Are Credit Spreads Too Low or Too High?
- A Hybrid Barrier Option Approach

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January 2008

ABSTRACT

Based on the works of Brockman and Turtle (2003) and Giesecke (2004), we proposed in this study a hybrid barrier option model with corporate capital gains tax which is free of problems within the structural model in explaining observed credit spreads. Our approach does not predict credit spreads that are too low for investment grade corporate bonds; neither does it predict credit spreads that are too high for high yield issues. Our empirical analysis supports the validity of this model over the structural model. When credit spreads are quoted abnormally higher than expected, they tend to persist. Otherwise the reversion to long term equilibrium is significant and prompt. This asymmetric pricing behavior is validated with a method introduced by Enders and Granger (1998) and Enders and Siklos (2001). The pricing asymmetry could not have been produced by a structural model employing only standard option. But it is consistent with a hybrid barrier option model. Our model characterizes the valuation of debt under financial stress and the asymmetric price pattern better than both the classical structural and the standard barrier option approaches. This study provides helpful implications especially for the medium and high yield issues in pricing as well as portfolio diversification.

Keywords: Asymmetric threshold cointegration, barrier option, credit risk, diversifiable risk
JEL Classification: C32, C52, G13, G33

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I. Introduction

This study adopts a new approach of examining behavior of credit spreads to resolve problems with the existing structural models. Criticisms have been that their prediction of credit spreads on a top-rated corporate bond is much too low than the actual credit spreads observed in the market[1], as documented in Huang and Huang (2003). On the other hand, Ericsson and Remby (2004) found, among others, that the structural model overpredicts heavily credit spreads for high yield corporate bonds. Our hybrid barrier option approach offers a resolution to these inconsistencies and it explains also particularly the asymmetric adjustments of credit spreads found in our empirical analysis. The structural model of credit spread employs a standard option under the framework of Black and Scholes (1973), which is a path-independent setup and cannot explain well corporate security valuation under financial stress. Based on the model of Merton (1973) and Black and Cox (1976), Brockman and Turtle (2003) (BT) and Giesecke (2004) introduced a barrier option approach to resolve this issue. We extend their approach and propose a hybrid model to analyze the effect of barrier on the distribution of credit spreads. Specifically, our extension of BT provides a framework to characterize asymmetric pricing behavior of corporate debt at the presence of a barrier, especially when financial stress is highly likely. Our modification on the liquidation probability makes it more realistic and consistent with empirical evidences. We have also incorporated the effect of corporate capital gains tax, following Lerner and Wu (2005). The validity of this framework indicates that the structural approach could have prescribed lower than needed credit spreads for investment grade corporate bonds but higher than needed credit spreads for medium to high yield corporate debt issues of longer maturity. The resolution offered by our study contributes to the pricing of corporate debt especially at situations where debt values are strongly sensitive to credit risks. The failure of structural models to capture the nonlinearity embedded in a barrier option can be further supported by our empirical evidences. When credit spreads are quoted abnormally higher than expected, they tend to persist. Otherwise the reversion to long term equilibrium is significant and prompt. The pricing asymmetry could not have been produced by a structural model employing only standard option but is consistent with a hybrid barrier option model. It characterizes the valuation of debt under financial stress and the asymmetric price pattern better than both the classical structural and the standard barrier option approaches.

Classical structural approach assumes no default prior to maturity and hence overlooks the related pricing behavior for a debt claim with imminent default before expiration. Extensions by Longstaff and

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[1] Geske and Delianedis (2001) has indicated that recovery rate, taxes, asset value jumps, liquidity and market risk factors could have contributed to the rest of corporate credit spreads.

Schwartz (1995) and Collin-Dufresne and Goldstein (2001) allowed pre-expiration defaults but were found to only explain 15% to 25% of the observed credit spreads according to Huang and Huang (2003) and Collin-Dufresne, Goldstein and Martin (2001). Considering risky debt as including a down-and-in call (DIC) option, Giesecke (2004) showed that if the empirical value of a bond reflects that of a portfolio composed of a risk-free loan, a short European put and a long DIC, then the classical structural approach would have undervalued the debt and over-prescribed credit spread. If the barrier is nontrivial empirically, then the value of DIC at different firm values and its term structure would affect credit spread correspondingly. The crucial feature of nonlinearity of DIC in firm value suggests that the behavior of credit spread can be substantially apart from the structural model where the debt value is driven only by an option linear in firm values. BT showed that the barriers for DIC are not only nontrivial, but also substantially high, which implies pre-maturity risk structure of a corporate debt would be quite different from what we learned from the structural approaches. As the corporate capital gains tax shield could raise the default barrier according to Lerner and Wu (2005), this extension with DIC produces implications on credit spreads consistent with empirical observations. Credit spreads predicted by the structural model would have been away from reality without considering the role of DIC. If, however, alternative structural credit spread models, see for example Leland (2004), Giesecke and Goldberg (2005) and Chen, Collin-Dufresne and Goldstein (2006), can establish default to be the major component of credit spreads, then it would be crucial to adopt a modified structural model with DIC which prescribes credit spread according to realistic risk structure of defaults.

One assumption implicit in the BT and other barrier option models is that liquidation or change of corporate control takes place once a prespecified barrier is reached for the value of a firm. As Broadie, Chernov and Sundaresan (2006) indicated, that is not always the case in practice. Firms can, in theory and practice, go through a 'successful' bankruptcy by clearing the default with financial arrangements. Our analysis also indicates that BT's assumption on liquidation would have predicted unreasonable behavior of debt values and implied credit spreads. We therefore relax that assumption to allow for partial liquidation scenarios. Our hybrid model thus retains certain features of the classical approach while stressing partial nonlinearity characteristic of the barrier option model. In cases of financial stress yet with low probability of liquidation or for debt issues with low credit risk, our model behaves better than one with 100% liquidation probability. Alternatively, our hybrid model still preserves the property of barrier option model in capturing risk premium for a jump-to-default scenario in firm value. In terms of empirical investigations, BT studied stock prices of a large cross section of firms to support the existence of a barrier that justifies a framework with DIC. Other studies have focused on pricing kernel, term structure and default barrier behavior. In this study, we try to establish the validity of this framework by examining market behavior from the side of corporate debt. With respect to default caused by jumps in firm values, Collin-Dufresne, Goldstein and Helwege (2003) have argued that contagion in default predictions could generate a market-wide increase of credit spreads. So we use corporate bond indices to extract barrier effects from the bond market to capture effects of potential firm value shift and to avoid potential individual noises. To the extent that default probabilities computed from a barrier-based model are better predictors for corporate bankruptcy as argued in BT, our investigation provides a more appropriate characterization of credit spreads. They would have been too low in cases of low credit risks, but too high in cases of ultra high credit risks, under structural models than what underlying credit risks should dictate. Although Giesecke (2004) indicates that default probability for a low quality firm under the barrier option model is higher than that of the classical approach, the embedded DIC prevents equityholders, the put buyers, from depleting firm assets before maturity. This change of risk structure in turn reduces credit spread needed to be received by debtholders for risk compensation. In the case of a top quality firm where a default is highly unlikely to happen, credit spreads would be higher as debt value added by DIC does not fully cover the reduction caused by corporate capital gains tax shield at default.

We have examined further in this study the dynamics of credit spreads in responses to state variables to determine how observed spreads compensate credit risks and react to noises. Our evidences suggest that default barrier produces asymmetric price adjustments at different levels of credit risks. The error correction or reversion for larger or positive innovations tends to be weak, while the correction for smaller of negative innovations is much stronger. Our results are consistent with that of Barnhill, Joutz and Maxwell (2000), which suggests that high-yield corporate bond indices revert slowly toward equilibrium. When the underlying state is such that bankruptcy is highly likely to happen, that is, when the DIC embedded in a debt claim is close to be in-the-money, the observed credit spreads reverts weakly or slowly to an equilibrium path. But the adjustment back to equilibrium is quick and significant when the DIC is well out-of-the-money. The asymmetry of price adjustments appear only within the systematic part of credit spreads, meaning the change of credit risk profile comes primarily from systematic risk factors such as interest rate or economy uncertainty. The empirical credit spreads of a long time series of corporate indices verify our simulation on a hybrid barrier option model. The validity of this model suggests that the neither the structural nor the standard barrier option approach is completely ideal for analyzing corporate credit spreads. The structural approach not only misprescribes required spreads, but it fails to capture the nonlinear effects of credit risk around potential financial distress when debt pricing is especially sensitive. The situation is more severe for debt issued by firms with higher credit risks or at time of excessive asset volatility, as well as issues with longer time to maturity. On the other hand, the standard barrier option approach overpredicts the probability of liquidation and hence overvalues the down-and-in call option. Resulting credit spreads would have been lower than needed.

Our results thus have the following implications. First, a barrier option model should be adopted in pricing especially high yield or long-term corporate debt issues. Our hybrid model, however, performs realistically better than a standard barrier model, especially in the case of low credit risk or short-term issues. Secondly, debt pricing should take into account the asymmetric adjustment pattern of credit spread as it provides useful information on relative riskiness of corporate debt within broad categories. Thirdly, corporate spreads for issues with immediate financial stress may have been too high and need to be recalibrated with a barrier model. The remainder of the paper is organized as follows. Section II describes the barrier option model and how credit spreads are to be affected by its introduction. Section III describes our data and empirical analysis. Section IV provides discussion on issues, implications and possible extension of our results. Section V concludes the paper.

II. A hybrid barrier option framework of credit spreads

According to the barrier option model of Merton (1973) and the first-passage model introduced by Black and Cox (1976), the market value of a firm's equity can be characterized as the value of a European down-and-out call (DOC) option on the firm's asset value, and the value of debt as that of a European down-and-in call (DIC) option. The sum of the two is the value of a standard call (SC) option. The DIC, representing part of the debtholder's payoff stays out-of-the money if the firm's asset is above the face value of debt. It gets in the money and takes on the value of SC once a bankruptcy proceeding is initialized, and is considered exercised if liquidation happens. Specifically, the value of a DIC can be expressed in equation (1) as follows. Assume V_t is the value of the firm at time t, H is an exogenous barrier that triggers the bankruptcy proceeding, T is the time of maturity, σ is the volatility of the firm's asset and r is the riskless rate, then for $X \geq H$[2] the value of DIC is given by

$$DIC = V_t (H / V_t)^{2\eta} N(b) - Xe^{-r(T-t)} (H / V_t)^{2\eta-2} N(b - \sigma\sqrt{T-t}) \qquad (1),$$

where

$$b = \frac{\ln(H^2 / V_t X) + (r + \frac{\sigma^2}{2})(T-t)}{\sigma\sqrt{T-t}} \quad \text{and} \quad \eta = \frac{r}{\sigma^2} + \frac{1}{2}.$$

In this characterization, the equityholders have no rebate, meaning that debtholders will take full control of the firm's asset once liquidation takes place. We discuss in this study only the case of $X \geq H$ following the argument of Huang and Huang (2003), which implies that bankruptcy is only triggered when the firm's net worth is negative[3]. Nevertheless, BT reports computed barriers as higher than the face values of debt[4], which if valid corresponds to the case of over-collateralization or a positive net worth requirement on the firm. It can be found in Leland (1994) where short-term debt is rolled over to serve as a proxy for the positive net worth.

The first term of equation (1) stands for the expected value of the debtholder's payoff when the

[2] The equation for X<H is more complicated and is subject to certain modification of model as suggested by Giesecke (2004). Detailed formula can be found in Brockman and Turtle (2003).

[3] Longstaff and Schwartz (1995), first of modern literature adopting an exogenous barrier in valuing corporate debt, assumes that *X*=*H*, which does not allow a negative net worth. Huang and Huang (2003) model the barrier as a fraction of the face value of debt as they argue that firms are allowed to run with negative net worth due to high default cost.

[4] They have reported, however, only significance test result on the existence of a barrier rather than comparing *H* against *X*.

firm is in default, while the second term is the expected value of loss that could be incurred if the firm's asset is not secured by the debtholders in case of a default. The value of DIC increases with H for nonzero H's. The earlier or easier a knock-out barrier is in effect, the more secured the debtholder's claim is. The value of DIC for a given time to maturity increases with asset volatility and equityholder does not necessarily benefit from it like in the classical structural approach. DIC value also increases monotonically as firm value decreases till X is reached. In order to characterize how DIC affects debtholder's value, hence the implied credit spread of the debt, we need to consider it in the context of an asset portfolio. A corporate debt can be considered as a portfolio made up of a riskless discount bond, a short European put option on the value of the firm and a DIC. The value of the debt at time t can be expressed as

$$B_t^T = Xe^{-r(T-t)} - P(\sigma, T-t, X, r, V_t) + DIC(\delta, H, \sigma, T-t, X, r, V_t) \tag{2},$$

where $P(\sigma, T-t, X, r, V_t)$ is a standard European put option. A liquidation factor, δ, is added as a variable for the DIC. It is less than 1 and is the probability that debtholders actually take control of the firm's asset after firm value falls below H[5]. In the original BT model, where δ=1 as laid out in Giesecke (2004), it is implicitly assumed that default ends up with surrendering corporate control to debtholders all the time. Broadie *et al*. (2006) show that how firms in theory can avoid that scenario and return to solvent state after certain arrangements, as seen in practice. So we introduce the hybrid model in (2) where debt value is a blend of liquidating and non-liquidating situations. The liquidation factor on the one hand reflects the reality that, even if firm value reaches the conceptual barrier, exercising a barrier option does not always happen. It is straightforward from (1) that $\partial DIC / \partial \delta \geq 0$ as lowering the likelihood of liquidation has the same effect as lowering H. Debt value would follow what the classical approach dictates rather than that in (2). On the other hand, as shown in our analysis that follows, without this remedy (or simply assuming δ=1) debt value may never decrease in firm values before the barrier is reached. The credit spread implied by (2) is given by

$$SP_t^T = -\log(B_t^T / X)/(T-t) \tag{3}.$$

If the observed corporate debt is properly priced by the market and this barrier option framework is appropriate, then the classical structural approach must have undervalued the debt as the value of DIC

[5] Broadie *et al*. (2006) formulated a model where some firms redeem their debt claims after filing Chapter 11 and return to a liquid state. Only in some of the bankruptcy cases end up filing Chapter 7 for liquidation and equityholders would surrender all firm assets to debtholders.

has been left out. Given proper level of riskless rate, the structural model could not have fit the debt value properly without overassessing SP_t^T in (3).

【Figure 1】

Figure 1 plots the values of DIC of high and low risk firms under our hybrid model at different firm values for various times to maturity[6], with corresponding values of put and debt values under both barrier option and the classical structural models. According the Stand and Poor (2006), the 2002-2004 three-year median debt ratio of B-rated industrial firms is at 75.9%, so we set the face value of the high risk firm at that level. For the low risk firm, we set it at 37.5% as it is the median for A-rated firms. Following arguments of Leland (2004), we set the default barrier at 73.1% of face values, which amounts to 55.5% and 27.4% respectively. We have also applied a volatility of 0.3 on the low risk firm and 0.45 on the high risk one. In our hybrid model the liquidation factor δ is set at 0.25. Regardless of time to maturity, values of both the DIC and the put increase at firm values above barrier. After that, the DIC becomes a standard call and decreases in firm value. To the extent that the presence of DIC makes debt values higher than those based on a classical approach, the difference is more significant at longer maturity and higher credit risks. So the classical approach would have prescribed higher than needed credit spreads especially for high yield or longer term debt issues However in a BT model when the DIC grows faster than the put, as in panel (b), (c), (e) and (f), the presence of DIC could actually raise the debt value as firm value goes down if a liquidation factor is added in. In another word, the DIC could become too valuable, as in panel (f) especially, to the debtholders to bring down credit spreads even when firm value decreases. As this feature of the standard barrier model may not be compatible with reality and practice, our hybrid model offers the liquidation factor δ as a resolution.

This hybrid arrangement of the implied barrier option in (2) is crucial both theoretically and empirically. For instance, consider a 7-year A-rated issue with a treasury note at 5.60%, when the firm value drops to 50% of that at the issuance of the debt the unadjusted spread (the case of $\delta=1$) from the BT model would amount to only 8 b.p. in this case. However, the adjusted spread (the case of $\delta=0.25$) from our hybrid model would come to 98 b.p. instead, which is much more reasonable in practice. Theoretically, arguments by Huang and Huang (2003), Giesecke (2004) and Leland (2004) suggest the case of $X<H$ as in findings of BT is incompatible in theory with either an exogenous or an endogenous barrier. Empirically, without the inclusion of δ debt values and credit spreads would not have behaved

[6] We have considered the maturities of 3, 7 and 15 years. Compared with the 52,828 spread-widening cases from Lehman Brothers database, which Collin-Dufresne *et al*. (2003) studied, the shortest duration is around 2.3 and 83% are averaged at 7.71. In this sense our selection is reasonably consistent with reality.

reasonably under a model like (2) as shown in this section. If BT had used market value instead of book value of debt as well as a liquidation factor in their model, the stock prices they examined would have supported a lower barrier and credit spreads more compatible with market practice[7]. Our calibration of the hybrid model also makes it an appropriate one to apply in our empirical analysis in the next section.

As there is no incorporation of corporate taxes in BT as well as (2), the value of debt without a DIC can never be greater than that with one. So the inclusion of a DIC can only produce lower credit spreads than the structural models. In light of Lerner and Wu (2005), we therefore modify (2) to become the following expression,

$$B_t^T = Xe^{-r(T-t)} - P(\sigma, T-t, X, r, V_t, \boldsymbol{\tau}_{cg}) + DIC(\delta, H, \sigma, T-t, X, r, V_t, \boldsymbol{\tau}_{cg}) \quad (4),$$

where τ_{cg} is the corporate capital gains tax rate. As τ_{cg} raises the value of the put and DIC in (4), its effect on the value of the debt depends on the likelihood of default, as well as the liquidation factor δ. For given value of δ, Figure 2 would have been modified where debt values of low risk firms would be lower than those without incorporating τ_{cg} and DIC. Higher credit spreads would have been prescribed for investment grade firms than by the structural models. Without modeling the liquidation factor in (4), τ_{cg} would have made DIC too valuable such that credit spreads could actually go down at the occurrence of a credit event[8].

With the risk-mitigating role of DIC, at firm values far away from the barrier or at times distant from maturity debt would therefore be less sensitive to potential jumps in firm values. If, however, the barrier appears to be more imminent along the dimension of firm value of time, unexpected changes of firm value may be cautiously interpreted. The smoothness feature of pricing a debt via a put by the classical approach lacks this property. In this sense the barrier option framework helps especially in characterizing the dynamics of credit spreads. Figure 2 shows simulated 5-year trajectories of credit spreads of a risky discount bond with 10 years to maturity at different starting firm values.

【Figure 2】

For simplicity we present only the case without including the capital gains tax, which does not affect the general patter of our plots. Panel (a) and (b) are plots of low risk firm group, or the group of A-rated

[7] BT indicated in the study that the economic interpretation of the implied barrier (69% of firm value) is not without questions. In addition, for given market value of stocks the adoption of book value of debt could, for a 7-year debt at a yield of 5.6%, have inflated the DIC up to 75% in that specific case. Implied credit spreads caused by overvalued DIC and inadequate assessment of contribution from the DIC would just be unrealistic.

[8] Lerner and Wu (2005) had to constrain the assumed asset volatility in their calibration of the structural model they used.

firms, as that specified for Figure 1. These plots are applicable only in the context of a group firms with similar risk characteristics. In order to have a fixed time to maturity while advancing month to month with varying firm values, we could consider the plots representing the average implied spread debt claims issued sequentially by firms in a group. The spirit of this analysis is also consistent with the findings of Collin-Dufresne *et al*. (2003) regarding contagion of default prediction for given risk classes of firms. Panel (a) is the case of this low risk group in a period of low asset volatility, while panel (b) simulates the case of high asset volatility. Similar comparison is performed for a high risk group, or the group of B-rated firms, as in panel (c) and (d). A firm can enter or exit a specific group depending on its capital structure, characteristics of the group, however, do not change over time. Starting firm values for each group are represented as percentages of those when debt claims are issued. All four panels suggest uniformly that within each group if on average a firm starts from a value very close to its barrier level then the average credit spreads of the group would have less fluctuation than when a firm starts from a much higher proportion of the original firm value. This phenomenon can be considered conceptually that at very low firm value levels, an exceptionally high credit spread would be considered as a signal of higher likelihood of financial stress. Credit spreads of debt issued by this group tend to remain to price in potential credit risks as the instantaneous volatility of the DIC is smaller when it is or close to be in the money. Similar to this finding, Barnhill, Joutz and Maxwell (2000) also reported specifically that lower-rated corporate bond indices exhibit slower reversion toward long-run equilibrium. But the higher the firm value goes; an observed exceptionally high credit spread is more likely to be interpreted as driven only by noises. As the DIC is out of the money and its instantaneous volatility tends to be larger. As a result, the subsequent credit spread tends to revert promptly and strongly toward the direction of the previous level. When the firm value is low, however, higher credit spread would more likely to be considered as a reflection of greater credit risks assessed by the market. The asymmetry is more pronounced for the high risk than for the low risk group. Higher asset volatility also tends to amplify the asymmetry.

It is worth noting that a liquidation factor compatible with practice makes the specification of (2) and hence the results in this section much more reasonable. If we set the liquidation factor at 0.75, for the low risk group (X=37.5% and H=27.4) the implied credit spread at 30% asset volatility and 10 years to maturity would only rise by 40 b.p. when firm value goes down to the face value of debt. However, setting δ at 0.25 would widen that difference by 110 b.p., which is a much more reasonable characterization of credit events in the spirit of Collin-Dufresne *et al*. (2003) where credit events were defined to have a jump of 200 b.p. instead. In the case of high risk group with the same asset volatility and time to maturity, similar situation with a δ at 0.25 would cause credit spread to rise from 125 b.p. to

166 b.p. while a δ at 0.75 would actually reduce 30 b.p. in the spread. As higher value of δ compresses credit spread, the asymmetric adjustment pattern shown in Figure 2 tends to disappear with higher value of δ. So without the introduction of δ, crucial implications from the barrier model may not be consistent with reality, or not readily observable.

Compared with implications of Figure 1, we can see that at states with weak reversions, debtholders are more confident in DIC's effectiveness in mitigating credit risks, and therefore DIC is worth more. So more of the debt undervaluation caused by the classical approach should be corrected or more credit spread needs to be reduced. On the other hand, when firm values are high or away from the barrier, the DIC is unlikely to be effective and what governs credit spreads are noises from state variables. So less debt overvaluation is corrected and less credit spread needs to be reduced. Our analysis in this section indicates that the existence of asymmetric price adjustment validates the adoption of the barrier approach. Credit spreads of high yield issues would exhibit stronger asymmetry then the low yield ones. Accordingly, high yield issues may need to have their spreads reduced more as market is more likely to omit the role of a default barrier there. Moreover, common risks such as asset volatility affect the extent of the asymmetry of price adjustment and the correction needed in overassessed credit spreads. The validity and magnitude of these effects entails an empirical model of asymmetric adjustment, which will be presented in the next section.

III. Empirical Analysis

The Data

In order to investigate behavior of credit spreads for groups with specific risk profile, we choose to explore our model with corporate bond indices. Studying indices also avoids possible liquidity effect[9] within observations of individual bond prices. We use the composite monthly and weekly yield observations from seasoned Aaa-, Aa and Baa-grade corporate bond indices compiled by the Moody's Investors Service, which are available from the Board of Governors of the Federal Reserve System. Each index contains various major corporate bonds with different maturities[10]. The data period starts from May 1953 and ends in September of 2003. The spreads are computed by taking the difference between the index yields and those of the 10- or 20-year treasury bonds. Beside monthly and weekly

[9] Collin-Dufresne *et al*. (2001) suggested that 'individual liquidity shock' causes a significant portion of unexplained variations in credit spreads of individual corporate bonds.

[10] Sun, Lin and Nieh (2007) has pointed out that, after matching prices and maturity, average maturity of Moody's indices is around 14 years.

series of the Aaa and Baa yield spreads, or SP^{Aaa} and SP^{Baa}, we have also analyzed the difference between the two, or ISP^{Baa}, which serves as a *naive* proxy for idiosyncratic credit spreads[11]. To conduct our preliminary analysis, data is divided among three subpriods to examine potential structural changes in the capital market, with break points computed by the algorithm of Bai and Perron (2003).

The kurtosis and skewness measures of the *levels* of SP^{Aaa} and SP^{Baa} for the entire sampling period are not far from a normal distribution. The naive *idiosyncratic* credit spread, ISP^{Baa}, has higher values in both measures for the whole period. A separate analysis has also been done on the *changes* of yield spreads, which exhibit excessive kurtosis also, a result similar to findings from Pedrosa and Ross (1998). Various studies employed yield spread changes that could suffer this problem[12]. Our subsequent analysis employs *levels* of yield spreads directly rather than *changes* to not only retain information contained in the original variable, but also avoid potential inferencing errors[13].

Preliminary Analysis

In view of Broadie, *et al*. (2006), for a given firm the occurrence of filing Chapter 7 or the likelihood of exercising the implied DIC is not an event that can take place repeatedly. Also as indicated in Section II, it is more appropriate to study the validity of a barrier-based model in the context of a class of firms with similar credit risk profile. However, if we analyze instead firms of a given risk class we would need to identify how the systematic or unsystematic risks influence the barrier effect on credit spreads. Diversifiable credit risks, as argued in Jarrow, Lando and Yu (2005), should have little effect on spreads of a large debt portfolio compared with systematic credit risk. So it is crucial to identify the cause of higher asset volatility that induces a more pronounced asymmetric adjustment or barrier effect as seen in our simulation results in Figure 2. If it is caused by economy-wide factor, then we would expect to observer according behavior on credit spreads on the corporate bond indices in our data. Higher asset volatility arising from individual firm risk should not have produced significant effect over time. To the extent of the validity of arguments above, we consider corporate bond index to be a satisfactory subject of our analysis.

To separate the systematic credit risk from the unsystematic one, we would need to conduct a preliminary analysis as in Sun, Lin and Nieh (2007). We begin from the following regression equation,

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[11] It also corresponds to a special credit spread decomposition scheme, one which implies $\theta = 1$ in (6)

[12] Pedrosa and Roll (1998) showed that a randomized Gaussian-mixture models yield spread changes better than a simple Gaussian distribution assumption.

[13] It will shown subsequently in our paper that applying *changes* only in a short-run analysis would also miss the picture of long-run equilibrium which only applying *level* of variables can possibly capture.

$$\Delta SP_{it} = \beta_{i0} + \beta_{i1}\Delta TB3M_t + \beta_{i2}\Delta TERM_t + e_{it}, i=1,2,...I; t=1,2,...T \quad (5).$$

where ΔSP_{it} denotes the *change* of Aaa, Baa yield spreads or the difference between the two at period t, whereas $\Delta TB3M_t$ is the change on 3-month Treasury Bill yield and $\Delta TERM_t$ is the difference between yields of 10 year Treasury Bond and 3-month TB. Equation (5) is our *Baseline Model*, as following Duffee (1998) and Collin-Dufresne, Goldstein and Martin (2001). They found both estimates of β_{i1} and β_{i2} to be negative, which draws the starting line of our analysis. Estimation results of this model are established as a benchmark of inferences. First differences of original variables are used regardless of the said excessive kurtosis in their sampling distribution. Table II reports the results of OLS regressions of (5) on three series of credit spreads, for both monthly and weekly samples. The division of subperiods is according to break points found for ISP^{Baa}, the *idiosyncratic* credit spreads of Baa (difference between Aaa and Baa yields) from an endogenous multiple structural change algorithms according to Bai and Perron (2003)[14].

【Table II】

Compared with various other studies, results from (5) are consistent with literatures on how change of yield spreads respond to change of interest rate and term structure. Generally, β_1 and β_2 should be negative and larger in magnitude for lower grade bond. The estimation results from weekly observations in Panel B provide examination of effects from infrequent trading, as well as a benchmark contrast to subsequent long- and short-run analyses. Our analysis in Table II indicates that ISP^{Baa}, the idiosyncratic credit spread of Baa, respond much less to interest rates. Estimates for β_1 and β_2 are much smaller in magnitude in all periods, and are at the order of tenth to twentieth of those for the full credit spreads. Especially in the last subperiod, the β_1 and β_2 estimates for SP^{Baa} are -0.3666 and -0.3137 respectively, while those for ISP^{Baa} are merely -0.0804 and -0.0227. Estimates for ISP^{Baa} are insignificant especially in the first and the last subperiod, in both monthly and weekly samples. Especially, the insignificance is even stronger when its sampling distribution, with positive skewness and high kurtosis, tends to produce incorrect significant results under standard *t*-values. If the idiosyncratic credit spread is properly identified under our specification, then it should not respond to interest rate, a state variable related to common or systematic credit risks. Results in Table II are

[14] The Bai and Perron procedure does allow for the consideration of heterscedasticity and autocorrelation. The number of breaks tends to be smaller (changing from 3 to 2) when taking into account the situations above. Parameter estimates for (5) turns out to maintain their signs with smaller magnitude, regardless of the number of breaks. The endogenous break identification procedure has also been carried out for both SP^{Aaa} and SP^{Baa}, with locations of break points not far from what we have found for ISP^{Baa}.

partially consistent with this argument, given influences of other contaminating factors[15]. The *idiosyncratic* credit spread is only significantly related to Treasury yields in the second subperiod, between 1972 and 1987, when short-term interest rate is so high that it often exceeded the long bond yields[16].

Asymmetric Adjustments of Credit Spreads – TAR and M-TAR models

Studies on credit spreads which are based on a time series framework mostly ascribed to structural or regime changes observed nonlinearity of the long term relationship between credit spreads and interest rates. We would adopt a cross-sectional approach by applying the empirical model of Enders and Granger (1998). They employed the Threshold AutoRegressive (TAR) and Momentum-Threshold AutoRegressive (M-TAR) models to study the asymmetric adjustments of short-long interest rate differentials. The unit root test results suggest that long rates respond only to positive lagged short-long differentials, while short rates react only significantly to negative discrepancies. The nonlinearity in the long term cointegration between the long and the short rate is then ascribed to explicit economic factors, rather than exogenous structural shift of economic environments. In light of their methodology we will investigate specifically how credit spreads behave along the dimension of corporate financial states, such as interest rates, which determine corporate debt pricing and hence credit spreads. The barrier option framework outlined in section II provides us with a valid perspective in the spirit of Enders and Granger (1998). Observing credit spreads over time helps understanding phenomena presented in Figure 2 and section II.

In order to obtain a more robust implication from our analysis, we will also examine on the *idiosyncratic* credit spreads for asymmetric price adjustments. To better extract the *idiosyncratic* spreads we have made a necessary modification. As a naive scheme, we first use credit spread of Aaa index as the *systematic* credit spread, while for other grades the spread beyond it is proxied as the *idiosyncratic* credit spread. Here we adopt a more general linear decomposition function as outlined in Sun *et al.* (2007), which can be expressed as follows,

$$ISP_t^j = SP_t^j - \theta_j SP_t^{Aaa}, \; j=1,2,\ldots J;\; t=1,2,\ldots T \qquad (6)$$

[15] Duffee (1998) argued that the reduction of callable bonds is the cause of lower interest rate sensitivity so results in Table II could have be affected. Jarrow *et al*. (2005) suggested that ultra high interest rate, as in the second subperiod, could be a problem in decomposing credit spreads.

[16] Duffee (1999) indicated specifically that this is the problem with of the type of reduced-form model introduced by Duffie and Singleton (1997).

where ISP_t^j stands for the idiosyncratic credit spread of the credit rating j, SP_t^j is the full credit spread of that rating, at time t and that SP_t^{Aaa} is the yield spread of the Aaa index. θ_j is the standardized long run cointegration coefficient between SP_t^j and SP_t^{Aaa}. The *naive* idiosyncratic spread defined in the previous section is only a special case of (6) with θ_j simply being 1. In the monthly sample, estimated θ_j has been estimated by Sun *et al.* (2007) as 1.26 for ISP^{Baa}, while in the weekly sample it is 1.35 for ISP^{Baa} and 1.2 for ISP^{Aa}. It will be shown that this decomposition proves to be important in subsequent estimations and it's implication on the asymmetric adjustments of credit spreads is crucial.

To apply TAR and M-TAR models on equation (5) where deterministic regressors are present, we have to adopt the specification of Enders and Siklos (2001) rather than the original model of Enders and Granger (1998). First we take the ranked residuals from equation (5) directly and perform a long run equilibrium TAR and M-TAR regressions. We find positive evidence supporting the asymmetric adjustment pattern on the residuals. Based on the residuals and threshold from that model, we first consider, in the case of SP_t^{Aaa}, an error-correction TAR model like (7),

$$\Delta SP_t^{Aaa} = \alpha + \rho_1 M_t \hat{\mu}_{t-1} + \rho_2 (1 - M_t)\hat{\mu}_{t-1} + \sum_{i=1}^{l} \gamma_{1i} SP_{t-i}^{Aaa} + \sum_{j=1}^{m} \gamma_{2j} \Delta TB3M_{t-j} + \sum_{k=1}^{n} \gamma_{3k} \Delta TERM_{t-k} + \varepsilon_t \qquad (7),$$

where

$$M_k = \begin{Bmatrix} 1 \text{ if } \mu_{k-1} \geq \tau \\ 0 \text{ if } \mu_{k-1} < \tau \end{Bmatrix}, \text{ along ranked series of } \mu_{k-1}.$$

This specification examines if there exists asymmetric adjustment with respect to a threshold τ[17] on the residuals from the *Baseline Model* in (5). The results for monthly data are shown in Table III. In addition, we also report the results from an error correction version of AutoRegressive Distributed Lags (ARDL-ECM) model like (8) for comparison.

$$\Delta SP_t^{Aaa} = a + \rho\hat{\mu}_{t-1} + \sum_{i=1}^{l} b_i \Delta SP_{t-i}^{Aaa} + \sum_{j=0}^{m} c_j \Delta TB3M_{t-j} + \sum_{k=0}^{n} d_k \Delta TERM_{t-k} + \phi_1 SP_{t-1}^{Aaa} + \phi_2 TB3M_{t-1} + \phi_3 TERM_{t-1} + \varepsilon_t \qquad (8)$$

Though not from a model of asymmetric adjustment, the coefficient ρ of the error correction term in (8) serves as a determinant of the cointegration relation among SP_t^{Aaa}, $TB3M_t$ and $TERM_t$.

[17] The TAR thresholds in monthly data are respectively -0.166 for Aaa bond, -0.095 for the Baa bond and -=0.059 for Baa idiosyncratic spread.

Statistical significance of ρ from (8), a model of symmetric adjustment, validates the relevance of (7)[18]. The cointegration hypothesis of the ARDL-ECM model is supported in Table III for SP^{Aaa} and SP^{Baa}, but not so for ISP^{Baa}.

【Table III】

For the TAR model, the hypothesis of $\rho_1 = \rho_2 = 0$ is rejected for all three measures of credit spreads[19], suggesting that the cointegration of credit spreads with *TB3M* and *TERM* is supported under the *Baseline Model*. Tests from the *t*-stastistics indicate that ρ_1 is not significantly different from zero, but ρ_2 is significantly negative. So at this level, our data suggests that reversions take place at lower levels of credit spreads, but not so when they are high. This result of significant asymmetric price adjustment is true for both full credit spreads SP^{Aaa} and SP^{Baa}, but not so for the *idiosyncratic* spread ISP^{Baa}. However, *F*-test on $\rho_1 = \rho_2$ for the hypothesis of symmetric adjustments of $\Delta\hat{\mu}_k$ to the error correction term $\hat{\mu}_{k-1}$, is not rejected according to a standard *F*-distribution for all the credit spreads.

Alternatively, the M-TAR model adopts equation (7) for regression with the heaviside indicator specified as

$$M_k = \begin{Bmatrix} 1 \text{ if } \Delta\mu_{k-1} \geq \tau \\ 0 \text{ if } \Delta\mu_{k-1} < \tau \end{Bmatrix}.$$

The use of M-TAR is justified as the AIC and SBC values are lower. The regression results for M-TAR in Table III show that the cointegration hypothesis is still uniformly supported, with all *F*-statistic exceeding critical values of the non-standard *F*-distribution. As expected, results from the M-TAR model are more pronounced, as it, in the terms of Enders and Granger (1998), 'captures possible sharp movements' of the sequence observed. Under M-TAR the symmetric adjustment hypothesis is not only rejected on the individual *t*-tests for coefficients of ρ_1 and ρ_2, but also strongly rejected on the *F*-test of $\rho_1 = \rho_2$ for SP^{Aaa} and SP^{Baa}. The evidence for asymmetric adjustment for ISP^{Baa} is not supported by the *t*-tests and also only marginally supported by the *F*-test. This is especially important as ISP^{Baa} is supposed to be the residual credit spread reflecting idiosyncratic firm risks and tends to show up only when credit spread is high. Therefore it should not exhibit reverting adjustment involving spreads at the low end. Evidences from Table III suggest that the asymmetric price adjustment feature of a barrier option model of debt is supported empirically when we examine credit spreads of certain risk classes. Within such debt portfolios, only systematic and

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18 The model is used in Sun *et al.* (2006) as an improved time series version of (7) to achieve better decomposition of credit spreads. (7) would only be relevant in employing inferences on ρ_1 and ρ_2 if (8) produces a significant estimate of ρ.

19 The critical values of the *F*-statistic, which follows a non-standard distribution, have to be obtained from Enders and Siklos (2001).

nondiversifiable credit risk is relevant in characterizing the barrier effect.

【Table IV】

Similar procedures with equation (7) and (8) are carried out on the weekly data with results shown in Table IV. We have added analysis for credit spreads of yet another rating, the Aa grade. For the full credit spreads of all three classes, the hypothesis of asymmetric adjustment and that no reversion takes place on the high end are again both supported. However, symmetric adjustment is supported instead for the idiosyncratic credit spreads of the two classes of Baa and Aa. For the purpose of illustration, scattered plots of credit spreads against innovations under a TAR procedure are supplied in Figure 3. The reversion pattern above the computed thresholds for SP^{Aaa} and SP^{Baa} is clearly weaker than that below it. However, for ISP^{Baa} the reversion pattern seems to be much more symmetric on either side of the computed threshold.

【Figure 3】

According to our discussion in Section II, the existence of asymmetric price adjustment is an evidence for the validity of a barrier option model of credit spread. Our findings in this section strongly support the hypothesis. The results from our analysis are consistent with the asymmetry of DIC volatility with respect to firm values. When firm value is relatively low and the DIC for debtholders is close to be in the money, the volatility of DIC is relatively small, corresponding to our results of weak or no reversion in the credit spreads implied by the value of the debt. On the other hand, the strong reversion property of the credit spreads supports higher volatility of DIC as predicted by equation (1). These evidences are reported uniformly for three classes of investment-grade corporate bond indices, and should carry substantial generality. Moreover, we have conducted similar procedures for the *idiosyncratic* credit spreads of two classes of indices for comparisons. We could not find the phenomenon of asymmetric adjustment, which further confirms that only the systematic portion of credit spread is affected by the stochastic state variables underlying equation (5) and other structural models. The credit risks characterized by a structural model with either a barrier option or a standard put option are systematic and driven by common components. Idiosyncratic or firm-specific components are not appropriate to be modeled within the similar framework.

IV. Related issues and discussions

Alternative cointegration equation

Alternatively, we could fit an ARDL model in place of the *Baseline Model* as in equation (5). According to Pesaran, Shin and Smith (2001) (or PSS hereafter) approach, the existence of a unique valid long run relationship among variables, and hence a sole error-correction term, is the basis for estimation and inference. Short run, or difference-based, relationship cannot be supported unless a unique and stable equilibrium relationship holds in significant statistical sense. Both Neal et al. (2000) and Joutz, Mansi and Maxwell 2001) have made extensive discussion over a *positive* long run relationship between credit spread and interest rates versus a *negative* short run relationship within a Johansen framework. The long run relationship, which is represented by a cointegrating vector, however, needs not to be unique. Sun *et al.* (2007) has presented in their study evidences for each credit spread series a similarly *unique* and significantly *positive* long run relationship between credit spread and interest rates, as well as a significantly negative short run relationship. The validity of a unique (set of) long run coefficient(s) can be obtained by passing a VAT on the levels of all the variables involved, without having to resort to the result of a short-run oriented VECM estimation as with the Johansen model. In fact, according to arguments on the crucial nature of *level* relationship and the two-step testing procedures outlined in PSS (2001), the second-stage short run estimation is unnecessary and meaningless if the first-stage long run VAT is failed. In this regard, our results based on (8) offers valid long run results with firmer and logically more consistent evidences than from and VAR type of models. More accurate decomposition of credit spread may help in identifying systematic credit risk as the one driving a barrier-based model.

However, extracting residuals from an ARDL model for the TAR and MTAR procedures in this study does not prove to be a good alternative. The results are quite similar to those using residuals filtered through equation (5). But the power of the analysis is lower. Although using equation (5) without lag adjustments is subject to certain time series problems, the performance in the TAR and MTAR stages helps clarifying issues addressed in this study.

High yield bonds

We have examined the Aaa, Aa and Baa bond indices in our study. Our results are probably only applicable for investment-grade corporate bonds. Previous studies have shown that the pricing of non-investment-grade issues is governed more by default or nonsystematic credit factors, while Barnhill, Joutz and Maxwell (2000) reported specifically that lower-rated corporate bond indices exhibit slower reversion toward long-run equilibrium. Their findings are consistent with the barrier option modeling of credit spread in this study. To obtain consistent comparisons and evidences including the high yield issues, we would need to investigate credit spread behavior of those risk classes using the same methodology.

Individual bond issues

As the methodology employed in this study is based on specific firm class and evidences are obtained from observed corporate bond indices, individual factors cannot be separated to conduct further detailed analysis. Studies of financial variables such as individual asset volatilities, operating leverage, industry related factors and market capitalization in BT would be necessary to explore how the asymmetric price adjustments are affected by various individual risk factors. The range of firm values also has to be calibrated to see how instantaneous volatility of DIC responds it. Detailed Monte Carlo studies need to be carried out before further clarifications can be made.

V. Conclusion

We have provided in this study a hybrid barrier option framework where an embedded down-and-in call option and a liquidation factor are both included in the pricing of a debt claim to explain the asymmetric adjustment of credit spreads to innovations. Under this framework, the volatility of the barrier option will be lower when the firm value is low and approaching the state of bankruptcy implied knock-in barrier for the debtholders of the firm. The volatility of the option will be higher at higher firm values where the barrier is highly unlikely to be effective. The implication of these phenomena is that the implied credit spreads will be more volatile on the low end when little default risk is present and less so on the high end. The adoption of our modified version of the original BT model maintains partly the property of a classical approach, which is especially more applicable for debt issues with lower credit risk and shorter maturity. The property pertaining to a barrier approach explains credit spread behavior better in the case of high yield and long maturity issues.

To test the hypothesis of asymmetric adjustment of credit spreads, we use two types of threshold autoregressive models to identify the asymmetric effect. Beside a TAR model developed earlier, we have also applied an M-TAR model specified in Enders and Siklos (2001). Our empirical results support the implication from a barrier option framework of corporate debt. Specifically, findings from both the monthly and weekly data indicate that credit spreads of given risk classes exhibit no or weak reversion, when above a consistently estimated threshold, to long-run equilibrium as is forecasted by a cointegration relation for innovations. But for smaller innovations there are strong evidences for quick reversions to equilibrium. The results are uniform for all three classes of corporate bond indices. Moreover, further evidence suggests that the asymmetric adjustment property applies to systematic credit risk only. The unsystematic credit risk, which is proxied by a decomposed *idiosyncratic* credit spread, does not exhibit asymmetry in reverting to long-run equilibrium.

Findings from this work suggest that under the alternative barrier option model of corporate debt the observed market credit spreads could have been too high, especially when default risk is high. With the proper evaluation of an embedded down-and-in call option within a debt contract, credit spread curve may need to be modified. Overall, with the theoretical framework and empirical results of this study, credit spreads should be reduced more on the high end and less on the low end.

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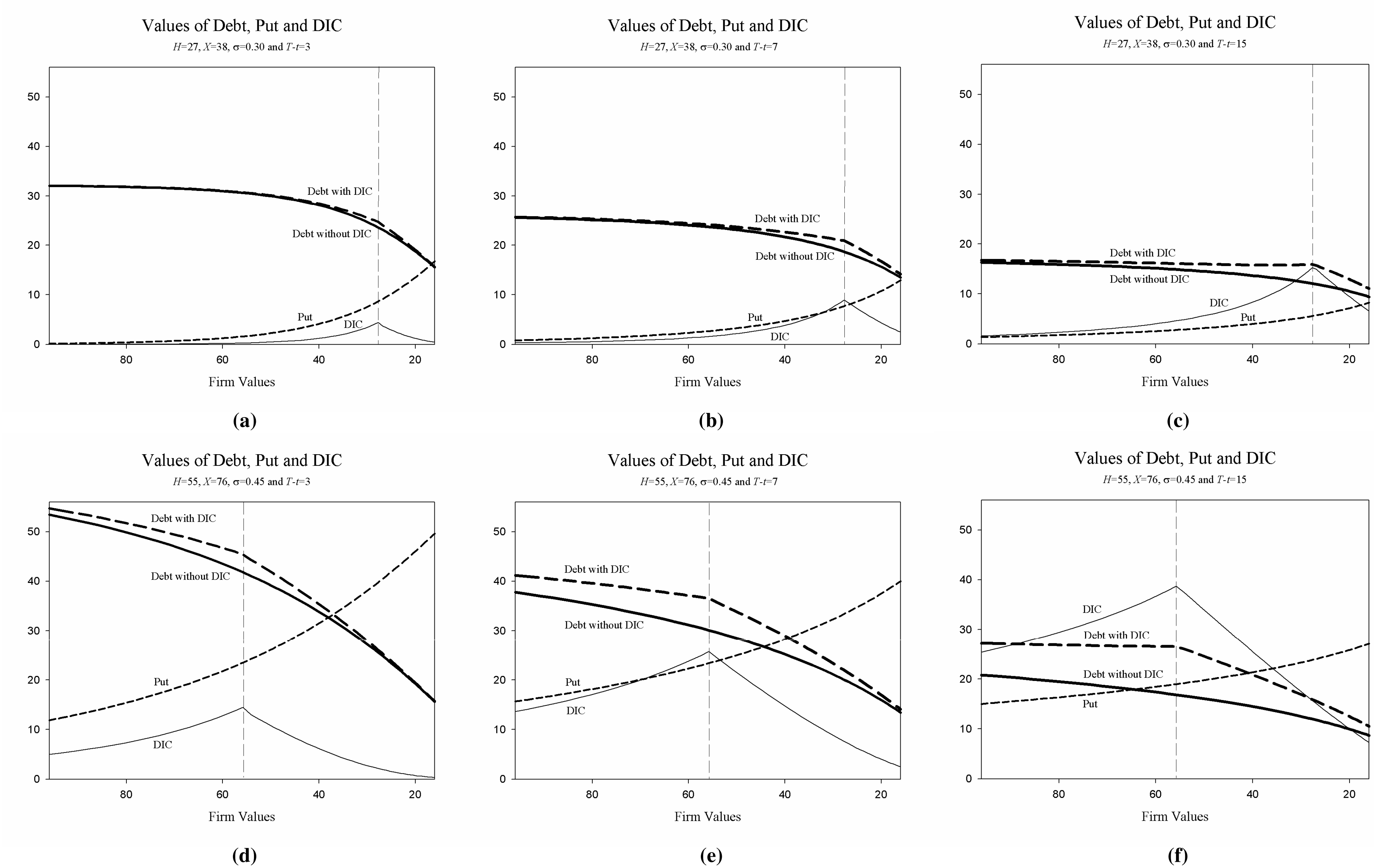
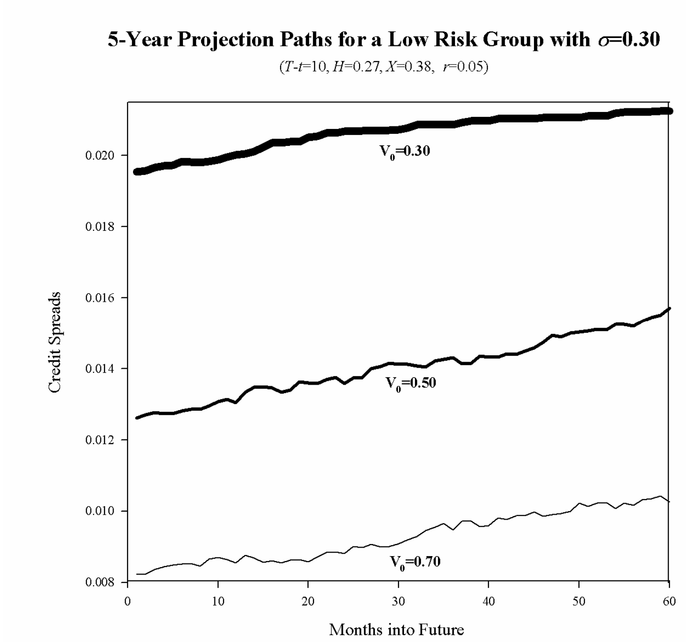


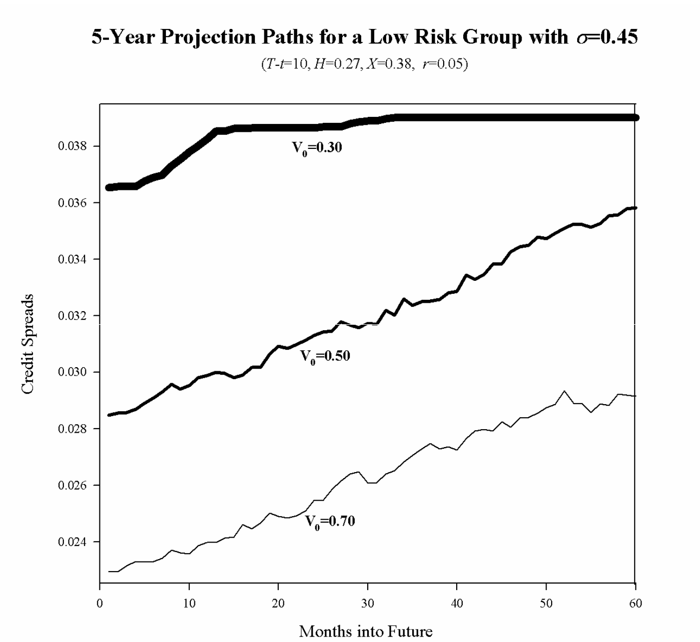
Figure 1

Values of DIC, Corresponding Debt and Standard Put at Given Firm Values for Time to Maturity

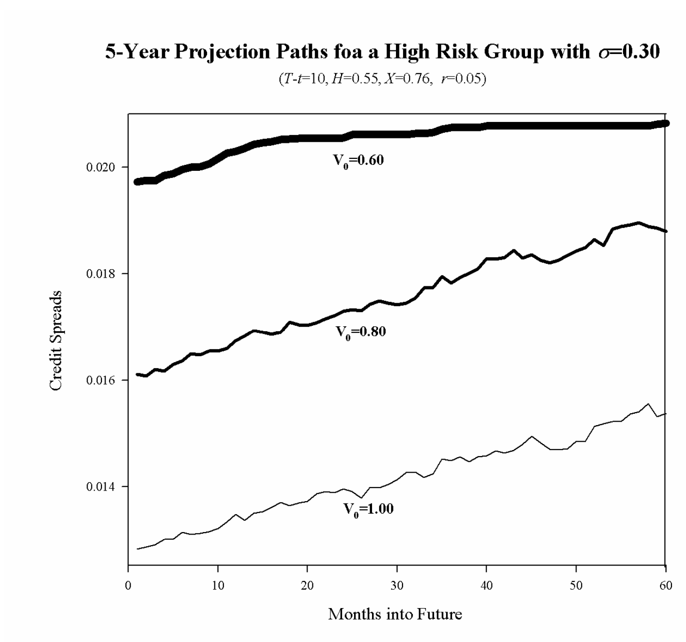
Top panels are plots for a low risk firm with a barrier of 27, whereas the bottom panels are for a high risk firm with a barrier of 55.



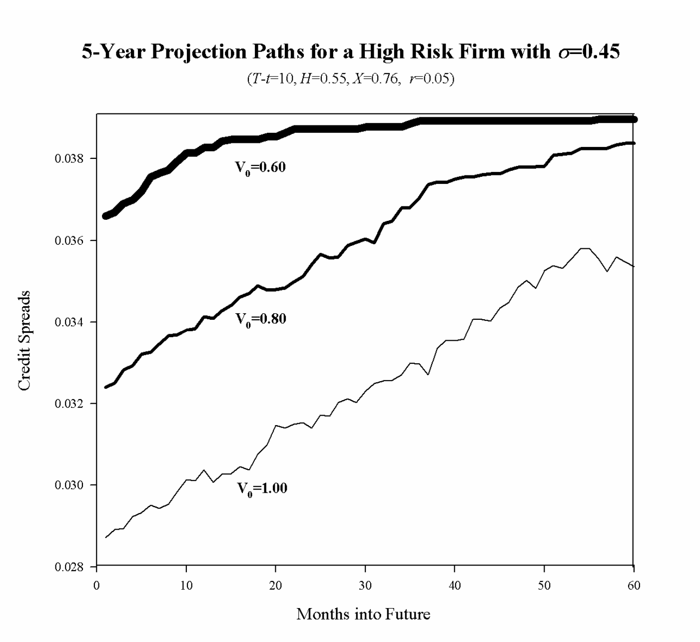
(a)



(b)



(c)



(d)

Figure 2

Simulated Credit Spreads for a Risky Pure Discount Bond as Including a Down-and-in Call Option at the Absence of Corporate Capital Gains Tax

Firm values for the subsequent 60 months are simulated with a geometric Brownian motion process. Starting firm values, as percentage of firm values at issuance of bond, are set respectively at 0.3, 0.5 and 0.7 for the low risk group. For the high risk group, they are set at 0.6, 0.8 and 1.0. Bond values are computed with the simulated firm values and parameters according to (2). When the firm value is below the barrier of the given risk group, values DIC are replaced by that of a standard call. Credit spreads are then calculated according to (3).

Table I
Summary Statistics of Credit Spreads

Data in this table is constructed with the Moody's seasoned Aaa and Baa corporate bond indices and the 10-year Treasury bond yield. Monthly and weekly observation of treasury yields are available from periods earlier than the corporate bond indices, but are trimmed to fit the time frame of the latter. SP^{Aaa} and SP^{Baa} are respectively the difference between the Aaa index and the 10-year Treasury bond yield, and that between the Baa index and the 10-year treasury yield. ISP^{Baa}, the difference between SP^{Baa} and SP^{Aaa} is taken as a simple measure of yield spread contained in Baa index which is not related to the Aaa index, or a naive measure of idiosyncratic credit spread. The division of subperiods is according to results from the Bai-Perron procedure reported in Table II.

Data	**Mean**	**Std. Dev.**	**Skewness**	**Kurtosis**	**Jarque-Bera**
Panel (a): Monthly Data					
Whole Period (1953:05~2003:09; 605 observations)					
SP^{Aaa}	0.7424	0.5025	0.8038	3.3763	68.7207 (0.0000)
SP^{Baa}	1.6929	0.7199	0.4505	2.6012	24.4718 (0.0000)
ISP^{Baa}	0.9504	0.4230	1.3806	5.0169	294.7316 (0.0000)
1st Period (1953:05~1972:04; 228 observations)					
SP^{Aaa}	0.3999	0.3020	1.5697	5.8254	168.4041 (0.0000)
SP^{Baa}	1.1043	0.4869	1.4273	4.9645	114.1452 (0.0000)
ISP^{Baa}	0.7043	0.2271	0.8487	3.7960	33.3872 (0.0000)
2nd Period (1972:05~1982:07; 123 observations)					
SP^{Aaa}	0.5954	0.3223	0.1785	2.7081	0.0902 (0.5798)
SP^{Baa}	1.8704	0.6173	0.4488	2.1725	7.6379 (0.0220)
ISP^{Baa}	1.2750	0.5058	0.5538	1.9383	12.0640 (0.0024)
3rd Period (1982:08~2003:09; 254 observations)					
SP^{Aaa}	1.1211	0.4589	0.5378	3.4725	14.6057 (0.0007)
SP^{Baa}	2.1353	0.5629	0.8659	3.0761	31.8016 (0.0000)
ISP^{Baa}	1.0142	0.3842	1.5594	6.7971	255.5334 (0.0000)
Panel (b): Weekly Data					
Whole Period (1962:01:12~2003:10:10; 2,179 observations)					
SP^{Aaa}	0.8326	0.5060	0.6205	3.2284	144.5698 (0.0000)
SP^{Baa}	1.8334	0.6965	0.2762	2.7501	33.3652 (0.0000)
ISP^{Baa}	1.0008	0.4324	1.2446	4.7654	845.5002(0.0000)
1st Period (1962:01:12~1972:08:04; 552 observations)					
SP^{Aaa}	0.4914	0.3752	1.1972	3.6907	142.8301 (0.0000)
SP^{Baa}	1.2177	0.6058	0.9695	3.1201	86.8135 (0.0000)
ISP^{Baa}	0.7262	0.2676	0.6388	2.9786	37.5555 (0.0000)
2nd Period (1972:08:04~1987:08:21; 785 observations)					
SP^{Aaa}	0.6743	0.3799	0.1826	2.8240	5.3742 (0.0680)
SP^{Baa}	2.0150	0.6455	0.4576	2.6890	30.5567 (0.0000)
ISP^{Baa}	1.3407	0.4737	0.7173	3.0386	67.3687 (0.0000)
3rd Period (1987:08:28~2003:10:10; 842 observations)					
SP^{Aaa}	1.2040	0.4455	0.8291	3.0897	96.7479 (0.0000)
SP^{Baa}	2.0679	0.5422	0.9271	3.1943	121.9332 (0.0000)
ISP^{Baa}	0.8639	0.2282	0.6473	2.4475	69.5049 (0.0000)

Table II

Structural-Change Estimation Results of the Baseline Model (Bai-Perron procedure)

A Baseline Model defined as, $\Delta SP_{it} = \beta_{i0} + \beta_{i1}\Delta TB3M_t + \beta_{i2}\Delta TERM_t + e_{it}$, where ΔSP_{it} stands for the changes of yield spread measure of SP_t^{Aaa}, SP_t^{Baa} or ISP_t^{Baa}, the difference between the first two, and $\Delta TB3M_t$ and $\Delta TERM_t$ are changes of three-month treasury yield and the yield difference between the 10-year and three-month treasuries respectively. This model is used to estimate endogenously possible structural changes over the sample period. The estimation procedure is according to the specification of Bai and Perron (2003). The number and locations of break points are obtained according to results of sequential procedure in particular. The estimation has also allowed for heterogeneity and autocorrelation in residuals, as well as AR(1) prewhitening prior to estimating the long run covariance matrix.

	β_0	β_1	β_2
Monthly, Whole Period (1953:05~2003:09; 605 observations) [a]			
SP^{Aaa}	0.0062 (0.0088)	-0.3049** (0.0242)	-0.3376** (0.0261)
SP^{Baa}	0.0439 (0.0121)	-0.4302** (0.0278)	-0.4459** (0.0341)
ISP^{Baa}	0.0007 (0.0070)	-0.1256** (0.0266)	-0.1120** (0.0301)
Monthly, First Subperiod (1953:05~1972:04; 228 observations)			
SP^{Aaa}	0.0129* (0.0058)	-0.6284** (0.0510)	-0.7128** (0.0567)
SP^{Baa}	0.0145* (0.0070)	-0.7014** (0.0562)	-0.8268** (0.0682)
ISP^{Baa}	0.0034 (0.0042)	-0.0674 (0.0353)	-0.1094** (0.0418)
Monthly, Second Subperiod (1972:05~1982:07; 123 observations)			
SP^{Aaa}	0.0127 (0.0167)	-0.2582** (0.0363)	-0.2855** (0.0478)
SP^{Baa}	0.0393 (0.0239)	-0.5183** (0.0484)	-0.5801** (0.0680)
ISP^{Baa}	0.0266 (0.0155)	-0.2602** (0.0380)	-0.2947** (0.0498)
Monthly, Third Subperiod (1982:08~2003:09; 254 observations)			
SP^{Aaa}	0.0078 (0.0072)	-0.2862** (0.0502)	-0.2910** (0.0319)
SP^{Baa}	-0.0154 (0.0090)	-0.3666** (0.03002)	-0.3137** (0.0252)
ISP^{Baa}	0.0076 (0.0064)	-0.0804 (0.0414)	-0.0227 (0.0258)
Weekly, Whole Period (1962:01:19~2003:10:10; 2,179 observations)			
SP^{Aaa}	0.0018 (0.0021)	-0.4196** (0.0181)	-0.4367** (0.0210)
SP^{Baa}	0.0031 (0.0032	-0.5746** (0.0160)	-0.5612** (0.0221)
ISP^{Baa}	0.0008 (0.0022)	-0.0680** (0.0188)	-0.0630** (0.0173)
Weekly, First Subperiod (1962:01:19~1972:08:04; 552 observations)			
SP^{Aaa}	0.0046 (0.0030)	-0.8641** (0.0404)	-0.8951** (0.0405)
SP^{Baa}	0.0053* (0.0026)	-0.8497** (0.0375)	-0.9164** (0.0378)
ISP^{Baa}	0.0007 (0.0015)	0.0144 (0.0199)	-0.0213 (0.0220)
Weekly, Second Subperiod (1972:08:11~1987:08:21; 785 observations)			
SP^{Aaa}	0.0011 (0.0027)	-0.3778** (0.0170)	-0.4035** (0.0251)
SP^{Baa}	0.0019 (0.0037)	-0.6089** (0.0250)	-0.6180** (0.0340)
ISP^{Baa}	0.0008 (0.0029)	-0.2312** (0.0212)	-0.2145** (0.0236)
Weekly, Third Subperiod (1987:08:28~2003:10:10; 842 observations)			
SP^{Aaa}	-0.0020 (0.0018)	-0.4611** (0.0404)	-0.3454** (0.0255)
SP^{Baa}	-0.0021 (0.0020)	-0.4716** (0.0431)	-0.3468** (0.0198)
ISP^{Baa}	0.0001 (0.0014)	-0.0106 (0.0152)	-0.0014 (0.0188)

[a] Break points and subperiod estimates for ISP^{Baa} only are generated from the Bai-Perron procedure, while all estimates for SP^{Aaa} and SP^{Baa}, and the whole period estimates for ISP^{Baa}, are from OLS procedures.

* Significant at 5% level.

** Significant at 1% level.

Table III

Cointegration and Asymmetric Adjustment Estimations on Credit Spreads, Monthly Data

The ARDL-ECM procedures are carried out for three sets of data, based on appropriate ARDL models for each class of credit spreads. For SP^{Aaa}, the only independent variable is *TB3M*. For SP^{Baa}, SP^{Aaa} and *TB3M* are the independent variables and for ISP^{Baa} , *TB3M* and *TERM*. The first model is in the form of

$$\Delta SP_t^{Aaa} = a + \sum_{i=1}^{l} b_i \Delta SP_{t-i}^{Aaa} + \sum_{j=0}^{m} c_j \Delta TB3M_{t-j} + \sum_{k=0}^{n} d_k \Delta TERM_{t-k} + \phi_1 SP_{t-1}^{Aaa} + \phi_2 TB3M_{t-1} + \phi_3 TERM_{t-1} + \varepsilon_t ,$$

where l, m and n are respective number of lags for difference terms of the three variables and are optimally selected, and ε_t is assumed to be a white noise. The TAR and MTAR models follow the specifications of Enders and Siklos (2001), with residuals obtained from the *Baseline Model* results in Table II. The threshold model takes the form of

$$\Delta SP_t^{Aaa} = \alpha + \rho_1 M_t \hat{\mu}_{t-1} + \rho_2 (1 - M_t)\hat{\mu}_{t-1} + \sum_{i=1}^{l} \gamma_{1i} \Delta SP_{t-i}^{Aaa} + \sum_{j=1}^{m} \gamma_{2i} \Delta TB3M_{t-j} + \sum_{k=1}^{n} \gamma_{3i} \Delta TERM_{t-k} + \varepsilon_t$$

where M_t is defined using μ_{t-1} for the TAR model and using $\Delta \mu_{t-1}$ for the M-TAR model.

	ARDL-ECM	TAR	M-TAR
***SP**^{Aaa} (1953:05~2003:09, 605 obs.)*			
ρ_1	-0.0362(0.0102)[a]	-0.0147 (0.0123)	-0.0035 (0.0123)
ρ_2	NA	-0.0785* (0.0274)	-0.1228* (0.0285)
ϕ (ρ_1=ρ_2=0)	NA	7.6941	13.4395[b]
ρ_1=ρ_2[c]		2.0280	15.1792[c]
$\hat{\tau}$	NA	-0.1301	-0.1320
Lags	ARDL(3,3)	3	2
***SP**^{Baa} (1953:05~2003:09, 605 obs.)*			
ρ_1	-0.0689(0.0115)[a]	-0.0219 (0.0122)	-0.0088 (0.0127)
ρ_2	NA	-0.0588* (0.0264)	-0.1073* (0.0259)
ϕ (ρ_1=ρ_2=0)	NA	8.9199[b]	15.6762[b]
ρ_1=ρ_2[c]		0.5227	13.6514[c]
$\hat{\tau}$	NA	-0.01660	-0.1660
Lags	ARDL(6,1,5)	5	5
***ISP**^{Baa} (1953:05~2003:09, 605 obs.)*			
ρ_1	-0.0606 (0.0143)[a]	-0.0592* (0.0168)	-0.0854* (0.0188)
ρ_2	NA	-0.0572* (0.0251)	-0.0278 (0.0219)
ϕ (ρ_1=ρ_2=0)	NA	11.0868[b]	12.3896[b]
ρ_1=ρ_2[c]		1.6507	4.1693[c]
$\hat{\tau}$	NA	-0.0594	-0.0152
Lags	ARDL(3,3,3)	5	5

* Significant at 5% level under a standard t-test.

a Significant at 5% level under a t-test according to the asymptotic critical value bounds outlined in PSS (2001).

b Significant at 5% level under a nonstandard F-test according to the asymptotic critical value bounds outlined in Enders and Siklos (2001).

c Significant at 5% level under a standard F-test.

Table IV

Cointegration and Asymmetric Adjustment Estimations on Credit Spreads, Weekly Data

The ARDL-ECM procedures are carried out for three sets of data, based on appropriate ARDL models for each class of credit spreads. For SP^{Aaa}, the only independent variable is *TB3M*. For SP^{Baa}, SP^{Aaa} and *TB3M* are the independent variables and for ISP^{Baa} , *TB3M* and *TERM*. The first model is in the form of

$$\Delta SP_t^{Aaa} = a + \sum_{i=1}^{l} b_i \Delta SP_{t-i}^{Aaa} + \sum_{j=0}^{m} c_j \Delta TB3M_{t-j} + \sum_{k=0}^{n} d_k \Delta TERM_{t-k} + \phi_1 SP_{t-1}^{Aaa} + \phi_2 TB3M_{t-1} + \phi_3 TERM_{t-1} + \varepsilon_t ,$$

where l, m and n are respective number of lags for difference terms of the three variables and are optimally selected, and ε_t is assumed to be a white noise. The TAR and MTAR models follow the specifications of Enders and Siklos (2001), with residuals obtained from the *Baseline Model* results in Table II. The threshold model takes the form of

$$\Delta SP_t^{Aaa} = \alpha + \rho_1 M_t \hat{\mu}_{t-1} + \rho_2 (1 - M_t)\hat{\mu}_{t-1} + \sum_{i=1}^{l} \gamma_{1i} \Delta SP_{t-i}^{Aaa} + \sum_{j=1}^{m} \gamma_{2i} \Delta TB3M_{t-j} + \sum_{k=1}^{n} \gamma_{3i} \Delta TERM_{t-k} + \varepsilon_t$$

where M_t is defined using μ_{t-1} for the TAR model and using $\Delta \mu_{t-1}$ for the M-TAR model.

	ARDL-ECM	TAR	M-TAR
SP^Aaa *(1962:01:12~2003:10:10, 2179 obs.)*			
ρ_1	-0.0149(0.0034)[a]	-0.0060 (0.0045)	-0.0026 (0.0041)
ρ_2	NA	-0.0156* (0.0066)	-0.0395* (0.0089)
$\phi(\rho_1=\rho_2=0)$	NA	11.7891[b]	19.4819[b]
$\rho_1=\rho_2$ [c]		0.5539	15.7783[c]
$\hat{\tau}$	NA	-0.0666	-0.0574
Lags	ARDL(3,2)	2	2
SP^Aa *(1982:01:08~1993:12:31, 626 obs.)*			
ρ_1	-0.0961(0.0224)[a]	-0.0183 (0.0140)	-0.0285 (0.0205)
ρ_2	NA	-0.0829* (0.0262)	-0.0659* (0.0152)
$\phi(\rho_1=\rho_2=0)$	NA	6.4939[b]	10.8782[b]
$\rho_1=\rho_2$ [c]		1.5212	10.1288[c]
$\hat{\tau}$	NA	-0.0681	0.0251
Lags	ARDL(1,2)	6	6
SP^Baa *(1962:01:12~2003:10:10, 2179 obs.)*			
ρ_1	-0.0229(0.0032)[a]	-0.0037 (0.0041)	-0.0002 (0.0037)
ρ_2	NA	-0.0129* (0.0057)	-0.0367* (0.0079)
$\phi(\rho_1=\rho_2=0)$	NA	12.3113[b]	24.2554[b]
$\rho_1=\rho_2$ [c]		0.3979	24.0226[c]
$\hat{\tau}$	NA	-0.0504	-0.0905
Lags	ARDL(2,2,2)	2	2
ISP^Aa *(1982:01:08~1993:12:31, 626 obs.)*			
ρ_1	-0.0432 (0.0091)[a]	-0.0608* (0.0159)	-0.1131* (0.0295)
ρ_2	NA	-0.1019* (0.0253)	-0.0547* (0.0151)
$\phi(\rho_1=\rho_2=0)$	NA	11.6865[b]	13.1369[b]
$\rho_1=\rho_2$ [c]		1.1372	3.9380[c]
$\hat{\tau}$	NA	-0.0307	0.0358
Lags	ARDL(3,2)	1	1
ISP^Baa *(1962:01:12~2003:10:10, 2179 obs.)*			
ρ_1	-0.0290 (0.0044)[a]	-0.0301* (0.0054)	-0.0249* (0.0051)
ρ_2	NA	-0.0292* (0.0079)	-0.0467* (0.0096)
$\phi(\rho_1=\rho_2=0)$	NA	21.3454[b]	22.9230[b]
$\rho_1=\rho_2$ [c]		0.0338	3.1284
$\hat{\tau}$	NA	-0.0371	-0.0356
Lags	ARDL(2,3,2)	1	1

* Significant at 5% level under a standard t-test.

[a] Significant at 5% level under a t-test according to the asymptotic critical value bounds outlined in PSS (2001).

[b] Significant at 5% level under a nonstandard F-test according to the asymptotic critical value bounds outlined in Enders and Siklos (2001).

[c] Significant at 5% level under an standard F-test

++ Significant at 5% level under a t-test according to the asymptotic critical value bounds outlined in PSS (2001).

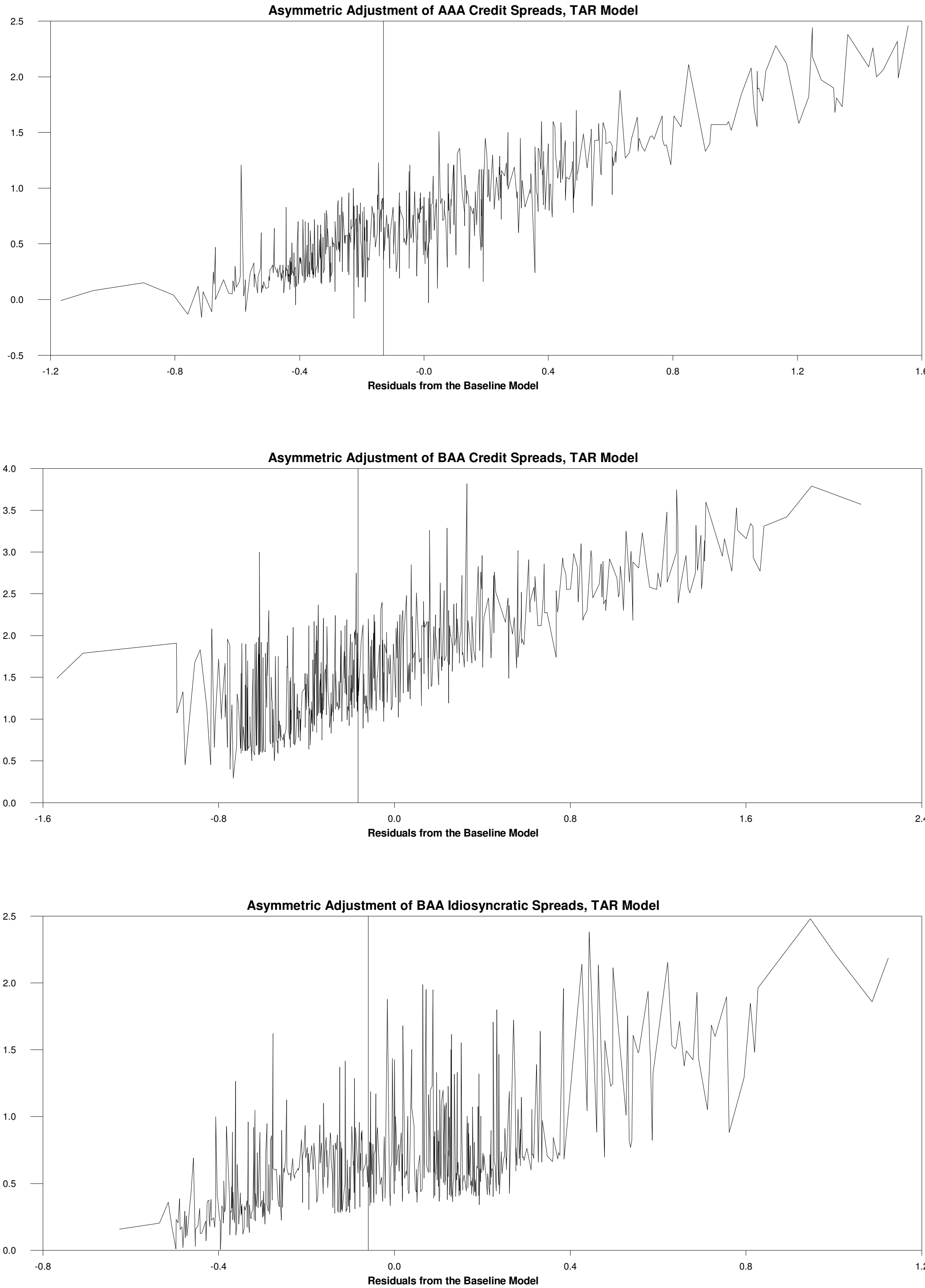


Figure 3

Asymmetric adjustments of SP^{Aaa}, SP^{Baa} and ISP^{Baa} to ranked residuals form the Baseline Model