Long-range Dependence and Non-linear Behaviours: A Case Study of the Malaysian Stock Market

Chin Wen Cheong1 & Abu Hassan Shaari Mohd Nor2, Zaidi Isa3
1Faculty of Information Technology, Multimedia University 63100 Cyberjaya, Selangor, Malaysia
2Faculty of Economic and Business, National University Malaysia, 43600 Bangi, Selangor, Malaysia
3Faculty of Science and Technology, School of Mathematical Sciences, National University Malaysia, 43600 Bangi, Selangor, Malaysia.

Abstract
This paper investigates the emerging market efficiency by using the Malaysian Stock Exchange daily data over a period of Jan-1991 to Apr 2005. The models of daily index returns are adjusted for infrequent trading and non-linearity behaviours. The leverage effect and clustering volatility of the conditional variance model is fitted by the EGARCH model. In addition, we employ the variance time plot and R/S approaches to test the fractal scaling behaviour of the volatility. Due to the evidences of predictable components in the returns series, we claimed that the Malaysian Stock Exchange is weak-form inefficient.

Keywords: random walk hypothesis, market efficiency, long-range dependence.

JEL classification: G12; G15; C14

1. Introduction
The presence of random walk process has an important impact to investors, trading strategies, portfolio managers, asset pricing models and weak-form market efficiency in financial market development. In Fama(1965, 1970) seminal paper, he summarized the concept of Efficient Market Hypothesis(EMH) into three relevant information subsets which are weak, semi-strong and strong-form efficiency. The strong-form efficiency implies semi strong-form efficiency and in turn implies weak-form efficiency. However the reverse is not true. Campbell, Lo and MacKinlay(1997), further this study by distinguishing the random walk model into three less restrictive sub-hypotheses. The random walk 1(RW1) is the most restrictive model which requires independent and identically distributed of the price changes.
In random walk 2 (RW2), the restriction of identically distributed condition is not imposed. Finally, by relaxing the independence restriction of RW2, the RW3 model is obtained.

Extension studies of new definition of market efficiency have been proposed such as fractal market hypothesis by Peter (1994), heterogeneous market hypothesis by Mullier et al (1993) and mixture of distribution hypothesis by Andersen et al (1997). The traditional definition of market efficiency assumes that the market is composed of homogeneous participants who response according to the rational expectation strategy regardless of the amount of available information. This assumption seems to be not reasonable in the real financial market. No all market participants are provided with equivalent information. According to Shiller (2000) most participants in stock market are not ‘expert investor’ but rather followers of market trend and fashions. Michel, et al (2001) suggests that the market is composed of heterogeneous agents. He also proposed that in the quantitative measure of market efficiency the extreme price changes within short time intervals should be considered. In Mandelbrot (1997), he suggests that the weak form market efficiency is rejected if the stock returns present long-range dependence behaviour. As a conclusion, the above studies suggest that the presence of long-range dependence behaviour in the equity markets and this fractal scaling behaviour is important in measuring the volatility, market efficiency and market risk.

In the early studies of KLSE efficiency, Barnes (1986) examined the monthly price data of 30 companies and 6 sector indices for the six years ended 30th June 1980 and find the results are statistically serially correlated and support the KLSE is weak form efficient. The studies of Othman (1989, 1990) on the randomly selected 30 KLSE industrial indexes and 170 stocks traded on all sectors of the KLSE, support the KLSE is weak form inefficient. Nassir and Mohamad (1993) study the 1975 to 1989 market reaction of earning and dividend announcements and conclude that new information is almost fully reflected in price by the
end of the announcement month. In Annuar et al(1994) study, they find out about 87% of the 82 stocks possess unit root and suggest that the market is inefficient over the fifteen-year period. These studies concentrate on the linear statistical test by using unit root test, serial correlation and multiple variance ratio test across the selected periods.

Under the regulation of International Finance Corporation(IFC) and the World Bank, Malaysia is categorized as a developing country and emerging market. As an emerging market, the nature of the Malaysian stock market is characterized by low liquidity, infrequent trading, low quality of information and rapid changes in regulatory framework. Furthermore, the market participants are irrational with loss aversion, over self-confidence in own forecasts and do not always respond instantaneously to information. The failure to account for all these conditions may lead to spurious statistical conclusion on market efficiency.

The aim of this paper is to study the market efficiency through the stock returns and volatility in Malaysia’s Kuala Lumpur Stock Exchange(KLSE). This study includes the infrequent trading, non-linearity and asymmetry properties in the model specifications. In addition, the long-range dependence behaviour of the stock market is studied and the results allow us to rank the sub-periods by relative inefficiency. The interesting case study of an emerging market using KLSE may imply significant contributions to the theoretical modelling and predictability of financial time series. This motivates us to look into the issue of testing the weak-form efficiency in Malaysian stock market.

2. Methodology

2.1 Infrequent trading and non-linearity in Returns

Emerging markets are often relate to the infrequently traded shares activities. This phenomena occurs when stocks market do not trade at every consecutive interval. The impact of infrequent trading issues in Antoniou et al.(1997) and Miller et al.(1994) studies,
introduce serial correlation in the time series of returns. To overcome this drawback, we adopt the method proposed by Miller et al (1994). Miller suggests a moving average that reflects the number of non-trading days should be estimated and later adjusts the returns recursively. Due to the difficulties in identifying the infrequent trading period, the moving average can be estimated by an autoregressive model. However, this infrequent trading adjustment is an approximate correction which does not fully capture the complex infrequent trading impact. The procedures of adjusted returns are stated as follows:

**Estimated Model:** 
\[ r_t = a_0 + a_1 r_{t-1} + \epsilon_t \]  
\[ (2.1) \]

**Adjusted return:** 
\[ r_{t(adj)} = \frac{\epsilon_t}{(1 - a_{t})} \]  
\[ (2.2) \]

where the \( i \) represents the selected period \((i=1,2,3,4)\). The model assumes that the non-trading adjustment required to adjusted returns is constant throughout the periods in most of the high traded markets. In this study, the emerging market’s required adjustments are varied in the four sub-periods with recursive estimation of Eq.(2.1).

Beside the thin trading, non-linearity is also often observed in the emerging markets worldwide such as evidences show in Antoniou et al. (1997), Crato and De Lima(1994) and Karemera et al. (1999) studies. The non-linearity may be caused by the self-regulatory market, transactions costs, risk lover and irrational market participants. The non-linearity is captured by a logistic map where a series evolves according to the function:

\[ r_t = ar_{t-1}(1 - r_{t-1}) = a r_{t-1} - a r^2_{t-1} \]  
\[ (2.3) \]

The function maps the return’s value at time \( t-1 \) into its value of time \( t \). The negative non-linear feedback term features the self-regulatory markets. If the deviations of prices/returns are not proportional to the initial value, then the feedback mechanism exhibits the non-linear self-regulation. The causes of this mechanism are discussed in DeBondt and Thaler(1985), Costa et al. (1994).
The aim of the adjusted return and logistic map approach are to ascertain the presence of non-linearity under the correction of infrequent trading. The non-linear and adjusted returns are estimated by using Eq.(2.1), Eq.(2.2) and Eq.(2.3):

\[ r_{t(adj)} = a_0 + a_1 r_{t-1(adj)} + a_2 r^2_{t-1(adj)} + a_3 r^3_{t-1(adj)} + \varepsilon_t \] (2.4)

The model follows the efficient market hypothesis if all the coefficients are equal to zero and the \( \varepsilon_t \) is a white noise process.

### 2.2 Volatility and Risk Premium Analysis

The financial asset returns often exhibit time-varying heteroskedasticity, volatility clustering, asymmetry effects and non-normality. In order to account for all these conditions, an EGARCH introduced by Nelson(1991), is fitted to the conditional variance equation. The EGARCH model is selected due to the robustness of parameter’s determination (less restriction compare to GARCH model) and its capability to model the positive and negative shocks in the conditional variance equation. Merton(1980) and French et al.(1987) suggest that the non-linearity may cause by the time-variation in the market risk premium. To validate this, the non-linearity of the returns series is examined by including the time variation of market risk premium in the EGARCH-mean model. The risk premium of the market can be estimated by using the GARCH-mean model. The EGARCH-mean model is stated as follow:

\[ r_{t(adj)} = a_0 + a_1 r_{t-1(adj)} + a_2 r^2_{t-1(adj)} + a_3 r^3_{t-1(adj)} + a_4 \sigma_t^2 + \varepsilon_t \] (2.5)

\[ \log \sigma_t^2 = \alpha_0 + \alpha_1 \log \sigma_{t-1}^2 + \alpha_2 \frac{\varepsilon_{t-1}}{\sigma_{t-1}} + \alpha_3 \left| \frac{\varepsilon_{t-1}}{\sigma_{t-1}} \right| \] (2.6)

where \( \sigma_t^2 \) is the conditional variance, \( a_4 \) is the relative risk aversion coefficient and \( a_4 \sigma_t^2 \) is the time-varying risk premium of a representative investor. The absence of time-varying risk
premium should result statistically significant for $a_2$ and $a_3$ coefficients which indicate the non-linearity.

2.3 Long-range Dependence Behaviour Analysis

The presence of long-range dependence in asset returns suggests the violation of the market efficiency hypothesis because the future returns are predictable by using the past information of returns. Some literatures by Barkoulas et al. (1996), Cajueiro and Tabak (2004, 2005) have focused on testing the emerging market efficiency by using long-range dependence analysis. The long-range dependence phenomena indicates that the market participants may vary in their endowments, availability of information, prior belief, investment regulation and constraints, reaction times to new information and risk profile. The different reaction times of market participants contribute different type of volatility. These volatilities are categorised by short-term investment activities with high trading frequency (intraday), medium-term with daily or weekly trading activities and finally long-term with monthly or even yearly trading activities. The combination of all the different time horizons volatility creates a long-range dependence volatility. In short, the market participants are composed by heterogeneous agents instead of homogeneous agents.

The long-range dependence behaviour is measures by the value of global Hurst parameter($H$) proposed by Hurst (1951). $H$ is evaluated from the stock markets absolute/squared returns by variance-time plot and R/S analysis. The absolute/squared returns as the proxies of volatility exhibit positive long-range dependence when $H$ is in between $\frac{1}{2}$ and 1. Some common estimators such as absolute value method, variance time plot, $R/S$ method, periodogram, Whittle’s estimator are discussed in Mandelbrot (1997) and Beran (1994). In this paper, we implement two approaches namely the ordinary approach where the Hurst’s parameter is determined over the entire periods and the dynamic approach
with an average ‘moving’ Hurst’s parameter over a fixed interval. The dynamic approach is similar to the ‘rolling sample’ approach discussed in Cajueiro and Tabak (2004, 2005).

2.3.1 Variance-time Plot

For stationary time series \( r \), the \( m \)-aggregated time series \( r(n) = \{ r_k^{(n)}, \ k=0,1,2,3,\ldots \} \) is obtained by summing the original time series over a non-overlapping, adjacent blocks of size \( m \). The expression is

\[
r_k^{(n)} = \frac{1}{n} \sum_{i=k(n-1)}^{k(n)} r_i
\]

For the aggregated time series \( r(n) \) of a self-similar process, the variance obeys the following large sample property:

\[
V[r^{(n)}] \sim \frac{V[r]}{n^\beta}, \text{ where the self-similarity parameter } H = 1 - (\beta/2). \tag{2.8}
\]

By taking the logarithm on both sides, this can be written as

\[
\log(V[r^{(n)}]) \sim \log(V[r]) - \beta \log(n) \tag{2.9}
\]

Since \( \log(V[r]) \) is a constant independent of \( n \), therefore the plot \( \log(V[r^{(n)}]) \) versus \( n \) on a log-log graph should be a straight line with a slope of \(-\beta\). Slope values between -1 and 0 suggest self-similarity and conclude that the existence of long memory effect in that series.

2.3.2 R/S plot

Given a stochastic process \( r_t \) at discrete time instances \( \{ r_t, t = 0, 1, 2, \ldots \} \), the rescaled range of \( r_t \) over a time interval \( M \) as defined by Hurst, the ratio of \( R/S \) as:

\[
\frac{R}{S} = \frac{\max_{1 \leq j \leq N} \left[ \sum_{k=1}^{N} (r_k - M(L)) \right] - \min_{1 \leq j \leq N} \left[ \sum_{k=1}^{N} (r_k - M(L)) \right]}{\sqrt{1/N} \sum_{t=1}^{N} (r_t - M(L))^2} \tag{2.10}
\]

where \( M(L) \) is the sample mean over the time period \( L \). Mandelbrot[9] showed that the \( R/S \) statistic converges to a random variable at rate \( L^H \) when the long-range dependence exist. In
the self-similar process, the ratio exceed 0.5 with the following characteristic: \( R/S \sim (L/2)^H \), where \( H > 0.5 \).

3. Empirical Studies of Malaysian Stock Market

The stock market price is taken from the daily closing price of Kuala Lumpur stock exchange (KLSE) through the Bank Negara Malaysia. The selection guidelines of Kuala Lumpur composite index (KLCI) component can be found in the official website of Bursa Malaysia. The continuously compounded daily return at time \( t \) is defined as:

\[
\text{return}_t = \log(\text{index}_t) - \log(\text{index}_{t-1})
\]  

(3.1)

In this paper, the sample period starts from 1\(^{\text{st}}\) January 1991 to 14\(^{\text{th}}\) April 2005 with 3516 observations. The long-spanning data set consists of 14 years enable us to run various tests with reliable statistical results. This is suggested by Taylor (1986) that large sample size of stock prices series may improve the error variance and increase the power of random walk tests.

The KLSE trades five days a week, start from Monday through Friday.

![Price index](image)

**FIG. 1. KUALA LUMPUR COMPOSITE INDEX**

In *Fig. 1*, the movement of the index prices are illustrated over approximately 14 years. The minimum index is 262.7 points on 1\(^{\text{st}}\) Sep 1998 and maximum at 1314.46 points on 5\(^{\text{th}}\) Jan 1994. The market prices index increase from approximate 500 points on year 1991 to 1300 points on year 1994. After that, the prices index fluctuating around 900 to 1300 points until December 1996. It then slid massively to around 300 points over two years period due...
to drastic depreciation of Malaysian Ringgit (RM) and consequently, investors continuing fled from the Malaysian market. The currency crisis has a deep impact on RM where the first half of 1997, the RM was maintained at a stable exchange rate of approximate RM2.50 to one US dollar and depreciated to the weakest rate recorded against USD as RM4.88 on 9th January, 1988. The RM traded in the range of RM3.50 to RM4.50 for the first half of 1998. Due to the weak performance of RM and high interest rate, Malaysian government had implemented the one USD pegged to RM3.80 in 1st September 1998 and it is non-convertible outside the country. Besides, the fixed currency control also requires the foreign investors to retain their principle capital in Malaysia for at least one year and the capital gain is repatriated. This implementation has stabilized the RM and protected it from currency speculation. After the USD pegged, prices index have shown positive increment and reached 1000 points in year 2000. However, the currency control policy has caused the direct foreign investors fled from the Malaysian market. Despite of this, the RM pegged has successfully boosted the growth in exports due to the low exchange rate. This leads to the recovery of price index in Malaysia stock market over two years period (November 2000) and fluctuating around 700 points until year 2005. The selected annual statistics of the values, volumes and market capitalization are illustrated in Table 1.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>index</td>
<td>505.92</td>
<td>1237.96</td>
<td>594.44</td>
<td>586.13</td>
<td>812.33</td>
<td>679.64</td>
<td>907.43</td>
</tr>
<tr>
<td>Listed company</td>
<td>285</td>
<td>621</td>
<td>708</td>
<td>736</td>
<td>757</td>
<td>795</td>
<td>963</td>
</tr>
<tr>
<td>Trading value (RM million)</td>
<td>29521</td>
<td>463264</td>
<td>408558</td>
<td>115180</td>
<td>185249</td>
<td>244054</td>
<td>215622</td>
</tr>
<tr>
<td>Trading unit (Million Unit)</td>
<td>13137</td>
<td>66461</td>
<td>72799</td>
<td>58287</td>
<td>85156</td>
<td>75408</td>
<td>107610</td>
</tr>
<tr>
<td>Market Capitalization (RM Billion)</td>
<td>131.66</td>
<td>806.77</td>
<td>375.80</td>
<td>374.52</td>
<td>552.69</td>
<td>444.35</td>
<td>722.04</td>
</tr>
</tbody>
</table>

In the early 90’s, Malaysian government is in its ongoing effort to enhance the transparency in the stock market. The quality of information is improved by the introduction of information and communication technology (ICT) application in exchange’s trading system such as semi-automated SCORE in 1989 and fully automated WinSCORE in 1995. In addition, the clearing service for stockbroking are provided by Securities Clearing Automated
Network Services Sdn. Bhd. (SCANS) and a Fixed Delivery and Settlement System (FDSS) is established in 1990. In October 1999, KLSE introduced the Listing Information Network (LINK), as an internet-based facility. These efforts have improved the availability and reliability of information in the stock market.

In order to observe and analyse the behaviour of the stock market, we split the overall sample data into four distinct periods for prices index as follows:

   i) pre-crisis (1-1-1991 until 31-12-1996 consists of 1485 data points)
   ii) during crisis (1-1-1997 until 31-8-1998 consists of 409 data points)
   iii) USD pegged to RM (1-9-1998 until 31-12-2000 consists of 590 data points)
   iv) post-crisis (1-1-2000 until 14-4-2005 consists of 1031 data points)

4. Empirical Results

<table>
<thead>
<tr>
<th>TABLE 2. DESCRIPTIVE STATISTICS OF STOCK RETURNS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-sample period</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Std. Dev.</td>
</tr>
<tr>
<td>Skewness</td>
</tr>
<tr>
<td>Jarque-Bera</td>
</tr>
<tr>
<td>p-value</td>
</tr>
</tbody>
</table>

A glance at the statistical behaviours of the five different time periods is illustrated in Table 2. The descriptive statistics measure the moments, skewness, kurtosis and normality of returns series. The returns series show highest standard deviation and volatile in the crisis period (from 1997 to 1998). The huge magnitude of Jarque-Bera statistics in all periods, enable us to reject the returns series are normally distributed by referring to the $p$-values. The returns exhibit the fat tailed phenomenon and the kurtosis is more than 3 for all the periods.

4.1 Thin trading and Non-linearity Results

<table>
<thead>
<tr>
<th>TABLE 3. RANDOM WALK MODEL WITHOUT ADJUSTED RETURN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period</td>
</tr>
<tr>
<td>Overall</td>
</tr>
<tr>
<td>Pre-crisis</td>
</tr>
<tr>
<td>Crisis</td>
</tr>
<tr>
<td>USD pegged</td>
</tr>
<tr>
<td>Post-crisis</td>
</tr>
</tbody>
</table>

Model: $r_t = a_0 + a_1 r_{t-1} + \varepsilon_t$. Figures in parentheses are $p$-values. $a$ and $c$ denote 10%, 5% and 1% level of significance. $Q(m)$: Ljung-Box $Q$-statistics for serial correlation with lag-$m$; White’s statistics: unconditional heteroscedasticity test.
Table 3 shows the results of random walk test without adjusted returns by excluding the non-linear components for all the periods. The coefficients \(a_1\), are statistically significant at 1% level for overall, pre-crisis, crisis and post-crisis periods while 10% level for the USD pegged period. This infers that the returns series contain predictability components and inefficient. However, the diagnostics tests for error terms show an unconditional heteroscedastic effect and no serial correlation across all the periods. This leads to the rejection of white noise process for error term.

In Table 4, an inclusion of non-linear terms for return’s lagged one indicate the linear and non-linear coefficients, \(a_1\), \(a_2\) and \(a_3\) are alternately statistically significant. The negative non-linear coefficients imply that the markets are self-regulatory. This explained the market participants are overreact to bad news and underreact to good news as discussed by DeBondt and Thaler(1985). The error terms remain with unconditional heteroscedastic effect. In order to determine the findings of non-linearities are not due to the volatility effects, an EGARCH model is fitted to all the predefined periods. The EGARCH models show that the non-linear
terms remain statistically significant for pre-crisis, USD pegged periods. This implies that the non-linearities are not caused by the clustering volatility in the two periods. However, contrasted results are indicated in crisis and post-crisis periods with the linear coefficients, \( a_1 \), stayed statistically significant. Due to the possibility of predictions for linear and non-linear components in the returns series, we again, suggest the returns series are predictable and inefficient for all the periods.

The results for linear and non-linear random walk tests with adjusted returns are illustrated in Table 5 and Table 6. After the correction of thin trading effect, the adjustment appears to have eliminated the apparent serial correlation of the linear model across all the periods as shows in Table 6. The coefficient, \( a_1 \), is insignificantly different from zero at the 1% level for all the periods. Across all the periods, only the residuals during the crisis period indicate a white noise process. On the other periods, the diagnostic tests show mixture of autocorrelation and unconditional heteroscedasticity effect. This leads to the conclusion of random walk process during the crisis period and acceptance of less stringent random walk process (RW2) with the relaxation of i.i.d conditions in others periods.

**TABLE 5. RANDOM WALK MODEL WITH ADJUSTED RETURN**

<table>
<thead>
<tr>
<th>Period</th>
<th>( \alpha_0 )</th>
<th>( \alpha_1 )</th>
<th>( \alpha_3 )</th>
<th>Q(12)</th>
<th>White’s statistics</th>
<th>ARCH LM test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>1.51x10^{-7}</td>
<td>-0.0019(0.9087)</td>
<td>48.564 (0.000)</td>
<td>914(0.000)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-crisis</td>
<td>4.11x10^{-7}</td>
<td>0.0035(0.8924)</td>
<td>11.503 (0.486)</td>
<td>137.91 (0.0000)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crisis</td>
<td>-1.09x10^{-7}</td>
<td>0.0036(0.9432)</td>
<td>9.2567 (0.681)</td>
<td>1.00 (0.6040)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USD pegged</td>
<td>-0.0001 (0.8903)</td>
<td>0.0041(0.9209)</td>
<td>19.412 (0.079)</td>
<td>350.66 (0.0000)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-crisis</td>
<td>2.02x10^{-7}</td>
<td>0.0007(0.9811)</td>
<td>13.347 (0.0.344)</td>
<td>9.12 (0.0105)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Model: \( r_{t(adj)} = \alpha_0 + \alpha_1 r_{t(adj)} + \epsilon \). Figures in parentheses are p-values. \( a, b \) and \( c \) denote 10%, 5% and 1% level of significance. Q(m): Ljung-Box Q-statistics for serial correlation with lag of m periods. White’s statistics: unconditional heteroscedasticity test.

**TABLE 6. NON-LINEAR RANDOM WALK MODEL WITH ADJUSTED RETURN**

<table>
<thead>
<tr>
<th>Period</th>
<th>( \alpha_0 )</th>
<th>( \alpha_1 )</th>
<th>( \alpha_3 )</th>
<th>Q(12)</th>
<th>White’s statistics</th>
<th>ARCH LM test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>2.60x10^{-5}</td>
<td>-0.1522</td>
<td>-11.0328</td>
<td>35363</td>
<td>592(0.000)</td>
<td>605 (0.000)</td>
</tr>
<tr>
<td>Pre-crisis</td>
<td>7.19x10^{-6}</td>
<td>0.0659</td>
<td>-29.3119</td>
<td>14.674</td>
<td>154(0.000)</td>
<td>225 (0.000)</td>
</tr>
<tr>
<td>Crisis</td>
<td>0.0001</td>
<td>0.0458</td>
<td>-2.7469</td>
<td>8.6063</td>
<td>4.460(0.4852)</td>
<td>13.4053 (0.3403)</td>
</tr>
<tr>
<td>USD pegged</td>
<td>-0.0001 (0.8793)</td>
<td>0.2539</td>
<td>-17.0433</td>
<td>19.602</td>
<td>486(0.000)</td>
<td>32.643 (0.0011)</td>
</tr>
<tr>
<td>Post-crisis</td>
<td>3.53x10^{-6}</td>
<td>-0.2229</td>
<td>18.6217</td>
<td>14.103</td>
<td>33.1431 (0.000)</td>
<td>121.55 (0.000)</td>
</tr>
</tbody>
</table>

Model: \( r_{t(adj)} = \alpha_0 + \alpha_1 r_{t(adj)} + \alpha_3 r_{t(adj)}^3 + \epsilon \). Figures in parentheses are p-values. \( a, b \) and \( c \) denote 10%, 5% and 1% level of significance. Q(m): Ljung-Box Q-statistics for serial correlation with lag of m periods. White’s statistics: unconditional heteroscedasticity test; Lagrange Multiplier ARCH test; conditional heteroscedasticity test.
In Table 6, the introduction of non-linear models show contrast conclusions with both the coefficients \(a_2\) and \(a_3\) are statistically significant with no serial correlation for the pre-crisis and USD pegged periods. This suggests that a non-linear process underlies the returns series. However, similar results exhibit for crisis and post-crisis periods where both the linear and non-linear coefficients show insignificant different from zero and implies no predictability. The diagnostic tests show that the error term is a white noise process in the crisis period with insignificant serial correlation, conditional and unconditional heteroscedastic effect. This implies that during the crisis period, the market is unpredictable and efficient. On the other hand, the rest of the periods exhibit mixtures of conditional and unconditional heteroscedasticity in the error terms. This leads to the acceptance of a less stringent random walk hypothesis (RW3)[3] and implies predictability and inefficiency in the returns series. Further validation of non-linearity is examines through the volatility analysis in the following session.

### 4.2 Volatility and Risk Premium

<table>
<thead>
<tr>
<th>Period</th>
<th>(a_0)</th>
<th>(a_1)</th>
<th>(a_2)</th>
<th>(a_3)</th>
<th>(a_4)</th>
<th>(Q(12))</th>
<th>ARCH test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>0.0002</td>
<td>0.1198</td>
<td>-9.2219</td>
<td>0.1673</td>
<td>0.9837</td>
<td>-0.0479</td>
<td>15.837</td>
</tr>
<tr>
<td></td>
<td>(0.4121)</td>
<td>(0.0000)</td>
<td>(0.0000)</td>
<td>(0.8931)</td>
<td>(0.0000)</td>
<td>(0.0000)</td>
<td>(0.1990)</td>
</tr>
<tr>
<td>Pre-crisis</td>
<td>-6.2x10^(-6)</td>
<td>0.0898</td>
<td>-44.8132</td>
<td>0.4016</td>
<td>0.9670</td>
<td>-0.0124</td>
<td>6.5928</td>
</tr>
<tr>
<td></td>
<td>(0.8864)</td>
<td>(0.0021)</td>
<td>(0.0021)</td>
<td>(0.8891)</td>
<td>(0.0000)</td>
<td>(0.0001)</td>
<td>(0.8830)</td>
</tr>
<tr>
<td>Crisis</td>
<td>-0.0001</td>
<td>0.0876</td>
<td>2.0993</td>
<td>0.9890</td>
<td>-0.2142</td>
<td>4.8431</td>
<td>12.4041</td>
</tr>
<tr>
<td></td>
<td>(0.8793)</td>
<td>(0.1630)</td>
<td>(0.0000)</td>
<td>(0.0000)</td>
<td>(0.0000)</td>
<td>(0.0000)</td>
<td>(0.9630)</td>
</tr>
<tr>
<td>USD pegged</td>
<td>-0.0001</td>
<td>0.2755</td>
<td>-16.6779</td>
<td>2.8439</td>
<td>0.8501</td>
<td>5.3896</td>
<td>3.5715</td>
</tr>
<tr>
<td></td>
<td>(0.3711)</td>
<td>(0.0000)</td>
<td>(0.0021)</td>
<td>(0.5477)</td>
<td>(0.0000)</td>
<td>(0.7212)</td>
<td>(0.9440)</td>
</tr>
<tr>
<td>Post-crisis</td>
<td>-0.0014</td>
<td>-0.0518</td>
<td>56.3818</td>
<td>14.2349</td>
<td>0.7973</td>
<td>-0.0243</td>
<td>6.568</td>
</tr>
<tr>
<td></td>
<td>(0.0341)</td>
<td>(0.2079)</td>
<td>(0.3968)</td>
<td>(0.2890)</td>
<td>(0.0000)</td>
<td>(0.2782)</td>
<td>(0.1670)</td>
</tr>
</tbody>
</table>

Table 7: EGARCH-M Non-linear Random Walk Model with Adjusted Return

Model: \( r_{t(adj)} = \alpha_0 + a_1 r_{t-1(adj)} + a_3 r_{t-1(adj)} + a_4 s_{t}^2 + \varepsilon_t \), \( \log \sigma^2_t = \alpha_0 + \alpha_1 \log \sigma^2_{t-1} + \alpha_2 \frac{\varepsilon_{t-1}^2}{\sigma^2_{t-1}} + \alpha_3 \frac{\varepsilon_{t-1}}{\sigma^2_{t-1}} \)

Figures in parentheses are p-values. a,b and c denote 10%, 5% and 1% level of significance.

\( Q(m) \): Ljung-Box Q-statistics for serial correlation with lag of m periods; Lagrange Multiplier ARCH test: conditional heteroscedasticity test

The ARCH effect tests indicate the presence of conditional heteroscedasticity except during the crisis period. This means that the non-linearity may be caused by the time-variation in the market risk premium. To validate the presence of risk premium, an EGARCH-mean is fitted in the respective return series. In Table 7, the estimated \(a_4\) indicates positive values but is insignificant from zero for all the periods and imply that the Malaysian markets do not
provide returns that compensate market participants for time-varying risk premium. On the other hand, the linear and non-linear coefficients in returns equation are significantly different from zero during the pre-crisis and USD pegged periods. This implies that the non-linear returns series are predictable and are free from the risk-return relationship. However, in crisis and post-crisis periods, both the linear and non-linear coefficients are not significantly different from zero and indicate no predictability in the returns equations. The statistically significant in past conditional variance coefficients \( \alpha_1 \), indicate the possibility of predicting the volatility terms using the past information. The negative and significantly different from zero of asymmetry coefficients \( \alpha_2 \), in pre-crisis and crisis periods suggest that the negative shocks have a greater influence of future volatility compare to the positive shocks. The diagnostic test for the specifications in GARCH models indicate no serial correlation in the mean equations and ARCH effect in the variance equations. Due to the mixtures components of predictability in returns series and conditional variance equations, we conclude that the Malaysian stock market is not efficient.

4.3 Long-range Dependence Behaviour

We are interested to study the long-range dependence properties of the selected sub-periods. The various sub-periods analysis enable us to examine the scaling properties of selected periods such as before and after the currency control. The fractal behaviour is examined using different time-scale for example hourly, daily, weekly or monthly. The sample autocorrelation function(SACF) is plotted as the preliminary analysis. The Hurst’s parameters for the different sub-sample periods are determined by using variance-time plot and R/S analysis. Several studies of financial time series reported that the absolute returns exhibit long-range dependence behaviours. Due to this, we concentrate our analysis in the absolute returns series only.
The SACF of the absolute returns,\(|r_t|\) for all the sub-sample periods exhibit hyperbolic decay with significant spikes up to more than 500 lags. This is a preliminary test to detect the presence of long-range dependence. In Figure 2, we only illustrate the absolute-value returns SACF.

![FIG. 2. SACF OF ABSOLUTE-VALUED RETURNS(LAGGED 500) OF OVERALL PERIOD](image)

The long range dependence behaviour is analyzed in two manners, firstly the intraday or high frequency data(Jan 2004 to July 2004) and interday or daily data(Jan 1991 to April 2005). Due to the limitation of data availability, the only possible intraday(minutely data within a day) we managed to get is from Jan 2004 until July 2004. For this particular period we are able to accumulate large numbers of data sets(46000 points) which enable us to extend the plotting of double-logarithmic scale until 10 compare to 8 for the largest interday data sets(3600 points). The results are shown in the Fig. 3. as a nice fitted straight line on a double-logarithmic scale over a wide range of frequencies from hourly to monthly intervals. The global Hurst’s parameter is determined by calculating the slope of the regression analysis with the estimation of 0.804 with correlation coefficient 97%. This implied that the absolute returns indicate self-similar fractal behaviour in the high frequency data analysis.

![FIG. 3. VARIANCE-TIME PLOT OF ABSOLUTE RETURNS](image)
TABLE 8. THE HURST’S EXPONENTS IN SUB-SAMPLE PERIODS

<table>
<thead>
<tr>
<th></th>
<th>Static approach</th>
<th>Dynamic approach</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall</td>
<td>Pre-crisis</td>
</tr>
<tr>
<td>(a) Variance – Time plot</td>
<td>0.711</td>
<td>0.772</td>
</tr>
<tr>
<td>(b) R/S analysis</td>
<td>0.712</td>
<td>0.687</td>
</tr>
<tr>
<td>average</td>
<td>0.712</td>
<td>0.730</td>
</tr>
</tbody>
</table>

Similarly, we compute absolute returns series of all the periods for daily (interday) and find out that the long-range dependence are fall within the range of 0.683 to 0.754 for static approach and around 0.600 for dynamic approach. For the dynamic approach, the plot for Hurst parameter and the overall results are illustrated in Table 8. All the Hurst’s parameters are larger than 0.5 indicating that the absolute returns series exhibit positive long-range dependence or persistence. The average Hurst’s parameter is selected as the indicator of market efficiency ranking. In Table 9, a mean equality test is implemented to ensure the significant of the ranking. The results show that the highest inefficiency is during the crisis period, follows by USD pegged period and pre-crisis period. The post-crisis period indicates the lowest inefficient. With the evidence of long-range dependence property, we reject the random walk hypothesis Malaysian stock market.

<table>
<thead>
<tr>
<th>TABLE 9. RANKING OF HURST’S PARAMETER AND MEAN EQUALITY TEST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period</td>
</tr>
<tr>
<td>Pre-crisis</td>
</tr>
<tr>
<td>Crisis</td>
</tr>
<tr>
<td>USD pegged</td>
</tr>
<tr>
<td>Post-crisis</td>
</tr>
</tbody>
</table>

Mean Equality test, df, Test statistic  
Anova F-statistic (3, 160) 268.0487(0.0000*)  
* denotes 1% level of significance.

4.4 Implications

The study of non-linearity, thin trading, volatility and long-range dependence returns series results the mixtures conclusions of Malaysian stock market efficiency. In year 1989, the government is in the initial stage of ICT application incorporates with the securities trading. Exchange’s trading system such as semi-automated SCORE and fully automated WinSCORE are introduced in year 1989 and 1995 respectively. The clarity and transparency of securities
are still in the stage of improvement. In the pre-crisis period (begin with year 1991), the Malaysian stock markets are characterized by infrequent trading, low liquidity and insufficient reliable as well as availability of information. Under these conditions, market participants most probably react irrationally due to the lack of information, delay respond by consideration of transaction cost and existence of risk lover investors. These conditions may lead to the contradiction of Peters (1994), where the rationality of investors imply that they are risk averse, unbiased in their forecasts and instantaneous responses to new information. The statistical test results the non-linear dependence in return series. This trading behaviour may suggest that the prices responding to the information in a non-linear manner. Furthermore, the significant EGARCH estimation and the presence of long-range dependence behaviour of returns suggest that the future returns are predictable by using the past information of returns. This imply that the pre-crisis period return series exhibits non-linearity, clustering volatility and long-range dependence behaviour. Thus, this suggests predictability and inefficiency.

During the crisis period (begin at early year 1997), the sharp drop and precipitous decline occurs in the stock prices and causes a speculative euphoria. This speculation period induce the market participants become more cautious and react rationally with respect to as much reliable information as possible. This leads to the hypothesis of randomness if all the market participants are homogenous and react based on the rational expectation model[7]. Due to the rationality, precautions and instantaneous responses to information of market participants, the statistical analysis implies no non-linearity in the returns series. However, the presence of volatility and long-range dependence again imply the predictable components in the returns series.

On the other hand, the Malaysian government employs the fixed USD currency in September 1998 to stabilize the RM and protected it from currency speculation. However, the currency
control policy requires the foreign investors to retain their principle capital in Malaysia for at least one year and the capital gain is repatriated. This restriction has caused the direct foreign investors fled from the Malaysian market. During the USD pegged period, the markets participants are cautious and do not always respond instantaneously to the information which subject to their beliefs to the information reliability. Especially foreign investors may delay their responses to see how local and informed market participants react due to the unavailability of reliable information. Again, this violates the investors’ rationality and leads to the non-linearity behaviour in the statistical specification of the return’s model. In addition, the presence of volatility and long-range dependence imply the market is predictable and inefficient.

In the recovery period, the Malaysian government has improved the market infrastructure in terms of cost effectiveness, competitiveness, corporate transparency and regulation of investor protection. In October 1999, KLSE introduced the Listing Information Network (LINK), as an internet-based facility which providing comprehensive, accurate and timely information of public listed companies’ announcements, thus enhancing corporate disclosure for market participants. During the post-crisis period and recovering period, the markets provide better quality information with perhaps better informed market participants. The rationality of investors is improved by the regulatory changes and sufficient information disclosure by listed issuers. This is supports by the statistical test which indicates insignificant non-linearity in the returns series. On the other hand, the presence of volatility and long-range dependence imply the market is predictable and inefficient.

5. Conclusion

In this paper, we investigate the weak-form efficiency of KLSE by using the return and volatility analysis. This study includes the non-linear, infrequent trading, clustering volatility and long-range dependence phenomena in the Malaysian stock exchange. The market
efficiency is analysed on the piecewise before, during and after the economic crisis so that it is possible to observe the evolution of the market, including changes in the KLSE regulatory framework, trading transparency and how investors evaluate the new information. Across the long spanning periods, the non-linearity presence in the pre and USD pegged periods with no risk premium relationship. This finding provides a deepen understanding of risk-return relationship in the portfolio analysis where with the absence of time-varying risk premium, the market is likely to be less volatile. The fitted EGARCH models show that the conditional heteroscedasticity coefficients across the periods are statistically significant. This leads to the acceptance of the less stringent random walk (RW3). However, the dependent of the squared increments provide predictability components and imply that in all periods the market is inefficient.

In addition, we construct a ranking of market inefficiency by using the long-range dependence parameter. The presence of long-range dependence behaviour indicates that the different reaction time horizons (short term, medium term and long term) in the market participants contribute to different type of volatility. The combination of all the different time horizons volatility creates a long-range dependence of volatility relationship. In short, the market participants are composed of heterogeneous agents. Therefore, the higher the Hurst’s parameter, the more inefficient is the stock market. Due to the evidences of predictable components in the returns series, we claimed that the Malaysian Stock Exchange is weak-form inefficient.

REFERENCES


