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Abstract
In this paper, a modified variance aggregated-time approach is used to examine the long-range dependence behaviour of the Malaysian stock exchange. We studied the 20 years daily data during the pre- and post-economic crises encountered in the Malaysian stock exchange. The empirical study indicated spurious long-range dependence by ignoring the economic shocks and short-range dependence in all the indices. It is also found that the modified approach estimation is robust under the presence of short-range dependence.

JEL: C01, C13, C22, G12.

Keywords: long-range dependence, variance aggregated-time plot, financial time series, self-similar process.

1.0 Introduction

Long-range dependence (LRD) financial time series (Mandelbrot,1997) has received great interests from academicians and researchers particularly in financial risks management as well as new finding (Muller et al., 1997) in efficiency market hypothesis. The LRD can be observed through the autocorrelation function of a self-similar process. Supposed that Y_t is a self-similar process with parameter H, the time series will pose the following property (Vervaat,1987):

$$Y_t \approx t^H Y_1 \qquad (1)$$

for $t>0$. Considered $\gamma(Y_k, Y_h) = \gamma(k,h)$, where $h<k$, with $E(Y_t)=0$ and $\sigma^2 = E[(Y_t - Y_{t-1})^2] = E[X_t^2]$ where σ^2 is the variance of the increment process, $Z_t = Y_t - Y_{t-1}$. For stationary self-similar process, the autocorrelation is

$$\gamma(k,h) = 0.5\sigma^2[k^{2H} - (k-h)^{2H} + h^{2H}] \qquad (2)$$

For the increments sequence, $Z_t = Y_t - Y_{t-1} (t = 1, \ldots)$, where the covariance between Z_t and Z_{t+i} is defined as

$$\begin{aligned}\gamma(i) &= \mathrm{cov}(Z_t, Z_{i+t}) \\ &= 0.5\left(E[(Y_{i+1} - Y_0)^2] + E[(Y_{i-1} - Y_0)^2] - E[(Y_i - Y_0)^2] - E[(Y_i - Y_0)^2]\right) \qquad (3)\end{aligned}$$

Followed **Eq.2** and divided by the variance, the autocorrelation function (ACF) become:

$$\rho(i) = 0.5[(i+1)^{2H} - 2i^{2H} + (i-1)^{2H}] \qquad (4)$$

for $i \geq 0$ and when $i<0$, $\gamma(i) = \gamma(-i)$ and $\rho(i) = \rho(-i)$. The asymptotic behaviour of $\rho(i)$ can be expressed as

$$\rho(i) = 0.5 i^{2H} f(i^{-1}) \qquad (5)$$

where in general, $f(n) = (1+n)^{2H} - 2 + (1-n)^{2H}$ and when $f(n)$ followed a Maclaurin series (expanded at the origin):

$$f(n) = f(0) + f'(0)n + \frac{f''(0)}{2!}n^2 + ... = 2H(2H-1)n^2 + ... \quad (6)$$

For $0 < H < 1$ and H ≠ ½,

$$\lim_{i \to \infty} \rho(i) = 2H(2H-1)i^{2H-2}. \quad (7)$$

For ½ < H < 1, the process is LRD and the effect is stronger for H closed to 1.

2.0 Data source

Five indices have been selected from year 1987 to year 2007 from the *Datastream*. In order to investigate the LRD behaviour of pre- and post- sudden economic changes of the Malaysian stock exchange, we implemented the Andrews (1993) test to identify the unknown structural change points for the five indices. To avoid the distribution degeneration of the statistic, it is customary trimmed out the 7.5% for the first and last of the overall observations in **Table 1.** In this study, only the square-return is chosen based on the asymmetry power FIGARCH (Tse,1998) model where the estimated power parameters[1] indicated the volatilities are preferable in term of conditional variance than standard deviation.

3.0 Modified variance aggregated-time plot

There are ample methodologies (Beran,1994) in determining the LRD of time series. We have selected the heuristic variance aggregated-time plot (or variance plot) due to its simplicity in terms of computational and derivation. However, variance plot is suffered from less robustness to the short-range dependence where most of the emerging financial markets (Miller et al.,1994) are observed to be serially correlated at the first lag. Thus, we modified the variance definition with the inclusion of weighted autocovariances to overcome this drawback.

Considered a stationary time series with T observations,$\{\boldsymbol{y}_t, t=1,2,\ldots\}$, the 2^n-aggregated time series $\{ y_{t_n}^{(2^n)}, t_n = 1,\ldots,T/2^n$ for even observations; $n=0,1,\ldots\}$ is obtained by summing the original time series over non-overlapping, adjacent blocks of size 2^n . The general sub-time series $y_{t_n}^{(2^n)}$ can be stated as

$$y_{t_n}^{(2^n)} = \sum_{k=t_n 2^n-(2^n-1)}^{t_n 2^n} \frac{y_k}{2^n}. \quad (8)$$

If the variance decayed slowly as 2^n become sufficient large, then a self-similar process is observed. For asymptotically self-similar process, the variance of the time average decayed as

[1] The power coefficients are ranged from 1.79 to 2.12 and the details of the overall results are provided upon request.

$$V\left(y_t^{(2^n)}\right) \sim \frac{V(y_t)}{\left(2^n\right)^{2H-2}} \qquad (9)$$

which is consistent with the derivation in **Eq. 7**. From the central limit theorem for stationary and ergodic process, $\boldsymbol{x_t}$, the mean is

$$\bar{x} \overset{asymptotically}{\sim} N\left(\mu, \frac{1}{N}\sum_{j=-\infty}^{\infty}\gamma_j\right). \qquad (10)$$

Due to the nature of serial correlation in time series, the asymptotic variance is more appropriate to define under the Newey and West (1987) weighted autocovariance as followed:

$$\hat{V}_{NW}\left(y_i^{(2^n)}\right) = \hat{\gamma}_0 + 2\sum_{h=1}^{q}\left(1-\frac{h}{q+1}\right)\hat{\gamma}_h\,, \qquad q<i, \qquad (11)$$

where $\left(1-\frac{h}{q+1}\right)$ is the Bartlett weight and q is equivalent to the integer $[4(T/100)^{2/9}]$. By taking the logarithm on both sides, we implemented the ordinary least squares (OLS) estimation in a simple regression analysis:

$$\log\left(V(y_t^{(2^n)})\right) \sim \log(V(y_t)) + (2H-2)\log\left(2^n\right) \qquad (12)$$

The slope values between −1 and 0 suggested self-similarity and concluded that the existence of long memory effect in that series.

4.0 Empirical results

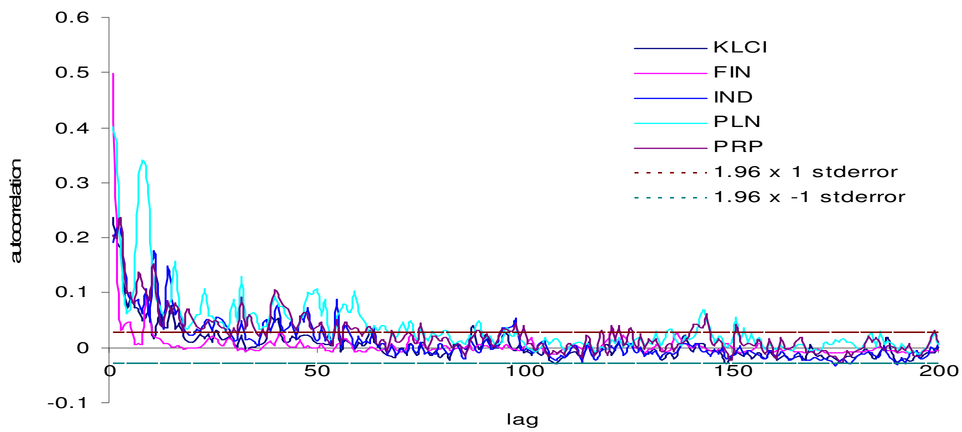
4.1 Preliminary analysis

Table 1: Break-point using Andrews test

INDEX	Date (Observation)	Economic events	Max LR F-stat
KLCI	28-Aug-1998 (2671)	Currency control and Asian financial crisis	249.48*
FIN	04-Sep-1998 (2675)	Currency control and Asian financial crisis	86.95*
IND	09-Sep-1998 (2678)	Currency control and Asian financial crisis	243.99*
PLN	17-Jan-1994 (1532)	Economic boom	109.96*
PRP	25-Aug-1998 (2668)	Currency control and Asian financial crisis	134.69*

Notes:
H_0: no breakpoint within the trimmed observations;
Asymptotic distributions p-values are based on Hansen (1995);
* denoted 5% level of significance.

Table 1 reported the structural changes in volatility for all the indices. Each of the indices indicated structural change mostly around 1st September 1998 where the Malaysian government implemented the currency control to lessen the depreciation of Ringgit Malaysia (RM). Exceptionally, the PLN indicated the break-point during the period of economic boom in year 1994. The two regimes are labelled as pre- and post-period for the sudden economic changes in the following discussions.



In **Figure 2**, the LRD is observed in all the five volatility proxies, where the sample autocorrelation function indicated significant spikes (5% significant level) even after a few hundreds lags.

Table 2. First autocorrelation for post-period sub-series

Sub-series**	KLCI	FIN	IND	PLN	PRP
1	0.676*	0.537*	0.239*	0.385*	0.651*
2	0.396*	0.131*	0.288*	0.489*	0.435*
4	0.446*	0.099*	0.466*	0.395*	0.428*
8	0.047*	0.067*	0.504*	0.413*	0.454*
16	0.038	0.124*	0.617*	0.241*	0.113*
32	0.072*	0.186*	0.714*	0.296*	0.206*
64	0.093*	0.251*	0.667*	0.212*	0.342*
128	0.088*	0.197*	0.568*	0.093*	0.308*
256	0.121*	0.156*	0.427*	0.259*	0.162*
512	0.023	0.050*	0.059*	0.268*	0.002
average	0.2000	0.1798	**0.4549**	0.3051	0.3101

Notes:

* indicated the value exceeded $(1.96 \pm 1/\sqrt{T})$;

** the values indicated the number of observation(s) in a block.

In **Table 2**, for the various sub-series $y_{t_n}^{(2^n)}$, the first autocorrelations are all significant at 5% level. Therefore, the short-range dependence should take into account in the variances determinations.

4.2 Modified variance plot results

Table 3: Modified variance plot results

period		Variance-time plot				
		KLCI	FIN	IND	PLN	PRP
overall :	a_0	5.4661* (0.0783)	5.9299* (0.0537)	5.0807* (0.0730)	4.8169* (0.0885)	5.3715* (0.0338)
	a_1	-0.5920* (0.0211)	-0.6182* (0.0145)	-0.6038* (0.0197)	-0.6004* (0.0239)	-0.5609* (0.0091)
	R^2	0.9898	0.9956	0.9915	0.9874	0.9978

H	***0.7040***	***0.6909***	***0.6981***	***0.6998***	***0.7154***
Pre-crisis: a_0	4.7183* (0.1280)	6.0657* (0.1239)	3.9759* (0.1562)	3.1987* (0.1430)	5.0270* (0.2065)
a_1	-0.5897* (0.0346)	-0.6628* (0.0334)	-0.6360* (0.0422)	-0.8298* (0.0433)	-0.6087* (0.0558)
R^2	0.9731	0.9799	0.9659	0.9812	0.9369
H	***0.7051***	***0.6686***	***0.6820***	***0.5851***	***0.6956***
Post-crisis: a_0	6.1426 * (0.1316)	5.4979* (0.1229)	1.7932* (0.1807)	4.7369* (0.0576)	5.5747* (0.1134)
a_1	-0.6481* (0.0355)	-0.6159* (0.0332)	-0.3040* (0.0488)	-0.5612* (0.0155)	-0.4962* (0.0306)
R^2	0.9764	0.9772	0.8288	0.9938	0.9703
H	***0.6759***	***0.6920***	***0.8480***	***0.7194***	***0.7519***
	Modified Variance-time plot				
	FIN	KLCI	IND	PLN	PRP
overall : a_0	6.8905* (0.0633)	6.5735* (0.0452)	6.1977* (0.0275)	5.9335* (0.1705)	6.4118* (0.0243)
a_1	-0.7409* (0.0241)	-0.7314* (0.0203)	-0.7591* (0.0133)	-0.7311* (0.0438)	-0.6753* (0.0072)
R^2	0.9908	0.9946	0.9971	0.9771	0.9959
H	***0.6296***	***0.6343***	***0.6205***	***0.6345***	***0.6624***
Pre-crisis: a_0	7.1505* (0.2484)	5.7544* (0.2088)	5.0340* (0.2152)	4.0441* (0.2727)	6.2879* (0.2324)
a_1	-0.9112* (0.0856)	-0.7621* (0.0614)	-0.8248* (0.0661)	-1.1102* (0.1112)	-0.8301* (0.0700)
R^2	0.9597	0.9689	0.9680	0.9483	0.9659
H	***0.5444***	***0.6190***	***0.5876***	***0.4490***	***0.5850***
Post-crisis: a_0	6.0393* (0.1087)	6.9901* (0.0404)	2.9476* (0.0674)	5.7659* (0.0180)	6.5224* (0.1174)
a_1	-0.6750* (0.0276)	-0.8012* (0.0135)	-0.4050* (0.0152)	-0.6961* (0.0068)	-0.6259* (0.0278)
R^2	0.9900	0.9979	0.9861	0.9971	0.9875
H	***0.6625***	***0.5994***	***0.7975***	***0.6520***	***0.6871***

Table 3 reported the overall period, pre-period and post-period for five indices LRD using the original and modified variance plots. Firstly, the modified approach shown substantial reduction of LRD (indicated by *H*) in all the indices after the appropriate adjustment for the short-range dependence in the overall, pre- and post-periods. This implied that the original variance plot has overestimated the LRD and created additional correlation impact that consequently caused spurious statistical inferences and predictions.

Another interesting finding is the LRD in overall period compared to the two sub-periods, pre- and post-periods. Different strengths of LRD have been observed before and after the sudden change events in the equity markets. For overall-period, the LRD is quite consistent within the range of 0.6205 to 0.6624. However, when the analysis take into account the sudden change of economic events, interesting outcomes have been observed in the pre- and post- periods. Overall, the pre-period indicated relative weak LRD with the range of 0.5444 to 0.5876 than the post-period (range from 0.6625 to 0.7975). Exceptional is viewed in the KLCI index where the Hurst parameters are almost equivalent in both the periods with the values approximately 6.000. Especially for PLN index in the pre-period, the index exhibited only the short-range dependence (H=0.4490) instead of LRD. Thus, the LRD is relied heavily on the presence of structural break. These results are similar to Granger, C.W.J. and Hyung (2004) where spurious LRD are found with the ignorance of structural break.

From an economic viewpoint, the LRD phenomenon is an important element in the heterogeneous market hypothesis (Muller et al. 1997). Due to the variations of endowments, risk profiles, degree of information, contractual constraints, reaction to news and etc., each time-horizon trading activities is going to create a unique volatility under the fluctuating price movements. Most of the market participants can be categorized (by *short*-term, *medium*-term and *long*-term investors ranging from seconds to decades period. These included intraday investment (seconds to hours), hedge funds and portfolio investments (daily to monthly) and central banks and pension funds that might trade over few years and even decades. Consequently, the financial markets created a volatility cascade ranging from low to high frequencies that believed to generate the LRD in the financial markets. Based on these statement, we discussed the LRD as follows:

Pre-period

For KLCI, FIN, IND and PRP indices, the pre-period analysis included the events such as the Asian financial and currency crises. Exceptional, only the PLN index indicated short-range dependence with the value 0.4490 in the Hurst's estimation. Various ICT applications incorporated with the KLSE securities trading have been implemented such as such as semi-automated SCORE (1989) and fully automated WinSCORE (1995), among others. The improvement in the market infrastructures has provided more reliable information to the investors. Consequently, the availability of public information and historical data might create an efficient market (either weak- or semistrong-form). If the market is more efficient, then most likely the randomness in the market might lessen the LRD behavior.

Another possible reason for randomness is during the Asian financial crisis where most of the panic-stricken investors reacted simultaneously by withdrawing their short-term capitals on a large scale from most of the Asian financial markets. These synchronized actions among the non-homogeneous investors, for some extent, could reduce the nature of heterogeneity in the Malaysian equity markets. As observed in **Table 3**, the LRD parameters in pre-period are close to 0.5 which indicated weak LRD.

Post-period

Most of the post-periods covered the period after the implementation of fixed USD currency to stabilize the RM. During this period, the investors become more cautious and do not always response instantaneously to the information which subjected to their beliefs to the information. Foreign investors might delay their responses to see how local and informed market participants reacted due to the unavailability of reliable information. After the bad experience during the financial crisis, most of the market participants interpreted the same public information differently according to their trading opportunities. Most probably, the market participants re-structured their investment plans based on *short*-term, *medium*-term and *long*-term ranging from seconds to decades period. Therefore, the cascaded volatilities have generated LRD in the five indices as indicated in **Table 4**.

5.0 Conclusion

This research aimed to investigate the LRD that commonly occurred in the financial stock exchange. For sub-period analysis, we found contrasted LRD outcomes as compared to the overall-period and concluded that the economic shocks have yielded significant impacts to the LRD estimations. In addition, the adjustment of short-range dependence in the proposed methodology is sufficient to eliminate the spurious additional LRD in all the indices.

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