

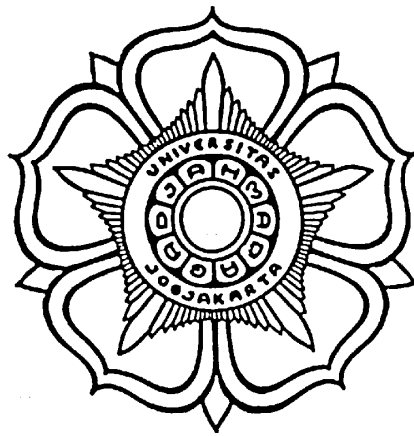
WARRANT PRICING

AN EMPIRICAL INVESTIGATION ON THE VALUATION MODELS
FOR WARRANTS TRADED AT THE JAKARTA STOCK EXCHANGE

by

Lucky Eko Santoso
2275/PS/MM/97

A thesis submitted in partial fulfillment of the requirements for the degree of
Master of Business Administration



Program of Graduate Studies
Gadjah Mada University
August 2000

ACKNOWLEDGEMENTS

The author would like to express his sincere thanks to the people who have played a part in the research and writing of the thesis:

1. MM-UGM for the scholarship, which is indirectly beneficial to this study, and for the administrative supports provided by its wonderful staffs.
2. Ms. Sri Handaru Yulianti for her guidance and encouragement throughout the research and writing of the thesis, and Prof. Bambang Riyanto for helpful suggestions during the thesis defense.
3. Dr. Suad Husnan, Mr. Agus Sartono, and Mr. Budi Purnomo of Gadjah Mada University, Dr. William “Risk” Margrabe of the William Margrabe Inc., Prof. Kuldeep Shastri of the University of Pittsburgh, Dr. Roy Sembel of the University of Indonesia, and members of saham@egroups.com discussion group for useful suggestions and encouragement.
4. Adib, Gus Farid, Pak Erning, and Pak Andi of 17th class of MM-UGM, who have been a continual source of encouragement as this study has progressed.

ABSTRACT

The purpose of this work is to investigate empirically the relative performance of pricing models commonly used for warrants traded at advanced markets as applied to those traded at the Jakarta Stock Exchange (JSX). Focus is given to option pricing models incorporating adjustment for dilution and changing volatility.

The data employed in this study consist of 3542 daily observations that belong to 10 most actively traded warrants traded at the JSX during the period January 1997 to June 2000.

The finding suggests that dilution adjustment improves the pricing performance of Black-Scholes-Merton model. It is also indicated that models that allow an inverse relation between stock price and volatility might promise superior pricing performance. In addition, it is showed that warrants traded at the JSX welcome risk-free arbitrage opportunities.

Keywords: warrant pricing, Indonesia.

TABLE OF CONTENTS

I. INTRODUCTION	1
I.1 Background	1
I.2 Objective and Scope of the Study	2
II. LITERATURE REVIEW	3
II.1 Practical Review	3
II.2 Theoretical Review	5
II.2.1 The Black-Scholes-Merton European Call Option Model (BS)	6
II.2.2 The Dilution-Adjusted Black-Scholes-Merton Model (DABS)	7
II.2.3 Models Allowing Volatility to be Inversely Related to Stock Price	9
II.3 Research Questions	10
III. METHODOLOGY	11
III.1 Data	11
III.2 Data Interventions	13
III.3 Parameter Estimation	14
III.4 Evaluation of the Models	18
IV. RESULTS AND DISCUSSIONS	23
IV.1 Evaluation of the Models	23
IV.2 Remaining Errors	23
IV.3 Violations of the Lower Bound	25
V. CONCLUSIONS AND RECOMMENDATIONS	29
V.1 Conclusions and Implications	29
V.2 Recommendations for Further Studies	30
BIBLIOGRAPHY	32
APPENDIX	35

LIST OF TABLES

Table 1. Warrants traded at JSX between January 1997 and June 2000	12
Table 2. The Effect of Dividend Forecasting Methods.....	16
Table 3. Regression of Current SBI Rate to Pricing Discrepancies	17
Table 4. Descriptive Statistics for the Warrants Included in the Sample	19
Table 5. Descriptive Statistics for the Warrants Not Violating the Lower Bound	20
Table 6. Descriptive Statistics for the Warrants Violating the Lower Bound	21
Table 7. Comparison of BS and DABS Model.....	23
Table 8. Factors Affecting the Remaining Errors	24
Table 9. Regression of Implied Volatility on Moneyness	24
Table 10. Extent of Violation by Exercisability	27
Table 11. Extent of Violation by Time to Maturity and Moneyness	28

I. INTRODUCTION

I.1 Background

A warrant is a right to purchase, within a specified period, a share of common stock at a specified price. The definition is so similar to that of the call option that it is only natural to value warrants using option pricing models, such as widely-used Black-Scholes model. In fact, the option pricing work of Black and Scholes was motivated by prior research on warrant pricing (Kremer and Roenfeldt, 1992).

However, there are important differences between calls and warrants. First, while the call option is issued by an individual, the warrant is issued by the company. If a warrant is exercised, it increases the number of outstanding shares of the company and thus dilutes the equity of the company (Galai and Schneller, 1978). Second, while calls expire within several months, warrants typically have maturities of at least several years. Black and Scholes warned early in 1973 that given the relatively long life of a warrant, the volatility of the underlying stock may be expected to change substantially (Lauterbach and Schultz, 1990).

Option pricing models that incorporate adjustments to the effect of potential dilution and changing volatility are therefore might be more appropriate for valuing warrants. Several theoretical studies have provided such models, and several empirical researches have tested them based on warrants traded at developed markets, such as U.S., as well as at the emerging markets. A review on the theoretical and empirical works is provided in Chapter II.

First listed on the Jakarta Stock Exchange (JSX) in 1995, warrants have since been the fastest growing Indonesian securities in terms of market capitalization. However, the study on warrant pricing as applied to Indonesian warrants has been, to the best of knowledge, unknown.

It is hoped that this study would contribute to the empirical literature on the valuation of warrants traded at the emerging markets, as well as stimulate further investigation in the valuation of warrants and other derivative securities traded at Indonesian exchanges. It is also hoped that the results of this study will be of value to practitioners to better grasp the pricing structure of warrants traded at the JSX, hereby assisting them in using warrants as hedging, arbitraging, or speculative vehicle. In particular, as warrants are of interest primarily because of their speculative appeal, it is hoped that perspective could be gained regarding the profile of warrant leverage.

I.2 Objective and Scope of the Study

The objective of this study is to address the following research problem:

Which valuation model is appropriate for pricing warrants traded at the JSX?

The problem is addressed by performing empirical investigation on the relative performance of pricing models commonly used for warrants traded at advanced markets as applied to those traded at the JSX. Focus is given to option pricing models incorporating adjustment for dilution and changing volatility.

II. LITERATURE REVIEW

II.1 Practical Review

Warrants were first listed on the JSX in July 13, 1995, corresponding to Ometraco Corporation's right issue. The issue offered 100 million shares of common stock at 1,475 rupiah per share, in an effort to raise fund to acquire 51% share of Bank Tiara Asia. Included in the package were 37.5 million warrants, provided the holder the option to buy one share of Ometraco Corporation common stock for 1,300 rupiah within five years. Unfortunately, these thinly traded warrants were prematurely delisted in March 12, 1999, in accordance with the delisting of their underlying stock.

With capitalization of only 1,666 billion rupiah in 1999, compared to 451,815 billion rupiah in common stocks, Indonesian warrant market were a relatively small one. However, comparison with 1997 data showed that warrants were the fastest growing securities in Indonesian market, in terms of market capitalization. By the end of 1999, 32 warrants were listed on the JSX. Among the most liquid were warrants issued by Bank International Indonesia (BNII-W) and Bank Pan Indonesia (PNBN-W), with 231 and 238 trading days in 1999, respectively.

Warrants are traded at the JSX on the same trading system as is used for trading the shares of listed companies and are subject to the same trading rules, with some minor exceptions, including the restriction on price movements. For warrants, minimum and maximum movement of price is 1 and 10 rupiah,

respectively, for warrants priced between 1 and 100 rupiah; 5 and 50 rupiah for warrants priced between 100 and 1000 rupiah; 10 and 100 rupiah for warrants priced between 1000 and 5000 rupiah; 25 and 200 rupiah for warrants priced above 5000 rupiah. During the observation period in this study, price movement has been 25 rupiah minimum and 200 rupiah maximum for shares, regardless of the stock price (The rule on stock price movement was changed later by the Exchange).

Specifications of warrants are heavily regulated by the Exchange:

1. Warrants could only be issued by companies listed on the Exchange. Hence Indonesian warrants are limited to company, or subscription, call warrants on stocks. By custom, warrants are issued as sweeteners to a right issue or first issue of ordinary shares.
2. Conversion ratio is a round number with the minimal of one. It is customary for issuers, though, to choose the minimal value.
3. The start of conversion period is at least 6 months from the listing date with the expiration date at least 3 years from the start of trading.
4. Exercise price is within 125% of the underlying stock's closing price in the day the decision is being made by the stockholders regarding the warrant issuance.
5. Exercise price and number of warrants outstanding are automatically adjusted by the Exchange in the events of stock splits, bonuses, and right issues. Other types of changes in the specifications require the agreement of at least 50% of the warrant holders.

It is perhaps worth noting that short-selling activities on securities, which require a special margin trading account, are restricted by the Exchange to a few stocks selected periodically. It is therefore safe to assume that short selling is practically inaccessible to traders in general.

II.2 Theoretical Review

Several studies have provided theoretical models for the pricing of warrants. These include the works of Black and Scholes in 1973, Schwartz in 1977 (Lauterbach and Schultz, 1990), Chen (1975), and Galai and Schneller (1978). Black and Scholes claimed that in many cases their famous model could be used as an approximation to give an estimate of the warrant value. Nevertheless, they warned that given the long life of a warrant, the volatility of the underlying stock might be expected to change substantially. Galai and Schneller further derived the warrant pricing formula, which regards a warrant as a diluted option of an identical firm without warrants outstanding. Both studies suggested that any call option-pricing model with some minor modifications could be used to price warrants. On the other hand, Chen used a dynamic programming approach to price warrants, while Schwartz generalized the Black-Scholes formulation by employing a finite difference technique to approximate solutions to a partial differential equation that governs the value of a warrant.

Empirical studies on warrant pricing include the works of Lauterbach and Schultz (1990), Leonard and Solt (1990), and Hauser and Lauterbach (1997) on U.S. warrants and Schulz and Trautmann (1994) on German warrants. Leonard

and Solt concluded that the Black-Scholes model performs as well as more complicated adjusted Black-Scholes models for warrant pricing. Schulz and Trautmann, using Schwartz-based model, helped to justify option-like warrant valuation ignoring dilution effect. On the other hand, Lauterbach and Schultz, followed by Hauser and Lauterbach, presented evidence that suggests that the Black-Scholes model be outperformed by a model that assumes a constant elasticity of variance diffusion process for stock price.

Empirical research on warrants traded at emerging markets include the work of Shastri and Sirodom (1993), who concluded that a constant elasticity of variance model outperformed Black-Scholes model in pricing Thailand warrants. On the other hand, Kwok (1994) confirmed the practical efficiency of Hong Kong traded warrant market using Black-Scholes model.

Several of the theoretical models for the pricing of warrants, along with relevant empirical researches, are provided in more detail below.

II.2.1 The Black-Scholes-Merton European Call Option Model (BS)

The Black-Scholes model, as adjusted for dividend by Merton, is

$$W = Se^{-dT} N(d_1) - Xe^{-rT} N(d_2) \quad (\text{II.1})$$

where

W = warrant price

S = stock price

d = dividend yield

T = time to warrant expiration

X = exercise price

r = risk-free interest rate

$$d_1 = \frac{\ln\left(\frac{Se^{-dT}}{X}\right) + \left(r + \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}}$$

$$d_2 = d_1 - \sigma\sqrt{T}$$

$N(x)$ = cumulative standard normal distribution evaluated at x

σ = volatility of stock price

The use of Merton's dividend adjustment is appropriate for long-term options as well as for warrants (Damodaran, 1996). The resulting BS model assumes that the dividend yield is certain and will not rise above the risk-free interest rate to induce early exercise. BS model also assumes that volatility, defined as the instantaneous standard deviation of stock return, as well as risk-free interest rate, is constant over the life of the warrant.

Lower bound for the warrant price according to this BS model is $Se^{-dT} - Xe^{-rT}$, which must be conformed as not to induce arbitrage opportunity. However, Shastri and Sirodom (1993) found that 39 percent of the prices of Thailand warrants in their study violate the lower bound. The average size of the violation is 28 percent, and they concluded that the violations are not practically significant after accounting for the effect of trading costs.

II.2.2 The Dilution-Adjusted Black-Scholes-Merton Model (DABS)

Galai and Schneller (1978) showed conceptually how to consider the dilution effect. Interpreting them, Lauterbach and Schultz (1990) proposed three modifications to be made to an option pricing method when applied to warrant pricing:

1. Substitute stock price S with $S + \frac{M}{N}W$.
2. Consider the volatility σ as the volatility of $S + \frac{M}{N}W$.
3. Multiply the result by $\frac{N}{N+M}$.

where W is the warrant price, N is the number of outstanding shares, and M is the number of outstanding warrants.

In the case of BS model, which uses Merton's adjustment, it is reasonable for any mention of S in the above modifications to be interpreted as Se^{-dT} . When these modifications are made to BS model, the resulting model, DABS, would be a formula for W in terms of W . The model could then be solved by employing an iterative search procedure. Apart from the adaptation to potential effects of dilution, DABS still inherits other limiting assumptions of BS model. By simple arithmetic manipulations, it could be shown that the lower bound for the price according to this model is also the same as according to BS model.

DABS model is widely used, including the adoption by Hull (1993) and Damodaran (1996) in their textbooks. Hauser and Lauterbach (1997), after comparing it with several more sophisticated warrant valuation models, concluded that DABS model remains a reasonable, economical alternative in many cases.

Sidenius (1996), however, argues that dilution adjustment is by no means necessary. This is consistent with the empirical study of Schulz and Trautmann (1994) on German warrants.

II.2.3 Models Allowing Volatility to be Inversely Related to Stock Price

Black and Scholes early in 1973 warned that given the long life of a warrant, the volatility of the underlying stock might be expected to change substantially. The changing volatility would then contradict the assumption of BS and DABS models that stock price returns follow a lognormal diffusion process, which implies constant volatility (Lauterbach and Schultz, 1990).

It is well established theoretically and empirically, however, that volatility is inversely related to stock price (Hauser and Lauterbach, 1997). Lauterbach and Schultz (1990) found that implied volatility of U.S. warrants based on DABS model is inversely related to stock price. Shastri and Sirodom (1993) also confirmed the evidence in Thailand warrants.

Coined by Chance (1999) as representing the first attempt to incorporate changing volatility into option pricing models, Cox in 1975 and Cox and Ross in 1976 (Beckers, 1980) studied alternative constant elasticity of variance (CEV) diffusion process. The process assumed volatility to be a direct inverse function of the stock price. Based on the study and some assumptions, Beckers then offered some simplifying approximations to two special cases of CEV, namely Square Root CEV and Absolute CEV. Hauser and Lauterbach (1997) also presented how to approximate the general case of CEV.

In the studies of Noreen and Wolfson in 1981 and Ferri, Kremer, and Oberhelman in 1986, BS model was commonly found to perform as well as and is often more accurate than the CEV models (Leonard and Solt, 1990). However, Lauterbach and Schultz (1990), followed by Hauser and Lauterbach (1997)

presented evidence suggesting that the Square Root CEV models indeed outperformed DABS model. Shastri and Sirodom (1993) also confirmed the evidence in Thailand warrants, although the difference in pricing performance is only 0.16 percent, which, as they suggested, might not be practically significant.

Other models that might be considered include Geske's compound option model, Rubinstein's displaced diffusion model, and stochastic volatility models (Hull, 1993).

II.3 Research Questions

Based on the literature review, the research problem stated in Chapter I could then be developed into research questions:

1. Regarding the mixed results on the appropriateness of dilution adjustment to BS: *Which one is more superior in pricing warrants traded at the JSX: BS or DABS?*
2. Regarding the evidence in the U.S. and Thailand warrants that implied volatility from DABS is inversely related to stock price: *Is there inverse relationship between implied volatility and stock price in applying DABS to warrants traded at the JSX?*
3. In relation to violations of the arbitrage-free lower bound evidenced in Thailand warrants: *Do violations of the lower bound exist in warrants traded at the JSX? and, if they do, what factors, if any, are systematically related to the extent of the violations?*

III. METHODOLOGY

III.1 Data

The data employed in this study consist of daily closing price and volume of all warrants and their underlying stocks traded at the JSX during the period January 1997 to June 2000. The period is selected because daily prices of the warrants prior to December 10, 1996 are unavailable in organized form. The data are acquired and compiled from the JSX Daily Market Summaries stored at http://w3.jsx.co.id/market_summary/daily. Table 1 presents all warrants traded at JSX between January 1997 and June 2000.

Twenty-one daily data are not obtainable due to either errors in data acquisition process, or incompleteness of the JSX's stored data. They represent three different years and do not seem to be systematically distributed. Also missing from the sample are 1997 data of warrants coded INKP-W1.

Initial specifications of the warrants, such as initial number of warrants outstanding, initial exercise price, and expiration date, are drawn from the *JSX Statistics*. Also obtained from the same source are dividend information, right issue information, and changes in the number of shares outstanding due to corporate actions (stock splits, bonuses, and right issues) and conversions of convertible securities (including warrants). Any inaccuracies and ambiguities are, whenever possible, confronted with other reliable sources, such as corporate action information stored at <http://www.jsx.co.id>, securities administration office (BAE), and RTI data services.

Table 1. Warrants traded at JSX between January 1997 and June 2000

<i>No</i>	<i>Company</i>	<i>Code</i>	<i>R/F</i>	<i>Trading Days</i>	<i>Activity</i>
1	APAC Centertex Corporation	MYTX-W	R	367	43%
2	Asiana Multikreasi	ASIA-W	R	138	19%
3	Bahtera Adimina Samudra	BASS-W	F	155	99%
4	Bank Bali	BNLI-W	R	417	49%
5	Bank CIC International	BCIC-W1	R	130	44%
6	Bank Danpac	BDPC-W	F	30	22%
7	Bank Global Internasional	BGIN-W	F	71	12%
8	Bank International Ind.	BNII-W2	R	298	97%
9	Bank International Ind.	BNII-W	R	694	95%
10	Bank Pan Indonesia	PNBN-W	R	661	90%
11	Bank Pan Indonesia	PNBN-W3	R	197	80%
12	Bank Pan Indonesia	PNBN-W2	R	7	1%
13	Bank Victoria Intl.	BVIC-W	F	85	34%
14	BDNI	BDNI-W	R	317	62%
15	Berlian Laju Tanker	BLTA-W	R	234	39%
16	Bhuwanatala Indah Permai	BIPP-W	R	230	27%
17	Bhuwanatala Indah Permai	BIPP-W2	R	1	0%
18	Clipan Finance Indonesia	CFIN-W	R	1	0%
19	Clipan Finance Indonesia	CFIN-W2	R	0	0%
20	Clipan Finance Indonesia	CFIN-W3	R	0	0%
21	Dharma Samudera Fishing Ind.	DSFI-W	F	64	100%
22	Indah Kiat Pulp & Paper	INKP-W1	R	385	53%
23	Indah Kiat Pulp & Paper	INKP-W	R	441	51%
24	Karwell Indonesia	KARW-W	R	185	24%
25	Kridaperdana Indahgraha	KPIG-W1	F	51	85%
26	Ometraco Corporation	OMTR-W	R	4	1%
27	Pabrik Kertas Tjiwi Kimia	TKIM-W	R	447	61%
28	Panin Insurance	PNIN-W	R	12	1%
29	Panin Insurance	PNIN-W2	R	1	0%
30	Panin Insurance	PNIN-W3	R	0	0%
31	Panin Life	PNLF-W3	R	10	8%
32	Panin Life	PNLF-W	R	0	0%
33	Panin Life	PNLF-W2	R	0	0%
34	Panin Sekuritas	PANS-W1	F	21	100%
35	Perdana Cipta Multi Finance	PCMF-W	R	9	2%
36	Pudjiadi & Sons Estate	PNSE-W	R	0	0%
37	Ristia Bintang Mahkotasejati	RBMS-W	F	6	1%
38	Sinar Mas Multiartha	SMMA-W	R	67	8%
39	Surabaya Agung Industry P.	SAIP-W	R	55	6%
40	Suryamas Dutamakmur	SMDM-W	R	88	10%

Note: R/F corresponds to whether the warrants are issued as part of a right (R) or first (F) issue. Activity is the number of trading days (obtained from the *JSX Statistics*) divided by the maximum number of possible trading days during the period.

For the purpose of risk-free interest rate estimation, discount rates of Bank Indonesia's SBI are collected. Monthly rates of 1-month SBI during the period January 1997 to June 2000 are drawn from the *Indonesian Financial Statistics* of Bank Indonesia and stored data at <http://www.bi.go.id>. Also drawn are rates of 3-month SBI during the period 1994-1996.

III.2 Data Interventions

After dropping daily data with zero warrant transaction volume, a total of more than 5300 observations are obtained. Data on warrant trading volume during the period October 30, 1998 to December 30, 1998 are missing so that the existence of trading volumes is inferred from daily price changes. This potentially reduces the number of observations from otherwise could be obtained from complete data.

A filter on trading liquidity is employed to arrive at the final sample. Only warrants with activity of around and above 50% are included in the sample. Nevertheless, although actively traded, DSFI-W and KPIG-W1 are related to firstly issued common stocks, which have no history of dividend payments. As difficulties in dividend yield estimation might arise from the fact, both warrants are discarded from the sample. Daily data of BASS-W before ex-dividend date of the underlying stock are also excluded.

Three observations are discarded from the sample because the warrant prices are in the neighborhood of corresponding stock prices, thus potentially

leading to erroneous calculations. They have low trading frequencies, however, which might explain the extreme values.

A final sample of 3542 daily observations that belong to 10 warrants are obtained.

III.3 Parameter Estimation

Some parameters required by BS and DABS models are readily observable in this study. Stock prices, along with warrant market prices, are proxied by daily closing prices in the observation. Daily data on the number of shares outstanding and time to warrant expiration are also easily calculated from the available materials.

As warrants traded at the JSX are protected against stock splits, bonuses, and right issues, adjustments to the number of outstanding warrants and the exercise price are made if the underlying stock experiences such corporate actions. Record of such changes in the warrant specifications, however, is not publicly available. Therefore, the changes are inferred from the changes in the number of shares outstanding in the case of splits and bonuses. In the case of right issues, right issue information is used for similar purpose. The number of outstanding warrants is also adjusted in the occurrence of warrant conversions.

Some parameters, however, cannot be observed or inferred directly, and hence need to be estimated.

Expected volatility is estimated by implied volatility calculated from the most recent observation available on corresponding warrant, using corresponding

model and warrant market price. This implied volatilities are approximated by employing bisection method, a robust iterative search procedure (Appendix).

All companies in the sample have history of dividend payments; hence, the estimation of the dividend yield is relevant. Dividend yield is typically calculated as the most recent 12-month dividend divided by the current stock price, and for purposes of forecasting convenience, is assumed to continue until the expiration of the warrant.

However, given the relatively large stock price change in the observations, the assumption might be somewhat unrealistic (For example, Bank International Indonesia has experienced 92% stock price drop, after adjusting for relevant corporate actions, during the observation period). It is reasonable to assume that expected dividends increase as the stock price rises and decrease as the stock price declines. Alternative dividend yield forecasting method is then offered, within which stock price of the most recent cum-dividend day is used in calculating the dividend yield. This in effect allows expected dividends to increase as the stock price rises and decrease as the stock price declines.

Since 1998 some companies in the sample have also suspended the dividend payment. thus effectively allowing the dividend yield to be zero, should the typical forecasting method be used. The practice is questionable considering the possibility that the companies would resume the dividend payment in the future. Alternative dividend yield forecasting method is then offered, with the following rule: if no dividends are paid during the current year, most recent dividends are used in the calculation, thus not allowing zero dividend yield.

Table 2 shows the effect of some simple dividend forecasting methods, including the above alternatives, in relation to pricing performance of BS model. Risk-free interest rate is assumed a constant 12 percent, which will be examined later.

The mean of percentage errors is defined as $E = (W - W^*)/W^*$, where E is the percentage valuation error, W^* is the theoretical warrant price obtained from the model, and W is the market price of the warrant. The violations is defined similarly as the deviation of warrant market price from the theoretical arbitrage-free lower bound, if the warrant market price is below such bound.

It is clear that adjustment for dividend is necessary as pure Black-Scholes model produces inferior result in terms of the size of violations. It is also clear that the application of D5 method results in the better pricing performance as compared to D2 method, which is more commonly used.

Table 2. The Effect of Dividend Forecasting Methods

<i>Dividend Forecasting Method</i>	<i>Mean Percentage Error</i>	<i>Number of Violation</i>	<i>Mean Percentage Violation</i>
D1	14.46%	39.7%	39.7%
D2	14.80%	37.6%	28.2%
D3	14.23%	37.7%	30.3%
D4	15.17%	34.7%	24.6%
D5	13.68%	34.5%	26.1%

Note: D1 corresponds to pure Black-Scholes model, where dividend yield is set to zero, whereas D2 represents commonly practiced calculation of dividend yield. In D2 and D3, expected dividends are allowed to be zero whereas in D4 and D5, they are not. D2 and D4 use current stock price as denominator in calculating dividend yield, whereas D3 and D5 use most recent cum-dividend stock price. Number of violation is expressed in percentage of total number of observations, which is 3542.

The comparison is in terms of producing smaller percentage error and reducing the number of violations in the observations. D5 method is then used for the rest of the study to estimate the dividend yield.

In relation to the research question number 3, it is also clear that violations of the lower bound indeed exist. The violations are represented by 34.5 percent of total observations.

Common proxy for risk-free interest rate in valuing a U.S. warrant is the current yield of Treasury bill or bond with maturities comparable to that of the warrant. Instruments with such length and variety of maturities are unavailable in Indonesia. Hence, for forecasting convenience, risk-free interest rate is proxied to be constant and equal to 12 percent p.a., a value rounded from the average of Bank Indonesia's 3-month SBI discount rate during the period 1994-1996.

It came to consideration, however, that interest rate significant climb during the period July 1997 to July 1999 might cause this constant proxy to be misleading. To test the speculation, pricing discrepancies introduced by the application of the constant proxy to BS model is then regressed to corresponding current rate of 1-month SBI. Table 3 shows the result of the test.

Table 3. Regression of Current SBI Rate to Pricing Discrepancies

<i>Pricing Discrepancy</i>	<i>Number of Observations</i>	<i>Slope</i>	<i>t-statistic</i>	<i>Adjusted R Square</i>
Percentage Error	2312	-0.09	-4.34***	0.01
Percentage Violation	1221	-0.24	-6.93***	0.04

*** Significant at the 0.001 level.

The significantly negative slope suggests that reduction of the value of the proxy along with adjustment to current discount rate might result in better pricing performance. However, to avoid questionable practice of arbitrarily specifying such reduction and adjustment, the constant 12 percent proxy of risk-free interest rate is kept and used for the rest of the study.

Table 4 presents all the warrants included in the final sample, along with some descriptive statistics. Sample without violations and sample with violations are presented in Table 5 and Table 6, respectively.

III.4 Evaluation of the Models

Models are implemented using user-defined functions written in Visual Basic for Application (Appendix). DABS values are approximated using Secant method, an efficient iterative search procedure. Errors introduced by the approximations are made sufficiently small relative to the average difference between BS price and DABS price, to reduce unnecessary biases.

As both BS and DABS models are having the same lower bound, none of the models is superior relative to each other in terms of reducing the number of violations in the sample. Therefore, only observations that don't violate the lower bound are needed to be concerned.

The mean of percentage errors will be used to measure the relative performance of both pricing models. Specifically $E = (W - W^*) / W^*$, where E is the percentage valuation error, W^* is the theoretical warrant price obtained from the model, and W is the market price of the warrant.

Table 4. Descriptive Statistics for the Warrants Included in the Sample

<i>Code</i>	<i>Date in sample</i>		<i>Number of Observations</i>	<i>Mean Stock Price</i>	<i>Mean Warrant Price</i>	<i>Mean Dilution Factor</i>	<i>Mean Moneyness</i>	<i>Mean Time to Expiration (years)</i>
BASS-W	05/08/00	06/30/00	37	2656	1817	0.09	3.49	2.43
BDNI-W	03/05/97	08/20/98	302	749	240	0.12	-0.12	2.16
BNII-W	02/03/97	12/22/99	663	596	206	0.06	-0.21	1.44
BNII-W2	04/15/99	06/30/00	295	147	71	0.08	-0.12	2.40
BNLI-W	01/06/97	06/29/00	376	1263	408	0.12	-0.11	1.74
INKP-W	01/03/97	06/29/00	358	1971	1093	0.04	2.07	3.05
INKP-W1	01/02/98	06/29/00	275	2357	1313	0.05	2.31	3.62
PNBN-W	07/03/97	06/22/00	637	677	145	0.08	-0.26	1.43
PNBN-W3	07/28/99	06/30/00	185	664	213	0.09	-0.09	2.45
TKIM-W	08/27/97	06/22/00	414	1836	878	0.12	1.59	3.83
Total			3542	1102	479	0.08	0.49	2.29

Note: Dilution factor is the number of shares that can be purchased by warrants divided by the sum of the number of existing shares and the number of the shares that can be purchased with warrants. Moneyness is calculated as $(Se^{-dT} - Xe^{-rT}) / Xe^{-rT}$, where Se^{-dT} is the stock price discounted at dividend yield and Xe^{-rT} is exercise price discounted at risk-free interest rate.

Table 5. Descriptive Statistics for the Warrants Not Violating the Lower Bound

<i>Code</i>	<i>Number of Observations</i>	<i>Mean Stock Price</i>	<i>Mean Warrant Price</i>	<i>Mean Dilution Factor</i>	<i>Mean Moneyness</i>	<i>Mean Time to Expiration</i>
BDNI-W	228	305	63	0.12	-0.48	1.98
BNII-W	552	348	80	0.06	-0.55	1.20
BNII-W2	294	147	71	0.08	-0.12	2.40
BNLI-W	326	1099	341	0.12	-0.24	1.75
INKP-W	41	2209	1679	0.00	2.39	2.52
INKP-W1	20	2331	1561	0.04	2.17	3.33
PNBN-W	607	635	135	0.08	-0.30	1.40
PNBN-W3	184	660	212	0.09	-0.09	2.45
TKIM-W	60	1255	651	0.12	0.75	3.71
Total	2312	598	195	0.08	-0.23	1.77

Table 6. Descriptive Statistics for the Warrants Violating the Lower Bound

<i>Code</i>	<i>Number of Observations</i>	<i>Mean Stock Price</i>	<i>Mean Warrant Price</i>	<i>Mean Moneyness</i>	<i>Mean Time to Expiration</i>	<i>Mean Violation</i>	<i>Mean Percentage Violation</i>
BASS-W	37	2656	1817	3.49	2.43	206	11.3%
BDNI-W	73	2136	794	1.02	2.71	137	19.8%
BNI-W	110	1837	839	1.45	2.63	219	26.1%
BNLI-W	49	2300	831	0.71	1.62	115	14.7%
INKP-W	316	1942	1017	2.03	3.12	204	25.3%
INKP-W1	254	2365	1298	2.33	3.64	217	24.2%
PNBN-W	29	1552	371	0.49	2.04	103	33.7%
TKIM-W	353	1935	915	1.73	3.85	194	32.1%
Total	1221	2057	1018	1.85	3.26	195	26.1%

Note: Violation is the deviation of warrant market price from the theoretical arbitrage-free lower bound, $Se^{-dT} - Xe^{-rT}$, if the warrant price is below such bound. Se^{-dT} is the stock price discounted at dividend yield and Xe^{-rT} is exercise price discounted at risk-free interest rate.

The null hypothesis is that there is no difference in mean percentage errors introduced by both pricing models. Rejection of the null would support the model with lower mean percentage error. Hence the research question number 1 could be answered.

To answer the research question number 2, an investigation would then be made by regressing the implied volatility on the moneyness of the warrant under consideration, where moneyness is defined as $\frac{Se^{-dT} - Xe^{-rT}}{Xe^{-rT}}$. Implied volatilities are obtained using DABS model.

Finally, in relation with the research question number 3, factors suspected to be systematically related to the extent of the violations (of the lower bound according to BS and DABS models) would be explored.

IV. RESULTS AND DISCUSSIONS

IV.1 Evaluation of the Models

Table 7 presents the comparison of the pricing accuracy of BS and DABS models. It shows that DABS model gives a statistically better pricing performance relative to BS model. On the other hand, the average improvement of 0.08 percent, or 0.16 rupiah as the mean warrant price of the sample is 195 rupiah, are likely to be practically insignificant. It could be argued, however, that the practical insignificance is due to relatively small dilution factor, 0.08 on average, of the warrants in the sample.

IV.2 Remaining Errors

Common suspects for factors affecting the remaining errors are time to maturity and moneyness. Regression of time to maturity and moneyness to mean percentage error resulted by DABS is then performed (Table 8).

Table 7. Comparison of BS and DABS Model

<i>Valuation Model</i>	<i>Mean Percentage Error</i>
BS	13.68%
DABS	13.60%
t-statistic	14.82***

Note: Number of observations: 2312.

*** Significant at the 0.001 level.

Table 8. Factors Affecting the Remaining Errors

<i>Factor</i>	<i>Slope</i>	<i>t-statistic</i>	<i>Adjusted R Square</i>
Time to maturity	-0.05	-10.31***	0.04
Moneyness	-0.05	-6.82***	0.02

*** Significant at the 0.001 level.

Though the slopes is significantly different than zero, the correlation is weak. By further investigation, it is found that moneyness is significantly correlated at the 0.001 level with time to maturity. Therefore little could be reliably concluded regarding this result.

Regression of implied volatility on moneyness is then performed and presented in Table 9. For reliability control, warrants with relatively small number of observations are excluded. They are INKP-W, INKP-W1, and TKIM-W, with 41, 20, and 60 observations, respectively.

The result suggests that implied volatility is significantly negatively correlated to moneyness, at least for warrants of low moneyness.

Table 9. Regression of Implied Volatility on Moneyness

<i>Code</i>	<i>Number of Observations</i>	<i>Slope</i>	<i>t-statistic</i>	<i>Adjusted R Square</i>
BDNI-W	228	-0.84	-32.86***	0.83
BNII-W	552	-1.67	-34.16***	0.68
BNII-W2	294	-0.38	-11.17***	0.30
BNLI-W	326	-0.42	-12.41***	0.32
PNBN-W	607	-0.35	-13.75***	0.24
PNBN-W3	184	-0.46	-15.93***	0.58

*** Significant at the 0.001 level.

It could then be argued that the assumption of constant volatility inherent in BS and DABS models are responsible for the models' deficiency in explaining Indonesian warrants. It could also be argued that pricing models allowing volatility to be inversely related to stock price might promise better pricing performance.

IV.3 Violations of the Lower Bound

To gain perspective on the violations of the arbitrage-free lower bound some alternative explanations are explored.

1. It could be speculated that the violations are related to the liquidity of the warrants. However, given trading activity of all warrants included in the sample, it is safe to assume that the violations are not liquidity driven.
2. It could be speculated that the violations are due to improper estimates on dividend yield and risk-free interest rate, given the relatively large room for subjectivity provided by these parameters and the simplicity of forecasting methods employed in this study. Mathematically, the lower bound is positively correlated with the risk-free interest rate and negatively correlated with the dividend yield, thus the lower bound could be decreased by arbitrarily decreasing the risk-free interest rate, increasing the dividend yield, or both. Nevertheless, the attempts to fit the lower bound to the market prices using this method have resulted in unrealistic values, such as zero or negative risk-free interest rate or extremely large dividend yield.

3. It could be speculated that, as some observations in the sample date back to as early as January 1997, the violations might come from the earlier period when the warrants were relatively new instruments and the market was still in a learning process. However, observations as recent as June 2000 also show such violations.
4. It could be speculated that the extent of the violations is within the trading costs associated with the arbitrage strategy. However, considering the mean stock price of 2057 rupiah and the mean warrant price of 1018 rupiah, as showed by Table 6, and assuming transaction fee to be 0.8%, it could be roughly estimated that costs due to bid-ask spreads and fees are worth around 55 rupiah on average. Mean violation of 195 rupiah is far in excess of this value, hence the violations could not be explained by trading costs.
5. It could be speculated that the existence of the arbitrage profit is due to the fact that the strategy to exploit the violations requires the short selling of the underlying stock, while short selling is restricted in the JSX. On the other hand, even if short selling is not allowed, one can duplicate the cash flows from a short sale by selling stock one already owns, and purchasing it back on a future date.

It could be concluded that the assumption of no arbitrage opportunities inherent in BS and DABS models are responsible for the models' deficiency in explaining Indonesian warrants which violate the lower bound. It could also be argued that other pricing models might not promise better pricing performance, as long as the assumption of no arbitrage is not relaxed.

It might be worth noting that the extent of some violations is such that the warrant price is below intrinsic value. Such violations might explain the early exercises which exist in the sample regardless of the absence of dividend payment, as arbitrageurs could purchase the warrant, exercise it immediately, and sell the shares received, thereby earning a profit without the need of short selling. The strategy might be risky, however, as there are significant administrative delay related to warrant exercise.

Factors suspected to be systematically related to the extent of the violations are then explored. Three suspects are exercisability of the warrant, as non-exercisability of warrants would prevent direct arbitrage as stated above, and time to maturity and moneyness, as these factors are usually suspects for factors affecting the systematic discrepancy in the warrants not violating the lower bound.

Table 10 shows that the extent of the lower bound violation is significantly greater in non-exercisable warrants than in exercisable warrants. At the JSX, for at least 6 months from the listing date, warrants are not exercisable.

Non-exercisable warrants are therefore offering larger arbitrage opportunity.

Table 10. Extent of Violation by Exercisability

<i>Warrant Exercisability</i>	<i>Number of Observations</i>	<i>Mean Percentage Violation</i>
Exercisable	972	22.1%
Non-exercisable	249	41.7%
t-statistic		-9.02**

** Significant at the 0.01 level.

Table 11 shows the percentage of the lower bound violation as regressed to the time of maturity and moneyness of the warrant. It could be argued that violations are greatest for warrants of low moneyness and warrants farther from expiration.

Table 11. Extent of Violation by Time to Maturity and Moneyness

<i>Factor</i>	<i>Slope</i>	<i>t-statistic</i>	<i>Adjusted R Square</i>
Time to maturity	0.11	15.97***	0.17
Moneyness	-0.10	-15.05***	0.16

*** Significant at the 0.001 level.

V. CONCLUSIONS AND RECOMMENDATIONS

V.1 Conclusions and Implications

Dilution adjustment on BS model offers statistically significant improvement. However, the improvement is likely to be practically insignificant, at least for warrants with relatively small dilution factor. The argument of Sidenius (1996) is thus confirmed that if choice should be made between BS and DABS model, BS model would be practically preferable because it is computationally simpler and more efficient. It could also be shown that warrant pricing performance is less sensitive to dilution adjustment than to the selection of proper dividend forecasting techniques and risk-free interest rate proxies. Therefore, time should better be spent in finding better estimation of those parameters than in adjusting for dilution.

The findings also indicate that models that allow an inverse relation between stock price and volatility might promise superior pricing performance.

In addition, it is clear from the practically significant violations of the lower bound that Indonesian warrants welcome risk-free arbitrage opportunities. The opportunities are greatest for warrants of low moneyness and warrants farther from expiration.

Evidence that implied volatility is negatively correlated with moneyness, backed further by the tendency of in-the-money warrants to violate the lower bound, suggest that, actual elasticity of warrant price relative to stock price is smaller than provided by BS or DABS model. Speculators are then likely to find

that calculating effective leverage by using BS or DABS model would result in overestimation, or putting it in other words, Indonesian warrants are less risky than otherwise predicted by BS or DABS models. This implication could be illustrated by BNII-W in Figure 1.

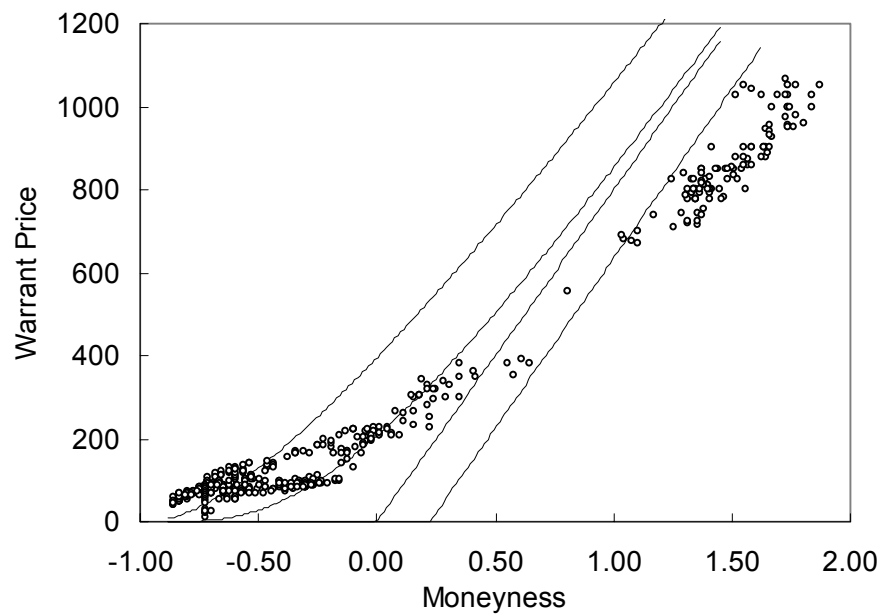


Figure 1. Model and Market Prices of BNII-W

Note: BS model prices are used and smoothed out by taking the average of actual values of model parameters. Curves and lines are corresponding to, from left to right, model price with volatility of 100%, model price with volatility of 50%, the lower bound, and the intrinsic value.

V.2 Recommendations for Further Studies

Basing the hypothesis on the result of this study, research could be done that test whether pricing models allowing volatility to be inversely related to stock price might indeed promise better pricing performance in valuing warrants traded at the JSX (Section II.2.3).

An alternative dilution adjustment is based on other interpretation of Galai and Schneller (1978) work, performed by simply multiplying the option pricing models by $N/(N + M)$, where N is the number of outstanding shares and M is the number of outstanding warrants. Model based on this adjustment is used by Leonard and Solt (1990) and Kremer and Roenfeldt (1992) in their studies.

The adjustment in effect lowers the lower bound otherwise stated by BS and DABS models, making it arguably more appropriate in pricing warrants traded at the JSX. However, this adjustment is theoretically erroneous as claimed by Galai (1989) and later by Crouhy and Galai (1991). The mixed results might be worth some further theoretical explorations, for the model produced by the alternative adjustment is computationally more efficient than DABS.

BIBLIOGRAPHY

- Bakshi, G., Cao, C., & Chen, Z. (1997). Empirical performance of alternative option pricing models. *Journal of Finance*, 52, 2003-2049.
- Beckers, S. (1980). The constant elasticity of variance model and its implications for option pricing. *Journal of Finance*, 35, 661-673.
- Chance, D.M. (1999). Research trends in derivative and risk management since Black-Scholes. *The Journal of Portfolio Management* (May), 35-46.
- Chen, A.H.Y. (1970). A model of warrant pricing in a dynamic market. *Journal of Finance*, 25, 1041-1059.
- Crouhy, M. & Galai, D. (1991). Common errors in the valuation of warrants and options on firms with warrants. *Financial Analysts Journal* (September/October), 89-90.
- Damodaran, A. (1996). *Investment valuation*. New York: John Wiley & Sons, Inc.
- Galai, D. & Schneller, M.I. (1978). Pricing of warrants and the value of the firm. *Journal of Finance*, 33, 1333-1342.
- Galai, D. (1989). A note on "Equilibrium Warrant Pricing Models and Accounting for Executive Stock Options." *Journal of Accounting Research* 27 (2). 313-315.
- Hauser, S. & Lauterbach, B. (1997). The relative performance of five alternative warrant pricing models. *Financial Analysts Journal* (January/February), 55-61.
- Hull, J.C. (1993). *Options, futures, and other derivative securities* (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall, Inc.
- Kremer, J.W. & Roenfeldt, R.L. (1992). Warrant pricing: Jump-Diffusion vs. Black-Scholes. *Journal of Financial and Quantitative Analysis*, 28 (2), 255-272.

- Kwok, K-H. (1994). Empirical investigation on the efficiency of the Hong Kong traded warrants market. Working paper, Sixth Annual PACAP Finance Conference.
- Latané, H.A. & Rendleman, R.J., Jr. (1976). Standard deviations of stock price ratios implied in option prices. *Journal of Finance*, 31, 369-381.
- Lauterbach, B. & Schultz, P. (1990). Pricing warrants: An empirical study of the Black-Scholes model and its alternatives. *Journal of Finance*, 45, 1181-1209.
- Leonard, D.C. & Solt, M.E. (1990). On using the Black-Scholes model to value warrants. *Journal of Financial Research*, 13 (2), 81-92.
- Mayhew, S. (1995). Implied Volatility. *Financial Analysts Journal* (July/August), 8-20.
- Merton, R.C. (1976). The impact on option pricing of specification error in the underlying stock price returns. *Journal of Finance*, 31, 333-350.
- Schmalensee, R. & Trippi, R.R. (1978). Common stock volatility expectations implied by option premia. *Journal of Finance*, 33, 129-147.
- Schulz, G.U. & Trautmann, S. (1994). Robustness of option-like warrant valuation. *Journal of Banking & Finance*, 18, 841-859.
- Shastri, K. & Sirodom, K. (1993). An empirical analysis of alternative valuation models for warrants listed on the Stock Exchange of Thailand. Working paper, University of Pittsburgh.
- Sidenius, J. (1996). Warrant pricing—is dilution a delusion? *Financial Analysts Journal* (September/October), 77-80.
- Whaley, R.E. (1982). Valuation of american call options on dividend-paying stocks. *Journal of Financial Economics*, 10, 29-58.

APPENDIX

Implementation of Models

Following are user-defined functions written in Visual Basic for Application, as the implementation of warrant pricing models used in this study:

```

'**** Warrant formulas ****
'**** Copyright (c) L.E.Santoso 2000. All rights reserved ****

Option Explicit

'**** Function to calculate warrant price using BS model ****
Public Function BS(S As Double, X As Double, T As Double, _
    r As Double, d As Double, sig As Double) As Double

Dim d1 As Double, d2 As Double

d1 = (Log(S / X) + (r - d + sig ^ 2 / 2) * T) / (sig * Sqr(T))
d2 = d1 - sig * Sqr(T)
BS = S * Exp(-d * T) * Application.NormSDist(d1) - _
    X * Exp(-r * T) * Application.NormSDist(d2)

End Function

'**** Function to calculate implied volatility using BS model ****
Public Function BSInv(S As Double, X As Double, T As Double, _
    r As Double, d As Double, W As Double) As Double

Dim sig_low As Double, sig_high As Double, sig As Double
Dim y As Double

Const ACCURACY As Double = 0.000000002
Const HIGH_VALUE As Double = 10#

sig_low = 0.0001
y = BS(S, X, T, r, d, sig_low) - W
If y > 0# Then
    BSInv = -1
    Exit Function
End If

```

```

sig_high = 0.3
y = BS(S, X, T, r, d, sig_high) - W
Do While y < 0#
    sig_low = sig_high
    sig_high = 2# * sig_high
    y = BS(S, X, T, r, d, sig_high) - W
    If sig_high > HIGH_VALUE Then
        BSInv = -2
        Exit Function
    End If
Loop

Do
    sig = (sig_low + sig_high) * 0.5
    y = BS(S, X, T, r, d, sig) - W
    If Abs(y) / W <= ACCURACY Then
        BSInv = sig
        Exit Function
    End If
    If y < 0# Then sig_low = sig Else sig_high = sig
Loop

End Function

Private Function SubDABS(S As Double, X As Double, T As Double, _
    r As Double, d As Double, ns As Double, nw As Double, _
    sig As Double, W As Double) As Double

Dim SArt As Double, d1 As Double, d2 As Double

SArt = S * Exp(-d * T) + W * nw / ns
d1 = (Log(SArt / X) + (r + sig ^ 2 / 2) * T) / (sig * Sqr(T))
d2 = d1 - sig * Sqr(T)
SubDABS = (ns / (ns + nw)) * (SArt * Application.NormSDist(d1) - _
    X * Exp(-r * T) * Application.NormSDist(d2))

End Function

```

```

'**** Function to calculate warrant price using DABS model ****
Public Function DABS(S As Double, X As Double, T As Double, _
    r As Double, d As Double, ns As Double, nw As Double, _
    sig As Double) As Double

```

```

Dim W As Double, W_old As Double, W_temp As Double
Dim y As Double, y_old As Double

```

```

Const ACCURACY As Double = 0.000000001

```

```

W_old = 0
y_old = W_old - SubDABS(S, X, T, r, d, ns, nw, sig, W_old)

```

```

W = 1
y = W - SubDABS(S, X, T, r, d, ns, nw, sig, W)

```

```

While Abs(y) / W >= ACCURACY
    W_temp = W
    W = W - y * (W - W_old) / (y - y_old)
    y_old = y
    y = W - SubDABS(S, X, T, r, d, ns, nw, sig, W)
    W_old = W_temp
Wend

```

```

DABS = W

```

```

End Function

```

```

'**** Function to calculate implied volatility using DABS model
Public Function DABSInv(S As Double, X As Double, T As Double, _
    r As Double, d As Double, ns As Double, nw As Double, _
    W As Double) As Double

```

```

Dim sig As Double, sig_old As Double, sig_temp As Double
Dim y As Double, y_old As Double

```

```

Const ACCURACY As Double = 0.000000001

```

```

sig_old = 0.00001
y_old = SubDABS(S, X, T, r, d, ns, nw, sig_old, W) - W
If y_old > 0# Then

```

```

    DABSInv = -1
    Exit Function
End If

sig = 0.5
y = SubDABS(S, X, T, r, d, ns, nw, sig, W) - W

While Abs(y) / W >= ACCURACY
    sig_temp = sig
    sig = sig - y * (sig - sig_old) / (y - y_old)
    y_old = y
    y = SubDABS(S, X, T, r, d, ns, nw, sig, W) - W
    sig_old = sig_temp
Wend

DABSInv = sig

End Function

'**** Function to calculate the lower bound ****
Public Function LowerBound(S As Double, X As Double, _
    T As Double, r As Double, d As Double) As Double

    Dim temp As Double

    temp = (S * Exp(-d * T) - X * Exp(-r * T))
    If temp < 0 Then LowerBound = 0 Else LowerBound = temp

End Function

'**** Function to calculate moneyness ****
Public Function Moneyness(S As Double, X As Double, T As Double, _
    r As Double, d As Double)

    Moneyness = (S * Exp(-d * T) - X * Exp(-r * T)) / _
        (X * Exp(-r * T))

End Function

```