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VALUATION OF ONE PERIOD COUPON BOND BASED ON DEFAULT TIME AND EMPIRICAL STUDY IN INDONESIAN BOND DATA

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Abstract

The value of corporate bond is conventionally expressed in terms of the zero coupon bond. In practice, the most common form of debt is coupon bond and allows early default before maturity as safety covenant for the bondholder. This paper studies some valuation methods for one period coupon bond, a coupon bond that only gives one time coupon at the bond period. First, we use classical model that allows the company defaults if the firm cannot fulfill its payment obligation at maturity date T. Second, we use classical first passage time model that gives bond investors the right to take over the firm if its asset value falls below a given barrier before the maturity date.

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Third, we give revised first passage time model that combines the two fore models. In this approach, a firm will default when its value of assets falls below a given barrier before maturity date or below the payment obligation at the maturity date. We construct a formula of probability of default for those specified models. For the empirical application, we valuate and analyze the default prediction of corporate Indonesian bonds.

1. Introduction

Credit risk valuation has been the subject of considerable research interest in finance and has recently drawn the attention of statistical researchers. There are two major approaches to price credit risk in the financial literature: structural approach and reduced-form approach. The structural approach that we have developed in this paper starts from the seminal work of Merton [16] and Black and Scholes [2]. In Merton model, both a single zero coupon bond and the equity of a firm are contingent on the value of the firm's assets. Asset value follows a geometric Brownian motion and default can only happen at maturity date.

In the past three decades, researchers have extended the idea of Black-Scholes-Merton in various directions. Black and Cox [1] developed a first passage time model that allows for the default before maturity. Geske [9, 10] treated a coupon bond as a compound option. Brennan and Schwartz [3] and Kim et al. [13] allowed a stochastic interest rate. Mason and Bhattacharya [14] assumed the firm asset value follows a pure jump process. Collin-Dufresne and Goldstein [4] allowed the leverage ratio of the firm to be a mean reverting stochastic process. Zhou [18] allowed the firm asset value follows a jump diffusion process. Fouque et al. [8] allowed the firm asset value to have stochastic volatility.

The two most comprehensive papers to date are Eom et al. [6] and Huang and Huang [12] that compared eight different structural models. These models span a wide range of structure model innovations: the asset value may follow a diffusion process or a jump diffusion process, possible early default by a first passage time process, fractional recovery of the principal after default, viewing a coupon bond as a compound option, stochastic interest rate, strategic default, endogenous default boundary and stochastic leverage.

Up to this time, most corporations tend to issue risky coupon bond rather than a zero coupon bond. At every coupon date until the final payment, the firms have to pay the coupon. At the maturity date, the bondholder receives the face value of the bond. The bankruptcy of the firm occurs when the firm fails to pay the coupon at the coupon payment and/or the face value of the bond at the maturity date. Geske [10] derived formulas for valuing coupon bonds. In earlier paper, Geske [9] suggested that when company has coupon bond outstanding, the common stock and coupon bond can be viewed as a compound option. KMV corporation uses Black and Scholes and Merton methodologies by first converting the debt structure into an equivalent zero coupon bond with maturity one year, for a total promised repayment (Vasicek [22] and Crosbie and Bohn [5]). Although KMV claims that its methodology can accommodate different classes of debt, they did not explain on how this equivalent amount is distilled from more complex capital structures (Reisz and Perlich [17]).

Bond indenture provisions often include safety covenants that give bond investors the right to reorganize a firm if its value falls below a given barrier. This theory can be seen as an early warning system for the bondholder. First passage time models build in the possibility of early default on the presumption that this is relevant for all corporate bonds.

In this paper, we built some structural models for valuing coupon bond, especially for one period coupon bond. First, we use a very classical model that only allows the company defaults if its asset value falls below the face value of the bond at time T. Second, we use classical first passage time model that gives bond investors the right to reorganize a firm if its value falls below a given barrier before the maturity date. Third, we give revised first passage time model that combines the two fore models. In this approach, a firm will default when its value of assets falls below a given barrier before maturity date or below the face value at the maturity date. We will construct a formula of probability of default for those specified models. For the empirical application, we valuate and analyze the default prediction of corporate Indonesian bonds.

2. Theoretical Framework

2.1. Zero coupon bond classical model

The basis of structural approach is that corporate liabilities are contingent claim on the assets of a firm. The market value of the firm is the fundamental source of uncertainty driving credit risk. To build this model, we have to make some assumptions for simplifying the analytic solution. Considering a geometric Brownian motion with volatility σ and no dividend payments, the asset value follows the following geometric Brownian motion model:

$$dV_t = \mu V_t \, dt + \sigma V_t \, dW_t^P \tag{1}$$

with W_t^P denoting a standard Brownian motion under the probability measure P, and σ and μ fixed. Further, the model makes all the other simplifying assumptions which are:

1. Constant return and volatility
2. No transaction costs
3. No dividends
4. No riskless arbitrage
5. Security trading is continuous
6. Risk free rate is constant for all maturities
7. Short selling proceeds are permitted.

2.2. Risk-neutral valuation

The derivation of the formula requires some assumptions. In this paper, we use Ito’s lemma to derive the equation. The basic idea here is that, by hedging away all risks in our portfolio, it becomes perfectly reasonable to assume that people are risk-neutral.

Definition 1. The forward price of an asset is the current price of the stock V_0, plus an expected return which will exactly offset the cost of holding the asset over a period of time *t*. Thus, as the only cost of holding the stock in our case is the risk-free interest lost, the forward price is

$$V_0 \exp(rt). \tag{2}$$

Definition 2. A universe is risk-neutral if for all assets *A* and time period *t*, the value of the asset $C(A, 0)$ at $t = 0$ is the expected value of the asset at time *t* discounted to its present value using the risk-free rate

$$C(A, 0) = \exp(-rt)E[C(A, T)], \tag{3}$$

where *r* is the continuously compounded risk-free interest rate.

With the asset V_t satisfying (1), we can define

$$W_t^Q = W_t^P + \frac{\mu - r}{\sigma} t. \tag{4}$$

Then Girsanov's theorem states that there exists a measure *Q* under which $\{W_t^Q\}$ is a Brownian motion. This yields

$$dW_t^P = dW_t^Q - \frac{\mu - r}{\sigma} dt, \tag{5}$$

then

$$dV_t = rV_t dt + \sigma V_t dW_t^Q \tag{6}$$

and the solution of this stochastic differential equation is

$$V_t = V_0 \exp\left(r - \frac{\sigma^2}{2}\right)t + \sigma W_t^Q. \tag{7}$$

Substituting $\sqrt{t}\, Y$ for W_t^Q with $Y \sim N(0, 1)$ yields

$$V_t = V_0 \exp\left(r - \frac{\sigma^2}{2}\right)t + \sigma\sqrt{t}\, Y. \tag{8}$$

2.3. Coupon bond

In practice, the most common form of debt instrument is a coupon bond. In the U.S. and in many other countries, coupon bonds pay coupons every six months and face value at maturity. Suppose the firm has only common stock and coupon bond outstanding. The coupon bond has *n* interest payments of *c* dollars each. The firm is assumed to default at the coupon date, if the total assets value of the firm is not sufficient to pay the coupon payment. Also, at the maturity date, the firm can default if the total asset is below the face value of the bond. For this case, if the firm defaults on a coupon payment, then all subsequent coupon payments (and payments of face value) are also default on.

At every coupon date until the final payment, the firm has the option of buying the coupon or forfeiting the firm to bondholder. The final firm option is to repurchase the claims on the firm from the bondholders by paying off the principal at maturity. The financing arrangement for making or missing the interest payments are specified in the indenture conditions of the bond. In general, bond valuation of coupon bond uses multiperiods coupon which cash flow can be seen in Figure 1. But, in this paper, we start from one period coupon bond which cash flow can be seen at Figure 2.

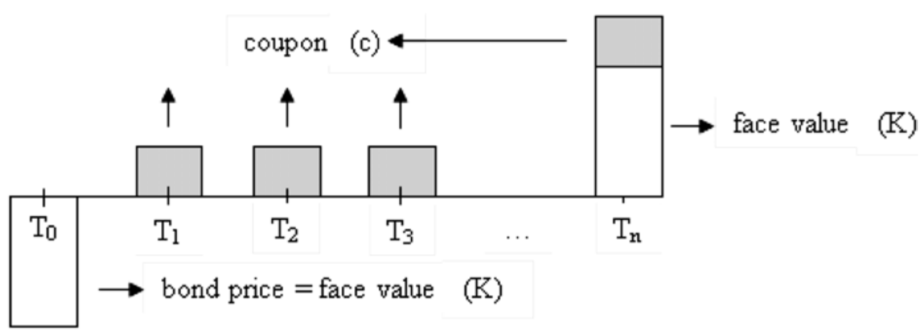

Figure 1. Cash flow of multiperiods coupon bond.

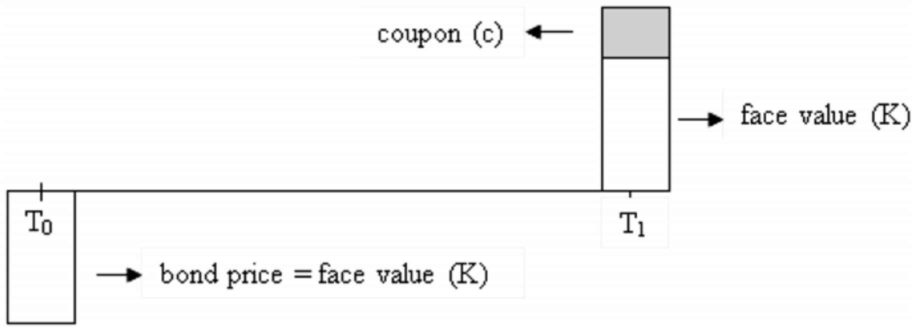

Figure 2. Cash flow of one period coupon bond.

3. One Period Coupon Bond Valuation Based on the Default Time

3.1. Classical default time for one period coupon bond

This model considers a corporation financed through a single debt and a single equity issue. The debt comprises one period coupon bond with notional value K maturing at time T_1. There are no payments until T_1, and equity holders will wait until T_1 before they decide whether to default or not (if they defaulted before T_1, they would forgo the chance of benefiting from an increase of the asset value). The equity pays no dividends.

The coupon bond has one time interest payments of c dollars. The firm is assumed to default at the coupon date (in case of one period coupon bond, the coupon date is the maturity date) if the total assets value of the firm is not sufficient to pay the coupon payment to bondholder. So, at the maturity date, the firm can default if the total asset is below payment obligation (the face value of the bond plus the coupon payment).

Consequently, the default probability will be the probability that at maturity T_1, the value of the asset is below the bond's maturity value $(K + c)$. Hence, the default time τ is a discrete random variable given by

$$\tau = \begin{cases} \infty & \text{if } V_{T_1} \geq K + c, \\ T_1 & \text{if } V_{T_1} < K + c. \end{cases} \tag{9}$$

By the definition of risk-neutral valuation and from equation (8), the probability of default at maturity date is

$$\begin{aligned} p(\tau = T_1) &= p(V_{T_1} < K + c) \\ &= p\left(V_0 \exp\left(\left(r - \frac{\sigma^2}{2}\right)T_1 + \sigma\sqrt{T_1}\,Y\right) < K + c\right) \\ &= p\left(\ln V_0 + \left(r - \frac{\sigma^2}{2}\right)T_1 + \sigma\sqrt{T_1}\,Y < \ln(K + c)\right) \\ &= p\left(\sigma\sqrt{T_1}\,Y < \ln(K + c) - \ln V_0 - \left(r - \frac{\sigma^2}{2}\right)T_1\right) \\ &= p\left(\sigma\sqrt{T_1}\,Y < \ln\left(\frac{K + c}{V_0}\right) - \left(r - \frac{\sigma^2}{2}\right)T_1\right) \\ &= p\left(Y < \frac{1}{\sigma\sqrt{T_1}}\left(\ln\left(\frac{K + c}{V_0}\right) - \left(r - \frac{\sigma^2}{2}\right)T_1\right)\right). \end{aligned}$$

Because of Y is normally distributed with mean 0 and variance 1 or $Y \sim N(0, 1)$, we get (Maruddani et al. [15])

$$\begin{aligned} p(\tau = T_1) &= p\left(Y < \frac{1}{\sigma\sqrt{T_1}}\left(\ln\left(\frac{K + c}{V_0}\right) - \left(r - \frac{\sigma^2}{2}\right)T_1\right)\right) \\ &= N\left(\frac{1}{\sigma\sqrt{T_1}}\left(\ln\left(\frac{K + c}{V_0}\right) - \left(r - \frac{\sigma^2}{2}\right)T_1\right)\right) \\ &= N\left(-\frac{1}{\sigma\sqrt{T_1}}\left(\ln\left(\frac{V_0}{K + c}\right) + \left(r - \frac{\sigma^2}{2}\right)T_1\right)\right), \end{aligned} \tag{10}$$

where $N(\bullet)$ is cumulative normal distribution.

3.2. First passage default time for one period coupon bond

First Passage Time (FPT) approach specifies default as the first time the firm’s asset value hits a lower barrier, allowing default to take place at any time. The barrier can be either constant or time varying variable. When the default barrier B is exogenously fixed, it acts as a safety covenant to protect the bondholders because they can take control of the company once its asset value has reached this level. Also, it is a protection mechanism for the bondholders against an unsatisfactory corporate performance.

FPT approach has common assumption with the classical approach:

1. Firm value follows a continuous time diffusion process.

2. Volatility σ and the risk free rate r are constants over time.

3. There are no default costs or tax advantages to debt, so no optimal capital structure.

FPT approach specific assumptions are:

1. Perpetual debt (no principal repayment), constant coupon rate c.

2. Default at any t, upon first passage of V_t to default barrier B.

3. If in case of default, bondholders get nonrandom value B, then equity holders get zero.

Suppose the default barrier B is constant valued in $(0, V_0)$. Then the default time is τ is modified to

$$\tau = \inf\{t > 0 | V_t \leq B\}. \tag{11}$$

This definition says a *default* happens when the assets of the firm fall to some positive level B for the first time. The firm is assumed to take the position of not default at time $t = 0$. Before calculating the probability of default for this model, the historical low of firm values is built, that is,

$$M_t = \inf_{s \leq t} V_s. \tag{12}$$

Then, with the definition of default time that is defined at (11), the probability of default is calculated as (Maruddani et al. [15])

$$\begin{aligned} p(\tau \leq T_1) &= p(M_\tau \leq B) \\ &= p(\inf_{s \leq \tau} V_s \leq B) \end{aligned}$$

$$= p\left(\inf_{s\le\tau}\left(V_0 \exp\left(\left(r - \frac{\sigma^2}{2}\right)s + \sigma\sqrt{T_1}\, Y\right)\right) \le B\right)$$

$$= p\left(\inf_{s\le\tau}\left(\ln(V_0) + \left(r - \frac{\sigma^2}{2}\right)s + \sigma\sqrt{T_1}\, Y\right) \le \ln(B)\right)$$

$$= p\left(\inf_{s\le\tau}\left(\left(r - \frac{\sigma^2}{2}\right)s + \sigma\sqrt{T_1}\, Y\right) \le \ln(B) - \ln(V_0)\right)$$

$$= p\left(\inf_{s\le\tau}\left(\left(r - \frac{\sigma^2}{2}\right)s + \sigma\sqrt{T_1}\, Y\right) \le \ln\left(\frac{B}{V_0}\right)\right)$$

$$= p\left(\inf_{s\le\tau}\left(r - \frac{\sigma^2}{2}\right)s + \sigma\sqrt{T_1}\, Y \le \ln\left(\frac{B}{V_0}\right)\right)$$

$$= p\left(\sigma\sqrt{T_1}\, Y \le \ln\left(\frac{B}{V_0}\right) - \inf_{s\le\tau}\left(r - \frac{\sigma^2}{2}\right)s\right)$$

$$= p\left(Y \le \frac{\ln\left(\frac{B}{V_0}\right) - \inf_{s\le\tau}\left(r - \frac{\sigma^2}{2}\right)s}{\sigma\sqrt{T_1}}\right). \qquad (13)$$

Since the distribution of the historical low of an arithmetic Brownian motion is inverse Gaussian, equation (13) will become

$$P(\tau \le T_1) = N\left(\frac{\ln\left(\frac{B}{V_0}\right) - \left(r - \frac{\sigma^2}{2}\right)T_1}{\sigma\sqrt{T_1}}\right)$$

$$+ \left(\frac{B}{V_0}\right)^{\frac{2}{\sigma^2}\left(r - \frac{\sigma^2}{2}\right)} N\left(\frac{\ln\left(\frac{B}{V_0}\right) + \left(r - \frac{\sigma^2}{2}\right)T_1}{\sigma\sqrt{T_1}}\right). \qquad (14)$$

3.3. Revised first passage default time for one period coupon bond

Reisz and Perlich [17] pointed out that if the barrier is below the payment obligation of the firm $(K + c)$, then the definition in equation (11) does not reflect economic reality anymore. It does not capture the situation when the firm is in default because $V_T < (K + c)$ although $M_T > B$. Bankruptcy is also reached if the barrier level is never hit before debt maturity, but the firm is unable to pay back its debt obligation at maturity.

For deriving the probability of default of one period coupon bond with revised first passage time approach, we re-define default in equation (11) with this equation below

$$\tau = \min(\tau_1, \tau_2), \tag{15}$$

where

$\tau_1 =$ maturity time T_1 if assets $V_T < K + c$ at T_1,

$\tau_2 =$ the first passage time of assets to the barrier B.

For calculating this probability of default, we recalled that the total market value of the firm V is modeled by geometric Brownian motion with constant drift μ and constant volatility σ. Since W_t^Q is normally distributed with mean zero and variance $(T_1 - t)$, so we get for the corresponding default probabilities

$$\begin{aligned} P(\tau \le T_1) &= P(\min\{\tau_1, \tau_2\} < T_1) \\ &= P(\tau_1 < T_1, \tau_2 < T_1) \\ &= P(V_{T_1} < K + c, M_{T_1} < B) \\ &= P\left(\left(\left(r - \frac{\sigma^2}{2}\right)t + \sigma W_t\right) < \ln\left(\frac{K + c}{V_0}\right),\right. \\ &\qquad \left.\min_{t \le T}\left(\left(r - \frac{\sigma^2}{2}\right)t + \sigma W_t\right) < \ln\left(\frac{B}{V_0}\right)\right). \end{aligned} \tag{16}$$

Equation (16) above can be separated into this three part below. The first part is

$$P(V_{T_1} < K + c) = P\left(\left(\left(r - \frac{\sigma^2}{2}\right)t + \sigma W_t\right) < \ln\left(\frac{K + c}{V_0}\right)\right)$$

$$= N\left(\frac{\ln\left(\frac{K + c}{V_0}\right) - \left(r - \frac{\sigma^2}{2}\right)T_1}{\sigma\sqrt{T_1}}\right). \tag{17}$$

The second part is

$$P(M_{T_1} < B) = P\left(\min_{t \le T}\left(\left(r - \frac{\sigma^2}{2}\right)t + \sigma W_t\right) < \ln\left(\frac{B}{V_0}\right)\right)$$

$$= N\left(\frac{\ln\left(\frac{B}{V_0}\right) - \left(r - \frac{\sigma^2}{2}\right)T_1}{\sigma\sqrt{T_1}}\right)$$

$$+ \left(\frac{B}{V_0}\right)^{\frac{2}{\sigma^2}\left(r - \frac{\sigma^2}{2}\right)} N\left(\frac{\ln\left(\frac{B}{V_0}\right) + \left(r - \frac{\sigma^2}{2}\right)T_1}{\sigma\sqrt{T_1}}\right). \tag{18}$$

Also, the third part is deriving by using the joint distribution of an arithmetic Brownian motion and its running minimum,

$$P(V_{T_1} < K + c \text{ and } M_{T_1} < B)$$

$$= \left(\frac{B}{V_0}\right)^{\frac{2}{\sigma^2}\left(r - \frac{\sigma^2}{2}\right)} N\left(\frac{\ln\left(\frac{B^2}{(K + c)V_0}\right) + \left(r - \frac{\sigma^2}{2}\right)T_1}{\sigma\sqrt{T_1}}\right)$$

$$-\left(\frac{B}{V_0}\right)^{\frac{2}{\sigma^2}\left(r-\frac{\sigma^2}{2}\right)} N\left(\frac{\ln\left(\frac{B}{V_0}\right)+\left(r-\frac{\sigma^2}{2}\right)T_1}{\sigma\sqrt{T_1}}\right) \tag{19}$$

so the result for probability of default is (Maruddani et al. [15])

$$P(\tau \leq T_1) = N\left(\frac{\ln\left(\frac{K+c}{V_0}\right)-\left(r-\frac{\sigma^2}{2}\right)T_1}{\sigma\sqrt{T_1}}\right)$$

$$+\left(\frac{B}{V_0}\right)^{\frac{2}{\sigma^2}\left(r-\frac{\sigma^2}{2}\right)} N\left(\frac{\ln\left(\frac{B^2}{(K+c)V_0}\right)+\left(r-\frac{\sigma^2}{2}\right)T_1}{\sigma\sqrt{T_1}}\right). \tag{20}$$

4. Empirical Study in Indonesian Bond Data

In this case study, we use data sets from Indonesian Bond Market Directory 2013 that is published by Indonesian Stock Exchange (IDX) in 2013 and Indonesian Bond Pricing Agency (IBPA) in 2013. We use a bond that is issued by PT Bank Rakyat Indonesia (BRI) with series name *Subordinated Bond* II *BRI Bank* 2009 and Bond Code BBRI02 IDA000043301. The profile structure of this bond is given at Table 1. Total assets data of the firm is published by Indonesian Bank in 2013 which consists of monthly prices January 2006 until December 2011.

Table 1. Profile structure of *Subordinated Bond* II *BRI Bank* 2009

Outstanding	**Listing date**	**Maturity date**	**Issue term**	**Coupon structure**
2.000.000,000,000	Dec 23, 2009	Dec 22, 2014	5 years	Fixed 10.94%

For deriving the probability of default, equity and liability of the bond, we have to do some steps to fulfill the assumptions. First, we have to check whether the natural logarithm of total assets data is normally distribution or not. Figure 3 gives us the normal Q-Q plot for the natural logarithm of total assets data. From this figure, we can see that the natural logarithm to total assets data is normally distributed. All the computations are done by R programming.

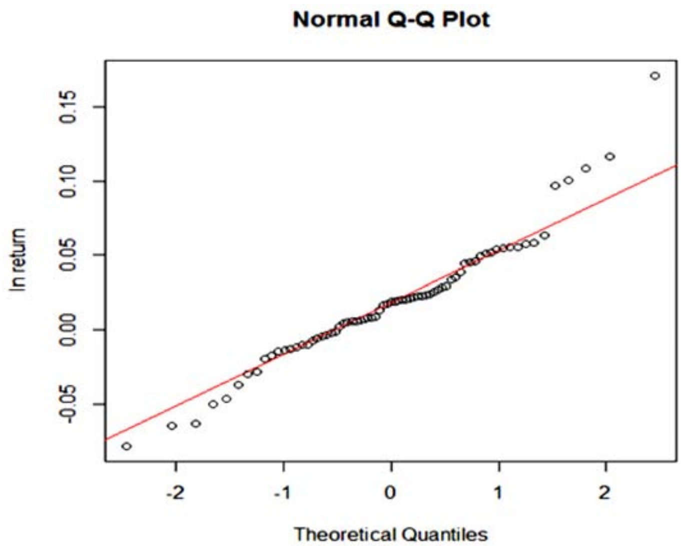

Figure 3. Normal Q-Q plot of natural logarithm of BRI total assets.

In the second step, we have to estimate some parameters. In Table 2, we give summarized value for those parameters. Also, in this study, we use a fixed barrier level in 1.800.000.000.000.

Table 2. Summarized value of the parameters

Parameter	**Value**
Asset value at December 2011 (V_0)	IDR 456.38 1.943.000.000
Face value (K)	IDR 2.000.000.000.000
Time to maturity (r)	5 years
Assets volatility (u)	14.52%
Interest risk free rate (r)	5.5%
Barrier value (B)	IDR 1.800.000.000.000
Coupon (c)	10.94%

Also, in the third step, we computed probability of default for the three model approaches. We summarize the result in Table 3.

Table 3. Probability of default *Subordinated Bond* II *BRI Bank* 2009

Method	**Probability of default**
Classical approach	4.563995E-66%
First passage time	2.6383058E-58%
Revised first passage time	5.645305E-47%

From Table 3, we can see that the probability of default is very small because of the outstanding of the bond is very low than the total assets value. It can be seen from Table 1 that the face value of the bond is 2.000.000.000.000 and the total assets value at the end of 2011 is Rp. 456.381.943.000.000. In normal situation, the total assets value is very sufficient for paying the principal of the bond.

5. Conclusion

The most important characteristic of classical model is the restriction of default time to the maturity of the debt, not taking into consideration the possibility of an early default, no matter what happens with the firm's value before the maturity of the debt. If the firm's value falls down to minimal level before the maturity of the debt, but it is able to recover and meet the debt's payment at maturity, the default would be avoided in classical approach.

The classical model is revised by a decision to default is made by managers who act to maximize the value of equity in order to satisfy shareholders. The first passage model specifies default as the first time the firm's asset value hits a lower barrier, allowing default to take place at any time.

In the classical model, equity pricing function is monotone in firm volatility. Equity holders always benefit from an increase in firm volatility. But in FPT model and revised FPT model, equity holders do not always benefit from an increase in asset volatility.

The default probability of revised FPT model is obviously higher than the corresponding probability in FPT model, which is obtained from equations (14) and (20) as the special case where $B = 0$.

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