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**DYNAMIC HYBRID PRICING FORMULATION FOR EQUITY  
WARRANTS**



**MASTER  
UNIVERSITI UTARA MALAYSIA  
2022**



Awang Had Salleh  
Graduate School  
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Universiti Utara Malaysia

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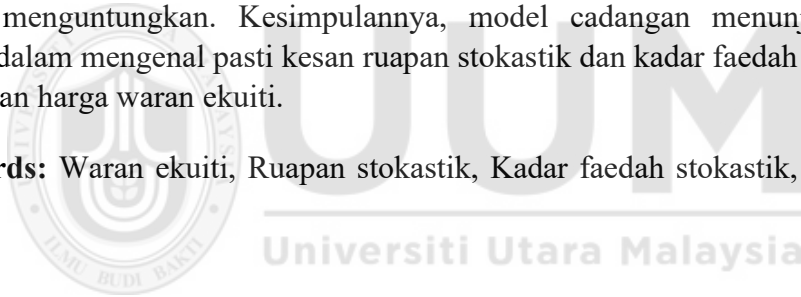
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## Abstrak

Waran ekuiti adalah instrumen yang dikeluarkan oleh syarikat yang memberi pemegang saham keistimewaan untuk membeli saham pada harga pelaksanaan tertentu dalam jangka masa tertentu. Berdasarkan kepada kajian empirikal, model penentuan harga opsyen Black-Scholes tidak sesuai dalam menentukan harga waran kerana kedua-dua andaian ruapan tetap dan kadar faedah tetap dalam model adalah tidak serasi. Kajian ini mencadangkan model hibrid Heston-Cox-Ingersoll-Ross (Heston-CIR) untuk mengenal pasti kesan ruapan stokastik dan kadar faedah stokastik dalam penentuan harga waran ekuiti. Kajian ini membangunkan formula baru bagi penentuan harga analitikal untuk waran ekuiti dengan menggunakan pendekatan transformasi Cauchy dan persamaan pembezaan separa. Kaedah pengoptimuman setempat digunakan untuk mencari anggaran nilai parameter dengan menentukur model Heston-CIR. Keberkesanan model dinilai melalui kajian empirik menggunakan data Bursa Malaysia. Model cadangan menunjukkan penambahbaikan yang bererti pada masa pengiraan anggaran sembilan parameter model, antara 38.12 hingga 62.62 saat berbanding model sedia ada. Selanjutnya, kajian empirikal menunjukkan model cadangan adalah tepat jika dibandingkan dengan pasaran sebenar sepanjang tempoh lima tahun. Model ini menunjukkan ralat penentuan harga terkecil berbanding model sedia ada. Hasil dapatan juga menunjukkan peluang *moneyness* bagi waran ekuiti, 88.75% daripada waran adalah menguntungkan. Kesimpulannya, model cadangan menunjukkan prestasi terbaik dalam mengenal pasti kesan ruapan stokastik dan kadar faedah stokastik dalam penentuan harga waran ekuiti.

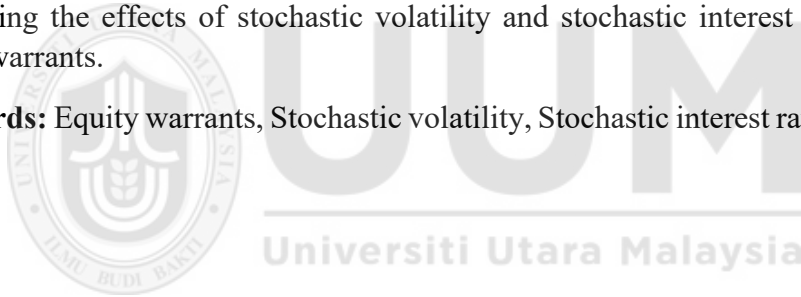
**Keywords:** Waran ekuiti, Ruapan stokastik, Kadar faedah stokastik, Model Heston-CIR.



## Abstract

Equity warrants are instruments issued by a company that give the stockholder the privilege of buying a stock at a certain strike price within a particular timeframe. Motivated by empirical studies, the Black-Scholes option pricing model is not suitable to price a warrant since both assumptions of constant volatility and constant interest rates in the model are incompatible. This study proposed the Heston-Cox-Ingersoll-Ross (Heston-CIR) hybrid model to identify the effects of stochastic volatility and stochastic interest rates in pricing equity warrants. The study constructed new analytical pricing formulas for equity warrants by using Cauchy transformation and partial differential equation approaches. The local optimization method is employed to obtain the estimated parameter values by calibrating the Heston-CIR model. The effectiveness of the proposed model is investigated through the empirical study using the data from Bursa Malaysia. The proposed model shows significant improvement on the computation time in estimating nine model parameters, ranging from 38.12 to 62.62 seconds compared to the existing models. Moreover, the empirical study suggested that the proposed model is accurate when compared to the real market over five years period. This model also produced smallest pricing errors among the existing models. The finding also suggested equity warrants in moneyness opportunity, 88.75% of the warrants are profitable. In conclusion, the proposed model performs the best in identifying the effects of stochastic volatility and stochastic interest rates in pricing equity warrants.

**Keywords:** Equity warrants, Stochastic volatility, Stochastic interest rates, Heston-CIR model.



## Acknowledgment

*In the name of Allah, the Most Gracious and the Most Merciful.*

All praises to Allah SWT and His blessing for the completion of this thesis. I am grateful to Allah SWT for all the opportunities, trials and strength that have been showered on me to finish writing the thesis. During these phases, I learned so much, not only from the academic aspect but also from the aspect of personality. I would like to express my humblest gratitude to the holy Prophet Muhammad (Peace be upon him) whose way of life has been a continuous guidance for me.

First and foremost, I would like to express my gratitude to my supervisor, Dr Teh Raihana Nazirah bt Roslan, my lecturer, Dr Sharmila bt Karim and my co-supervisor, Dr Ali Fareed Jameel, who has given me a lot of advice and extensive guidance in writing this thesis. Their expertise and research experience have been a source of inspiration for me throughout the writing of this master's thesis and confirmed my desire to dive further into academic research.

I also dedicate these acknowledgements to Mrs. Zakiah bt Hashim and Dr Azizah bt Mohd Rohni for their motivation, immense knowledge and keep supporting me spiritually throughout this master's journey. They have all provided a huge amount of their precious time and effort for me.

Last but not least, I am truly grateful to my beloved family members and colleagues who have always inspired me to work on this thesis throughout the entire period. I would also like to thank them for their endless support, understanding and love.

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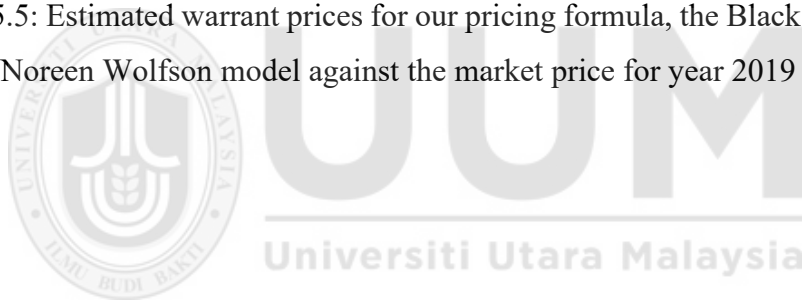
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## List of Abbreviations

<b>ATM</b>	At-the-money
<b>CEV</b>	Constant Elasticity Variance
<b>CDF</b>	Cumulative distribution function
<b>CIR</b>	Cox-Ingersoll-Ross
<b>ESO</b>	Executive stock options
<b>FBM</b>	Fractional Brownian motion
<b>GARCH</b>	Generalized AutoRegressive Conditional Heteroskedasticity
<b>GBM</b>	Geometric Brownian motion
<b>HJM</b>	Heath-Jarrow-Morton
<b>HW</b>	Hull-White
<b>ITM</b>	In-the-money
<b>KLSE</b>	Kuala Lumpur Stock Exchange
<b>LIBOR</b>	London Interbank Offered Rates
<b>LSM</b>	Least square method
<b>MAE</b>	Mean absolute error
<b>MAPE</b>	Mean absolute percentage error
<b>MSE</b>	Mean square error
<b>OTM</b>	Out-of-the-money
<b>PDE</b>	Partial differential equation
<b>RMSE</b>	Root mean square error
<b>RVMSE</b>	Relative value of the mean squared error
<b>SABR</b>	Stochastic Alpha Beta Rho
<b>SDE</b>	Stochastic differential equation

## List of Symbols

$\mu$	Stock price return
$\sigma$	Stock price volatility
$w(t)$	Brownian motion or Wiener process
$S(t)$	Stock price of an asset at time $t$
$G$	Exercise price or strike price
$\phi(\cdot)$	Standard normal cumulative distribution function
$C(S(t), t)$	Call option value
$W_{BS}$	Warrant value for the Black-Scholes model
$W_{NW}$	Warrant value for the Noreen Wolfson model
$T - t$	Time to expiration
$\sigma_S$	Standard deviation of the log returns
$r(t)$	Instantaneous interest rate
$\vartheta$	Elasticity of variance
$v(t)$	Stochastic volatility parameter
$\kappa$	Mean reversion speed for instantaneous variance
$\theta$	Long-term mean for instantaneous variance
$\sigma$	Volatility of the $v(t)$
$\rho$	Correlation coefficient between stock price and volatility
$F$	Forward price of an asset
$\alpha$	Mean reversion speed for instantaneous rate
$\beta$	Long-term mean for instantaneous rate
$\eta$	Volatility of the interest rate
$P(r, t, T)$	Zero-coupon bond price at time $t$ with maturity $T$
$c(t)$	Time-dependent of drift term
$df(t, T)$	Instantaneous forward interest rate of zero-coupon bond at time $T$
$L_j(t)$	Forward rate at time $[T_j, T_{j+1}]$
$w(t)^d$	Brownian motion with $d$ -dimension
$\Omega$	Sample space
$\omega$	All possible outcomes
$\mathcal{F}$	Event space
$\mathbb{P}$	Probability measure



$\gamma$	Random variable
$X(t)$	Stochastic process
$g(y)$	<i>Borel</i> -measurable function
$N$	Number of shares
$M$	Number of warrants outstanding
$k$	Share per warrant
$+$	Warrant's role as a call or put option
$n$	Set of warrants
$W_i$	Market price
$W_i^\Omega$	Model price
$v(0)$	Initial volatility
$r(0)$	Initial interest rate
$F(t)$	Future price



# CHAPTER ONE

## INTRODUCTION

This chapter aims to provide a comprehensive overview and pertinent information linking to this research. Section 1.1 and Section 1.2 are devoted to the background of the study and information about warrants in Malaysia. Section 1.3 stipulates the stochastic elements with focus on the stochastic volatility and stochastic interest rates, followed by Section 1.4 which discusses the problem statement. Section 1.5 and Section 1.6 present the research questions and research objectives, respectively. Next is Section 1.7 which highlights the limitation of the study, whereas Section 1.8 underlines the significance of the research. Finally, Section 1.9 provides the outline of the thesis.

### 1.1 Background of the Study

A derivative is a financial instrument that procures value from an underlying asset. This underlying asset might be any currency, equity, interest rate or commodity. Moreover, derivatives play an essential role in the financial system and are also found important in risk management. In Malaysia, several risk management products are options or embedded options, for example, equity warrants and call warrants (Qizam, Irdiansyah, & Haron, 2015). In agreement with Gunawan, Ibrahim and Rahim (2017), warrants have been considered as a leveraging instrument for investment that have the potential to generate greater capital gains.

Being a derivative, warrant is a type of contract that confers upon the contract holder the right, but without necessity to purchase or sell the underlying asset at a predetermined price until the fixed expiration date. Here, the predetermined price is also known as the exercise price, which is fixed. Furthermore, the expiration date refers to the date when the privilege to purchase or sell warrants become obsolete. There are

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