UNIVERSITI PUTRA MALAYSIA

GENERALISED AUTOREGRESSIVE CONDITIONAL HETEROSCEDASTICITY (GARCH) MODELS FOR STOCK MARKET VOLATILITY

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By

CHOO WEI CHONG

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To Sensei, my most dedicated parents,

my beloved wife , my supportive brothers and sisters

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LIST OF ABBREVIATIONS

ABC	Approximate Bootstrap Confidence Interval
AIC	Akaike's Information Criterion
ARCH	Autoregressive Conditional Heteroscedasticity
ARMA	Autoregressive Moving Average
BCA	Bias-Corrected and Accelerated
BSKL	Bursa Saham Kuala Lumpur
EG(1,1)	Exponential GARCH(1,1)
EGARCH	Exponential GARCH
EGARCH-M	Exponential GARCH-M
EWMA	Exponentially Weighted Moving Average
G(1,1)-M	GARCH(1,1) in Mean or GARCH(1,1)-M
GARCH	Generalised Autoregressive Conditional Heteroscedasticity
IG(1,1)	Integrated GARCH(1,1)
KLSE	Kuala Lumpur Stock Exchange
LM	Lagrange Multiplier
Log L	Log Likelihood
ML	Maximim Likelihood
MLE	Maximum Likelihood Estimation
MSE	Mean of Square Error
NG(1,1)	Non-negative GARCH(1,1)
OLS	Ordinary Least Square
Q	Portmanteau Test

QGARCH	Quadratic GARCH
RW	Random Walk
SBC	Schwarz's Bayesian Information Criterion
SG(1,1)	Stationary GARCH(1,1)
TAHB	Teritlak Autoregresi Heteroskedasticiti Bersyarat
UG(1,1)	Unconstrained GARCH(1,1)

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science.

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April 1998

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The performance of generalised autoregressive conditional heteroscedasticity (GARCH) model and its modifications in forecasting stock market volatility are evaluated using the rate of returns from the daily stock market indices of Kuala Lumpur Stock Exchange (KLSE). These indices include Composite Index, Tins Index, Plantations Index, Properties Index and Finance Index. The models are stationary GARCH, unconstrained GARCH, non-negative GARCH, GARCH in mean (GARCH-M), exponential GARCH (EGARCH) and integrated GARCH.

The parameters of these models and variance processes are estimated jointly using maximum likelihood method. The performance of the within-sample estimation is assessed using several goodness-of-fit statistics and the accuracy of the out-of-sample forecasts is judged using mean squared error.

The results of the study indicate that the EGARCH performs better than the other models in describing the observed skewness in stock market indices and in

out-of-sample (one-step-ahead) forecasting. The integrated GARCH, on the other hand, is the poorest model in both aspects.

This thesis also presents a new application of parametric bootstrap method to examine the characteristics of the unknown underlying populations of the parameter estimates of the EGARCH model.

Through a simulation study, artificial time series corresponding to EGARCH(1,1) model, covering the extreme points of the parameter space of each one of them were generated. The standard error for each bootstrap parameter estimate is compared to the standard error of maximum likelihood estimates.

The standard normal intervals using maximum likelihood estimates (symmetric ML), standard normal intervals using bootstrap estimates (symmetric bootstrap) and the parametric bootstrap percentile methods are considered for the confidence intervals of the parameter estimates.

The unknown distributions of the parameter estimates are found to be skewed and leptokurtic. The parametric bootstrap standard errors are reasonably close to that of the maximum likelihood standard errors. Moreover, the length of the parametric bootstrap percentile intervals are also quite near to the length of the maximum likelihood intervals. Hence, the parametric bootstrap method can be recommended as one of the reliable alternatives to estimate the parameters, to obtain the standard errors and to construct the confidence intervals of the parameter estimates. This method should be adopted if the distributions of the parameter estimates are unknown or non-normal.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains.

MODEL-MODEL TERITLAK AUTOREGRESI HETEROSKEDASTISITI BERSYARAT BAGI KETIDAKTENTUAN PASARAN SAHAM

oleh

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Prestasi bagi Model Teritlak Autoregresi Heteroskedastisiti Bersyarat (TAHB) dan pengubahsuaiannya dalam meramal ketidaktentuan pasaran saham dinilaikan dengan menggunakan kadar pulangan daripada indeks harian pasaran saham di Bursa Saham Kuala Lumpur (BSKL). Indeks tersebut adalah Indeks Komposit, Indeks Perlombongan, Indeks Perladangan, Indeks Hartanah dan Indeks Kewangan manakala modelnya adalah TAHB pegun, TAHB tak berkekangan, TAHB tak negatif, TAHB dalam min, TAHB eksponen dan TAHB terkamir.

Parameter bagi model dan proses variansnya dianggarkan serentak dengan menggunakan kaedah kebolehjadian maksimum. Prestasi penganggaran dalam sampel dinilai dengan beberapa statistik kebagusan penyuaian dan ketepatan ramalan di luar sampel pula ditentukan dengan menggunakan min ralat kuasa dua.

Keputusan kajian menunjukkan bahawa TAHB eksponen memberikan prestasi yang lebih baik berbanding dengan model yang lain dalam memerihalkan kepencongan indeks pasaran saham dan dalam ramalan di luar sampel (satu-langkah-

kehadapan). Sebaliknya, TAHB terkamir merupakan model yang paling buruk dalam kedua-dua aspek.

Tesis ini juga membentangkan satu penggunaan baru mengenai kaedah butstrap berparameter untuk memeriksa ciri-ciri taburan anu bagi anggaran parameter model TAHB eksponen.

Berdasarkan kajian simulasi dengan siri masa tiruan secocok dengan model TAHB(1,1) eksponen yang meliputi titik ekstrim bagi ruang setiap parameter telah dijanakan. Ralat piawai bagi setiap anggaran parameter butstrap berparameter dibandingkan dengan ralat piawai bagi anggaran parameter kebolejadian maksimum.

Selang keyakinan normal piawai dengan menggunakan anggaran parameter kebolehjadian maksimum (ML simetrik), selang keyakinan normal piawai dengan menggunakan anggaran parameter butstrap berparameter (butstrap simetrik) dan selang keyakinan menggunakan kaedah persentil butstrap berparameter juga dipertimbangkan dalam pembinaan selang keyakinan bagi anggaran parameter.

Taburan anu bagi anggaran parameter didapati pencong dan leptokurtosis. Ralat piawai butstrap berparameter adalah hampir secara munasabah dengan ralat piawai kebolehjadian maksimum. Tambahan pula, panjang selang keyakinan persentil butstrap berparameter juga hampir kepada panjang selang keyakinan kebolehjadian maksimum. Maka, kaedah butstrap berparameter boleh diperakui sebagai salah satu pendekatan pilihan yang boleh dipercayai untuk menganggar parameter, mendapatkan ralat piawai dan membina selang keyakinan bagi anggaran parameter. Kaedah ini patut digunakan sekiranya taburan bagi anggaran parameter adalah anu atau tak-normal.

CHAPTER I

INTRODUCTION

The so-called random walk hypothesis of stock price movements generated an enormous amount of controversy in financial literature during the 1960s (Fielitz, 1974). For many years the following question has been the source of continuing controversy in both academic and business circles: To what extent can past history of a common stock's price be used to make meaningful predictions concerning the future price of the stock? (Fama, 1965) Answers to this question have been provided on one hand by the various chartist theories and on the other hand by the theory of random walks.

Although there are many different chartist theories, they all make the same basic assumption. That is, they all assume that the past behaviour of a security's price is rich in information concerning its future behaviour. Just like the saying "history repeats itself" in that the patterns of past price behaviour will tend to recur in the future. Thus, if through careful analysis of price charts one develops an understanding of these patterns, this can be used to predict the future behaviour of prices and in this way increase expected gains.

By contrast the theory of random walks says that the future path of the price level of a security is no more predictable than the path of a series of cumulated random numbers. In statistical terms the theory says that successive price changes are independent, identically distributed random variables. Most simply this implies that the series of price changes has no memory, that is, the past cannot be used to predict the future in any meaningful way.

Since the seminal works of Mandelbrot (1963) and Fama (1965), evidence indicates that the empirical distribution of the financial time series of daily stock returns is significantly different from the normal (Gaussian) distribution. The empirical distribution is leptokurtic and skewed. Furthermore, the variance of the financial time series is significantly changing over time. This is the biggest problem for the conventional constant variance time series and econometric models.

Besides the distribution of the stock market returns, the distribution of a parameter estimate can be skewed and leptokurtic too. The underlying population of any parameter estimates of a model is always unknown and the assumption of normality is usually enforced on it.

The main purposes of this study will be to discuss in more detail the models of changing variance (heteroscedasticity) over time and to find an alternative approach which does not rely on the normality assumption in order to estimate the parameters of the models, to evaluate the standard error and to construct the confidence interval of the parameter estimates.

The Random Walk

The random walk hypothesis is a statement that price changes are in some way random and so prices wander ('walk') in an entirely unpredictable way. Consequently, forecasts based on today's price cannot be improved by using the information in previous prices.

The earliest studies of the random walk hypothesis include important investigations by Working (1934), Kendall (1953) and Fama (1965). In every case the best forecast of tomorrow's price requires today's price but not previous prices. Fama's paper rightly had a significant impact on academic research.

Bachelier (1900) in a most remarkable thesis implied that price changes have independent and identical normal distributions. The first complete development of theory of a random walk in stock prices by him is in 1964. Bachelier maintained that speculative prices behaved largely as if they were generated by a random process. Then it is assumed that successive price changes are independent, Gaussian or normally distributed random variables with zero mean and variance proportional to the differencing interval.

Fama (1965) removed the assumption of normal distributions in his hypothesis. The theory of random walk in stock prices actually involves two separate hypothesis: (i) the successive price changes are independent, (ii) the price changes conform to some identical probability distribution.

Granger and Morgensten (1970) do not require the price changes to be identically distributed. The random walk hypothesis is defined by : (i) constant expected price changes, (ii) zero correlation between the price changes for any pair of different days. According to Berkman (1978), a random walk model is based on two assumptions: (i) the expectations are rational, (ii) the stock market is efficient.

The hypothesis concerning the distribution says that the price changes conform to some probability distribution. From the point of view of the investor, the form of the distribution is a major factor in determining the riskiness of investment in common stocks. The form of the distribution is also important in (i) providing descriptive information concerning the nature of the process generating prices changes, (ii) helping a researcher to use a more appropriate statistical methodology for the purpose of making inferences about weak form efficiency in the capital markets.

The Efficient Market Hypothesis

When prices follow a random walk the only relevant information in the series of present and past prices, for traders, is the most recent price. Thus the people involved in the market have already made perfect use of the information in past prices. Suppose that prices are available very frequently. Then if only the latest price is relevant it follows that prices very quickly reflect the information in the historical record of prices. A market will be called perfectly efficient if the prices fully reflect available information, so that prices adjust fully and instantaneously when new information becomes available (Fama, 1976)

A market for some asset will be called efficient if the results obtained by using certain information to trade are not better than the results obtained by using the information to help decide the optimal quantity (if any) of the asset in a static portfolio (Jensen, 1978). If the market is efficient with respect to this information we say that the efficient market hypothesis is true, otherwise the hypothesis is false.

Fama (1970), in his discussion of the information concerning stock prices, divided the information into three subsets : (1) weak form, in which the information set is just historical prices; (2) semi-strong form, in which the information set is historical prices plus other information that is publicly available (e.g., announcements of annual earnings, stock splits, etc.); and (3) strong form, in which the concern is for the investor or groups (e.g., management of mutual funds) who have monopolistic access to any information relevant to the formation of stock prices.

Fielitz (1974), however, took a slightly different approach. He divided the random walk model into three different but closely related theories of the behaviour of stock market prices : (1) the random walk model narrowly defined, which is similar to the weak form; (2) the random walk model broadly defined, which is similar to the semi-strong form; and (3) the efficient markets model, which is similar to the strong form.

Most researchers followed the approach after Fama published his work in 1970. In this study, we investigate neither the random walk nor the efficient market hypothesis.

The Behaviour of The Stock Market Data

Most of the current studies use data from the US stock market. A few exceptions are given by Attanasio's (1988) study on the UK stock market, Kearns and Pagan's(1993) study on Australian data, Hamao, Masulis and Ng's (1990) study on volatility spillovers among three international stock markets, de Jong, Kemna and Kloek's (1992) study on the Dutch stock market, Tse (1991) study on the Japanese stock market, Tse and Tung (1992) study on Singapore stock market, Brailsford and Faff (1993) study on the Australian stock market.

As suggested by Bollerslev *et al.* (1992), it would also be interesting to use different data sets to further assess the degree of persistence in stock return volatility. Hence, we use the data obtained from the Kuala Lumpur Stock Exchange in this study. Because the volatility models used in this study require specific assumptions regarding the distribution of the stock returns data, the statistical features of Malaysia stock market data will be further discussed in Chapter II.

The Changing Variances over Time

After the seminal works of Mandelbrot (1963) and Fama (1965), many researchers found that the variance of the stock market data is not constant over time. Since most of the conventional time series and econometric models work only if the variance is constant, the changing variances will cause the models to be inaccurate. Until lately, the financial and econometric researchers have started modelling time variation in second or higher-order moments. Engle (1982) has characterised the changing variances using the Autoregressive Conditional

Heteroscedasticity (ARCH) model and Bollerslev (1986) introduced the alternative and more flexible lag structure known as Generalised ARCH (GARCH) model.

Since then, many researchers have applied these model, its extensions and modifications to the financial time series data. These models will be further discussed in Chapter III.

The Bootstrap

Efron (1979) proposed a new general statistical procedure known as 'bootstrap', a computer-intensive method used when finite-sample theory is impossible or difficult to derive, or when only asymptotic theory is available. This technique has been successfully used in various applied statistical problems, but only a few applications have been reported in the area of financial time series. A new application of parametric bootstrap simulation study to exponential GARCH model is further discussed in Chapter IV.

Objectives of The Study

The main objectives of this study are:

i) To compare the performance of the six variations of GARCH models in modelling the volatility of the stock market indices of Kuala Lumpur Stock Exchange.

ii) To investigate the bootstrap estimates and compare them with the maximum likelihood estimates.

The other objectives are as follow:

iii) To verify whether the hypotheses of constant variance model can be rejected.

iv) To investigate the restriction on the parameters of the GARCH models.

v) To find some evidence of applying the long memory GARCH model instead of the short memory and high-order ARCH model using the Q statistics and Lagrange multiplier test.

vi) To evaluate the performance of the GARCH models in within sample estimation using various goodness-of-fit statistics

vii) To further investigate the performance of GARCH models in one-step-ahead forecasting using the random walk model as the important naive benchmark.

viii) To examine the unknown distributions of the parameter estimates of EGARCH model.

ix) To use the parametric bootstrap method on the EGARCH estimates to obtain the standard errors and bootstrap confidence intervals.

Planning of Dissertation

This dissertation is organised as follows: Chapter I reviews the history and progress of the studies done by the researchers throughout the world about the controversy caused by the random walk hypothesis of stock price movements in financial literature. It also includes a brief introduction to the random walk hypothesis and efficient market hypothesis, the emerge of the Autoregressive Conditional Heteroscedasticity (ARCH) model and its extensions and modifications to characterise the changing variances in financial time series. There is also a discussion on the bootstrap technique introduced by Efron (1979).

Chapter II present a closer look at the statistical features of stock market data obtained from the Kuala Lumpur Stock Exchange. Daily price series and daily rate of returns are discussed and illustrated by using graphs. Some important definitions such as standard deviation, variance, skewness, kurtosis, distribution, autocorrelation and heteroscedasticity are also included in this chapter.

Chapter III begins with an introduction of the GARCH model. This is followed by an evaluation of the performance of six variations of GARCH models in within sample estimation and one-step-ahead forecasting of the Malaysia stock market volatility. The comparisons of the various models were based on some goodness of fit statistics.

The parameter estimates of the best model among those considered are then being investigated further in Chapter IV via bootstrap method. In this chapter, the computation and the construction of the confidence interval for the parameter estimates of the EGARCH model using the parametric bootstrap approach are also presented.

Finally, Chapter V states the main conclusions of the study and several recommendations are also presented for future research.