การวิเคราะห์เชิงประจักษ์เรื่องตัวแบบเชิงโครงสร้างของหุ้นกู้ของบริษัทในประเทศไทย

นายอัศวิน วงศ์วีระวิทย์

สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

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ลิขสิทธิ์ของจุฬาลงกรณ์มหาวิทยาลัย

AN EMPIRICAL ANALYSIS OF STRUCTURAL MODELS OF
THAI CORPORATE BONDS

Mr. Asawin Wongweerawit

สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

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Accepted by the Faculty of Commerce and Accountancy, Chulalongkorn University in Partial Fulfillment of the requirements for the Master's Degree

Danuja Kunpanitchakit ....Dean of the Faculty of Commerce and Accountancy

(Assistant Professor Danuja Kunpanitchakit, Ph.D.)

THESIS COMMITTEE

....Chairman

(Thawatchai Jittrapanun, Ph.D.)

Sunti Tirapat ....Thesis Advisor

(Associate Professor Sunti Tirapat, Ph.D.)

....Committee

(Anant Chiarawongse, Ph.D.)

สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

นายอัศวิน วงศ์วีระวิทย์ : การวิเคราะห์เชิงประจักษ์เรื่องตัวแบบเชิงโครงสร้างของหุ้นกู้ของบริษัทในประเทศไทย (AN EMPIRICAL ANALYSIS OF STRUCTURAL MODELS OF THAI CORPORATE BONDS) อ. ที่ปรึกษา: รศ.ดร. สันติ ถิรพัฒน์, 49 หน้า. ISBN 974-53-2393-4.

วิทยานิพนธ์นี้ได้นำตัวแบบเชิงโครงสร้าง 4 ตัวแบบมาทดสอบกับตลาดหุ้นกู้ของไทย เพื่อเปรียบราคาจากตัวแบบกับราคาในตลาด (pricing errors) และหาการกระจายตัวของความผิดพลาดของราคา (standard deviation of pricing errors) ซึ่งตัวแบบประกอบไปด้วยตัวแบบของ Geske (1977), Leland-Toft (1996), Longstaff-Schwartz (1995), และ Collin-Dufresne-Goldstein (2001) การทดสอบนี้ได้ใช้ข้อมูลราคาหุ้นกู้ทั้งหมด 2,464 ตัวอย่างจากบริษัทที่มีโครงสร้างของเงินทุนแบบไม่ซับซ้อนระหว่างปี ค.ศ. 1999 ถึง 2004 พบว่าตัวแบบของ Collin-Dufresne-Goldstein ให้ผลเทียบกับราคาในตลาดได้ถูกต้องที่สุด อย่างไรก็ตามถ้าข้อมูลได้รวมหุ้นกู้ของ บริษัท บางจากปิโตรเลียม จำกัด (มหาชน) ซึ่งราคาหุ้นสามัญได้มีการเปลี่ยนแปลงอย่างมีนัยสำคัญในช่วงเวลาหนึ่งเนื่องจากตลาดมีความกังวลในเรื่องผลประกอบการ ตัวแบบของ Geske จะให้ผลถูกต้องที่สุด และยังพบว่าตัวแบบของ Geske ให้ความเสี่ยงจากการผิดชำระ (credit risk) น้อยกว่าตลาด ขณะที่ตัวแบบที่เหลือให้ความเสี่ยงจากการผิดชำระมากกว่าตลาด สำหรับการกระจายตัวของความผิดพลาดของราคาของทั้ง 4 ตัวแบบ พบว่าค่อนข้างสูงเมื่อเทียบกับความผิดพลาดของราคา โดยตัวแบบของ Leland-Toft ได้ให้การกระจายตัวของความผิดพลาดของราคาสูงที่สุดโดยเฉลี่ย นอกจากนี้การศึกษานี้ได้ศึกษาความอ่อนไหวของความผิดพลาดของราคากับอัตราการจ่ายคืน (sensitivity of recovery rate) พบว่าถ้าให้อัตราการจ่ายคืนจากการผิดชำระสูงขึ้นจะช่วยให้ความผิดพลาดราคาลดลงโดยได้ทดลองเปลี่ยนค่าอัตราการจ่ายคืนตั้งแต่ 30%–60% ซึ่ง อัตราการจ่ายคืนที่ 60% จะให้ความผิดพลาดของราคาต่ำสุด ท้ายที่สุดการศึกษาพบว่าตัวแบบเหล่านี้ค่อนข้างอ่อนไหวต่อตัวแปรที่ต้องประมาณค่า (estimated parameters) เช่น ตัวแปรที่เกี่ยวกับอัตราส่วนหนี้สินเป้าหมาย (target leverage ratio) ในตัวแบบ Collin-Dufresne-Goldstein จะให้ผลต่างกันอย่างสิ้นเชิง เมื่อตัวแปรคำนวณมาจากวิธีที่ต่างกัน

ภาควิชา การธนาคารและการเงิน ลงลายมือชื่อนิสิต....................

สาขาวิชา การเงิน ลงลายมือชื่ออาจารย์ที่ปรึกษา....................

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ASAWIN WONGWEERAWIT: AN EMPIRICAL ANALYSIS OF STRUCTURAL MODELS OF THAI CORPORATE BONDS. THESIS ADVISOR: ASSOC. PROF. SUNTI TIRAPAT, PH.D., 49 pp.
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This paper applies four structural models of corporate bond pricing to the Thai bond market. The study compares predicted bond prices with actual bond prices and finds the standard deviations of pricing errors. The four structural models tested are proposed by Geske (1977), Leland and Toft (1996), Longstaff and Schwartz (1995), and Collin-Dufresne and Goldstein (2001). The sample consists of 2,464 observations of bond prices from firms with simple capital structures during 1999–2004. We find that the Collin-Dufresne and Goldstein model generates the lowest pricing errors and standard deviations among the four models using a slightly truncated sample. However, the Geske model provides the lowest pricing errors and standard deviations. In addition, the Geske model understates the credit risk while the other models overstate the credit risk on average. Also, We find that the standard deviations of pricing errors of the four models are quite high compared to pricing errors. The Leland and Toft model has the highest standard deviation on average. Moreover, this study examines the sensitivity of pricing errors to the recovery rate assumptions. The results show a high recovery rate can reduce the pricing errors. Specifically, we test the effect of recovery rate on pricing errors by changing the recovery rate from 30% to 60% and find that the recovery rate at 60% provides the least pricing errors. Finally, the study finds that each model is quite sensitive to the estimated parameters. For example, the Collin-Dufresne and Goldstein model, using different parameters estimates of the target leverage ratio, generates extremely different results.

Department of Banking and Finance
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Student's signature..Asawin Wongweerawit.....
Advisor's signature..Sunti Tirapat.......

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CHAPTER I

Introduction

1.1 Background and Problem Review

To price risky bonds we have to take into account the probability of default. In the finance literature, there are many structural models that propose to price risky bonds, depending on the decision to default and assumptions about recovery value when they default. The seminal work of Black and Scholes (1973) and Merton (1974) contributed theoretical frameworks to price risky debt based on an option pricing framework. Yet it is well documented that the Merton model generates yield spreads that are too low comparing to those observed in the market. Therefore, the recent theoretical literature uses various new factors, for example allowing for coupons, stochastic interest rates, and default before maturity.

Geske (1977) extends Merton (1974) by applying a technique for valuing compound options to the risky coupon bonds problem. Leland and Toft (1996) used the optimal capital structure and endogenous bankruptcy to price risky debt. They derived endogenous conditions under which bankruptcy will be declared, and compare their model to others in which bankruptcy is exogenous. Longstaff and Schwartz (1995) allow stochastic interest rate and default risk to be incorporated when valuing risky corporate debt. Collin-Dufresne and Goldstein (2001) extend Longstaff and Schwartz by allowing stationary leverage ratios.

Recently, Eom, Helwege and Huang (2004; henceforth EHH) compare the original Merton model and four newer structural models to the actual prices of bonds, to determine which models best fit with the US. bond market during 1986-1997. They implement these five structural models: Merton (1974), Geske (1977), Leland and Toft (1996), Longstaff and Schwartz (1995) and Collin-Dufresne and Goldstein (2001). This paper will refer to these models as the M, G, LT, LS and CDG models, respectively.

EHH find that the five structural bond pricing models do not accurately price corporate bonds. The M and G models underpredict spreads on average. The LS, LT and CDG models overpredict spreads on average. The predicted spreads are lowest for firms with low volatility and low leverage in most of models. The maturity factor was virtually no effect on the spread, the same conclusion as the previous literature, in which the structural models cannot generate high spreads on short maturity bonds. The LT model overestimates bond spreads in many cases, because of a simplifying assumption concerning coupons. In addition, the LT model tends to overestimate credit risk on shorter maturity bonds.

Although the LS, LT and CDG models avoid the problem of estimated spreads that are too low, they have a problem with accuracy because of dramatic dispersions of predicted spreads. The effects of stochastic interest rates and costs of financial distress have a significant influence through a recovery rate. Thus, the authors feel stochastic interest rates more accurate than the Vasicek model would help.

Many researchers test patterns predicted by structural models, such as the shape of the credit term structure, on the shape of the credit yield curve, on bond rating changes, on changes in bond spreads, on the relation between bond spreads and Treasury yields, on real default probabilities implied by structural models, and the correlation between interest rates and spreads. Those empirical studies conclude the models underpredicted spreads and do not find support for the models.

The Thai bond market is an emerging market with increasing trading liquidity. Recently, the Thai government established the Bond Electronic Exchange (BEX) to improve liquidity, because most bonds are now traded in over the counter (OTC). However, research papers for the Thai bond market are rare because it was not well-known with insufficient data to apply in research. Now, we can find enough data to apply the structural models.

As there is no empirical result for the Thai bond market, this study will apply the structural models and compare each. This study describes the characteristics of each model and how to estimate it. Other researchers can use the empirical results to refer and compare to other structural models.

1.2 Statement of Problem / Research Questions

To investigate whether structural models can accurately price corporate bonds in the Thai market. Which model is appropriate to value bonds in Thailand?

1.3 Objective of the Study

- To apply four structural models, i.e. the Geske (1977), Leland and Toft (1996), Longstaff and Schwartz (1995), and Collin-Dufresne and Goldstein (2001) models; the G, LT, LS and CDG, respectively, for corporate bonds.

- To investigate pricing errors from each model.

1.4 Scope of the Study

The study covers corporate bonds listed with the Thai Bond Dealing Center (ThaiBDC) from 1999 to 2004. This study will not cover non-listed firms and financial firms.

1.5 Contribution

The structural models in this paper can generate the bond prices that can be a guideline for investors and fund managers to decide whether bonds are overpriced or underpriced. In addition, the structural models fitting with the Thai bond market could be further study.

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CHAPTER II

Literature Review

This section discusses related theories and empirical studies of each structural model. This section is structured as follows: concept and theoretical background, and empirical evidence of each structural model.

2.1 Concept and Theoretical Background

2.1.1 Default-free Bond Pricing

The valuation of a default-free bond can be found by assuming no free lunch, or no arbitrage opportunity of the assets. That means we discount all cash flows of the bonds by the interest rates that match with the maturity; the number from this method gives the price of the bond. If the market prices are higher or lower, we can arbitrage or take the profit by no investment. We assume no market frictions or transaction costs. We can find the price from equation (1).

$$D(T) = \sum_{t=1}^{T} \frac{c_t}{(1+i(0,t))} + \frac{F}{(1+i(0,T))} \tag{1}$$

where F is the principal of the bond, c_t is the coupon of the bond at the time t, and i(0,t) is the spot rate at now for period t, while t=1,…,T. The spot rate can be determined from various term structure models such as Nelson-Siegel (1987) and Vasicek (1977).

2.1.2 Risky Bond Pricing

Traditionally, there are two approaches to value the corporate debt by the credit risk. Firstly, the 'structural' approach models the bankruptcy process explicitly. It defines both the event that triggers default and the payoffs to the bondholders at default in term of the assets and liabilities of the firm. The structural approach has only been able to produce the closed-form solutions under simplistic capital structure assumptions. Secondly, the 'reduced-from' or 'statistical' approach treats default as an event governed by an exogenously specified jump process. This method is more tractable. However, this study will focus on the structural model.

The main concept of risky bond pricing is that the price of bonds should contain default risk by applying the probability of default (PD) and the loss given default (LGD) in the default-free bond pricing formula.

$$D_{\text{risky}}(T) = D(T) \times PD(\cdot) \times LGD(\cdot) \tag{2}$$

The structural models describe the PD, but in different ways. For example, they differ in important features, including the specification of the coupons, interest rates, default boundary, and recovery rates.

For the simplest model, Merton (1974) assumes bondholders receive the entire value of the firm in distress and that interest rates are constant. The M model treats a coupon bond as a portfolio of zero-coupon bonds, each of which is priced using the zero-coupon version of the model, and spot rates are used to discount bond cash flows also. In Black and Scholes (1973) and Merton (1974), all debts mature on the same day, and the firm defaults when the firm value is lower than the payment due. Hence, the default boundary, K, consists of a single point in time, equals to the face value of the maturing debt. Unfortunately, the model becomes intractable because the default occurs at maturity. The formulas of the M model can be calculated as follows:

$$\begin{aligned} P(0,T) = \sum_{i=1}^{T-1} D(0,i) E\left[c\, I\{V_i \geq K\} + \min(wc, V_i)\, I\{V_i < K\}\right] \\ + D(0,T) E\left[c\, I\{V_T \geq K\} + \min(w(1+c), V_T)\, I\{V_T < K\}\right] \end{aligned} \quad (3)$$

It is known that

$$E[I\{V_t \geq K\}] = N(d_2(K,t)) \quad (4)$$

$$E[I\{V_t < K\} \min(x, V_t)] = V_0 D(0,t)^{-1} e^{-\delta t} N(-d_1(x,t)) + x\left[N(d_2(x,t)) - N(d_2(K,t))\right] \quad (5)$$

where $x \in [0, K], N(\cdot)$ represents the cumulative standard normal function and

$$d_1(x,t) = \frac{\ln(V_0 / (xD(0,t))) + (-\delta + \sigma_v^2 / 2)t}{\sigma_v^2 \sqrt{t}}; \qquad d_2(x,t) = d_1(x,t)\sigma_v \sqrt{t}$$

Given the term structure *D(0,i)*, coupon *c*, payout ratio δ, the firm value at time 0 V_0, assets volatility σ_v and the face value of the liabilities *K*, we can find price from the model *P(0,T)*.

The Geske model (the G model; 1977) is the same as the M model, except it treats the coupon of the bond as a compound option. The firm would not default if the shareholders pay the coupon by issuing new equities. If default occurs, bondholders receive the entire value of the firm.

The Leland and Toft model (the LT model; 1996) specifies that the firm continuously issues a constant amount of the debt with a fixed maturity. Also, it pays a continuous coupon, like the G model, and equityholders have the option to issue new equity to repay the debt. Otherwise, the default situation occurs and then equityholders get nothing, but bondholders receive some proportion of the firm asset value by assuming the existing of liquidation costs.

Black and Cox (1976) and Longstaff and Schwartz (1995) assume that the firm is forced to default when the first time its value fall below a constant threshold, K. In general case, K can be viewed as the face value of the liabilities of a firm that has a constant amount of debt outstanding at all times. Here, the default may occur at any point in time, even when no payment is due. Black and Cox (1976) model the default payoffs like Black and Scholes (1973), which makes the model intractable for realistic capital structures.

The Longstaff and Schwartz model (1995) and the Collin-Dufresne and Goldstein (CDG; 2001) models both use stochastic interest rates, e.g. the Vasicek model (1977). In these models, default occurs when the firm's asset value is lower than the trigger point that must be pre-specified. In the event of default, bondholders receive a constant proportion of the principal and coupon. The difference between the CDG and LS models is that the CDG model includes a stationary leverage ratio. Therefore, the CDG model allows the firm leverage ratio to deviate from its target leverage ratio over the short run.

In Longstaff and Schwartz (1995), the debt issued by the firm is assumed to remain constant irrespective of the firm value. Collin-Dufresne and Goldstein (2001) realize that in reality the firm's liability does not remain constant. They propose the model to reflect the firm's tendency to maintain a stationary leverage ratio. The ratio V/K can be interpreted as the inverse leverage ratio. Hence, V/K is modeled as mean-reverting, and the firm is assumed to enter the default when V/K falls very low.

2.2 Empirical Study

The useful implementation of structural model was contributed by Jones, Mason, and Rosenfeld (1984), (hereafter JMR). In that paper, the M model was applied with a sample of firms with simple capital structures during 1977-1981. The predicted prices from the M model were 4.5% too high on average, meaning too low a spread of the actual prices on average. JMR summarizes that the M model works better for low grade bonds because it had the greater incremental explanatory power for riskier bonds, but the errors are largest for speculative-grade firms. Also, pricing errors were significantly related to maturity, equity variance, leverage and the time period.

Ogden (1987) is similar to JMR but uses new offering prices, and found that the M model underpredicted spreads by 104 basis points on average. Both JMR and Ogden conclude that the M model suffers from non-stochastic interest rates. One reason is that they price bonds from the a time period when treasury rates swung wildly between 8.5% and 20%, while the M model did not take interest rate volatility into account in the model. Hence, the M model tends to overprice bond because the price of risky bonds should take interest risk and credit risk, which the LS and CDG model can take both risk into their models.

Lyden and Saraniti (2000) were the first to implement and compare the M and LS models using individual bond prices. They use prices for the noncallable bonds of 56 firms that were reported in Bridge. Similarly the studies, the other implementations of the models, Wei and Guo (1997) and Anderson and Sundaresan (2000), used aggregate data, and Ericsson and Reneby (2001) implemented a perpetual bond model considered in Black and Cox (1976). Both the M and LS models underestimate yield spreads. Although they allow interest rates to vary stochastically, it has little impact on errors. Moreover, the main errors are systematically related to coupon and maturity. For the LS model, predicted errors are related to the estimation of asset volatility.

Moreover, researchers have examined general patterns predicted by structural models; for example, the correlation between interest rates and spreads or the shape of the credit term structure. Sarig and Warga (1989), Helwege and Turner (1999), and He, Hu and Lang (2000) studied the shape of the credit yield curve. Delianedis and Geske (1998) studied bond rating change. Collin-Dufresne, Goldstein and Martin (2001) and Elton, Gruber, Agrawal and Mann (2001) studied changing in bond spreads. Dufee (1998), Brown (2001), and Neal, Rolph and Morris (2001) studied the relationship between bond spreads and Treasury yields. Huang and Huang (2002) studied real default probabilities implied by structural models. However, most of these empirical studies conclude that the structural models severely underestimate spreads on average.

Recently, EHH tested five models. They used bond prices between 1986 and 1997. Contrary to the previous empirical literatures, they did not characterize the structural models as unable to generate sufficiently high spreads. Hence, the empirical results of their study are shown here.

The M model tends to overprice bonds on average, whether they use the Nelson-Siegel model or the Vasicek model. They test bonds rated A or higher, BBB-rated bonds, and below investment-grade, by assuming a recovery rate of 51.31% of face value. The results include both extreme overprediction and underprediction of bond spreads, but underprediction on average. The tendency toward underprediction appears to the short maturity bonds rated BBB or higher. In conclusion, all five models tend to generate low spreads on the safer bonds but high spreads on the riskier bonds.

In the Geske model, they assume 51.31% of the face value of debt and whole firm value as the recovery rate. The result of setting 51.31% of face recovery is like the M model, but it works better on the shorter maturities. In addition, they remark that for whole firm recovery, the M model has the average spread prediction error. Including cost of financial distress, it generates higher average spreads, but with a loss of accuracy.

The LT model has a tendency to overpredict bond spreads; two-third of spreads are overestimated. The LT model also lacks accuracy. For three of the one-factor models, i.e. M, G and LT, each model was created without considering the stochastic of risk-free interest rate. The authors note that two of these models tend to underestimate spreads while the third usually overestimate spreads.

Both the LS and CDG models have higher predicted spreads than the M and G models, but they lose accuracy to predict the spreads. Chan, Karolyi, Longstaff and Sanders (1992) conclude that the Vasicek model is a poor fit for short-term rates. It may suffer accuracy of LS and CDG models. The LS model has a tendency to predict either very high or low spreads, but more often the highest spreads belongs to the lowest rated bonds. In addition, the dispersion is also more extreme at shorter maturities, especially in the range of five to ten years.

From CDG, the results of the CDG model are almost the same as the results of LS model. However, the CDG model defines two new parameters: the speed of adjustment and mean asset returns. The authors adjust these two parameters to observe the result. To sum up, two additional parameters can solve the underestimated credit risk problem but severely overestimate credit risk.

For most of the structural models, predicted spreads are lowest when the bonds belong to firms with low volatility and low leverage. They find no role for maturity if these factors are constant. Nevertheless, the previous literatures which claim that structural models cannot generate sufficiently high spreads on short maturity bonds are different from EHH. They claim that the LT model overestimates bond spreads in most case because of simplifying assumptions about coupons. Hence, the result of the LT model actually tends to overestimate credit risk on short maturity bonds.

In conclusion, the M and G models underestimate bond spreads on average. However, this problem is less severe for the G model. They refer that the option to make coupon payments in distress improves the dispersion of predicted spreads relative to other models. In the other hand, the dispersion of predicted spreads is exacerbated by the use of a fixed face value recovery rate in the G model. The problems of the LT model are over spreads on average and not sensitive to the parameter estimates. Indeed, the LT model overpredicts spreads on shorter maturity bonds. The LS and CDG models incorporate stochastic interest rates and a correlation between firm value and interest rates. They find that the correlation is not significant to the results. Stochastic interest rates can raise the average predicted spreads but the interest rate volatility from the Vasicek model is sensitive to the results. While the LS and CDG models generate high spreads on average and they lose accuracy of prediction. The CDG model might alleviate the problem of high dispersion of predicted spreads if the underprediction occurs among low leverage firm and the overprediction belongs to high leverage firm. The main problem of five structural models is difficulty in accurately predicting credit spreads.

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CHAPTER III

Data and Methodology

3.1 Data

The bond data is collected from the Thai Bond Dealing Center (ThaiBDC) since 1999 to 2004. The frequency and type of the data is closing prices of the days that bonds are traded, because the Thai bond market has lower liquidity than other developed countries. We have many types of bonds that should be excluded, like those issued by financial firms, because the leverage ratio and risk of the debt of financial firms are different from non-financial firms.

For the risk-free interest rates, we use Thai government bonds as a reference. In addition, this data will be calculated by using the Nelson-Siegel model and the Vasicek model. The other data needed are available from ISIM (see also Table 1 and Table 2).

Table 1
Summary of the Industries of the Bonds

We have a problem from too few data samples because there are 25 firms since 1999 to 2004. So, we use samples from bond prices that are traded, i.e. 2464 samples.

Industry	# of firms	# of sample	% of sample	Average of Year to Maturity	Average of Yield to Maturity (%)
Construction Materials	3	844	34.25%	1.683	3.948
Communication	2	700	28.41%	3.023	3.554
Energy & Utilities	5	595	24.15%	3.972	4.140
Petrochemical & Chemicals	2	137	5.56%	4.510	5.298
Printing & Publishing	1	70	2.84%	1.785	4.013
Property Development	7	40	1.62%	1.942	5.705
Transport & Logistics	2	29	1.18%	2.880	5.857
Food & Beverage	1	23	0.93%	1.900	7.187
Hotels & Travel	1	19	0.77%	1.400	5.500
Commerce	1	7	0.29%	1.081	5.627
Total	25	2,464	100%	2.793	4.057

3.2 Research Hypotheses

Hypothesis: Consistent with the empirical results from the U.S. market, the pricing error from the Geske model is lowest among the four structural models.

3.3 Methodology

In this section, we first define and estimate parameters for these models. Then, we discuss the implementation of the four structural models, i.e. G, LT, LS and CDG.

Table 2
Summary of Parameters

ThaiBDC is the Thai Bond Dealing Centre. NS refers to the Nelson and Siegel (1987) model. The speed of adjustment to target leverage, sensitivity of target leverage to interest rates, and related to the target leverage are estimated from the regression and pre-specified which these parameters will be used in the CDG model.

Parameter		Description	Source of Data
Bond features:	c	Coupon	ThaiBDC
	T	Maturity	ThaiBDC
	F	Face value	total liabilities
	ω	recovery rate	Assumed at 51.31% or given
Firm characteristics:	V	Firm value	total liabilities plus market value of equity
	μ_{υ}	Asset return	average monthly return change in V
	σ_{υ}	Asset volatilities	Historical equity volatility adjusted for leverage
	δ	payout ratio	Weighted average of coupon and the share repurchase-adjusted dividend yield
	κ_{ℓ}	speed of adjustment to target leverage	coefficient from a regression of changes in log leverage against lagged leverage and r
	ϕ	Sensitivity of target leverage to interest rates	coefficient from a regression of changes in log leverage against lagged leverage and r
	ν	related to the target leverage	from a regression of changes in log leverage against lagged leverage and r
	T	tax rate	Assumed at 0.30
Interest rates:	r	riskfree rate	the NS or Vasicek models
	ρ	Correlation between V and r	correlation between equity returns and r
	σ_r	Interest rate volatility	the Vasicek model

For the parameter of each structural model, the models require the following parameters as inputs: firm value (V), coupon (c), face value (F), maturity (T), recovery rate (ω), the payout parameter (δ), asset return (μ_{υ}), asset return volatility (σ_{υ}), the speed of a adjustment to target leverage (κ_{ℓ}), and sensitivity of target leverage to interest rates (ϕ), risk free rate (r), correlation between V and r (ρ), tax rate (τ). The parameters that we observe are c, T, δ and τ (see also Table 2). We cannot observe V, F, ω but these can be implied from total liabilities, market value of equities and assumption. The other parameters that we need to estimate are described in parameter estimation section.

For the recovery rate, ω is the average bond recovery rate is 51.31% of face value from research of Keenan, Shtogrin, and Sobehart (1999) that is the empirical result from U.S. market. Although the recovery rate is not appear in Thai bond market, we use 51.31% as the recovery rate in base case but it can vary to any value. Among the five models, the LT model required tax, thus we specify tax rate (τ) as 30%.

In the defaultable bonds, we use the book value of total liabilities instead of the face value of the bond. To find the leverage ratio, we use the firm value, which can be estimated as the sum of the market value of equity and the market value of total debt, but we substitute the latter with the book value of debt. So, the leverage ratio comes from the total liabilities over the firm value.

The correlation coefficient ρ between asset returns and interest rates in the LS and CDG model is approximated by the correlation between equity return and changes in interest rates (3-month T-Bill).

3.3.1 Parameter Estimation

3.3.1.1 Asset Return Volatility

Although the asset return volatility is unobservable, we can imply it from historical equity return volatility (σ_e). So, σ_v can be estimated by using the relationship $\sigma_e = \sigma_v \cdot \frac{V_t}{S_t} \cdot \frac{\partial S_t}{\partial V_t}$, where σ_e base on historical 90-day volatility, S_t denotes the market value of equity at time t. The $\partial S_t / \partial V_t$ can use $N(d_1(Kt, t))$ as proxy,

where $$d_1(K,t) = \frac{\ln\left(\frac{V}{Ke^{-rt}}\right) + (-\delta + \sigma_v^2/2)t}{\sigma_v \sqrt{t}}$$

Then, numerical method is used to find σ_v by iteration σ_v and makes the equation equally.

3.3.1.2 Parameters in a Mean-Reverting Leverage Process

For the CDG model, we have to estimate κ_ℓ, ϕ and v. The κ_ℓ and ϕ can be estimated by regression. However, this would not produce a direct estimate of $\bar{v}$. So, a regression of the change in the log leverage ration against log leverage lagged one period and the interest rate will generate parameter estimates: $\hat{\alpha}_\ell$, $\hat{\kappa}_\ell$ and $\hat{\phi}$. Then $\bar{\hat{v}} = (\hat{\alpha}_\ell - \hat{\mu}_v)/\hat{\kappa}_\ell$, and μ_v is estimated by the mean return of the asset value over time.

3.3.1.3 Interest Rate Parameters

Let $y(t, T; \Theta_r)$ denote the spot rate at time t with term equal to T - t predicted by a particular model characterized by its parameter set Θ_r. To fit the model to interest rates on day t, one chooses parameters in Θ_r to minimize the sum of errors squared, where the error is measured as the deviation between the model yield and the market yield.

In the Nelson and Siegel (1987) model,

$$y(t,T;\Theta_r) = \beta_0 + \delta_1(\beta_1 + \beta_2)\frac{(1 - e^{-(T-t)/\delta_1})}{T-t} - \beta_2 e^{-(T-t)/\delta_1} \quad (3)$$

where $\Theta_r = (\beta_0, \beta_1, \beta_2, \delta_1)$, and β_0 and δ_1 need to be positive. The NS model will be applied in the Geske model and the Leland Toft model.

In the Vasicek (1977) model,

$$y(t,T;\Theta_r) = -\ln D(t,T)/(T-t) = \frac{-\ln(A(t,T)) + r_t B(t,T)}{(T-t)} \tag{6}$$

$$A(t,T) = \exp\left[(B(t,T) - T + t)\left(\frac{\alpha}{\beta} - \frac{\sigma_r^2}{2\beta^2}\right) - \frac{(\sigma_r B(t,T))^2}{4\beta}\right] \tag{7}$$

$$B(t,T) = \frac{1}{\beta}(1 - e^{-\beta(T-t)}) \tag{8}$$

where $\Theta_r = (\alpha, \beta, \sigma_r, r_t)$. The Vasicek model will be applied in the LS and CDG model.

3.3.2 Structural Models

Before starting with the structural models, we describe some equation to apply to all structural models. Let V_t, K_t and r_t be the time-t values of the firm's assets, total liabilities, and the riskfree interest rate, respectively. Assume that

$$dV_t = (r_t - \delta)V_t\, dt + \sigma_v V_t\, dZ_{1t} \tag{9}$$

$$dr_t = (\alpha - \beta r_t)\, dt + \sigma_r dZ_{2t} \tag{10}$$

$$d\ln K_t = \kappa_\ell \left[\ln(V_t / K_t) - \nu - \phi(r - \theta)\right] dt \tag{11}$$

where $\sigma_v, \delta, \alpha, \beta, \sigma_r, \kappa_\ell, \nu,$ and ϕ are constants, $\theta = \alpha/\beta$, and Z_1, Z_2, two one-dimensional standard Brownian motion process under the risk-neutral, are assumed to have a constant correlation coefficient of ρ. All four of structural models assume (9). The LS and CDG model assume also (10) and (11), but κ_ℓ assumes to be 0 in LS.

However, the three structural models have an analytical or quasi-analytical formula for coupon bond prices, except the G model. The Geske formula involves multivariate normal integrals and is not straightforward to implement accurately. We can find the bond price from the G model by using binomial method from Huang (1997).

3.3.2.1 The Geske Model

This model treats debt structure of the firm as a coupon bond, in which each coupon payment is viewed as a compound option, which is an option on an option, and a possible cause of default. At each coupon payment, shareholders have the option either to make the payment to bondholders or default.

Following formula is the compound option pricing from Yue (2002).

$$S = C = Ve^{-\delta T_2} N_2(a_+, b_+; \sqrt{T_1/T_2}) - Fe^{-rT_2} N_2(a_-, b_-; \sqrt{T_1/T_2}) - ce^{-rT_1} N(a_-)$$

$$B = V\left(1 - e^{-\delta T_2} N_2(a_+, b_+; \sqrt{T_1/T_2})\right) + Fe^{-rT_2} N_2(a_-, b_-; \sqrt{T_1/T_2}) - ce^{-rT_1} N(a_-) = V - S \quad (12)$$

$$a_+ = \frac{\ln(V/V^*) + (r - \delta + \sigma_v^2/2)T_1}{\sigma_v \sqrt{T_1}} \qquad a_- = a_+ - \sigma_v \sqrt{T_1}$$

$$b_+ = \frac{\ln(V/F) + (r - \delta + \sigma_v^2/2)T_2}{\sigma_v \sqrt{T_2}} \qquad b_- = b_+ - \sigma_v \sqrt{T_2}$$

where *r* from the NS model at time 0 and *C* is price of call option. *V** is boundary value of firm and coupon will pay at time T_1, while all face values are maturity at T_2. In view of whole firm, stock is compound option that exercises each period (pay coupon) to not default, otherwise default. So, bondholder, i.e. B in equation, receive whole firm value minus the stock value.

However, this model may use at bond that pay only one coupon. For n coupon of the bond, the formulas have the multivariate normal to estimate which it is hard to calculate the multivariate normal function. So, we use the binomial option pricing for using with any type of bonds.

3.3.2.2 The Geske Model (Binomial Method)

Firstly, we generate the firm value process tree. The firm value is calculated at the coupon payment point. For example, the coupon is paid annually but next coupon will be paid in three month, the next calculation of the firm value is three month and next one year until the maturity. (See example Appendix A) It can be calculated as follows:

$$V_u = u \cdot V; \qquad V_d = d \cdot V \qquad \text{where } u = e^{\sigma_v \sqrt{t}} \text{ and } d = 1/u \qquad (13)$$

In the last coupon payment, the equity value is the rest of the firm value less the face value and the last coupon payment or zero when the firm cannot pay the face and coupon. Before any coupon payment, the shareholders must decide to exercise or not, and the exercising occurs when the equity value from the future more than the coupon payment. So, the stock is the compound option when each strike price is coupon and the last strike price is the face value and the coupon. The formulas can be calculated as follows:

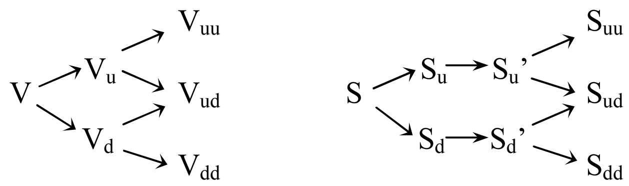
$$S_{uu} = \text{Max}(V_{uu} - F - c); \;\; S_u = \text{Max}(S_u' - c, 0) \qquad (14)$$

$$S = \left(\frac{(r-d)}{(u-d)} S_u + \frac{(u-r)}{(u-d)} S_d\right) r^{-1} \qquad (15)$$

where *F* and *c* is the face value of bond and the coupon of bond, respectively. *S* from equation (15) is derived from basic binomial method, while S_u' and S_d' are derived from the basic binomial method too. See Figure 1.

Figure 1
The Binomial Tree of the Firm and Equity Value

S_{uu}, S_{ud}, and S_{dd} are the equity value at maturity of debt. Then, S_u' and S_d' are the equity value after the coupon payment in that period, S_u and S_d are the equity value before the coupon payment.



Then, the bond price from the Geske model is B, where

$$B = V - S \tag{16}$$

3.3.2.3 The Leland and Toft Model

In LT, coupons are paid continuously and the total coupon is c per year. All formulas given in this section are from Leland and Toft (1996). The value of defaultable bond is given by

$$P^{LT}(0,T) = \frac{c}{r} + \left(1 + \frac{c}{r}\right)\left(\frac{1-e^{-rT}}{rT} - I(T)\right) + \left(wV_B - \frac{c}{r}\right)J(T) \tag{17}$$

where r from the NS model at time 0, and

$$I(T) = (G(T) - e^{-rT}F(T))/(rT)$$

$$J(T) = \frac{1}{z\sigma_v\sqrt{T}}\left[-e^{(z-a)b}N(q_-(T))q_-(T) + e^{-(z+a)b}N(q_+(T))q_+(T)\right]$$

$$G(T) = e^{(z-a)b}N(q_-(T)) + e^{-(z+a)b}N(q_+(T))$$

$$F(T) = G(T)\big|_{z=a}$$

with $\quad a = \frac{r-\delta}{\sigma_v^2} - \frac{1}{2}; \quad b = \ln(V_0/V_B); \quad z = \left(a^2 + \frac{2r}{\sigma_v^2}\right)^{1/2}; \quad q_{\mp}(t) = \frac{-b \mp z\sigma_v^2 t}{\sigma_v\sqrt{t}}$

And V_B is the endogenous default boundary from LT.

$$V_B = \frac{(c/r)(A/(rT) - B) - A/(rT) - \tau\, cx/r}{1 + (1-w)x - wB}$$

where

$$A = 2ae^{-rT}N(a\sigma_v\sqrt{T}) - 2zN(z\sigma_v\sqrt{T}) - \frac{2}{\sigma_v\sqrt{T}}n(z\sigma_v\sqrt{T}) + \frac{2e^{-rT}}{\sigma_v\sqrt{T}}n(a\sigma_v\sqrt{T}) + (z-a)$$

$$B = -\left(2z + \frac{2}{z\sigma_v^2\sqrt{T}}\right)N(z\sigma_v\sqrt{T}) - \frac{2}{\sigma_v\sqrt{T}}n(z\sigma_v\sqrt{T}) + (z-a) + \frac{1}{z\sigma_v^2\sqrt{T}}$$

3.3.2.4 The Collin-Dufresne and Goldstein Model

In CDG, the value of a defaultable bond that pays semi-annual coupons is given by

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$$P^{CDG}(0,T)=\left(\frac{c}{2}\right)\sum_{i=1}^{2T-1}D(0,i)[1-w_{\ell}Q^{F_i}(0,i)]+\left(1+\frac{c}{2}\right)D(0,T)[1-w_{\ell}Q^{F_T}(0,T)] \qquad (18)$$

where D(0,i) denotes the time-0 value of a i-maturity default-free zero-coupon bond given by the Vasicek (1977) model, $Q^{F_i}(0,i)$ represents the time-0 default probability over (0,i] under the i-forward measure (e.g. Geman, El Karoui, and Rochet (1995) and Jamshidian (1989)), and w_{ℓ} the loss rate, equals $1-w$. In CDG, the loss rate on coupon is 100%. Here we use the same loss rate on both coupons and principal. (EHH discover that this reduces the model's overprediction error in spreads.) As be seen from equation (18), the key step in implementing the CDG model is to determine $Q^{F_i}(0,i)$. It can be calculated as follows:

$$Q^{F_i}(t_0,T)=\sum_{i=1}^{n}q(t_{i-1/2};t_0), \qquad t_0=0,\ t_i=iT/n \qquad \text{where for i =1, 2, …, n.} \qquad (19)$$

$$q(t_{i-1/2};t_0)=\frac{N(a(t_i;t_0))-\sum_{j=1}^{i-1}q(t_{j-1/2};t_0)N(b(t_i;t_{j-1/2}))}{N(b(t_i;t_{i-1/2})} \qquad (20)$$

$$a(t_i;t_0)=-\frac{M(t_i,T|X_0,r_0)}{\sqrt{S(t_i|X_0,r_0)}} \qquad (21)$$

$$b(t_i;t_j)=-\frac{M(t_i,T|X_{t_j})}{\sqrt{S(t_i|X_{t_j})}} \qquad (22)$$

and where the sum on the RHS of equation (20) is defined to be zero when i = 1, X = V/K, and n is pre-specified number which theoretical n should be infinity.

$$M(t,T|X_0,r_0)=E_0^{F_T}[\ln X_t];$$

$$S(t|X_0,r_0)=Var_0^{F_T}[\ln X_t];$$

$$M(t,T|X_u)=M(t,T|X_0,r_0)-M(u,T|X_0,r_0)\frac{Cov_0^{F_T}[\ln X_t,\ln X_u]}{S(u|X_0,r_0)}, \quad u\in(t_0,t)$$

$$S(t|X_u)=S(t|X_0,r_0)-\frac{\left(Cov_0^{F_T}[\ln X_t,\ln X_u]\right)^2}{S(u|X_0,r_0)}, \quad u\in(t_0,t)$$

Under the T-forward measure,

$$e^{\kappa_{\ell}t}\ln X_t = \ln X_0+\bar{v}(e^{\kappa_{\ell}t}-1)+\int_0^t[(1+\phi\kappa_{\ell})r_u-\rho\sigma_v\sigma_rB(t,T)]e^{\kappa_{\ell}u}du+\int_0^t\sigma_ve^{\kappa_{\ell}u}dZ_{1u}^{F_T} \qquad (23)$$

$$\begin{aligned} r_t &= r_0e^{-\beta t}+\left(\frac{\alpha}{\beta}-\frac{\sigma_r^2}{\beta^2}\right)(1-e^{-\beta t})+\frac{\sigma_r^2}{2\beta^2}e^{-\beta T}(e^{\beta t}-e^{-\beta t})+\sigma_re^{-\beta t}\int_0^te^{\beta u}dZ_{2u}^{F_T} \\ &= E_0^{F_T}[r_t]+\sigma_re^{-\beta t}\int_0^te^{\beta u}dZ_{2u}^{F_T} \end{aligned} \qquad (24)$$

where $$\bar{\nu} \equiv (\nu - \phi\theta) - (\delta + \sigma_v^2 / 2) / \kappa_\ell \tag{25}$$

$$B(t,T) = \frac{1}{\beta}(1 - e^{-\beta(T-t)}) \tag{26}$$

Equations (23) and (24) can then be used to calculate $M(t,T|X_0,r_0)$ and $Cov_0^{F_T}[\ln X_t, \ln X_u]$ and thus the expectations in (20)-(22). It follows from (23) that

$$\begin{aligned}
e^{\kappa_\ell t} E_0^{F_T}[\ln X_t] &= \ln X_0 + \bar{\nu}(e^{\kappa_\ell t} - 1) + \int_0^t (1 + \phi\kappa_\ell) e^{\kappa_\ell u} E_0^{F_T}[r_u] du \\
&\quad - \frac{\rho\sigma_v\sigma_r}{\beta}\left[\frac{e^{\kappa_\ell t} - 1}{\kappa_\ell} - e^{\beta T}\frac{e^{(\kappa_\ell + \beta)t} - 1}{\kappa_\ell + \beta}\right] \\
&= \ln X_0 + \bar{\nu}(e^{\kappa_\ell t} - 1) \\
&\quad + (1 - \phi\kappa_\ell)\frac{(e^{\kappa_\ell t} - 1)}{\kappa_\ell}\left[r_0 e^{-\beta t} + \left(\frac{\alpha}{\beta} - \frac{\sigma_r^2}{\beta^2}\right)(1 - e^{-\beta t}) + \frac{\sigma_r^2}{2\beta^2} e^{-\beta T}(e^{\beta t} - e^{-\beta t})\right] \\
&\quad - \frac{\rho\sigma_v\sigma_r}{\beta}\left[\frac{e^{\kappa_\ell t} - 1}{\kappa_\ell} - e^{\beta T}\frac{e^{(\kappa_\ell + \beta)t} - 1}{\kappa_\ell + \beta}\right]
\end{aligned} \tag{27}$$

Equation (24) can then be used to evaluate explicitly the integral on the RHS of (27) and hence to arrive at $M(t,T|X_0,r_0)$. Similarly,

$$Cov_0^{F_T}[\ln X_t, \ln X_u] e^{\kappa_\ell (t+u)} = \tag{28}$$

$$\begin{aligned}
&+ \sigma_v^2 E_0^{F_T}\left[\int_0^t e^{\kappa_\ell v} dZ_{1v}^{F_T} \int_0^u e^{\kappa_\ell v} dZ_{1v}^{F_T}\right] && (\equiv I_1) \\
&+ \sigma_v (1 + \phi\kappa_\ell) E_0^{F_T}\left[\int_0^t e^{\kappa_\ell v} dZ_{1v}^{F_T} \int_0^u e^{\kappa_\ell v} r_v dv\right] && (\equiv I_2) \\
&+ \sigma_v (1 + \phi\kappa_\ell) E_0^{F_T}\left[\int_0^u e^{\kappa_\ell v} dZ_{1v}^{F_T} \int_0^t e^{\kappa_\ell v} r_v dv\right] && (\equiv I_3) \\
&+ (1 + \phi\kappa_\ell)^2 E_0^{F_T}\left[\int_0^t e^{\kappa_\ell v} r_v dv \int_0^u e^{\kappa_\ell v} r_v dv\right] && (\equiv I_4)
\end{aligned}$$

One can show that $\forall t \geq u$,

$$I_1 = \frac{\sigma_v^2}{2\kappa_\ell}(e^{2\kappa_\ell u} - 1)$$

$$I_2 = (1 + \phi\kappa_\ell)\frac{\rho\sigma_v\sigma_r}{\kappa_\ell + \beta}\left[\frac{e^{2\kappa_\ell u} - 1}{2\kappa_\ell} - \frac{e^{(\kappa_\ell - \beta)u} - 1}{\kappa_\ell - \beta}\right]$$

$$I_3 = (1 + \phi\kappa_\ell)\frac{\rho\sigma_v\sigma_r}{\kappa_\ell + \beta}\left[\frac{1 - e^{(\kappa_\ell - \beta)t}}{\kappa_\ell - \beta} + \frac{e^{2\kappa_\ell u} - 1}{2\kappa_\ell} + e^{(\kappa_\ell + \beta)u}\frac{e^{(\kappa_\ell - \beta)t} - e^{(\kappa_\ell - \beta)u}}{\kappa_\ell - \beta}\right]$$

$$I_4 = (1 + \phi\kappa_\ell)^2 \frac{\sigma_r^2}{2\beta}\left[\begin{aligned} &-\frac{(e^{(\kappa_\ell - \beta)t} - 1)(e^{(\kappa_\ell - \beta)u} - 1)}{(\kappa_\ell - \beta)^2} + (e^{(\kappa_\ell + \beta)u} - 1)\frac{e^{(\kappa_\ell - \beta)t} - e^{(\kappa_\ell - \beta)u}}{\kappa_\ell^2 - \beta^2} \\ &-\frac{\beta}{\kappa_\ell^2 - \beta^2}\frac{e^{2\kappa_\ell u} - 1}{\kappa_\ell} + \frac{1}{\kappa_\ell^2 - \beta^2}(1 - 2e^{(\kappa_\ell - \beta)u} + e^{2\kappa_\ell u})\end{aligned}\right]$$

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3.3.2.5 The Longstaff and Schwartz Model

The concept of the LS model is the same as the CDG model, but the LS model can be nested within CDG. So, the price of a defaultable bond in the LS model can be obtained by setting κ_ℓ to zero. The resultant formulas are shown as:

$$P^{LS}(0,T)=\left(\frac{c}{2}\right)\sum_{i=1}^{2T-1}D(0,i)[1-w_\ell Q^{F_i}(0,i)]+\left(1+\frac{c}{2}\right)D(0,T)[1-w_\ell Q^{F_T}(0,T)] \tag{29}$$

$$Q(t_0,T)=\sum_{i=1}^{n}q_i\ ;\ q_1=N(a_1)\ ;\qquad q_i=N(a_i)-\sum_{j=1}^{i-1}q_jN(b_{ij}),\ \ i=2,3,...,n$$

$$a_i=\frac{-\ln X-M(iT/n,T)}{\sqrt{S(iT/n)}} \tag{30}$$

$$b_{ij}=\frac{M(jT/n,T)-M(iT/n,T)}{\sqrt{S(iT/n)-S(jT/n)}} \tag{31}$$

$$S(t)=\left(\frac{\rho\sigma_v\sigma_r}{\beta}+\frac{\sigma_r^2}{\beta^2}+\sigma_v^2\right)t-\left(\frac{\rho\sigma_v\sigma_r}{\beta^2}+\frac{2\sigma_r^2}{\beta^3}\right)(1-\exp(-\beta t))+\left(\frac{\sigma_r^2}{2\beta^3}\right)(1-\exp(-2\beta t)) \tag{32}$$

$$\begin{aligned}M(t,T)=&\left(\frac{\alpha-\rho\sigma_v\sigma_r}{\beta}-\frac{\sigma_r^2}{\beta^2}-\frac{\sigma_v^2}{2}\right)t+\left(\frac{\rho\sigma_v\sigma_r}{\beta^2}+\frac{\sigma_r^2}{2\beta^3}\right)\exp(-\beta T)(\exp(\beta t)-1)\\&+\left(\frac{r_t}{\beta}-\frac{\alpha}{\beta^2}+\frac{\sigma_r^2}{\beta^3}\right)(1-\exp(-\beta t))-\left(\frac{\sigma_r^2}{2\beta^3}\right)\exp(-\beta T)(1-\exp(-\beta t))\end{aligned} \tag{33}$$

where $\Theta_r=(\alpha,\beta,\sigma_r,r_t)$ from the Vasicek (1977) model.

To sum up, the characteristics of all four structural models are shown in Table 3.

3.4 Hypothesis Testing

The prices from four structural models are calculated as six types of errors, i.e. percentage pricing error, absolute percentage pricing error, percentage error in yield, absolute percentage error in yield, percentage error in spread and absolute percentage error in spread, between actual data and predicted data. The errors are calculated as the predicted spread (yield, price) minus the observed spread (yield, price) divided by the observed spread (yield, price). The formula is shown as:

$$\text{Absolute error in spread(yield,price)}=\left|\frac{\text{predicted spread(yield,price)}-\text{observed spread(yield,price)}}{\text{observed spread(yield,price)}}\right|$$

The structural model that generates the least absolute error in prices is the most consistent model in Thai bond market.

Table 3
The Characteristics of Four Structural Models

Table 3 summarizes the characteristics of four structural models, i.e. the Geske model (1977), the Leland and Toft model (1996), the Longstaff and Schwartz model (1995), and Collin-Dufresne and Goldstein model (2001).

Structural Model	Characteristic of the Model	Coupon payment	Default Point	Default Occurring
Geske	Compound Option; stock is assumed to be a compound option. The firm defaults when stock is not exercised.	Discrete; whether annually, semi-annually. It is specified by the characteristic of bonds	Exogenous; generally, the face value of liabilities.	At a payment due; if stock is not exercised.
LT	Compound Option; Similarly to the Geske model. But some assumption can make the LT model to derive closed-form solution.	Continuous; coupon is assumed to pay continuously at all time.	Endogenous; V_B is a default point.	At any point of time; if stock is not exercised.
LS	Portfolio of zero coupon bonds; it assumes the amount of debt is constant. The default occurs when the firm value is lower than the default point	Discrete; whether annually, semi-annually. It is specified by the characteristic of bonds	Exogenous; generally, the face value of liabilities.	At any point of time; if the firm value is lower than the default point
CDG	Portfolio of zero coupon bonds; it assumes the amount of debt will move to target leverage ratio. The default occurs when the firm value is lower than the default point	Discrete; whether annually, semi-annually. It is specified by the characteristic of bonds	Exogenous; generally, the face value of liabilities.	At any point of time; if the firm value is lower than the default point

CHAPTER IV

Results

4.1 Predicted Spreads from the Structural Models

Table 4 summarizes the prediction errors of the four structural models which are included BCP bonds in Panel A and excluded BCP bonds in Panel B. For each of the measures of errors in columns 2 through 7, the numbers in parentheses are standard deviations of the prediction errors. Column 2, 4, and 6 show measures of model errors whereas columns 3, 5, and 7 show the absolute values of errors. The reason to divide into two tables is that the errors from BCP bonds are tremendous large comparing to the others; this may not measure real accuracy or errors of the bonds. The Bangchak Petroleum PCL (BCP) was bankrupt if it was not supported by Thai government. So, bond spreads of BCP do not take into account of the firm performance.

Although the errors in tables are reported into two types, i.e. including BCP and excluding BCP, we report Table 5 and all figures based on excluding BCP, except the errors analysis, i.e. t-test and regression analysis, are including BCP samples.

4.1.1 The Geske Model

The first and second rows of Table 4 in Panel B shows that the Geske model with face recovery, bondholders receiving 51.31% of face value, and firm recovery, bondholders receiving the rest of the firm value. From the percentage error in spreads, the face recovery model is overpredict spreads on average, while the other is underpredict spreads on average. In addition, the G with firm recovery is the only one model that underpredict spreads on average. In Panel B, the errors in spreads of every model are larger but the Geske model with firm recovery is quite stable comparing to remaining models, while its standard deviation is a little bit larger.

Panel A–C in Figure 3 plot the predicted bond spreads from the Geske model with face recovery and the actual bond spreads against maturity for three classes of leverage ratio. The top panel shows the predictions of the model for low leverage firms; panel B shows medium leverage firms; and panel C shows high leverage firms. The data in the graphs are reported in Table 5 and Figure 2.

In Table 5, The G model with face recovery is overpredict spreads on average whether low, medium, and high leverage, which the low leverage firms are the least overpredict spreads. For higher leverage, the spread prediction errors are higher too. From Panel A in Figure 3, the errors in short maturity are under spreads and overspreads but tend to a little bit overspreads, while the errors in medium maturity tend too more overpredict spreads but some is under spreads, and rarely under spreads at long maturity. From Panel B, the errors are under spreads at short maturity but over spreads at medium and long maturity. While the errors from panel C are almost all data overpredict spread but some under spreads in short maturity.

In Table 5, The G model with firm recovery is underpredict spreads in low and medium leverage firms but overpredict in high leverage firms. This model is underpredict spreads in the low and medium leverage firm but overpredict spreads in the high leverage firm. From Figure 4, both of low and medium leverage results are quite under spreads, except the results of short maturity in low leverage are over and under spreads. The results of high leverage quite match to the actual data but a little bit over spreads in long maturity and under spread in short maturity.

The reasons of different in spreads by changing recovery rate are that the average of recovery from the firm recovery is more than the face recovery. Although it is possible that the firm recovery is less than the face recovery, the probability is quite less than. The results are not quite different if the recovery rate of the face recovery is higher.

4.1.2 The Leland and Toft Model

In Panel B of Table 4, the results of the LT model are overpredict spreads on average. The reason of these errors may be that the default boundary of the LT model is too high for Thai corporate. One thing that supports this reason is that the results in Figure 5 are overpredict spreads whether short and long maturity, or low and high leverage.

In Panel A of Table 4, the errors from the LT model are tremendous large. The reason is that this model has a really bad predict to BCP samples, because the BCP company should be bankrupt before, the firm values are under the endogenous bankruptcy point of the LT model. So, the bondholders do not receive from these bonds.

In Table 5, the model is overpredict spreads in any kind of firm leverage. It tends to over spread when higher firm leverage. From Figure 5, the results from low leverage are overpredict spreads for all, but some is under spreads at medium and long maturity. In the same way, the results from medium and high leverage are over spreads and it is rarely to be seen under spreads in any maturity.

4.1.3 The Longstaff and Schwartz Model

In Table 4, the results of the LS model are overpredict spreads on average. In addition, its standard deviation is not high. From EHH (2004), loss of accuracy, i.e. high standard deviation, from the LS and CDG model might be from allowing stochastic interest rate. So, the interest rate volatility has quite impact to the price from the LS and CDG model, then they loss accuracy to predict spreads. In contrast, the results in Thai bonds are different from the U.S. bonds; it is probable that the Vasicek model is good enough to predict the term structure in Thai.

In Table 5 and Figure 6, the model is overpredict spreads at long maturity of any kind of firm leverage, while it tends to underpredict spreads at short maturity of any kind of firm leverage. Especially in high leverage, the model is more overpredict spreads.

The problem of the Merton and Geske models is too low predict the spreads, which the LS model try to shift the spreads up but it is loss the accuracy to predict spreads in the U.S. In Thai, the Geske model is underpredict and the LS model is overpredict the spread like the U.S., but the LS model is not loss of accuracy.

4.1.4 The Collin-Dufresne and Goldstein Model

The CDG model is divided into two sub models. Firstly, the stationary leverage parameters in the model are specified by regression model (See section 3.3.1.2). Secondly, the stationary leverage parameters in the model are specified that κ_ℓ equals to 0.18, ϕ equals to 2.8, and ν equals to 0.6. These numbers derive from Collin-Dufresne, and Goldstein (2001).

In Table 4, the first model generates more errors than the other. The main reason is that the stationary leverage parameters are sensitive to the CDG model, because the parameters from regression which its R-square is almost to zero are more different to the second model; κ_ℓ equals to 0.005, ϕ equals to 79.59, and ν equals to -5.93 on average. The first model provides the worst absolute prediction errors in spreads and standard deviation, despite the second model is the best.

In Figure 7, the model is underpredict spreads on short maturity at any leverage and huge overpredict spreads on medium and long maturity at any leverage. The errors are larger at high leverage firm.

In Figure 8, the model is underpredict spreads on short maturity at any leverage. For the low and medium leverage, the errors are a little bit under spreads at medium maturity and a little bit over spreads at long maturity. In addition, the model tends to overpredict spreads at high leverage on medium and long maturity.

CDG (2001) included analysis of stationary leverage ratio that effects the spreads or not, and these parameters shift the spreads of corporate bonds higher. That is why the CDG model (second) less under spread than the Geske model with firm recovery.

4.2 Systematic Prediction Errors

In the last section, we mentioned the results from each model whether overpredict or underpredict spreads and its standard deviation. In this section, we consider that which parameters generate inaccurate in prediction errors. We estimate a regression analysis of spread prediction errors to determine which factors are significant to the errors. Before the regression analysis, we construct the t-tests of variables on two sub-samples, those with the lowest spread prediction errors and those with the highest spread prediction errors.

4.2.1 T-tests to Determine Systematic Errors in Spread Predictions

Table 6 reports the t-tests for the four structural models. The t-tests examine differences in characteristics of two groups: those with spread prediction errors below the median and those with spread prediction errors above the median.

The meaning of t-tests is that averages of tested variables in the first group are different from those in the second group. For example, t-tests of market leverage in the Geske model with firm recovery is -16.60, i.e. almost zero probability; so it is significant at 5% level. The t-tests are negative too, meaning that the averages of market leverage in the low prediction errors group are higher than those in the high prediction errors group.

The results of the t-tests indicate that all of the models have systematic errors related to market leverage, because of size of t-stat. In contrast, the t-stat of leverage in the Geske model with firm recovery is negative, meaning the model predicts more precisely when the market leverage is high, while the others are positive. For the mean leverage, it is almost the same as market leverage, except the Geske model with face recovery.

The other variables are significant in some model, but there are three models that all variables are significant to, that are the LT model, the LS model, the CDG (reg) model. In addition, the t-tests from LS and CDG (reg) model report the same sign, so the systematic errors of two models have the same characteristic.

Note that the market leverage is the only one variable that is significant to all models. So, the analysis of last section is shown by class into three types of leverage.

4.2.2 Regression Analysis

Table 7 shows four sets of regressions and each regression is for each structural model. The dependent variable is the actual spread prediction error, rather than the absolute spread prediction error, because the independent variables can effect whether underpredict and overpredict spreads. The detail of each variable is defined in Table 7. The main problem of regression analysis is that the R-squares are quite low. So, the explanation in the regression might not be significant to actual errors.

The Geske model with face recovery is the only one model that any variables are not significant to the prediction errors. Moreover, R-square equals to 0.007 that is the lowest R-square of all models. In contrast, the Geske model with firm recovery has the most significant variables with highest R-square. While interest rate, years to maturity, assets volatility, payout, and total assets make the model underpredicting the spreads, because of negative of coefficients.

In the same way, the regression of LT model reports quite low R-square, but years to maturity variable is significant. The variable generates underpredict spreads, while the model is overpredict spreads on average.

The prediction errors in spreads are overpredict in the LS model because of years to maturity and correlation factors. Assets return provides overpredict spreads to the model too although it is not significant, but almost.

In the CDG (reg) model, assets volatility effects to under spreads, while assets return makes over spreads. While the other model is overpredict spreads because of years to maturity.

4.3 Comparison between Liabilities and Endogenous Default Point

The LT model uses the endogenous default point (V_B) which is not the same as the face value of liabilities like the other models. Hence, the endogenous default point can make the model overspreads if it is too high. Table 8 reports the comparison of the face value of liabilities and endogenous default point.

Despite the average of endogenous default point is lower its liabilities, the model generate a lot of number of overspreads. Hence, the predicted errors that are over the spreads may be generated from other parts of the model. One point that makes the model overpriced in Panel A of Table 4 is that the default points of BCP bonds are higher than 1. The meaning is that the BCP firm should be already bankrupt because V_B is higher than V. So, this data makes tremendous errors in the model.

4.4 Comparison of the Empirical Results between Thai and the U.S.

The empirical results from the U.S. are based from the EHH (2004). The paper apply the model of Merton (1974), Geske (1977), Leland and Toft (1996), Longstaff and Schwartz (1995) and Collin-Dufresne and Goldstein (2001). However, this study compares the last four structural models, i.e. G, LT, LS, and CDG, to the U.S.

Table 9 shows the descriptive statistics of Thai and the U.S. market. The average of years to maturity in Thai is less than the U.S., because Thai bonds data are selected at every traded day while the U.S. data are selected at last day trade on December. From results in Thai, the errors in spreads on Thai corporate bonds are larger than the U.S. despite the errors in prices are not much different, so we expect the average yield spreads in Thai might be less. However, Table 9 reports less of average yield spreads. One reason is that selected corporate bond in Thai are more risky than the U.S.

Table 10 shows the best and the worst in prediction and accuracy of the models in Thai and the U.S. The results in Thai are quite the same as the U.S. The best prediction model in the U.S. is the Geske with firm recovery while the model in Thai is the second and the CDG (const) model is the first. The worst prediction model is the CDG (reg) in both. The best accuracy model in the U.S. is the Geske with firm recovery while the model in Thai is the second and the CDG (const) model is the first. The worst accuracy model is the LT in the U.S. while the model in Thai in the second and the CDG (reg) model is the first. The Geske with firm and face recovery in the U.S. are underpredict the spreads while it happens in the Geske with firm recovery in Thai.

To sum up, the empirical results in Thai and the U.S. are not quite different. The Geske (firm) and CDG (const) are the best perform in Thai but the Geske with firm and face recovery in the U.S. While the CDG (reg) and LT are the worst perform in Thai and the U.S. There are some conflict about the magnitude of pricing errors and errors in spreads, because at the same level of errors in price provide the larger errors in spreads in Thai. The reason might be that there are some huge errors in spreads in Thai reflecting in small magnitude in errors in price while this case rarely happen in the U.S. One point that supports this reason is higher standard deviation of error in Thai.

4.5 Effect of Recovery Rate in Spreads

Table 11–Table 14 show the percentage errors in spreads and the absolute percentage errors in spreads from the model with various recovery rate. The recovery rate is varied between 30% and 60% which is stepped by 5%.

Table 11 reports the errors in spreads of the Geske model with face recovery. The model tends to less overpredict the spreads at higher recovery rate. Moreover, the standard deviation is less at higher recovery rate. In the same way, it happens in the absolute percentage errors in spreads.

The results reflect that there are some data that overpredict the hugh spreads, so the higher recovery rate reduces a lot of magnitude of errors. So, the errors in spreads are decrease at higher recovery rate.

Table 12–Table 14 report the errors in spreads of the LT, LS, and CDG model, respectively. The results of each table are not quite different; the models are less overpredict the spreads and less absolute percentage errors at higher recovery rate. The explanation is the same as the Geske model.

In conclusion, the higher recovery rate provides less overpredict the spreads and less absolute percentage errors in decelerate rate. The reason is that recovery rate reduces a lot of overpredict spreads in some data that overpredicted the tremendous spreads.

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Figure 2
The comparison of Error in Spread for Each Model

Figure 2 shows the comparison between the models which are classified by leverage ratio. Each bar shows the absolute prediction error in spreads of each model classified by leverage ratio. This graph is generated by excluding BCP bonds.

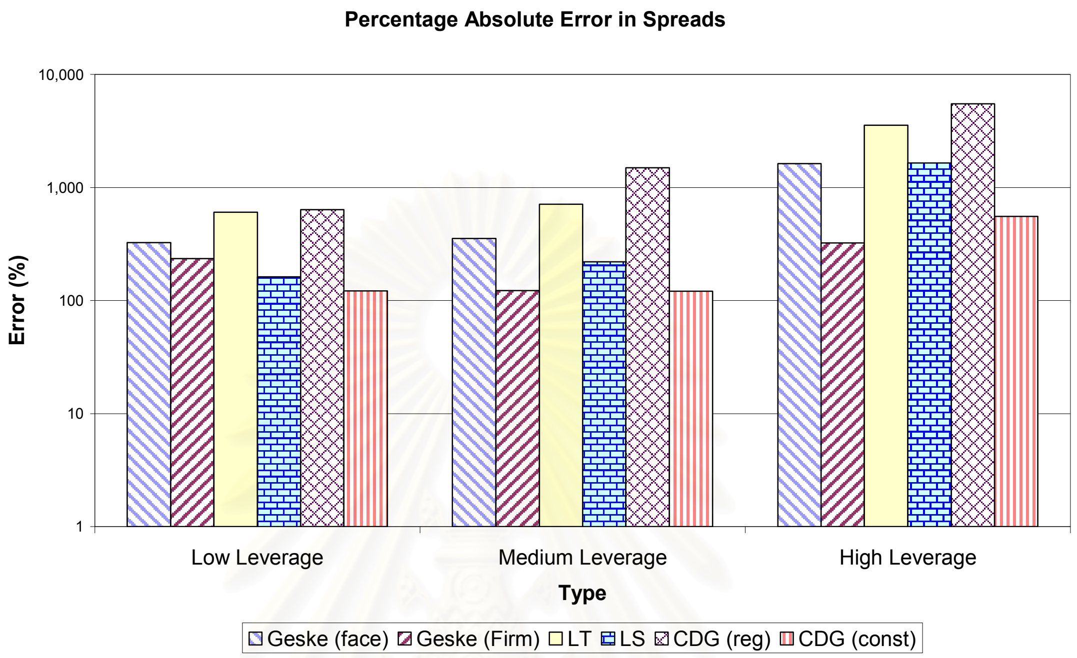

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Table 4

Performance of the Structural Models

Table 4 reports means and standard deviations of the percentage errors in the models' predictions. The percentage errors in prices, yields, and spreads, as well as their absolute values. The errors from panel A are generated from implementing the structural models using 2,464 samples which is included BCP bonds during 1999 to 2004. While panel B are generated by using 2,432 samples which is already excluded BCP bonds during 1999 to 2004 with the assumption that recovery rate are 51.31% of face value and that asset volatility is measured using 90-day historical volatility.

Panel A

Bond Pricing Models	Percentage Pricing Error	Absolute Percentage Pricing Error	Percentage Error in Yld	Absolute Percentage Error in Yld	Percentage Error in Sprd	Absolute Percentage Error in Sprd
	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)
Geske (face)	-6.18%	7.75%	80.19%	108.90%	1049%	1495%
	(10.16%)	(9.02%)	(690.12%)	(686.17%)	(35140%)	(35124%)
Geske (firm)	1.21%	3.17%	2.50%	50.81%	-12%	273%
	(7.36%)	(6.75%)	(252.86%)	(247.71%)	(1768%)	(1747%)
Leland-Toft	-8.08%	8.22%	1.43E+07	1.43E+07	1.87E+07	6.70E+08
	(47.00%)	(46.98%)	(3.74E+08)	(3.74E+08)	(2.06E+10)	(2.06E+10)
LS	-5.75%	6.54%	52.02%	73.29%	1036%	1450%
	(8.70%)	(8.12%)	(171.92%)	(163.99%)	(34897%)	(34883%)
CDG (reg)	-13.09%	13.57%	150.27%	166.64%	2003%	3498%
	(15.00%)	(14.58%)	(277.11%)	(267.59%)	(45198%)	(45107%)
CDG (const)	-1.85%	3.19%	12.63%	38.93%	401%	620%
	(4.81%)	(4.05%)	(98.14%)	(90.97%)	(15498%)	(15491%)

Panel B

Bond Pricing Models	Percentage Pricing Error	Absolute Percentage Pricing Error	Percentage Error in Yld	Absolute Percentage Error in Yld	Percentage Error in Sprd	Absolute Percentage Error in Sprd
	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)
Geske (face)	-6.04%	7.63%	63.38%	92.47%	258%	588%
	(10.13%)	(9.00%)	(140.76%)	(123.60%)	(4765%)	(4736%)
Geske (firm)	1.29%	3.16%	1.80%	50.74%	-34%	224%
	(7.37%)	(6.78%)	(254.40%)	(249.29%)	(1252%)	(1233%)
Leland-Toft	-6.06%	6.20%	166.61%	167.37%	762%	1070%
	(8.16%)	(8.05%)	(450.67%)	(450.39%)	(9751%)	(9722%)
LS	-5.46%	6.26%	42.55%	64.10%	266%	514%
	(8.32%)	(7.74%)	(87.03%)	(72.63%)	(2427%)	(2387%)
CDG (reg)	-12.85%	13.33%	139.55%	156.13%	1053%	2359%
	(14.91%)	(14.48%)	(210.49%)	(198.50%)	(13761%)	(13599%)
CDG (const)	-1.68%	3.04%	7.56%	34.21%	55%	197%
	(4.55%)	(3.78%)	(48.46%)	(35.14%)	(687%)	(661%)

Table 5
Error in Spread: Classified by Market Leverage Ratio

Table 5 reports the percentage error in spreads and the absolute percentage error in spreads of the structural models which are classed by market leverage ratio. The samples are divided equally into three parts by market leverage ratio. Panel A reports the prediction error from low market leverage ratio while medium leverage ratio in Panel B and high leverage ratio in Panel C. The results are from Table 4.

Panel A

Bond Pricing Model		Geske (Face)	Geske (Firm)	LT	LS	CDG (reg)	CDG (const)
Percentage Error in Spread	Mean	73%	-137%	437%	39%	375%	-17%
	Std.Dev	1099%	1040%	2959%	431%	1757%	289%
Absolute Percentage Error in Spread	Mean	324%	240%	614%	161%	636%	123%
	Std.Dev	1052%	1021%	2928%	402%	1680%	262%

Panel B

Bond Pricing Model		Geske (Face)	Geske (Firm)	LT	LS	CDG (reg)	CDG (const)
Percentage Error in Spread	Mean	213%	-111%	499%	71%	664%	-14%
	Std.Dev.	579%	309%	2572%	1032%	10154%	454%
Absolute Percentage Error in Spread	Mean	363%	122%	698%	224%	1515%	122%
	Std.Dev.	499%	305%	2525%	1010%	10063%	438%

Panel C

Bond Pricing Model		Geske (Face)	Geske (Firm)	LT	LS	CDG (reg)	CDG (const)
Percentage Error in Spread	Mean	485%	143%	1343%	684%	2107%	194%
	Std.Dev.	8137%	1867%	16379%	4009%	21374%	1045%
Absolute Percentage Error in Spread	Mean	1072%	313%	1891%	1151%	4890%	343%
	Std.Dev.	8081%	1846%	16324%	3900%	20913%	1005%

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Table 6
T-test of Spread Prediction Errors

Table 6 reports t-statistics the different between the average values of variables in table. The t-test compares samples with absolute spread errors above the median and below the median. Each column reports t-statistics of each variable and their two-tailed probabilities at 5% level are in the parentheses. The asterisk and bold characters are defined as the insignificant variables. Market leverage is the total liabilities divided by the total assets. Mean leverage is the six years average of market leverage ratio. Equity volatility and assets volatility are 90-day historical volatility. Payout is weighted average of coupon and dividend. Correlation is correlation of equity returns and three-month T-bills. Interest volatility is the parameter from the Vasicek model. Assets return is 90-day historical return of total assets.

	Geske (face)	Geske (firm)	LT	LS	CDG (reg)	CDG (const)
Market leverage	12.56	-16.60	17.11	33.35	27.51	13.10
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Mean leverage	-0.80	-8.89	24.00	13.04	9.43	12.12
	*(0.43)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Total assets	0.40	-0.68	10.46	5.85	12.37	11.09
	*(0.69)	*(0.50)	(0.00)	(0.00)	(0.00)	(0.00)
Equity volatility	4.20	-10.63	-5.76	3.66	2.03	0.82
	(0.00)	(0.00)	(0.00)	(0.00)	(0.04)	*(0.42)
Assets volatility	2.26	1.50	-23.43	-11.86	-9.90	-9.77
	(0.02)	*(0.13)	(0.00)	(0.00)	(0.00)	(0.00)
Years to maturity	17.71	-0.43	-15.14	23.87	27.31	3.94
	(0.00)	*(0.67)	(0.00)	(0.00)	(0.00)	(0.00)
Coupon	-11.17	-0.04	17.84	-5.75	-9.79	-1.31
	(0.00)	*(0.97)	(0.00)	(0.00)	(0.00)	*(0.19)
Payout	1.54	-9.58	21.25	13.04	9.70	10.22
	*(0.12)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Correlation	-7.31	-4.27	8.75	-12.03	-17.42	0.83
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	*(0.40)
Interest volatility	-1.01	4.50	-11.43	-6.11	-7.29	-9.69
	*(0.31)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Assets return	10.94	-0.95	-11.38	12.64	21.60	2.79
	(0.00)	*(0.34)	(0.00)	(0.00)	(0.00)	(0.01)

* insignificant at 5% level

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Table 7

Regression of Model Prediction Errors on Firm and Bond Characteristics

Table 7 reports regression coefficients and their t-value in parentheses where the dependent variable is the spread prediction error (in percentage terms). Each column reports coefficient of the regression and its t-stat is in parentheses. The asterisk and bold characters are defined as the significant variables at 5% level. Term structure is the difference between 10-year and 2-year interest rates. Interest rate is 3-month interest rate. Interest volatility is the parameter from the Vasicek model. Market leverage is the total liabilities divided by the total assets. Assets volatility is 90-day historical volatility. Payout is weighted average of coupon and dividend. Correlation is correlation of equity returns and three-month T-bills. Current leverage minus mean leverage is market leverage in the day of observed bond price less the six years average of market leverage. Total assets are in unit of thousand baht. Assets return is 90-day historical return of total assets.

Independent Variables	Geske (face)	Geske (firm)	LT	LS	CDG (reg)	CDG (const)
Intercept	30.259	29.944	123.328	5.395	125.002	-8.148
	(0.97)	***(3.57)**	(1.73)	(0.38)	(1.89)	(-1.56)
Term structure	-294.023	-69.948	-596.593	-118.333	-283.645	-59.773
	(-1.30)	(-1.14)	(-1.15)	(-1.15)	(-0.59)	(-1.57)
Interest rate	-141.990	-274.754	-843.898	117.512	-709.002	28.825
	(-0.34)	***(-2.45)**	(-0.89)	(0.62)	(-0.80)	(0.41)
Interest volatility	7.036	28.985	102.179	22.247	94.715	12.717
	(0.05)	(0.76)	(0.32)	(0.35)	(0.32)	(0.54)
Years to maturity	-0.470	-0.527	-3.373	1.343	1.735	0.571
	(-0.73)	***(-3.02)**	***(-2.28)**	***(4.56)**	(1.26)	***(5.27)**
Market leverage	22.178	3.872	21.812	-9.583	-63.564	0.045
	(1.23)	(0.79)	(0.53)	(-1.16)	(-1.65)	(0.01)
Assets volatility	-278.9	-835.3	-3681.3	-564.4	-5752.1	210.0
	(-0.28)	***(-3.07)**	(-1.60)	(-1.23)	***(-2.68)**	(1.24)
Payout	-1644.7	-1190.3	-5267.8	930.5	-406.0	413.8
	(-1.22)	***(-3.27)**	(-1.71)	(1.51)	(-0.14)	(1.83)
Coupon	-145.469	-31.543	7.194	-17.891	35.238	14.066
	(-1.66)	(-1.33)	(0.04)	(-0.45)	(0.19)	(0.96)
Correlation	-38.394	14.635	-77.004	128.179	415.979	30.800
	(-0.37)	(0.53)	(-0.33)	***(2.73)**	(1.89)	(1.78)
Cur. – Mean. lev.	8.371	5.082	22.823	18.286	109.400	4.695
	(0.33)	(0.73)	(0.39)	(1.56)	(2.00)	(1.09)
Total assets	-1.36E-08	-2.28E-08	-6.36E-08	3.19E-09	-4.52E-08	5.70E-09
	(-0.82)	***(-5.06)**	(-1.66)	(0.42)	(-1.27)	(2.03)
Assets return	-59.625	102.937	555.734	357.912	2151.924	49.420
	(-0.16)	(1.05)	(0.67)	(2.17)	***(2.79)**	(0.81)
R-Square	0.0070	0.0268	0.0090	0.0243	0.0154	0.0257

* significant at 5% level

Figure 3
Spread from the Geske Model with Face Recovery

Figure 3 reports the predicted and actual spreads from the model by low, medium, and high leverage firm. The graph plots the spreads (in basis point) in log scale against maturity.

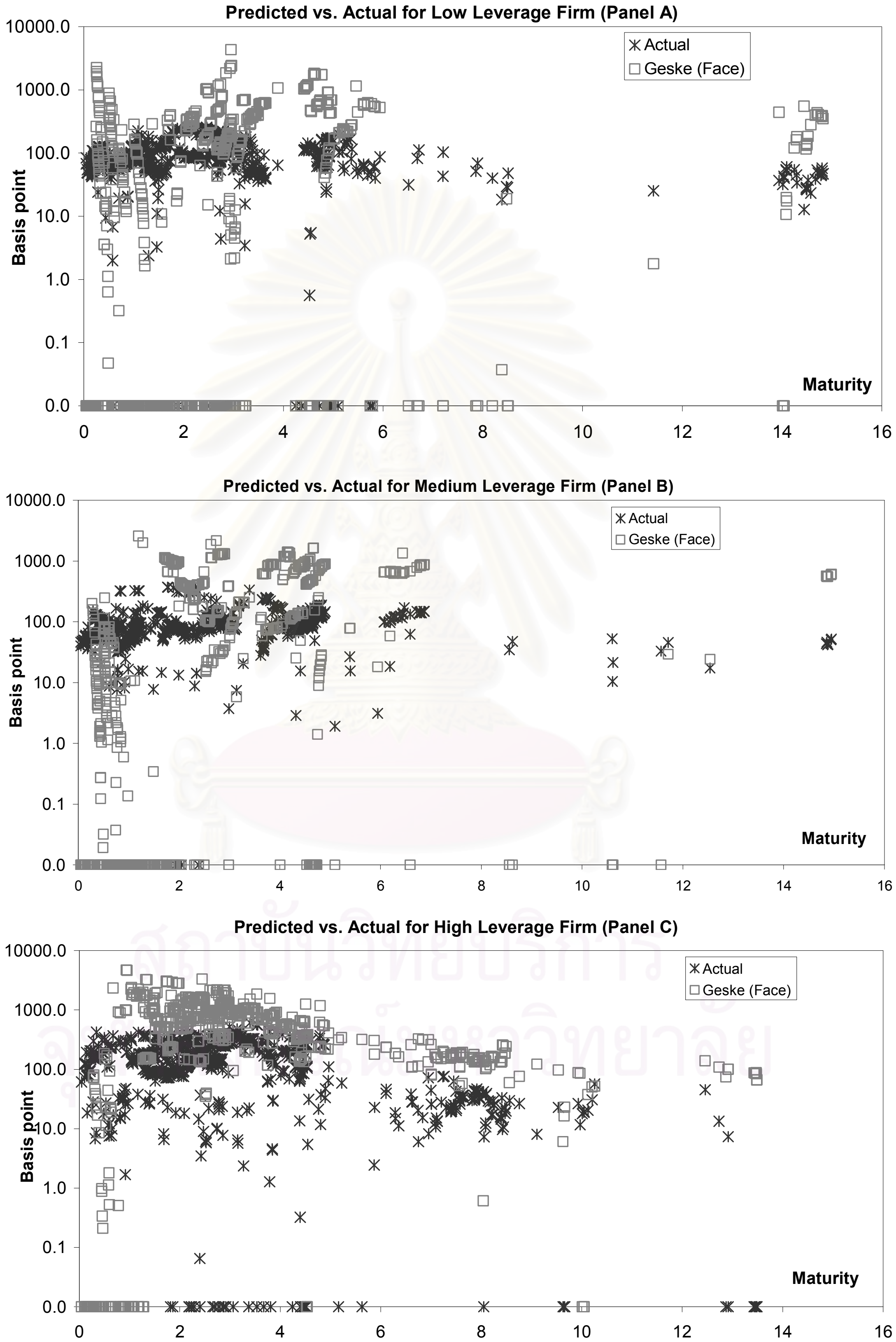

Figure 4

Spread from the Geske Model with Firm Recovery

Figure 4 reports the predicted and actual spreads from the model by low, medium, and high leverage firm. The graph plots the spreads (in basis point) in log scale against maturity.

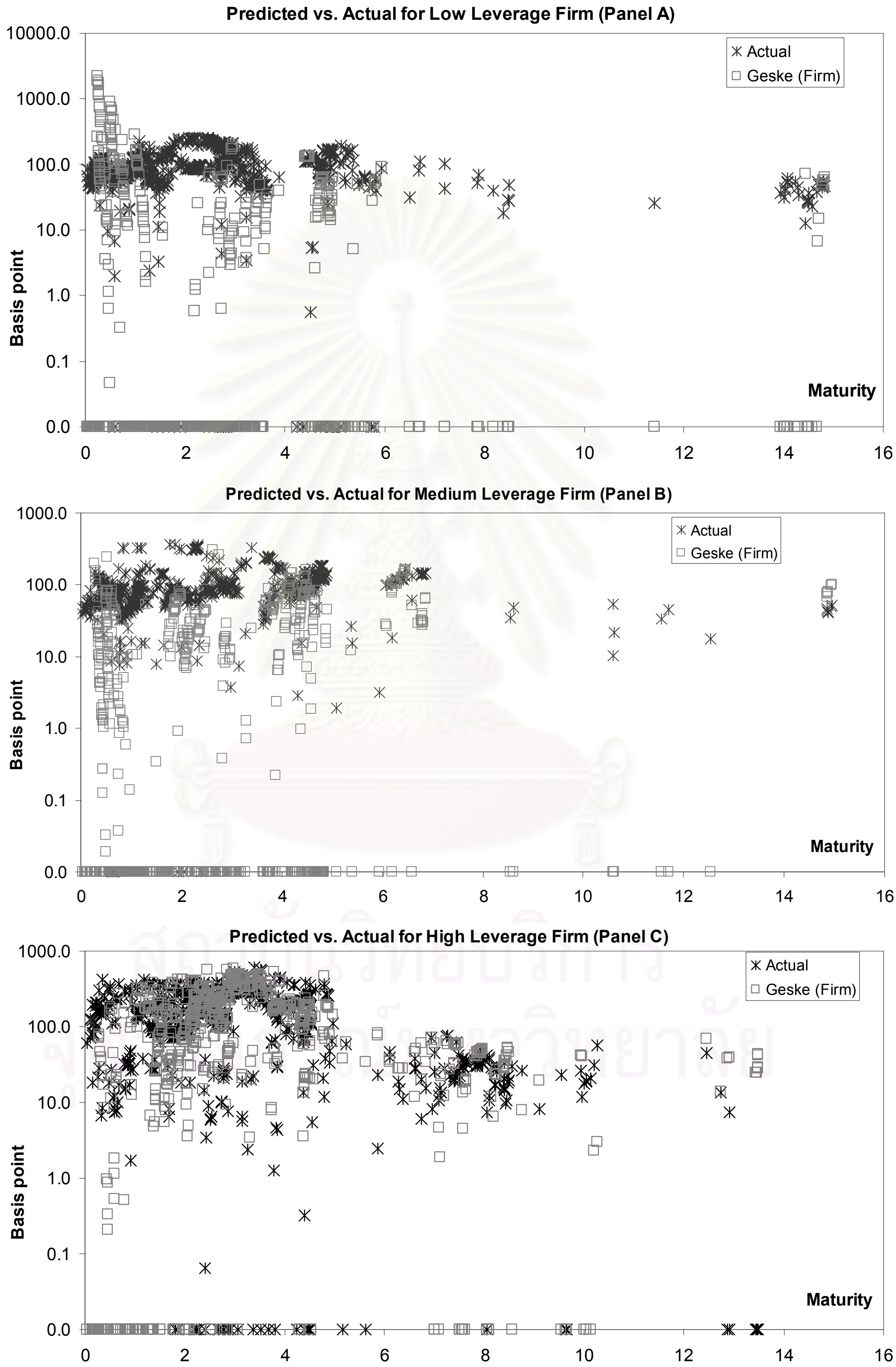

Figure 5
Spread from the Leland-Toft Model

Figure 5 reports the predicted and actual spreads from the model by low, medium, and high leverage firm. The graph plots the spreads (in basis point) in log scale against maturity.

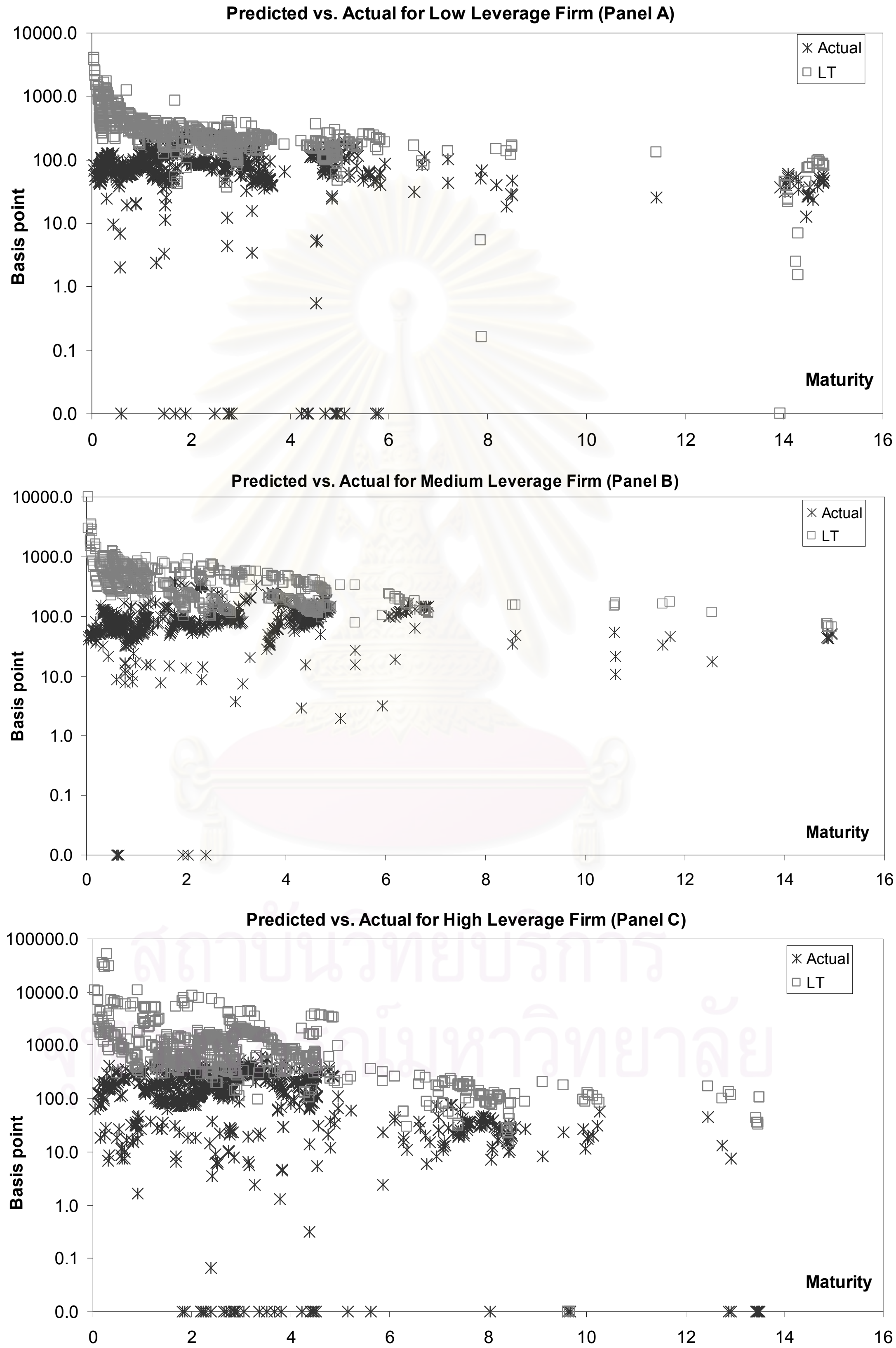

Figure 6
Spread from the Longstaff-Schwartz Model

Figure 6 reports the predicted and actual spreads from the model by low, medium, and high leverage firm. The graph plots the spreads (in basis point) in log scale against maturity.

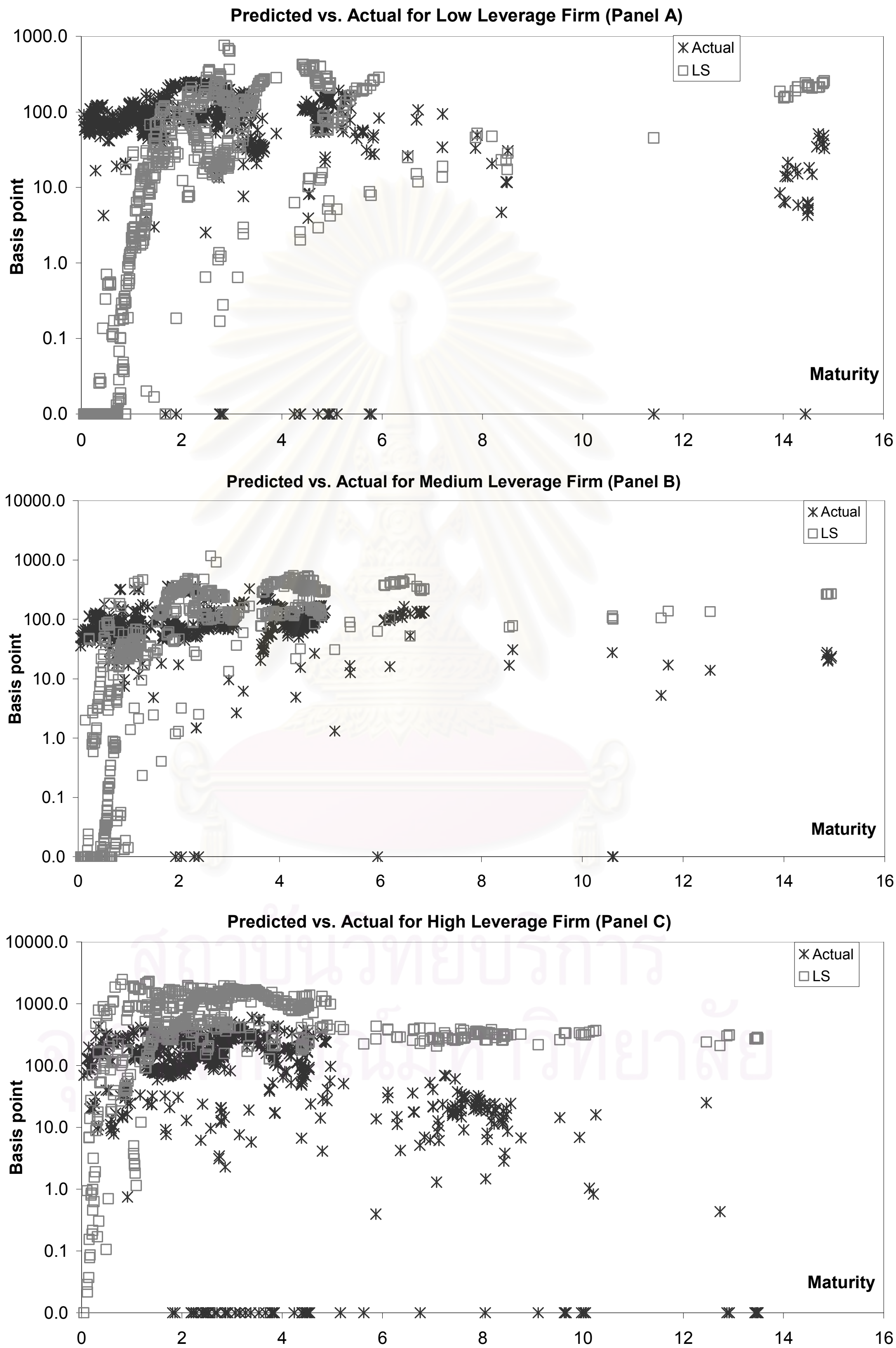

Figure 7
Spread from the CDG Model with Parameter from Regression

Figure 7 reports the predicted and actual spreads from the model by low, medium, and high leverage firm. The graph plots the spreads (in basis point) in log scale against maturity.

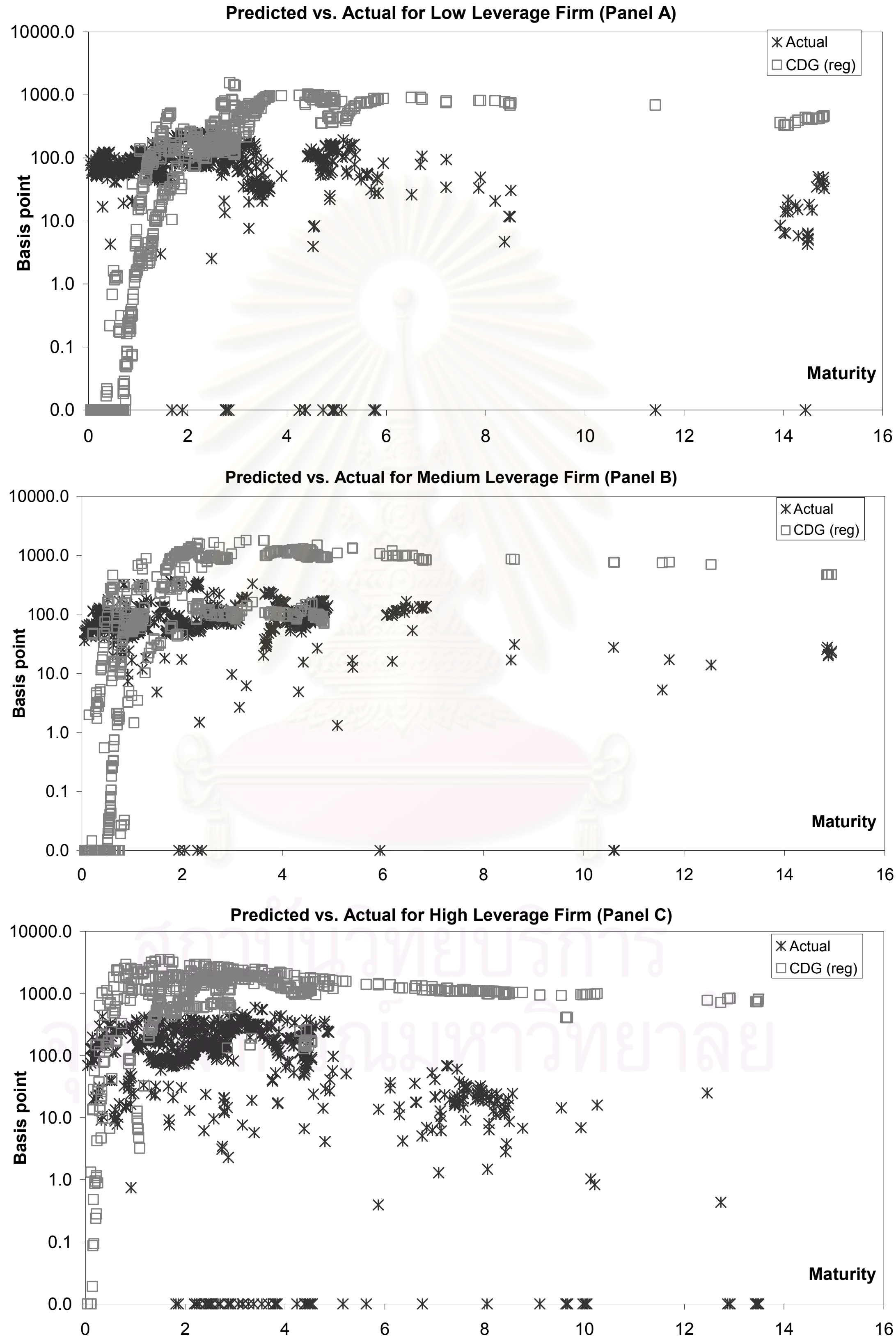

Figure 8
Spread from the CDG Model with Constant Parameter

Figure 8 reports the predicted and actual spreads from the model by low, medium, and high leverage firm. The graph plots the spreads (in basis point) in log scale against maturity.

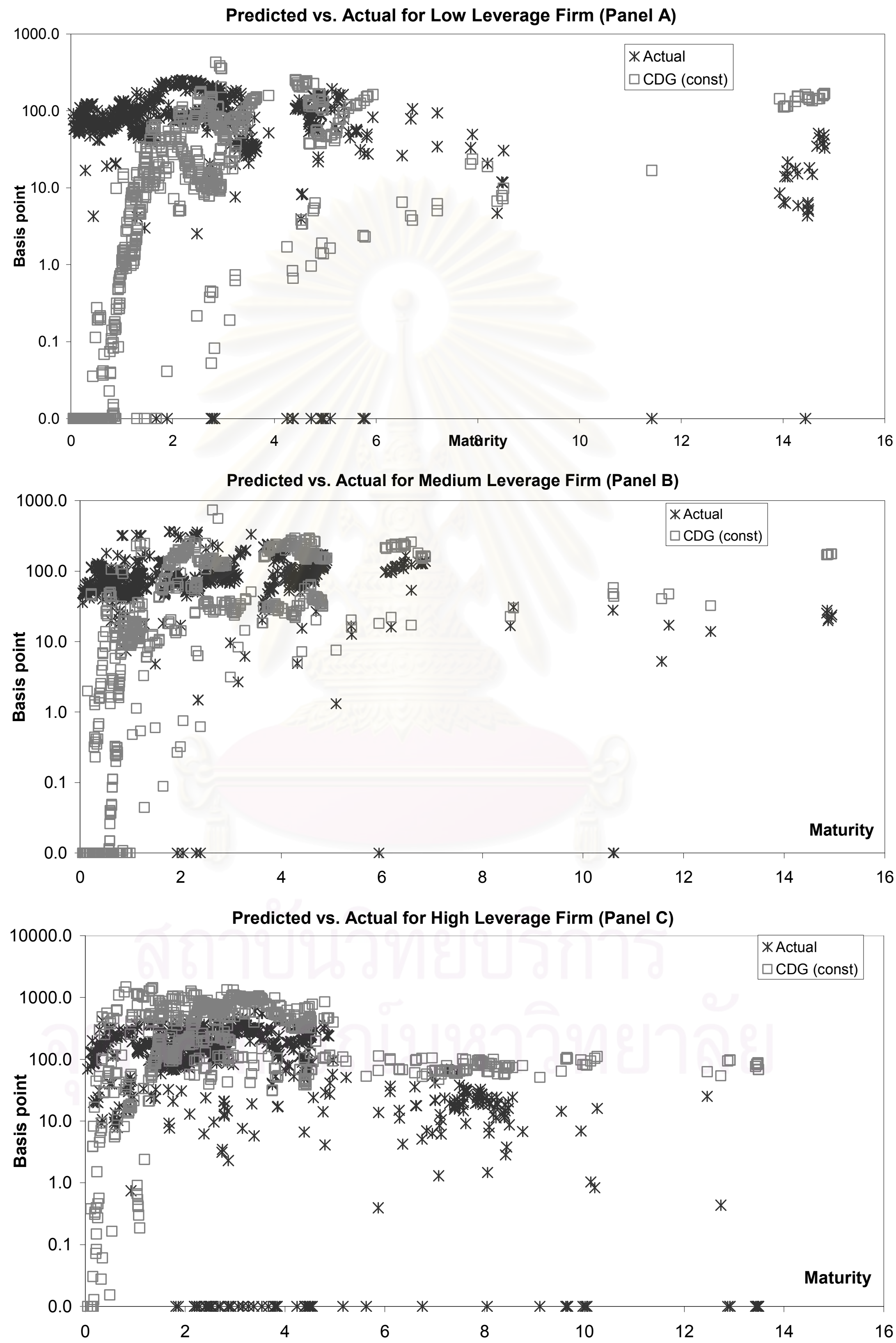

Table 8

Statistical of Endogenous Default Point in the LT Model

Table 8 reports average of leverage ratio (K/V) and average of endogenous default point per total assets (V_B/V) from the LT model. The asterisk and bold characters are defined as average of endogenous default point higher than total liabilities. These data is calculated from 2,464 samples in 25 firms between 1999 and 2004. In 25 lists of firms, endogenous default point is higher in 12 firms.

Bond	K/V	V_B/V	Bond	K/V	V_B/V
AIS	0.34	0.22	PTT	0.34	0.30
AP	0.30	0.18	PTTEP	0.57	0.28
BANPU	0.78	0.42	QH	0.68	***0.71**
BCP	0.86	***1.02**	RCL	0.74	***0.82**
CK	0.89	0.70	RGR	0.64	0.57
CPN	0.62	0.59	SCC	0.60	***0.64**
EASTW	0.48	***0.52**	SCCC	0.21	***0.22**
ITD	0.72	0.55	SHIN	0.34	0.20
LH	0.20	0.16	SPC	0.68	***0.91**
MFG	0.46	***0.52**	TGCI	0.73	0.51
NMG	0.66	***0.71**	THAI	0.60	***0.61**
NOBLE	0.42	0.28	TPC	0.62	***0.72**
NPC	0.36	***0.41**			
		K/V	V_B/V		
Average all sample		0.47	0.41		
Number of sample that V_B/V:					
Higher than K/V		1,029	Lower than K/V	1,435	
Number of predicted error from the LT model:					
Over the spreads		2,244	Under the spreads	220	

* V_B/V is higher than K/V

Table 9

Compare the Descriptive Statistics between Thai and the U.S. Market

Table 9 shows the comparison of descriptive statistics between Thai and the U.S. market. The U.S. data is referred from EHH (2004). The data in the U.S. is 2,184 samples, which consist of 182 bonds on the last trading day of each December between 1986 and 1997. The data in Thai is 2,464 samples, which consist of 25 bonds on the traded day between 1999 and 2004. Asset volatility is annualized and is 90-day historical volatility, while 150-day historical volatility in the U.S.

Country	Thai		The U.S.	
Parameters	Mean	Std Dev	Mean	Std Dev
Years to maturity	2.793	2.471	8.968	6.929
Coupon	7.144	1.990	7.916	1.506
Yield spread over risk-free rate (bp)	118.43	106.95	93.53	84.75
Market leverage ratio	0.465	0.192	0.303	0.152
Asset volatility	0.292	0.076	0.236	0.088
Corr. Between firm value and 3m T-bills	-0.021	0.029	-0.02	0.044
Payout	5.829	1.662	4.833	2.349

Table 10

The Comparison of Empirical Result between Thai and the U.S.

Table 10 compares the empirical result of Thai and the U.S. The issues that we raise are the best and the worst prediction model and the models that generate the best and the worst accuracy and the underpredicted spreads model.

Empirical result	Thai	The U.S.
The best prediction model	The CDG (const) with absolute prediction spread at 197%	The Geske (firm) with absolute prediction spread at 66%
The worst prediction model	The CDG (reg) with absolute prediction spread at 2359%	The CDG (reg) with absolute prediction spread at 319%
The best accuracy model	The CDG (const) with std. dev. of error in spreads at 661%	The Geske (firm) with std. dev. of error in spreads at 28%
The worst accuracy model	The CDG (reg) with std. dev. of error in spreads at 13,599%	The LT with std. dev. of error in spreads at 482%
The models that underpredict the spreads	The Geske (firm) which underpredict the spreads at 34%	The Geske (face) which underpredict the spreads at 30%. The Geske (firm) which underpredict the spreads at 53%

Table 11

Impact of Recovery Rate in the Geske Model

Table 11 reports the percentage errors in spreads, absolute percentage errors in spreads, and their standard deviation of the Geske model with face recovery. The table provides recovery rate between 30% and 60% of face value which is stepped by 5%.

Recovery rate	Percentage error	Standard deviation	Absolute percentage error	Standard deviation
30%	331.5%	5690.4%	689.9%	5658.2%
35%	308.3%	5482.0%	671.2%	5449.5%
40%	294.8%	5255.1%	642.8%	5223.9%
45%	278.9%	5035.7%	617.7%	5005.4%
50%	264.7%	4815.5%	591.4%	4786.4%
55%	249.2%	4601.5%	567.1%	4573.2%
60%	235.4%	4381.0%	540.6%	4353.8%

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Table 12
Impact of Recovery Rate in the LT Model

Table 12 reports the percentage errors in spreads, absolute percentage errors in spreads, and their standard deviation of the Leland-Toft model. The table provides recovery rate between 30% and 60% of face value which is stepped by 5%.

Recovery rate	Percentage error	Standard deviation	Absolute percentage error	Standard deviation
30%	8.1E+06%	2.0E+08%	8.1E+06%	2.0E+08%
35%	4.9E+06%	1.9E+08%	4.9E+06%	1.9E+08%
40%	3.8E+06%	1.9E+08%	3.8E+06%	1.9E+08%
45%	64151.9%	2.7E+04%	64460.4%	2.7E+04%
50%	778.1%	9794.8%	1086.5%	9765.3%
55%	686.2%	9726.1%	994.6%	9699.4%
60%	655.9%	9724.7%	964.4%	9699.0%

Table 13
Impact of Recovery Rate in the LS Model

Table 13 reports the percentage errors in spreads, absolute percentage errors in spreads, and their standard deviation of the Longstaff and Schwartz model. The table provides recovery rate between 30% and 60% of face value which is stepped by 5%.

Recovery rate	Percentage error	Standard deviation	Absolute percentage error	Standard deviation
30%	462.0%	3682.2%	790.3%	3625.9%
35%	413.4%	3374.2%	721.7%	3322.0%
40%	366.5%	3074.9%	655.5%	3026.5%
45%	321.1%	2783.6%	591.5%	2738.9%
50%	277.2%	2500.0%	529.6%	2458.9%
55%	234.7%	2223.4%	469.6%	2185.9%
60%	193.4%	1953.6%	411.5%	1919.5%

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Table 14
Impact of Recovery Rate in the CDG Model

Table 14 reports the percentage errors in spreads, absolute percentage errors in spreads, and their standard deviation of the Collin-Dufresne and Goldstein model. The table provides recovery rate between 30% and 60% of face value which is stepped by 5%. Panel A shows the details of the Collin-Dufresne and Goldstein model with regressed parameters. Panel B shows the details of the Collin-Dufresne and Goldstein model with specified parameters that κ_ℓ equals to 0.18, ϕ equals to 2.8, and ν equals to 0.6.

Panel A

Recovery rate	Percentage error	Standard deviation	Absolute percentage error	Standard deviation
30%	1880.9%	24967.4%	4256.5%	24673.6%
35%	1653.7%	21759.9%	3719.5%	21503.2%
40%	1451.5%	18987.7%	3250.9%	18763.5%
45%	1268.5%	16544.9%	2835.1%	16349.4%
50%	1100.9%	14360.3%	2461.3%	14190.5%
55%	946.0%	12383.9%	2122.0%	12237.3%
60%	801.7%	10579.4%	1811.6%	10453.8%

Panel B

Recovery rate	Percentage error	Standard deviation	Absolute percentage error	Standard deviation
30%	132.2%	1014.0%	288.4%	981.1%
35%	113.9%	937.9%	266.2%	906.5%
40%	95.9%	862.4%	244.7%	832.5%
45%	78.2%	787.6%	223.6%	759.2%
50%	60.8%	713.3%	203.2%	686.4%
55%	43.7%	639.6%	183.2%	614.3%
60%	26.9%	566.4%	163.7%	542.9%

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CHAPTER V

Conclusion and Recommendation

5.1 Conclusion

This study directly tests four structural models using Thai corporate bond data during 1999 to 2004. The sample consists of corporate bonds which have no callable and putable options. The sample also excludes corporates bonds issued by financial firms. In particular, the study employs the models of Geske (1977), Leland and Toft (1996), Longstaff and Schwartz (1995), and Collin-Dufresne and Goldstein (2001) to estimate bond prices. We examine each of these models under similar assumption to compare their abilities to predict corporate bond spreads.

We find that all the models have substantial errors of predicted spreads, but prediction errors differ in both sign and magnitude. Specifically, the models' predictive power is quite poor, because the dispersion of predicted spreads is quite large, as be seen in the high standard deviations and large average absolute prediction errors. In addition, most of the models tend to generate extremely high spreads on average, especially bonds issued by high leverage firms while the Geske model with firm recovery generates low spreads on average.

Although the Geske with firm recovery model generates low spreads on average, the Geske with face recovery model generates high spreads on average. This can be explained by the effect of recovery rate in the Geske with face recovery model. Therefore, the recovery rate would be a key variable to improve accuracy of the Geske with face recovery model. The recovery rate at 51.31% employed in this study might be too low, which lead to the overestimation of predicted spreads.

The problem of the LT model is that it generates high standard deviations. The regression analysis of errors from predicted spread shows that the errors are significantly related to the years to maturity, which makes the model underestimate predicted spreads. Moreover, the t-tests of spread errors suggest that all variables significantly affect the accuracy of the model. The insignificance of explanatory variables, except years to maturity, in the regression analysis may suggest that the model should include other variables to improve the accuracy of the model.

The LS and CDG models incorporate stochastic interest rates and correlation between equity returns and interest rates. We find that the correlation can explain the errors in the LS model, but it does not affect in the CDG model. The finding also shows that the LS and CDG with estimated parameters models work well when the correlation is high, while there is no obvious evidence in the case of CDG model with constant parameters. The study also finds that interest rate volatility relates to the accuracy of these models, i.e. LS and CDG model, whereas it does not affect the errors. These models generate a good prediction when the interest rate volatility is high. This may explain that the Vasicek model helps to improve the accuracy of these models.

In addition, the CDG model takes into account the stationary leverage ratio. The errors from the CDG model calculated by using estimated and constant parameters are relatively different. Thus, the stationary leverage ratio variables are quite sensitive to the accuracy of the model. The plausible explanation that the errors of the CDG with estimated parameters model is higher may be due to the low R-square of regression to estimate these parameters.

However, the Geske model is the only one model that underpredict the spreads. The reason is probably that this model does not recognize the first time passage of firm value to default point while the other models take into account this factor. The factor makes the Geske model underestimate the credit risk. In contrast, The LT model constructs the continuous coupon payment that tends to overestimate the risk, because the firms are obligated to pay coupon continuously. In addition, the LS and CDG models capture the interest rate risk by using the Vasicek model and the CDG model assumes changing of the leverage ratio to long run leverage ratio. Therefore, the problem is that we cannot exactly estimate the parameters and the recovery rate. This leads the models, i.e. LT, LS, and CDG, report the overestimated spreads.

In conclusion, this study shows that the pricing error and its standard deviation estimated from the CDG model with constant parameters are the lowest, while the pricing error and its standard deviation estimated from the Geske model with firm recovery are the lowest when including the BCP's bonds. We think that the spreads of BCP's bonds were unusual because the equity price changed significantly as a result of high leverage and unsatisfied business operation. Thus, this firm may collapse and the spreads are unlikely to be equal to those of other firms, but the bond market did not react this issue in price of BCP's bonds. However, the issue of BCP's bonds provides more information about the prediction sensitivity for each model when BCP's bonds are included in the sample. We find that the Geske model with firm recovery has the lowest sensitivity but the LT model has the highest sensitivity to this issue.

5.2 Limitation

The limitations of this study are related to number of corporate bonds. There are only 25 bonds in the sample between 1999 and 2004. If we use this data in the same manner of EHH (2004), there would be only 150 observations. However, we improve number of data by using the prices of the day that bonds are traded. By doing this, we have 2,464 observations. The problem of this method is that the data may be dominated by a few firms, such as AIS and PTT, because the proportions of these firms in the sample are high. Moreover, the results of structural models may be not acceptable, because the errors are generated from a few firms and these firms may dominate all errors.

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APPENDICES

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APPENDIX A

Example: Suppose we want to value ABC bond, which its characteristics are: coupon at 5% semi-annually paid, asset volatility at 8% per month, risk-free rate at 3% per year, the face value of liabilities at 100, and total assets at 130. The bond will be matured at 1.25 years.

First step, we set up the firm value process tree which every point is the payment due point. So, the tree will be Figure 9.

At T = 0.25, we calculate the $V_u = Ve^{\sigma_v \sqrt{t}} = 130 \cdot \exp(0.08\sqrt{3}) = 149.32$ because of asset volatility at 8% per month and *t* equals to 3 month, i.e. 0.25 year. Do it at all nodes and the results are in Figure 9.

Next step, we value the stock by treating it as compound option. At T = 1.25, the value of stock will be Max(0,V – F – c), which F is the face value of liabilities and c is its coupon payment. While the face value of liabilities is 100 and c is 2.5, because of semi-annually coupon paid. At the first row, S_{uuu} = Max(0, 220.97 – 100 – 2.5) = 118.47, and do it at every row of last column. The second number of the first row in T=0.75 is calculated from the binomial method so,

$$S_{uu}' = \left(\left(\frac{1.015-0.82}{1.22-0.82}\right)118.47 + \left(\frac{1.22-1.015}{1.22-0.82}\right)46.82\right)1.015^{-1} = 81.50$$

Because of r_f = 1.03, i.e. risk-free at 3%, the semi-annual risk free rate is $1.03^{0.5}$ = 1.015. While u and d calculated from Figure 9 are 1.22 and 0.82, respectively.

At the first number of fist row in T = 0.75, this is the point that the stock holders decide to exercise or not. If the value of stock in the future is more than the coupon in this period, the stock holders would exercise. Hence, the value of stock will be Max(0, S_{uu}' – c), S_{uu}' = Max(0, 81.50 – 2.5) = 79.00.

Now, the stock value tree which is calculated by previous step is shown in Figure 10. We know the stock value at time-0 as 30.80. So, the bond value is 130-30.80 = 99.20, while the face value of bond is 100. From this number, we find the interest rate that discount the bond value to 99.20, the interest rate is 6.84%. The fair value of the bond is 99.20 and the fair yield to maturity is 6.84% or spread at 384 bps.

Figure 9
The Firm Value Tree of ABC Firm

Figure 9 shows the tree of firm value in the future by V_0 = 130 and σ_υ = 0.08. Time length is 0.5 year but the first length at 0.25 year because next coupon will be paid at next 0.25 year, in order that every node corresponds to coupon payment.

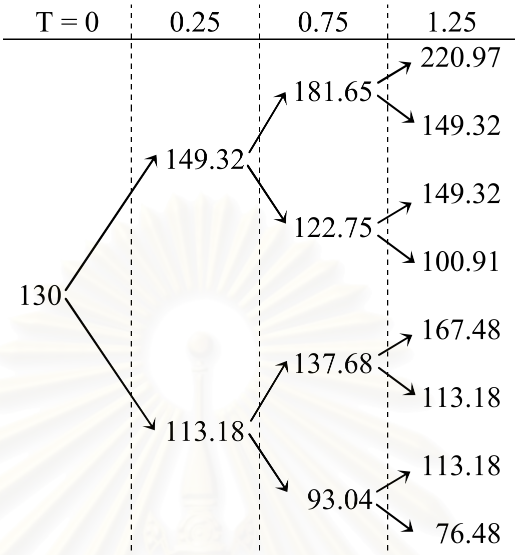
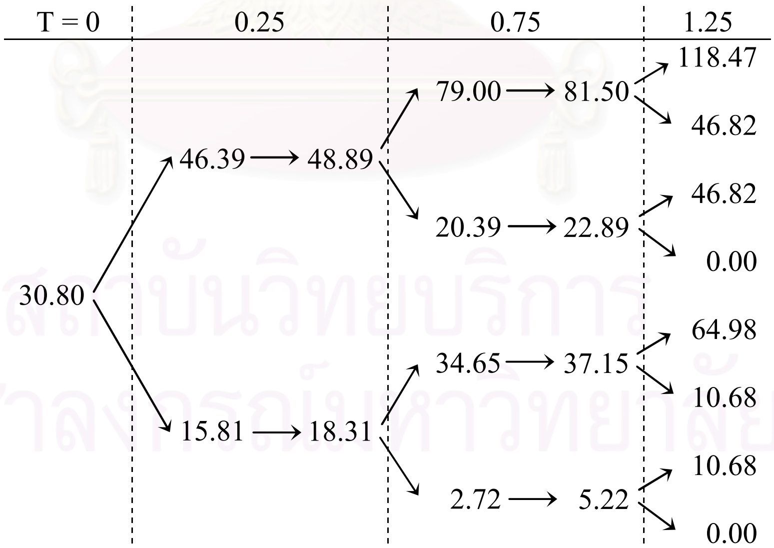


Figure 10
The Stock Value Tree of ABC Firm

Figure 10 shows the tree of stock value which is calculated by backtracking from maturity to present. Every node of the stock value corresponds to coupon payment. The parameters are r_f = 1.03, σ_υ = 0.08, F = 100, and c = 2.5.



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APPENDIX B

Table 15
Estimated Parameters in Interest Rate Models

Table 15 reports the mean and standard deviation of parameters in the Nelson-Siegel (1987) model and the Vasicek (1977) model during year 1999 to 2004. Panel A shows the estimated parameters of the Nelson-Siegel model and it's R-square. Panel B shows the estimated parameters of the Vasicek model and it's R-square. All parameters are estimated every trading day in specified year and the tables show only the average and standard deviation value in that year.

Panel A

Parameter	β_0	β_1	β_2	δ_1	R^2
Year	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)
1999	10.8710	-1.744	-3.571	4.2087	0.9941
	(0.1255)	(0.1372)	(0.3045)	(0.1109)	(0.0006)
2000	12.6081	-20.210	4.946	4.2395	0.9931
	(1.5235)	(7.1931)	(4.1987)	(0.1115)	(0.0055)
2001	11.5521	-19.131	4.919	4.4083	0.9815
	(3.7223)	(12.909)	(6.3611)	(0.1086)	(0.0115)
2002	9.5292	-18.580	5.399	4.2236	0.9848
	(1.2280)	(2.5978)	(1.1401)	(0.1038)	(0.0055)
2003	7.4751	-16.637	5.220	4.2601	0.9837
	(0.7450)	(2.3525)	(1.7780)	(0.0930)	(0.0056)
2004	8.7630	-13.689	2.855	4.1657	0.9768
	(0.9529)	(4.5772)	(2.7948)	(0.1086)	(0.0065)

Panel B

Parameter	α	B	r_t	σ_r	R^2
Year	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)	Mean (Std. Dev.)
1999	0.0242	0.0293	0.0240	0.0562	0.9998
	(0.0017)	(0.0211)	(0.0004)	(0.0033)	(0.0001)
2000	0.0158	0.0360	0.0225	0.0298	0.9993
	(0.0080)	(0.1166)	(0.0016)	(0.0122)	(0.0005)
2001	0.0123	0.0314	0.0219	0.0261	0.9971
	(0.0083)	(0.1202)	(0.0031)	(0.0183)	(0.0035)
2002	0.0071	-0.0447	0.0168	0.0206	0.9928
	(0.0028)	(0.0258)	(0.0010)	(0.0057)	(0.0030)
2003	0.0043	-0.0787	0.0116	0.0150	0.9808
	(0.0036)	(0.0359)	(0.0021)	(0.0080)	(0.0108)
2004	0.0110	-0.0310	0.0083	0.0295	0.9854
	(0.0033)	(0.0404)	(0.0006)	(0.0090)	(0.0043)

APPENDIX C

All bond data lists in this study are available in this section.

Industry: Commerce

Bond Name:

SPC#1

Industry: Communication

Bond Name:

AIS#11,	AIS04NA,	AIS06NA,	AIS073A,	AIS093A

Industry: Construction Materials

Bond Name:

SCC044A,	SCC044B,	SCCC#1,	TGCI#2,	TGCI#3

Industry: Energy & Utilities

Bond Name:

BANPU#2,	BCP#15,	BCP06NA,	BCP141A,	EASTW#1,	PTT029A,
PTT036A,	PTT03DA,	PTT04NA,	PTT04OA,	PTT053A,	PTT053B,
PTT057A,	PTT05NA,	PTT05NB,	PTT05NC,	PTT063A,	PTT067A,
PTT06NA,	PTT073B,	PTT077A,	PTT083A,	PTT083B,	PTT086A,
PTT087B,	PTT08NA,	PTT091A,	PTT092A,	PTT093B,	PTT093C,
PTT09NA,	PTT102A,	PTT103A,	PTT103C,	PTT106A,	PTT106B,
PTT107A,	PTT107B,	PTT10NA,	PTT112A,	PTT113A,	PTT113C,
PTT126A,	PTT127A,	PTT146A,	PTT157A,	PTT162A,	
PTTC10NA,	PTTC125A,	PTTEP#1			

Industry: Food & Beverage

Bond Name:

MFG025A

Industry: Hotels & Travel

Bond Name:

RGR#1,	RGR#2

Industry: Petrochem & Chemicals

Bond Name:

NPC#1,	NPC#2,	PTEP183A,	TPC#1,	TPC#2

Industry: Printing & Publishing

Bond Name:

NMG043A,	NMG055A,	NMG072A

Industry: Property Development

Bond Name:

AP075A,	CK#1,	CPN#4,	ITD#1,	LH063A,	LH073A,
NOBL06NA,	QH#2,	QH064A,	QH074A		

Industry: Transport & Logistics

Bond Name:

RCL#1,	THAI08OA

สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

BIOGRAPHY

Mr. Asawin Wongweerawit was born in May 14, 1982 in Bangkok. At the primary school and secondary school, he graduated from Kularbvithaya School and Wat Suthivararam School, repectively. At the undergraduate level, he graduated from the Faculty of Engineering, Chulalongkorn University in May 2004 with a Bachelor of Engineering degree, majoring in Computer Engineering. He joined the Master of Science in Finance program, Chulalongkorn University in June 2004.

สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย