECM generally exceed 10 weeks.

11) The lag length is selected by AIC (Akaike Information Criterion).

respectively. The test regression equation for Panel B is as follows:

$$\Delta y_t = \beta_1 + \pi y_{t-1} + \sum_{j=1}^{k} \gamma_j \Delta y_{t-j} + u_t, \quad (4)$$

where τ_2 and ϕ_1 represent *t*-statistic for $H_0 : \pi = 0$ and likelihood ratio statistic for $H_0 : \beta_1 = \pi = 0$, respectively. Panel A of table 3 shows that the yields of four bonds contain unit root without trend since the three null hypotheses cannot be rejected. Also, the null hypothesis cannot be rejected when the test regression with a drift term is used. Therefore, it is concluded that those four time series contain unit roots, but neither a linear trend nor a drift term is present.

Table 3 ADF Test (Level)

	TB	*AAA*	*AA*	*AP*	CV 1%	CV 5%	CV 10%
Panel A: with Trend							
τ_3	–2.86	–2.93	–2.39	–2.73	–3.96	–3.41	–3.12
ϕ_2	3.26	3.22	2.36	2.77	6.09	4.68	4.03
ϕ_3	4.1	4.29	2.85	3.74	8.27	6.25	5.34
Panel B: with Drift Term							
τ_2	–1.6	–1.79	–1.63	–2.03	–3.43	–2.86	–2.57
ϕ_1	2.06	2.27	2.03	2.47	6.43	4.59	3.78

Table 4 ADF Test (1st Difference)

	TB	*AAA*	*AA*	*AP*	CV 1%	CV 5%	CV 10%
Panel A: with Trend							
τ_3	–12.88	–9.72	–9.77	–8.58	–3.96	–3.41	–3.12
ϕ_2	55.35	31.49	31.84	24.58	6.09	4.68	4.03
ϕ_3	83.03	47.23	47.75	36.85	8.27	6.25	5.34
Panel B: with Drift Term							
τ_2	–12.89	–9.73	–9.78	–8.59	–3.43	–2.86	–2.57
ϕ_1	83.14	47.3	47.82	36.92	6.43	4.59	3.78

Table 5 KPSS Test

	TB	*AAA*	*AA*	*AP*	CV 1%	CV 5%	CV 2.5%	CV 10%
$\hat{\eta}_{\mu}$	2.75	2.4	2.26	2.09	0.74	0.57	0.46	0.35
$\hat{\eta}_{\tau}$	0.37	0.42	0.43	0.39	0.22	0.18	0.15	0.12

Note: $\hat{\eta}_{\mu}$ and $\hat{\eta}_{\tau}$ represent the test statistic for level-stationarity and trend-stationarity, respectively.

When the yield data is first differenced, the unit root test results change significantly. As table 4 presents, we see that the null hypothesis of a unit root is strongly rejected in the two test regressions. Consequently, it is concluded that the four yield series is *I*(1).

To confirm the conclusion, we conducted Kwiatkowski, Phillips, Schmidt, and Shin (1992) test which has a stationary process as the null hypothesis. The test statistic $\hat{\eta}_{\mu}$ and $\hat{\eta}_{\tau}$ represent the test statistic for level-stationarity and trend-stationarity, respectively. As table 5 indicates, the null hypotheses of a level-stationarity and trend-stationarity of the yield data are strongly rejected, which supports the conclusion based on the ADF test that bond yield series are unit root processes.

3.3. Cointegration Rank Test

Since it is concluded that AAA_t, AA_t, and AP_t series are all *I*(1), we conduct Johansen cointegration rank test on the pairs of the corporate bond and Treasury Bond yields. Table 6 shows the values of trace statistic, $\lambda_{\max}$ statistic, and corresponding critical values. Both of the trace statistic and the $\lambda_{\max}$ statistic indicate that the null hypothesis of cointegration rank $r = 0$ is strongly rejected over the three pairs of yields. On the other hand, we could not reject the null hypothesis of $r \leq 1$ at the least 10 percentage of significance level. Hence, we conclude that the cointegration rank is $r = 1$.

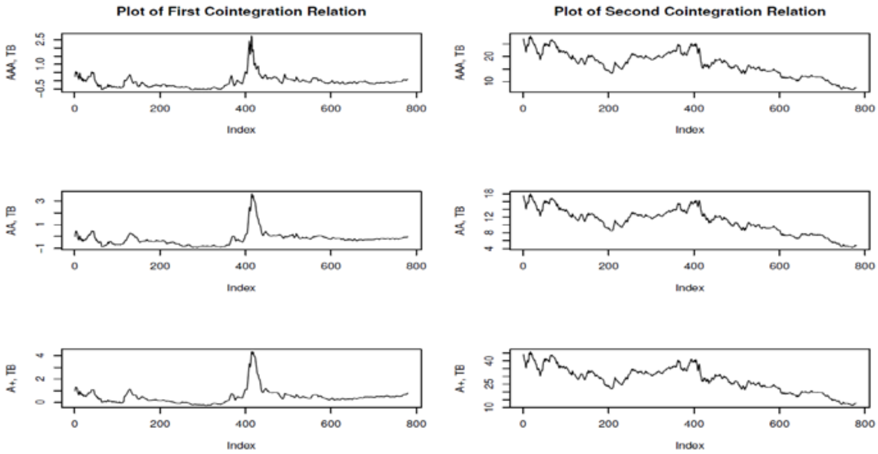
Figure 4 supports the conclusion on the cointegration rank. The first cointegration relation seems to be stationary, while the second one is undoubtedly nonstationary, which goes along with cointegration rank $r = 1$.

Table 6 Johansen Test

	AAA, TB	*AA, TB*	*AP, TB*	CV 1%	CV 5%	CV 10%
Panel A: Trace Statistic						
$r \leq 1$	2.56	2.18	1.92	11.65	8.18	6.50
$r = 0$	19.93	18.54	16.09	23.52	17.95	15.66
Panel B: λ_{max} Statistic						
$r \leq 1$	2.56	2.18	1.92	11.65	8.18	6.50
$r = 0$	17.37	16.36	14.18	19.19	14.9	12.91

Notes: 1) Trace test sets the cointegration rank for the alternative hypothesis at $r_1 = r_0 + 1 = 2$.
2) Maximum eigenvalue (λ_{max}) test sets $r_1 = 3$.

Figure 4 Cointegration Relations



Note: Two cointegration vectors are estimated. The left column shows the correlation relation $\beta_1' y$ and the right one does the correlation relation $\beta_2' y$.

3.4. Tests for Threshold Cointegration

First of all, we apply the test of threshold cointegration proposed by Hansen and Seo (2002), namely, sup LM test to the data. The sup LM statistic has a nonstandard asymptotic distribution as shown by Hansen and Seo (2002). Therefore, they propose two bootstrapping techniques for calculating the *p*-values for the test: One is the fixed regressor bootstrap and the other is the residual bootstrap. Both of the *p*-values are calculated with 1000 simulation

Table 7 Hansen-Seo Test

Pairs	Boot Type	Nboot	sup*LM*	*P*-value
AAA, *TB*	FixedReg	1,000	136.1	0.037
	ResBoot	1,000	136.1	0.001
AA, *TB*	FixedReg	1,000	126.9	0.049
	ResBoot	1,000	126.9	0.000
AP, *TB*	FixedReg	1,000	135.5	0.055
	ResBoot	1,000	135.5	0.010

Table 8 Tsay Test

Pairs	$m_0 = 56$	$m_0 = 84$	$m_0 = 112$	$m_0 = 140$
AAA, *TB*	1,526.78 (0.0000)	1,466.80 (0.0000)	1,301.46 (0.0000)	997.87 (0.0000)
AA, *TB*	1,089.23 (0.0000)	768.47 (0.0000)	736.45 (0.0000)	797.57 (0.0000)
AP, *TB*	753.71 (0.0000)	723.95 (0.0000)	756.45 (0.0000)	648.53 (0.0000)

Notes: 1) The statistic represents the threshold nonlinearity measure of Tsay (1998). 2) The values in the parentheses are corresponding *p*-values. 3) Lag lengths are selected based on AIC. 4) m_0 represents the size of initial sample for RLS (recursive least square) estimation.

replications. We reject the null hypothesis of linear cointegration if the bootstrapping *p*-values are smaller than the size chosen. Before we implement the test of threshold cointegration, we estimate the threshold VECM. AIC is used to select the lag length. The $\sup LM$ test statistics and *p*-values for the models with three different pairs of yields are presented in table 7. Both of the tests using fixed regressor bootstrap (represented by FixedReg) and residual bootstrap (represented by RegBoot) clearly rejects the null hypothesis of linear cointegration. Therefore, it is concluded that threshold cointegration is more appropriate for our data.

To check the robustness of Hansen and Seo (2002) test results, we conducted Tsay (1998) test. The results are summarized in table 8. The size of initial sample (m_0) is chosen as $m_0 = cT^{1/2}$ and $c \in \{2, 3, 4, 5\}$ as Tsay (1998) suggests. Since we have 783 sample points, we selected $m_0 \in \{56, 84, 112, 140\}$. The results show that the *p*-values of the test statistic are very close to 0 regardless of the size of the initial sample. Therefore, the null hypothesis that the model is linear can be easily rejected, which confirms the previous Hansen and Seo (2002) test results.

3.5. Estimation of TVECM

Since Hansen and Seo (2002) test and Tsay (1998) test evaluate only the relevance of linear VECM over threshold VECM, the number of regime cannot be determined by the tests. Therefore, table 9 compares two-regime and three-regime TVECM's using AIC, BIC, and sum of squared residual (SSR). When the pair of AAA_t and TB_t is used, three-regime model fits data better than two-regime model in terms of AIC and SSR. But two-regime model is the winner of the horse race when we adopt BIC.[12)] There is no clear-cut answer either when AA_t or AP_t are used for the estimation. Two-regime model is selected when BIC is used, and three-regime model is better in terms of AIC and SSR. Therefore, two-regime and three-regime models are utilized together for the analysis, considering that the comparison of information criteria can not be used as a basis for statistical reasoning about the superiority of a particular model.

Table 9 Comparison of 2-Regime and 3-Regime Models

Thresholds	AIC	BIC	SSR
Panel A: AAA and TB			
1	–9,202.6	–8,346.2	8.500
2	–9,330.4	–8,153.9	7.528
Panel B: AA and TB			
1	–9,377.9	–8,558.3	8.415
2	–9,467.7	–8,125.6	6.903
Panel C: AP and TB			
1	–8,971.5	–8,041.5	8.556
2	–9,011.1	–7,724.1	7.493

12) Since the number of parameters are generally greater in three-regime model, BIC is greater in the model.

Table 10 Cointegration Parameters, Threshold Values, and Share of Each Regime

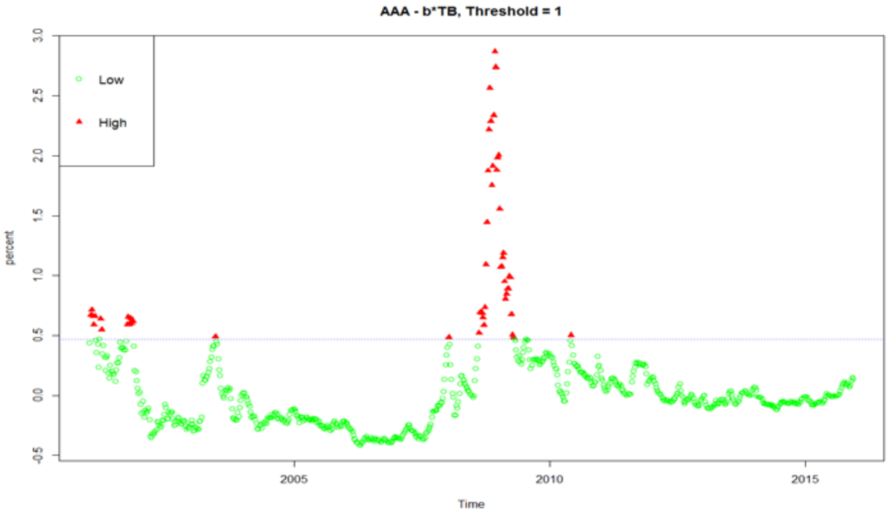
Thresholds	β	γ_1	γ_2	Low	Middle	High
Panel A: AAA and TB						
1	1.111	0.472	−	0.939	−	0.061
2	1.123	0.264	0.453	0.889	0.055	0.055
Panel B: AA and TB						
1	1.176	0.617	−	0.942	−	0.058
2	1.193	0.239	0.499	0.827	0.108	0.065
Panel C: AP and TB						
1	1.193	0.633	−	0.934	−	0.066
2	1.194	0.297	0.633	0.753	0.182	0.065

Table 10 summarizes important parameter estimates, including cointegration parameter (β) and threshold values (γ_1 and γ_2). The table also presents the share of data points in each regime. Since error correction term is defined by $s_t \equiv y_{1,t} - \beta y_{2,t}$, the estimate of β indicates the long-run relationship between two yields. The table shows that the cointegration parameters are estimated at less than 1.2, suggesting that the three corporate bonds are substitutes of Treasury Bond. The magnitude of estimated β are not much different over two-regime and three-regime model. The results show that the bond issuer's credit ratings and the cointegration coefficients are inversely related, which is consistent with the fact that credit spreads are proportional to the risk of assets.

To infer financial stress, let us begin with the two-regime models which has one threshold. The first regime, or low-stress regime, can be regarded as a state of normal market functioning in which the error correction term s_t fluctuates at levels not far from the long-run equilibrium. The second regime, or high-stress regime is characterized by an elevated funding pressures. In case of grade AAA corporate bond market, $AAA_t - 1.111TB_t$ greater than 47.2 basis points implies that AAA rated bond issuers have difficulties in funding. When $AA_t - 1.176TB_t$ and $AP_t - 1.193TB_t$ exceed 61.7 and 63.3 basis points, grade AA^- and grade A^+ corporate bond financial markets are considered in high-stress regime. It is clear that the threshold value γ_1

increases as the credit rating declines. Figure 5 - figure 7 display the dating of the regimes.[13] Green circle corresponds to the period of low-stress regime and red triangle indicates the period of high-stress regime. Figure 5 shows that grade AAA corporate bond market starts with high-stress regime in 2001 and then shifts back to low-stress regime until mid-2008. Because of the deleveraging of banks following the U.S. financial crisis, the firms were driven to the corporate bond market. As a result, grade AAA corporate bond market stays in high-stress regime from August 2008 to April 2009. After this point, credit spread of AAA_t is stabilized until the end of the sample. Figure 6 and figure 7 implies that the stresses of grade AA^- and grade A^+ corporate bond markets have similar movement as that of grade AAA bond market. The credit spread of AA_t and AP_t exceeds the threshold from September 2008 to mid-2009. The stress of Grade AA^- corporate bond market stays low in

Figure 5 Financial Stress in AAA Corporate Bond Market, One Threshold



Note: Dotted line represents the threshold value.

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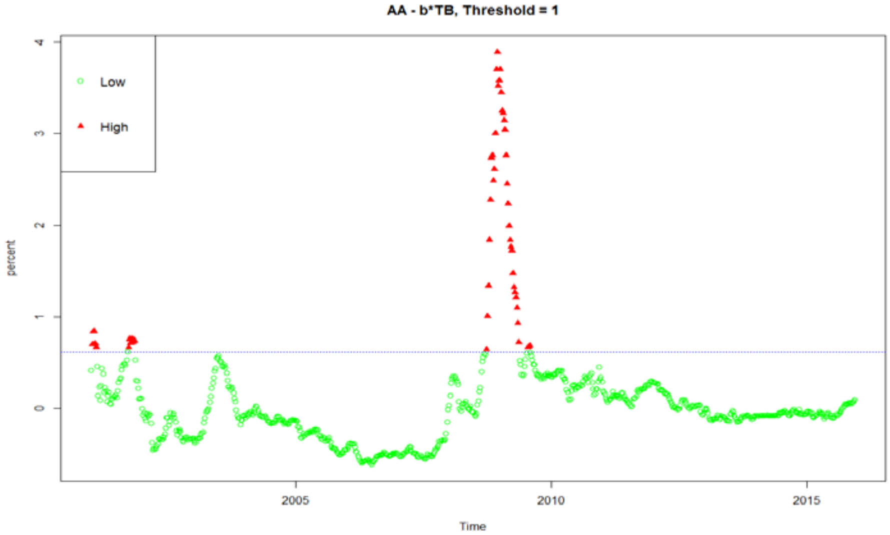
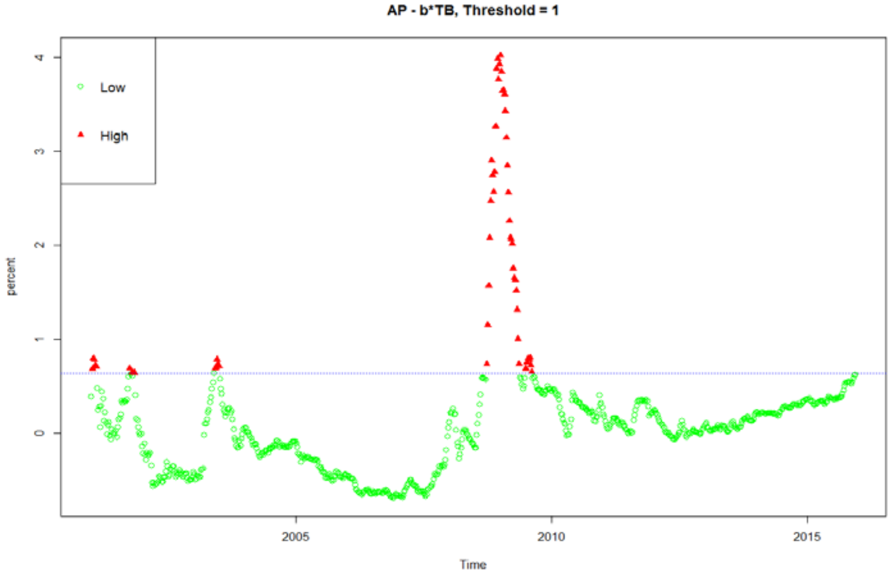
[13] It should be noted that the difference between the bottom panels of figure 1 - figure 3 and figure 5 - figure 10. The former figures describe spread of the two yields and the latter ones are the error correction terms $(s_t \equiv y_{1,t} - \beta y_{2,t})$. They have similar shapes, but levels are obviously different.

Figure 6 Financial Stress in AA⁻ Corporate Bond Market, One Threshold



Note: Dotted line represents the threshold value.

Figure 7 Financial Stress in A⁺ Corporate Bond Market, One Threshold



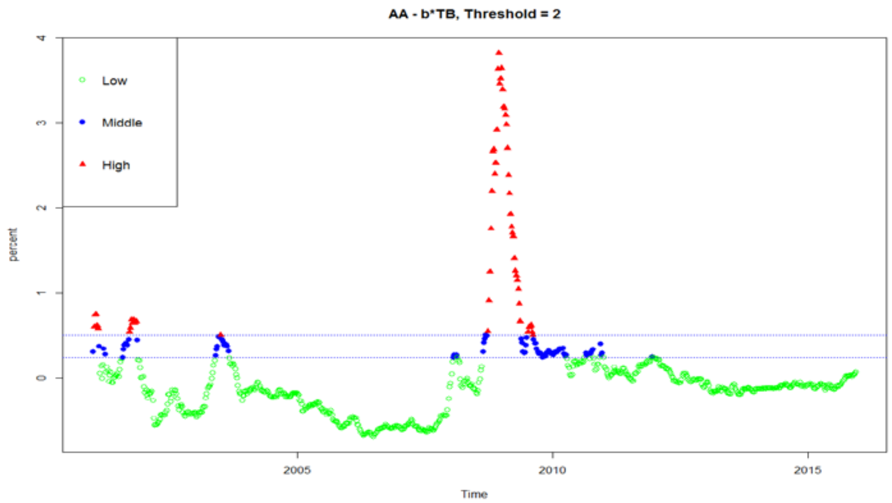
Note: Dotted line represents the threshold value.

the post-crisis period until the end of 2015. However, the credit spread of AP_t increases consistently since 2012 and it almost reaches to the threshold level in the end of 2015. These results imply that the firms with a relatively low credit rating have tighter terms of funding even after the financial crisis.

In three-regime model, low-stress regime is regarded as the state of normal market where the spread fluctuates around the long-run average. Middle-stress regime is characterized by an increase in funding pressures, while high-stress regime such pressures reach high levels and market functioning may be substantially impaired. Two threshold parameters γ_1 and γ_2 are estimated in three-regime model and presented in table 10.[14) In grade AAA corporate bond market, the low (γ_1) and high (γ_2) threshold estimates are 26.4 and 45.3 basis points, respectively. When grade AA^+ corporate bond is considered, the point estimates for the first and second thresholds are 23.9 and 49.9 basis points, respectively. The estimate of γ_2 is slightly greater than that of grade AAA bond market. The thresholds of $AP_t - \beta TB_t$ are estimated at 29.7 and 63.3 basis points, which are obviously higher than those of AAA_t or AA_t cases, implying relatively greater credit risk of grade A^+ corporate bond. Regime-classification in three-regime model is presented in figure 8 - figure 10. Green circle, blue circle, and red triangle denote low-stress, middle-stress, and high-stress regimes, respectively. Implication is a bit different from the previous two-regime case. When AAA_t and TB_t pair is considered, after the early high-stress period in 2001, funding pressure level passes the first threshold in August 2008 and stabilizes after June 2010, which is longer periods of stress than when two-regime model is considered. We find similar implication in grade AA^- bond market. The effect of financial crisis appears in August 2008 and lasts until the end of 2010. The financial stress in grade A^+ bond market looks greater when three-regime model is used. The credit spread reaches middle-stress regime in August 2008 and stays away from low-stress regime until 2011. Further, the credit

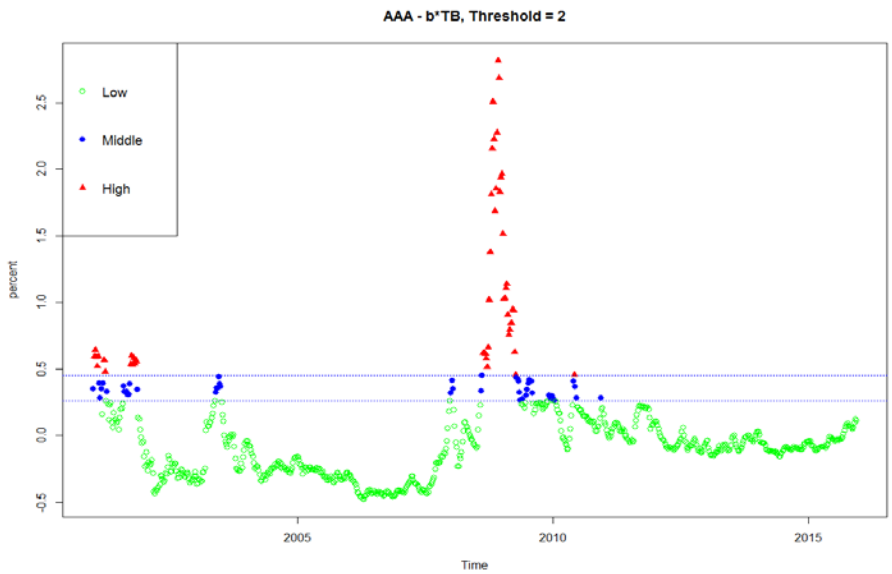
14) It is noticible in table 10 that the shares of high regimes in two regime and three regime models are very similar. We can interpret that two regime model picks only the extreme state while three regime model can indicate the state which requires attention as well as the state with strong financial pressure.

Figure 8 Financial Stress in AAA Corporate Bond Market, Two Thresholds



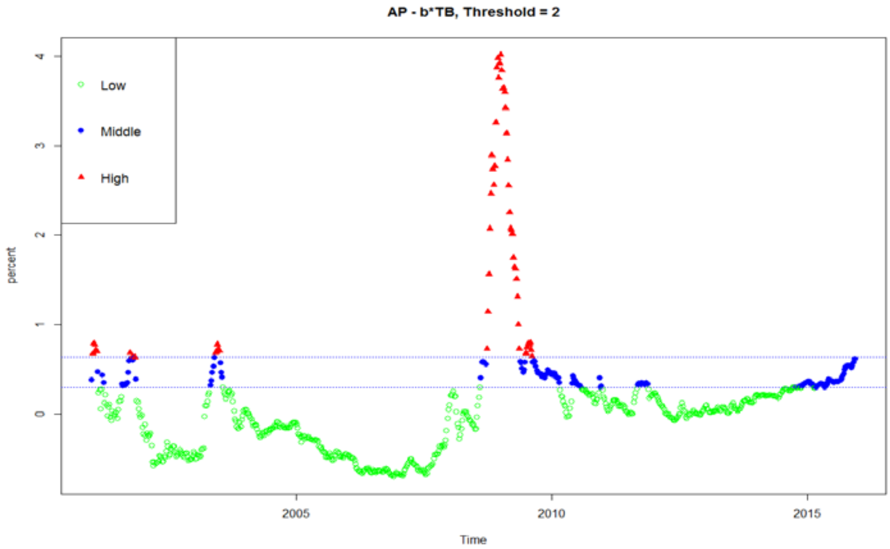
Note: Dotted line represents the threshold value.

Figure 9 Financial Stress in AA^{-} Corporate Bond Market, Two Thresholds



Note: Dotted line represents the threshold value.

Figure 10 Financial Stress in A^{+} Corporate Bond Market, Two Thresholds



Note: Dotted line represents the threshold value.

spread increases again from 2012 and shifts into middle-stress regime in October 2014. These results give similar implication as the two-regime model that lenders in Korea inclined toward highly-rated asset more after the financial crisis because they wanted to avoid uncertainty.

The overall financial stresses of the assets can be measured by the share of sample points in each regime. According to table 10, grade AAA corporate bond market stays in middle or high-stress regime in 11% of all sample points. On the other hand, the credit spreads of AA_t and AP_t are under middle or high pressure in 17 and 25% of sample, respectively. These numbers confirm that low-rated financial assets are more susceptible to the effects of exogenous shocks.

4. CONCLUSION

The credit spread, which indicates the difference between the highly-rated corporate bond and Treasury Bond yields, is generally stable. In this case, the VECM methodology can be applied, assuming that there is a long-run equilibrium relationship between the two yields. Further, it is based on the assumption that the spread linearly returns to the long-run equilibrium level through arbitrage transactions or policy interventions. If the pressure to return to the equilibrium depends on the level of the departure from the equilibrium, then linear VECM would not account for the movements of bond yields effectively. Therefore, we examine whether the linear VECM is appropriate after determining the cointegration relationship between the corporate bond yields and the Treasury Bond yields. If nonlinearity is found to exist in the pressure to return to equilibrium, the analysis is carried out using TVECM. Estimation results of TVECM is useful to evaluate the financial stress embedded in each of the bond markets.

From the result of the empirical analysis, the following implications are obtained: First, it is found that there exist unit roots in all of the bond yields. When corporate bond yields are paired with Treasury Bond yields, there is a unique cointegration relationship, implying the long-run equilibrium in each pair of yields. Second, Hansen and Seo (2002) test and Tsay (1998) test results indicate that there exists nonlinearity in the pressure to return to equilibrium. Therefore, TVECM could be utilized to evaluate financial stress. Third, the TVECM estimates suggest that the financial market is generally stabilized since 2012, when the impact of the U.S. financial crisis has been extinguished, but the corporate bond issuers which have relatively low credit ratings, face a considerably high level of financial stress even after the financial crisis.

The TVECM used in this study can be estimated with relatively low computation costs. Therefore, if sample size is large enough, meaningful implications on financial stress can be conveniently derived. This approach can be effectively utilized for banking supervision, since policymakers may monitor each firm's funding pressure in almost real time using this model.

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