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THE LINEARITY PROPERTY OF ASEAN-5 REAL EXCHANGE RATES IN PRE-ASIAN CURRENCY CRISIS PERIOD

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ABSTRACT

This study extends the work of Liew et al. (2003) in two directions. First, it examines whether or not the 1997 Asian currency crisis has resulted in the nonlinearity of ASEAN-5 real exchange rates. Second, it characterizes the type of nonlinearity governing these rates. Results of the current study, among others, show that nonlinearity existed even before the outbreak of the crisis, suggesting that nonlinearity in these rates is not crisis-induced. Moreover, this study provides robust empirical evidence that most of the pre-crisis ASEAN-5 real exchange rates exhibit LSTAR-type nonlinear dynamics, indicating that the market responds with respect to (1) appreciation and depreciation of real exchange rates and (2) the overvaluation and undervaluation of nominal exchange rates towards the purchasing power parity equilibrium levels are asymmetrical in nature. This study is important to central banks and other foreign exchange market players in this ASEAN region especially in the sense that it provides insightful information regarding the effective way of understanding, measuring and monitoring the ASEAN-5 exchange rates movement.

Keywords: *Nonlinearity; Linearity test; ASEAN-5; Real exchange rates.*

ABSTRAK

Kajian ini melanjutkan hasil kerja Liew et al. (2003) dalam dua cabang. Pertama, ia mengkaji sama ada krisis kewangan Asia 1997 telah menyebabkan

ketaklinearan dalam kadar pertukaran asing benar ASEAN-5. Kedua, ia menaakul apakah jenis ketaklinearan yang dihadapi oleh kadar pertukaran asing tersebut. Antara hasil-hasil yang utama, kajian ini telah menunjukkan bahawa ketaklinearan sudah wujud sebelum krisis berlaku. Ini bermakna krisis bukan faktor bagi kewujudan ketaklinearan dalam kadar pertukaran asing ini. Malahan, kajian ini memberi bukti yang kukuh bahawa terdapat ketaklinearan alah LSTAR dalam kadar pertukaran asing benar ASEAN-5 sebelumkrisis.

Implikasi hasil kajian ini ialah tindak balas pasaran terhadap (1) peningkatan dan kemerosotan nilai kadar pertukaran asing benar, dan (2) lebihan nilai dan kurangan nilai pertukaran asing nominal berbanding dengan nilai yang seimbang dengan pariti kuasa beli adalah tidak simitri. Kajian ini penting bagi bank-bank pusat dan peserta dalam pasaran pertukaran asing di rantau ASEAN kerana ia memberi pengetahuan yang cukup berguna dalam soal bagaimana pergerakan kadar pertukaran asing ASEAN-5 boleh difahami, diukur dan dikawal.

INTRODUCTION

One of the popular research areas in the current international economics literature is the exchange rate study. In this respect, many exchange rate researchers have special interest in understanding the long run behaviour of real exchange rate, in particular its stationarity or mean-reverting property. Real exchange rate is in essence the deviation of nominal exchange rate from its purchasing power parity (PPP) equilibrium value (Peel, Sarno & Taylor, 2001). As such, stationarity in real exchange rate implies the validity of PPP hypothesis; otherwise, nominal exchange rate persistently deviates from relative prices. Among the bulk of empirical study on this issue include Glen (1992); Lothian and Taylor (1996, 1997), Parikh and Williams (1998), Aggarwal, Montanes and Ponz (2000); Gil-Alana (2000); Taylor and Peel (2000); Kakkar (2001); Peel *et al*. (2001); Razzaghipour, Fleming and Heaney (2001); Kapetanios, Shin and Snell (2003); Shively (2003); Liew, Baharumshah and Lau (2002); Liew, Baharumshah and Chong (2004a); Liew, Baharumshah and Lim (2004b) and many others.

The issue of stationarity of real exchange rates, however, is not the focus of this study. Rather, this study deals with another time series property of real exchange rates that is linearity, which compared to the stationary property, was very much neglected in past studies but has received more and more attention in the contemporary literature. To this end, Liew, Chong and Lim (2003) and Liew *et al*. (2004a) have

done some work in the context of the Asian region, whereas Sarno (2000a, b), Baum, Barkoulas and Caglayan (2001), focus their studies on other parts of the world. These studies have a common feature in the sense that they found nonlinearity in the real exchange rates by the Luukkonen-Saikkonen-Teräsvirta (*LST*) linearity test (Luukkonen, Saikkonen & Teräsvirta, 1988). A typical example is the work of Liew *et al.* (2003), which found strong evidence of nonlinear behaviour of US dollar based Asian real exchange rates including the Indonesian rupiah, Malaysian ringgit, Philippines peso, Singapore dollar and Thai baht, over the sample period 1973Q1 to 2001Q2. Note that the sample period covers the 1997 Asian currency crisis (referred to as crisis hereafter unless otherwise stated) and one may suspect that the nonlinearity set in because of the crisis. This suspicion is reasonable as Baig (2001) found that post-crisis exchange rate data have different characteristics as compared to pre-crisis period and that Razzaghipour *et al*. (2001) found that this crisis did have an effect (although statistical insignificant) on the mean-reverting tendency of ASEAN-5 (Indonesia, Malaysia, Philippines, Singapore and Thailand) real exchange rates. Moreover, Liew and Baharumshah (2003) have shown that the pre- and post-crisis periods have different fundamental conditions in the ASEAN-5 economies and that the post-crisis ASEAN-5 exchange rates are less predictable using linear time series models. It is unknown whether or not the reduction in predictability is due to the set-in of nonlinearity in the post-crisis period. Hence, it is interesting to find out whether nonlinearity is just a phenomenon after the crisis or it already existed before the crisis, an issue not addressed in Liew *et al.* (2003).

Another remark to be made at this moment is that given how the real exchange rates behaved nonlinearly, it is important to discover whether this nonlinear dynamic is symmetrical or asymmetrical in nature. In fact, it is also reported in Liew *et al.* (2003) that the nonlinear behaviour of real exchange rates under study can be characterised by the Smooth Transition Autoregressive (STAR) model, a type of nonlinear time series model that allows the real exchange rate to adjust smoothly every moment in between two regimes, which may either be appreciating and depreciating regimes or undervaluation and overvaluation regimes. There are basically two types of STAR models, namely logistic STAR (LSTAR) and exponential STAR (ESTAR) models. The former is capable of characterising asymmetrical adjustment dynamics whereas the latter is useful in capturing the symmetrical adjustment dynamics of the series under examination (Teräsvirta & Anderson, 1993; Sarno, 2000a, b). Nonetheless, in accord with the theoretical view that exchange rates adjustment towards stable equilibrium level is symmetrical in

nature (Dumas, 1992), few researchers such as Sarno (2000a, b), Taylor and Peel (2000) and Baum *et al*. (2001) contend that exchange rate should exhibit symmetrical adjustment behaviour regardless of whether it is undervalued or overvalued. As such, Sarno (2000a, b) postulates that ESTAR model rather than LSTAR is consistent with the real exchange rate behaviour, whereas Taylor and Peel (2000) and Baum *et al*. (2001) assert that ESTAR should be used to cater for the symmetrical adjustment of exchange rates positive and negative deviations from equilibrium level. Subsequently, these studies have ruled out the application of LSTAR model in their exchange rate studies.

However, it is argued here that to be fair and square, one should let the data speak for itself regarding the nature of nonlinearities. In particular, given that STAR-type nonlinearity is present in a real exchange rate, one should further identify whether LSTAR or ESTAR model is a better fit of the data. This would allow us to add empirical content to the literature in the understanding of symmetrical or asymmetrical real exchange rate adjustment behaviour.

Motivated by the reasons discussed above, the present study extents the work of Liew *et al.* (2003) in two directions. First, we apply the same methodology as employed in Liew *et al.* (2003) to identify the linearity property of ASEAN-5 exchange rates in the period 1973:1 to 1996:4. The motive of using this period is to investigate whether the nonlinearity as reported in Liew *et al.* (2003) is already present before the outbreak of the 1997 Asian currency crisis or otherwise, which would then have the implication that nonlinearity is crisis-induced. We nonetheless include only ASEAN-5 data as the currencies in these countries have been reported to be badly affected by the crisis (Carbaugh, 2000). Second, to address the issue of whether real exchange rate adjustment follows a LSTAR or ESTAR path, if nonlinearity exists, we further examine whether the LSTAR or ESTAR model is a better representation of the data, in cases where STAR-type nonlinearity is detected.

Related Literature in the ASEAN-5 Context

The most closely related literature is the very recent work of Liew *et al.* (2003), which examines the adequacy of the linear autoregressive (AR) model for 11 US dollar denominated Asian real exchange rates including the so-called ASEAN-5 real exchange rates: Indonesian rupiah, Malaysian ringgit, Philippines peso, Singapore dollar and Thai baht. Based on formal linearity test developed by Luukkonen *et al*. (1988) known as Luukkonen-Saikkonen-Teräsvirta (*LST*) linearity test,

they show that nonlinear STAR model rather than linear AR model is the correct representation of these real exchange rates, over the sample period 1973Q1 to 2001Q2. As such, the authors remark that the applications of unit root tests, the causality tests and cointegration tests which have implicit assumption of AR model may be inappropriate in the study of exchange rates behaviour. Unfortunately, most previous exchange rate studies are not free from the mis-use of these econometric testing procedures due to the lack of awareness regarding the presence of nonlinearity as well as the short age of formal nonlinear econometric testing procedures. For instance, the conclusions drawn from the previous works of Do_anlar (1999), Salehizadeh and Taylor (1999), Goh and Mithani (2000) and Azali, Habibullah and Baharumshah (2001) on the ASEAN-5 exchange rate study may be misleading as they employed the above-mentioned mis-specified testing procedures.[1,2] However, it is unknown whether other earlier studies in the same region — which also have unspoken linear assumption — such as Nguyen and Yao (1989), Gan (1991), Abeysinghe and Lee (1992), Bahmani-Oskooee (1993), Kim (1993), Cooper (1994), Cao and Ong (1995), Chia and Bauer (1995), Mansur and Ariff (1995), Toh and Kendall (1996) and Baharumshah and Ariff (1997), which use data up to or before the crisis are valid or not, as the linearity nature of exchange rates in this sample period remains unknown to this end.[3] Discussion on the empirical contents of these studies is omitted here and interested readers may refer to Liew (2004) for an overview.

ASEAN-5 Real Exchange Rates

Following closely the work of Liew *et al*. (2003), we use the seasonally unadjusted end-of-quarter spot exchange rates over the sample period 1973Q1 to 2001Q2. For the reason stated earlier on, five US dollar based ASEAN real exchange rates including the Indonesian rupiah (IDR/USD), Malaysian ringgit (MYR/USD), Philippines peso (PHP/USD), Singaporean dollar (SGD/USD) and Thais baht (THB/USD) are considered in this study. These real exchange rates are derived from the relative form of purchasing power parity (PPP) hypothesis, namely $y_t = s_t + p^*_t - p_t$ where y_t is the logarithm of nominal exchange rate (domestic price of foreign currency) at time t, and p^*_t and p_t are the logarithms of foreign and domestic price levels (measured by consumer price indices) respectively. As there is no point to reinvent the wheel, this study will not examine linearity property of these exchange rates in the full sample. Rather, this study will estimate the linearity test using the sample period up to 1996Q4 only.

However, it is worth including in this study a preliminary analysis of the statistics on these data in full sample. To solicit more insightful

information on the behaviour of these real exchange rates data within different market conditions, the descriptive statistics of their growth rates, which represent the rates of appreciation and depreciation or the real exchange rates returns, are scrutinized and the results are summarised in Table 1.[4] The upper panel in Table 1 shows the summary statistics for the sub-sample before crisis (1973Q1 to 1996Q4). From the mean values, it is observed that on average IDR/USD and MYR/USD are appreciating (as shown by the negative mean growth rates) with a rate of 0.005% and 0.313% respectively. On the other hand, the other three rates are depreciating (by the positive mean growth grates) with a value of 0.068%, 0.399% and 0.016% for PHP/USD, SGD/USD and THB/USD accordingly. Thus, it is clear that SGD/USD (MYR/USD) has depreciated (appreciated) the most during this sample period, among the five selected ASEAN economies.

On the other hand, from the standard deviation values, which may be regarded as measurement of volatility (larger standard deviations implies more volatility) of the corresponding real exchange rates (Baig, 2001), we know that SGD/USD return is the most risky (uncertain) of all, followed by the return of PHP/USD, whereas MYR/USD return is the least risky. This finding is clearly shown in Figure 1, which shows that the returns of PHP/USD and SGD/USD are far more volatile than the rest in this sub-sample. Turning to the skewness (symmetry if it assumes a value of zero, otherwise asymmetry) value which describes the "shape" of the distribution of the return, it is obvious that all the returns are asymmetrical in nature, thereby implying that the adjustment dynamic of exchange rate in the appreciating and depreciating regimes are different. Based on another "shape" statistics known as kurtosis (normal if it takes a value of 3, otherwise short- (<3) or long-(>3) tailed is displayed), we know that all ASEAN-5 real exchange rate returns, in accord with other related studies (Choo, Loo & Ahmad, 2002) are leptokurtic as they all have kurtosis values of more than 3. Summing up the findings from the "shape" statistics, it can be concluded that the returns are non-normally distributed. This conclusion is supported by the substantially large Jarque-Bera Normality Test statistics (or the extremely small probability values of the statistics) in all cases.

The middle panel of Table 1 shows the summary statistics during and after the crisis (1997Q1 to 2001Q2). It illustrates that on average IDR/USD and MYR/USD are appreciating at a higher rate as compared to the pre-crisis period, with the values rising from 0.052% to 0.617% in the former case, and from 0.313% to 1.056% in the latter case. Meanwhile, all the other real exchange rates are found to have switched

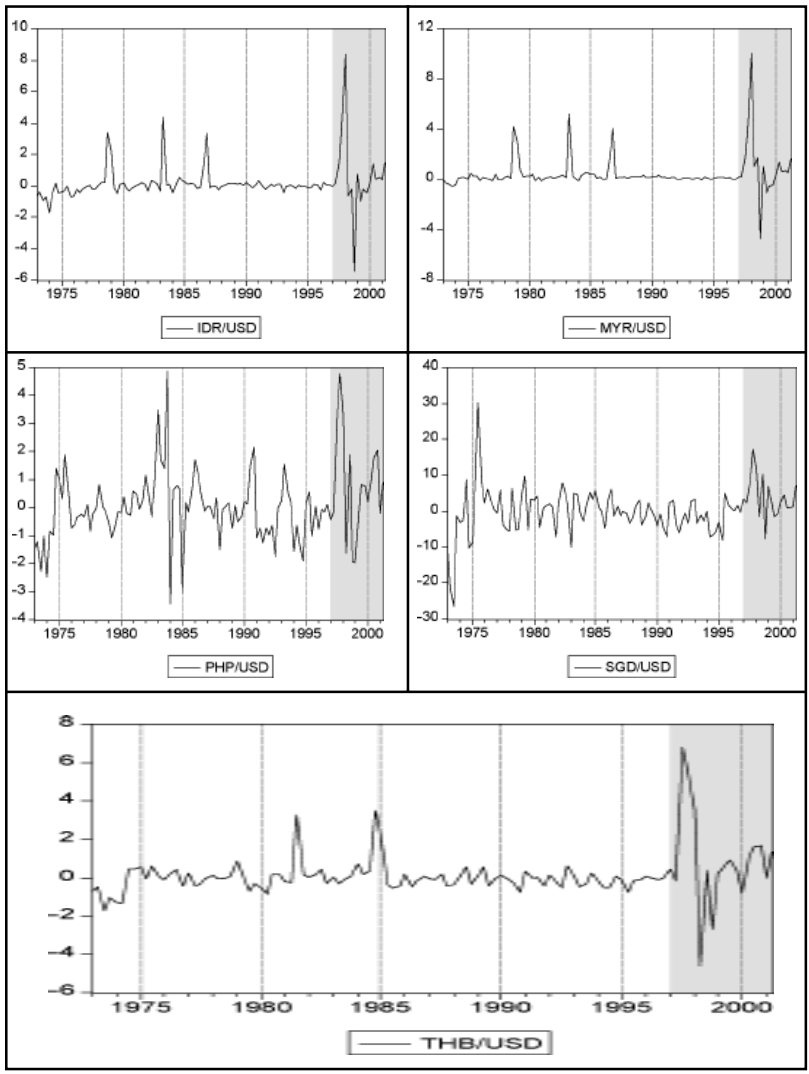
to negative growth rates from the positive growth rates during and after the crisis. Moreover, the smaller skewness and kurtosis statistics as compared to the pre-crisis period show that the distributions of the returns are more asymmetrical and less leptokurtic than before. Interestingly, this improvement in "shape" allows the returns of PHP/USD, SGD/USD and THB/USD to assume normal distribution by the Jarque-Bera statistics. This finding may be taken as evidence that the Asian currency crisis is a market adjustment mechanism that helps to self-correct exchange rate mis-evaluation.[5] Nonetheless, based on the standard deviation values, the returns are far more volatile than the pre-crisis period for IDR/USD, MYR/USD and THB/USD and this finding can be visualised from the section regions in Figure 1.[6]

Table 1
Summary Statistics of Growth Rates of ASEAN-5
Real Exchange Rates

Growth Rate Series	IDR/USD	MYR/USD	PHP/USD	SGD/USD	THB/USD
Sub-Sample Period1973Q1 to 1996Q4 (Before Crisis)					
Observations	96	96	96	96	96
Mean	-0.052	-0.313	0.068	0.399	0.016
Median	0.005	-0.137	0.052	0.054	0.033
Maximum	1.721	0.542	3.442	26.743	1.742
Minimum	-4.377	-5.206	-4.883	-30.290	-3.514
Standard Deviation	0.777	0.848	1.177	6.564	0.716
Skewness	-3.464	-4.300	-0.624	-0.059	-2.348
Kurtosis	18.135	21.824	6.426	9.631	13.201
Jarque-Bera	1108.267	1713.258	53.179	175.916	504.437
[Probability]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Sub-Sample Period1997Q1 to 2001Q2 (Crisis and After)					
Observations	18	18	18	18	18
Mean	-0.617	-1.056	-0.788	-3.841	-0.894
Median	-0.264	-0.668	-0.784	-2.551	-0.510
Maximum	5.478	4.710	1.975	7.633	4.593
Minimum	-8.352	-10.041	-4.786	-17.192	-6.799
Standard Deviation	2.662	2.860	1.857	5.731	2.579
Skewness	-0.892	-1.441	-0.397	-0.426	-0.354
Kurtosis	6.396	7.264	2.618	3.315	3.914
Jarque-Bera	11.033	19.867	0.583	0.619	1.002
[Probability]	[0.004]	[0.000]	[0.747]	[0.734]	[0.606]
Full Sample Period1973Q1 to 2001Q2					
Observations	114	114	114	114	114
Mean	-0.141	-0.430	-0.067	-0.270	-0.128
Median	-0.002	-0.160	0.014	-0.620	-0.001
Maximum	5.478	4.710	3.442	26.743	4.593
Minimum	-8.352	-10.041	-4.883	-30.290	-6.799
Standard Deviation	1.271	1.382	1.335	6.601	1.242

(continued)

Skewness	-2.552	-3.524	-0.815	-0.045	-1.987
Kurtosis	21.943	25.652	5.429	8.508	14.164
Jarque-Bera	1828.256	2673.356	40.640	144.142	667.025
[Probability]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]



Note: Shaded region represents the "crisis and after" sub-sample period (1997:Q1 to 2001Q2).

Figure 1
Percentage returns of ASEAN-5 real exchange rates
(1973Q1 to 2001Q2)

Another analysis via the diagnostic checking of the ASEAN-5 real exchange rate autoregressive models as shown in Table 2 also demonstrates the substantial change in the underlying attribute of the models' residuals for the case of SGD/USD and THB/USD. Specifically, by contrasting the residuals attributes of the models for pre-crisis subperiod and the full sample period which include the crisis, it seems that the crisis has induced ARCH effect into the former and heteroscedasticity effect into the latter.

Table 2
Residual Diagnostics of Linear Autoregressive Models.

Real Exchange Rate	*p*-values of test statistics							
	1973Q1 to 2001Q2[a]				1973Q1 to 1996Q4			
	Q_{20}	H_{20}	A_{20}	G_{11}	Q_{20}	H_{20}	A_{20}	G_{11}
IDR/USD	0.719	0.869	0.247	0.999	0.522	0.333	0.894	0.499
MYR/USD	0.994	0.952	0.070#	0.998	0.783	0.890	0.043*	0.770
PHP/USD	0.281	0.157	0.359	0.888	0.728	0.669	0.320	0.970
SGD/USD	0.815	0.182	0.027*	0.107	0.147	0.429	0.539	0.209
THB/USD	0.952	0.045*	0.863	0.435	0.708	0.913	0.994	0.683

Notes: Q_{20}, H_{20} and A_{20} are, in that order, Ljung-Box Q test, Breusch-Pagan test and ARCH Lagrange Multiplier test to check the presence of serial correlation, heteroscedasticity and ARCH problems up to the 20th order. G_{11} refers to the GARCH (1,1) Lagrange Multiplier test. # and * denote significant at 10% and 5% level respectively.
[a] Source: Abstract from Table 2 of Liew *et al.* (2003) for comparison purpose.

All in all, our results of statistical analysis on the growth rates of ASEAN-5 real exchange rates and the residuals diagnostic checking of the linear real exchange rate models are in line with the findings of Baig (2001) and Razzaghipour *et al*. (2001) that ASEAN-5 exchange rates have different characteristics before and after the crisis.

STAR Models, Linearity Test and Determination of LSTAR- or ESTAR-Type Nonlinearity

Smooth Transition Autorgressive (STAR) model of order p, for a real exchange rate series y_t may be expressed as:

$$y_t = \alpha_0 + \sum_{i=1}^{p}(\alpha_i y_{t-i}) + (\alpha^*_0 + \sum_{i=1}^{p}\alpha^*_i)\, F(y_{t-d}) + \varepsilon_t \qquad (1)$$

where α_0 is the linear intercept term, α_i (i =1, …, p) is the linear autoregressive parameter; α^*_0 is the nonlinear intercept term, α^*_i (i =1, …, p) is the nonlinear autoregressive parameter, $F(y_{t-d})$ is the transition

function which characterized the smooth transition in between 2 regimes, with the speed of transition governed by the lagged term of the real exchange rate, y_{t-d} where d is the delay lag length. ε_t is the white noise residuals with zero mean and constant variance.

Depending on the specification of the transition function, , there are variants of STAR model, namely the LSTAR or Logistic STAR and ESTAR or Exponential STAR models. The former has a logistic transition function:

$$F(y_{t-d}) = [1 + e^{-\gamma 2(y_{t-d-\mu})}]^{-1} \quad (2)$$

where γ^2 transition parameter is a measure of the speed of transition in between the 2 regimes, and μ is the threshold parameter indicating the mid-way in between the two regimes of real exchange rate.

Meanwhile, the latter has an exponential specification:

$$F(y_{t-d}) = [1 - e^{-\gamma 2(y_{t-d-\mu})}]^{-2} \quad (3)$$

Interested readers may consult Teräsvirta and Anderson (1993) for a thorough discussion, but at this moment it is sufficient to draw our attention to the potential usefulness of these two models. Teräsvirta and Anderson (1993) point out that LSTAR model is able to capture the asymmetric behavior of business cycle indicators, where expansion and contraction phases of an economy may have rather different dynamics, and a change in the dynamics from one to the other may be smooth. The ESTAR model, on the other hand, can represent an economy which returns from high growth towards normal growth in same fashion as it accelerates from low or negative growth towards the normal growth. In other words, ESTAR model implies that contraction and expansion have rather similar adjustment structures. As for the application of these two models, originally proposed for the modeling of a business cycle, in the field of exchange rate, Sarno (2000a, b) put forward that the transition function (this function will be described later) of the ESTAR model is symmetrical in shape and therefore it captures symmetrical adjustment dynamics of exchange rate. As for the LSTAR model, its monotonic increasing transition function implies an asymmetric adjustment towards equilibrium value.

Granger and Teräsvirta (1993) noted that it is important to test for linearity prior to estimating any nonlinear model. Liew *et al*. (2003) remarked that the application of any linear model is only appropriate when linearity test has failed to detect any nonlinearity in the time

series of interest. In sum, we must conduct linearity test before the selection of linear or nonlinear models.

As in Liew *et al*. (2003), formal linearity test formulated by Luukkonen *et al*. (1988) are deployed to determine whether the ASEAN-5 real exchange rates are linear or nonlinear in nature in the pre-crisis sub-sample period:

$$y_t = a_0 + \sum_{i=1}^{p} a_i y_{t-i} + \sum_{i=1}^{p} (b_{1i} y_{t-i} y_{t-d} + b_{2i} y_{t-i} y_{2t-d} + b_{3i} y_{t-i} y_{3t-d}) + \zeta_t \quad (4)$$

where ζ_t is white noise residuals with zero mean and constant variance under the null hypothesis. Note that the true lag length, p and the delay parameter, d are unknown and their optimal values have to be determined based on certain considerations. Following Liew *et al*. (2003), this study fixes the optimal p as suggested by partial autocorrelation functions (*PACF*) and the principle of no autocorrelation, whereas d is chosen from 1 to 12 and the one that minimizes the p-value of the *LST* (acronym for Luukkonen-Saikkonen-Teräsvirta) statistics will be selected.

The null hypothesis of Equation 4,: $b_{11} = \ldots = b_{1p} = b_{21} = \ldots = b_{2p} = b_{31} \ldots = b_{3p} = 0$ is tested against the alternative hypothesis of: At least one b is not 0, by the *LST* statistics[7]. In our case, the rejection of the null hypothesis means that the real exchange rate being tested exhibits nonlinearity and this nonlinearity can be characterized by the Smooth Transition Autorgressive (STAR) model. In short, there is evidence of STAR-type nonlinearity in the real exchange rate. However, if the null hypothesis is not rejected, than the real exchange rate behaves in a linear manner.

If linearity has been rejected in favor of the STAR model, one may proceed to test the following sequential tests, for the determination of LSTAR- or ESTAR-type nonlinearity (Teräsvirta and Anderson, 1993):

$$H_{03} : b_{31} = ... = b_{3p} = 0 \mid \text{Reject } H_0 \quad (5)$$

$$H_{02} : b_{21} = ... = b_{2p} = 0 \mid \text{Accept } H_{03} \quad (6)$$

$$H_{01} : b_{11} = ... = b_{1p} = 0 \mid \text{Accept } H_{02} \quad (7)$$

where in each of the above cases, the alternative hypothesis is H_{Ak} At least one is non-zero for $k = \{1, 2, 3\}$. The null hypothesis is tested against the alternative hypothesis by the F-test of restriction (Gujarati, 1995).

The following decision rules are useful in the determination of LSTAR- or ESTAR-type nonlinearity: (1) Rejecting H_{03} implies LSTAR-type nonlinearity. (2) Accepting H_{03} and rejecting H_{02} implies ESTAR-type

nonlinearity. (3) Accepting both H_{03} and H_{02} and rejecting H_{01} implies LSTAR-type nonlinearity. (4) Accepting all H_{03}, H_{02} and H_{01} lead to inconclusive determination.[8]

The results of *LST* test for linearity or nonlinearity and the sequential tests for LSTAR-type or ESTAR-type nonlinearity are presented and discussed in the next section.

RESULTS AND DISCUSSIONS

The *LST* linearity test results are summarised in Table 3. Table 3 shows that the null of linearity has been rejected at 5% significance level for all real exchange rates for the pre-crisis sample period, with the exception of THB/USD, in which the null can be rejected at 10% significance level only.

Table 3
Linearity Test Results (1973Q1 to 1996Q4)

Real Exchange Rate	*p*	*d*	*LST* statistic	*Bootstrap p* value
IDR/USD	1	2	8.624	0.044
MYR/USD	3	3	19.482	0.008
PHP/USD	2	3	16.264	0.021
SGD/USD	5	9	56.236	0.000
THB/USD	1	3	8.848	0.066

There are several implications of this finding. First, the rejection of the null hypothesis indicates that the nonlinear parameters are jointly significant by the *LST* test, thereby suggesting that linear AR model is inadequate in characterizing the behaviour of real exchange rates in all the five selected ASEAN economies. The implication of this evidence is that estimating the linear AR exchange rate model disregarding the presence of non-linearity will yield a mis-specified model. In fact, some researchers have shown that: (1) it is difficult to model exchange rates using linear framework if they are governed by non-linear process; (2) ignoring non-linearity nature of exchange rates is the major explanation for the failure of linear models to provide satisfactory out-sample forecasts (Taylor and Peel, 2000). As such, the results and conclusions from the works of Nguyen and Yao (1989), Gan (1991), Abeysinghe and Lee (1992), Bahmani-Oskooee (1993), Kim (1993), Cooper (1994), Cao and Ong (1995), Chia and Bauer (1995), Mansur and Ariff (1995), Toh and Kendall (1996) and Baharumshah and Ariff (1997), which assume linearity have to be taken with reservations. Second, the detection of nonlinearity even in the pre-crisis period suggests that

the 1997 Asian crisis is not the main cause of nonlinear dynamics in the ASEAN foreign exchange market as we expected earlier on. Third, in line with the findings of the recent related studies, the rejection of the null hypothesis provides empirical evidence that the nonlinear STAR model is the correct specification. Thus, exchange rate forecasters should consider the STAR model and its variants as better alternatives to the existing linear forecasting models. We believe that distinguishing between LSTAR-type or ESTAR-type nonlinearity may help maximising the gains of utilising nonlinear models.

The results of sequential tests for LSTAR-type or ESTAR-type nonlinearity are tabulated in Table 4. It is clearly depicted in Table 4 that the null hypothesis H_{03} can be rejected in the case of PHP/USD (at 5% significance level) and SGD/USD (1% level) implying that these two real exchange rates exhibit LSTAR-type nonlinearity. Meanwhile, H_{03} is not rejected in the case of MYR/USD but H_{02} can be rejected at 5% significance level, revealing that ESTAR-type nonlinearity is present in MYR/USD. On the other hand, both H_{03} and H_{02} are not rejected for IDR/USD and THB/USD even at 10% significance level. Anyway, the rejection of at less than 1% significance level indicates that the movement of H_{01} these rates is governed by the LSTAR-type nonlinearity.

Table 4
Sequential Tests Results (1973Q1 to 1996Q4)

Real Exchange Rate	*F*-Test [*p*-value]			Decision on Type of Nonlinearity
	H_{03}	H_{03}	H_{03}	
IDR/USD	1.657[0.201]	0.176[0.677]	14.415[0.000]	LSTAR
MYR/USD	0.657[0.581]	3.605[0.017]	1.469[0.228]	ESTAR
PHP/USD	3.281[0.042]	9.049[0.000]	0.896[0.412]	LSTAR
SGD/USD	4.409[0.002]	0.028[0.868]	6.065[0.000]	LSTAR
THB/USD	0.041[0.839]	2.345[0.129]	21.839[0.000]	LSTAR

The finding of the presence of LSTAR-type nonlinearity in all the ASEAN-5 real exchange rates except MYR/USD is quite striking. It is against the widely-held belief of the symmetrical adjustment dynamics of real exchange rate towards depreciating and appreciating regimes (Sarno, 2000a, b; Baum *et al*., 2001). Rather, this study finds strong evidence of the homecoming of ASEAN-5 (except MYR/USD) real exchange rates from the positive growth rates (depreciation) to the equilibrium level have rather different dynamics as it accelerates from negative growth (appreciation) to the equilibrium level.

Another implication of this the findings is that the deviations of nominal exchange rates from the PPP equilibrium levels follow nonlinear path and that the response of market adjustment mechanism towards over-valuation and under-valuation of ASEAN-5 (except MYR/USD) nominal exchange rates are asymmetric in nature. This conclusion is in sharp contrast to Taylor and Peel (2000) and Liew *et al*. (2002) which find ESTAR-type adjustment process of exchange rate deviations towards equilibrium levels. Nonetheless, the results of the current study are more robust than these two studies as they discard LSTAR model in *priori* and based their analysis solely on ESTAR-type linearity test.

Concluding Remarks and Policy Implications

The descriptive statistical analysis of the current study conforms to a number of previous studies that have shown the characteristics of the real exchange rates in the ASEAN region have changed substantially following the outbreak of the 1997 Asian currency crisis. It is unclear whether or not these changes have induced the nonlinear behaviour of ASEAN-5 real exchange rates as documented in Liew *et al*. (2003). This study therefore conducts a formal test based on Luukkonen *et al*. (1988) to examine the linearity property of these real exchange rates using the pre-crisis sample period. Results of this study show that nonlinearity already existed even before the crisis, therefore refuting the proposition that the crisis is the underlying explanation of nonlinearity. These findings point to the need of cautious ness among decision-makers in addressing the results and conclusions of most of the previous exchange rate studies in this region as they have implicit linear assumption.

Following the sequential tests as proposed in Teräsvirta and Anderson (1993), this study is able to further identify that the US dollar based real exchange rates of Indonesia, Philippines, Singapore and Thailand exhibit LSTAR-type nonlinearity. This implies that the real exchange rates of these countries have asymmetrical response towards appreciation and depreciation. Hence, it is argued that foreign exchange market participants should adopt the LSTAR model rather than ESTAR model in their attempts to effectively comprehend the behavior of these exchange rates.

The key policy implications of the robust empirical evidence of asymmetrical adjustment dynamics in response of the appreciation and depreciation of real exchange rates and the overvaluation and undervaluation of nominal exchange rates towards the purchasing power parity equilibrium levels are twofold. First, central banks, international financial institutions, multinational corporations and

other foreign exchange market players should adopt the LSTAR model rather than ESTAR model in their attempt to comprehend the future behavior of these exchange rates as the former is believed to be a more effective tool. Second, the identification of the correct nonlinearity nature of exchange rate adjustment towards its equilibrium level is important as exchange rates may serve as one of potential intermediate policy tools in boosting the economy of this region, which has experienced different extends of negative shocks such as 1997 Asian currency crisis, the 911 incident, the recession in the US (ASEAN-5's major trading partner) economy and the recent Asian bird flu. It is suggested here that central banks should pursue different policies in their attempts to stabilize their exchange rates movement. In particular, the understanding of the different response of market adjustment dynamics on the restoration of excessive overvaluation to the equilibrium levels and the bouncing back of excessive undervaluation to the equilibrium levels may be of great help to the central banks in this region in their efforts to improve the measurability and controllability of the exchange rates. In this context, the better the measurability and controllability of an exchange rate (real or nominal), the more potential it is in acting as immediate targeting tool in boosting the economy in this region, which to a large extent depends on international trade and foreign investments.

In short, this study provides robust empirical evidence that most of the pre-crisis ASEAN-5 real exchange rates exhibit LSTAR-type nonlinear dynamics. The findings of this study is important considering the fact that exchange rates may serve as one of the potential intermediate policy tools in boosting the economy of this region, which has experienced different extent of negative shocks in the past few years.

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ENDNOTES

1. Their sample data cover the 1997 Asian currency crisis period, which has been shown in Liew *et al.* (2003) that linear AR model is inadequate in characterizing the exchange rate behaviour in

this sample period. An exceptional case is the work of Aggarwal *et al*. (2000), which allow for structural breaks in their unit root test of stationary in the yen-based Asian real exchange rates for the period 1974Q1 to 1997Q4.

2. An exceptional case is the work of Aggarwal *et al*. (2000), which allow for structural breaks in their unit root test of stationary in the yen-based Asian real exchange rates for the period 1974Q1 to 1997Q4.

3. Valid, only if linear AR model is found adequate. One of the contributions in the current study is to shed light on the validity of these studies.

4. Growth rate is computed as 100 $(P_t - P_{t-1})/(P_{t-1})\%$ where P is the real exchange rate and t and $t-1$ denote the current and the immediate past values respectively. It may be interpreted as percentage return of real exchange rate (Choo *et al*., 2002). Thus, this study uses both terms interchangeably. Growth rate or return is scale free and therefore is employed here instead of the real exchange rate so as to enable comparison across countries.

5. It is also mentioned in Liew *et al.* (2002) that the 1997 Asian currency crisis has something to do with market-adjustment mechanism. However, Chinn (2000) found the that misalignment in ASEAN-5 exchange rate had no relationship with the currency crisis.

6. The characteristics of the real exchange rates returns in the full sample period (lower panel of Table 1) may be interpreted in the usual manner as we have done above and thus is omitted here.

7. Among others, Liew *et al*. (2003) provides guidelines on the computation of this statistics.

8. We believe that once H_0 is rejected indicating that at least one b is non-zero, it is unlikely for one to end up in case (4).

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