Real Exchange Rate Behavior: Evidence From Malaysia, Singapore, and Thailand

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In this paper, the mean reversion behavior of CPI-based real exchange rates in US dollar is investigated for three Southeast Asian economies: Malaysia, Singapore, and Thailand. Using linear and non-linear unit root tests to detect possible endogenous break(s), real exchange rates for currencies of the three countries are examined for the long-run purchasing power parity (PPP) during the period of January 1980 to December 2014. Results show that structural breaks mostly occur in two periods: 1985 and 1997/1998, and that, the evidences for the PPP hypothesis are relatively mixed for these three countries. Results obtained from all test fail to provide sufficient evidences for the non-linear adjustment of real exchange rates towards PPP. The misalignment in exchange rates cannot be found during the study period due to a relatively high persistency of real exchange rates (half-life > three years) found for all the three countries. Moreover, Engle-Granger procedure and Johansen multivariate cointegration methods are also carried out. The results indicate that a stronger evidence of PPP exists for the three countries relative to the USA after allowing for the presence of structural break(s), implying that the three Asian countries were affected by global financial crises during the study period. In brief, the findings reveal that misalignment in the three Southeast Asia economies is relatively slow; both exchange rates and price levels of these countries converge in the long run.

Keywords: purchasing power parity (PPP), real exchange rate, unit root tests, endogenous break, exchange rate behavior, Engle-Granger cointegration test, Johansen cointegration test

Introduction

Since the breakdown of the Bretton Woods system, studies on real exchange rates have been received much attention from the academic world. Real exchange rates have great impacts towards the competitiveness of a country in the international trade market, reflecting in return its national productivity. The fluctuation of purchasing power parity (PPP) exchange rates over a long period of time has been at the centre of macroeconomics study. As a PPP exchange rate is used to measure a long-run exchange rate for individual

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currencies, it requires a constant real exchange rate that demonstrates mean reversion over time and is not driven by stochastic trends. Examining the behavior of real exchange rate through its adjustment towards the equilibrium level may provide a comprehensive view of self equilibrating of the international macroeconomic system. If an economy experiences real structural changes which then require adjustments of relative prices, PPP may not be the guide for day-to-day fluctuation of exchange rates, but valid for the long run (Harvey, 2001).

According to Elliot and Pesavento (2004), a lengthy long-run mean reversion in real exchange rates may suggest that weak competition among nations do not lead to their long-run price convergence. Moreover, the economic and political forces regularly buffet the currency of a nation, keeping its value away from equilibrium. Moreover, the misalignment of exchange rates during the 1990s causing financial turbulences and currency crises across borders has drawn researchers’ attention on the use of time series of real exchange rate.

In this paper, the volatility of real exchange rates in three selected South East Asia countries: Malaysia, Singapore, and Thailand, is investigated for a period of January 1980 to December 2014. Specifically, mean reversion of real exchange rates will be tested in the presence of endogenously determined structural breaks for all the three countries in the sample. The study is expected to provide further empirical evidences on the long-run PPP phenomenon in the three selected countries.

To overcome the weakness of classical univariate unit root tests that often occur with a small sample, unit root tests used in works of Zivot and Andrews (1992), Lumsdaine and Papell (1997), and Saikkonen and Lütkepohl (2002) are adopted to allow endogenous breaks. The paper further distinguishes itself by applying cointegration tests, namely Engle-Granger test (Engle & Yoo, 1987) as well as Johansen Cointegration test (Johansen, Mosconi, & Nielsen, 2000) to examine the long-run PPP for Malaysia, Singapore, and Thailand relative to US dollars for periods that contain significant structural breaks.

The rest of the paper is structured as follows: Section 2 presents literature review related to the PPP theory; research methodology adopted for this study is provided in section 3; section 4 discusses findings of the study; and section 5 provides main conclusions.

**Literature Review**

PPP was introduced into economic lexicon less than a century ago (Cassel, 1918). Studies done on the PPP theory for the past few decades have arrived at mixed conclusions for both developed and developing nations.

In the study of McCloskey and Zecher (1976), a PPP relationship was found to hold over both short- and long-run periods. However, other studies, i.e., Hakkio (1984), Frenkel (1978), Edison (1985), and Mark (1990), did not find significant evidences that PPP held for developed nations for their sample of data. Krugman (1978) found that the deviations of exchange rates from PPP were persistent and large, and even larger for countries with unstable monetary policy. Furthermore, studies by Rogoff (1995) and Papell (2002) found that real exchange rates display stationary over a sufficiently long horizon and that univariate random walk specifications could be rejected in favor of stationary alternatives. However, past studies focused mostly on the low power of traditional unit root tests, but not on the PPP theory.

Correspondingly, empirical evidences from developing Asian economies with respect to floating rate regimes are at best and varied. On one hand, Aggarwal and Mougoue (1996) found an increasingly closer relationship between the Japanese yen and the other Asian currencies. On the other hand, findings on the
equilibrium exchange rate in Chinn (2000) did not closely correspond to the findings acquired from the PPP calculations. Aron, Elbadawi, and Khan (1997) constructed a cointegration framework with single equation equilibrium correction models to investigate the short- and long-run equilibrium determinants of quarterly real exchange rates from year 1970 Q1 to 1995 Q1. Short-run changes as well as a change in the fundamentals probably trigger real appreciation and depreciation in exchange rate. The findings also implied that the dynamics in real exchange rate could be due to various factors, such as levels of liberalization, terms of trade, levels of government spending, capital flows, and official reserves. Empirical evidences on exchange rate movements using PPP were mixed. This could be due to the differences in study periods and countries of interest. Catherine and Ariff (2009) found out that despite PPP explains movements in exchange rates in the longer term, the length of time to reach equilibrium varies for different regions of countries.

In terms of the low power of the standard unit root tests with long half-lives, much attention has been paid to the application of univariate approaches on a very long-horizon real exchange rate. Lothian and Taylor (1996) used annual data spanning two centuries for dollar-sterling real exchange rates. They successfully found a strong evidence on mean-reverting real exchange rate behavior. Furthermore, Taylor (2003) examined PPP since the late 19th century by using data collected for a group of twenty nations over a period of 100 years. The author found strong evidences for the long-run PPP when using multivariate and univariate tests with higher powers. However, contradicting evidence was found in the study of Murray and Papell (2002), claiming that univariate approaches provide virtually no information about the size of half-lives despite most of the point estimates lie within three-to-five-year range.

In terms of testing method, panel data analysis, which captures both cross-sectional and time series data, has been used by some researchers, especially after the Asian financial crisis. Papell (1997) investigated the long-run PPP. Using the panel data analysis, the author tested for unit roots in real exchange rates time series of industrial countries under the current float and found evidences that support the long-run PPP. Nevertheless, O’Connell (1998) reported strong evidence of mean-reversion in real exchange rate. The author realized that past studies using panel data often failed to control for cross-sectional dependence and concluded that heterogeneity in the cross sectional dimension could probably be the reason. This may suggest that although being in favor, panel data analysis may not be able to support the long-run PPP.

Besides the two above-mentioned methods, i.e., univariate techniques and panel data analysis, the use of median-unbiased estimation can also provide reasonably short half-lives to support PPP theory (Rogoff, 1996). The importance of structural breaks that was caused by various events, such as oil shocks and financial crises, is recently explored by researchers. The focal point has been shifted to the influence of these structural breaks towards the assessment of the PPP relationship. Perron (1989) and Rappoport and Reichlin (1989) are the two first studies that point out the importance of structural breaks during the implementation and interpretation process of unit root tests. However, the assumption made by Perron (1989) on the break date was criticized by Zivot and Andrews (1992), which lead to the development of a single endogenous structural break test for the unit root. The endogenous break methodology was extended later by Lumsdaine and Papell (1997) to allow for a two-break alternative. They successfully proved more evidence of PPP against the unit root hypothesis than Zivot and Andrews (1992). These findings demonstrate the need for tests with correct number of structural breaks are imperative. In another study by Saikkonen and Liitkepohl (2002), an endogenous break model was developed to encompass the deterministic term shift functions of a general non-linear form using generalized least squares (GLS) de-trending. They conceded that nonlinear break tests follow the reasoning, that breaks
occur upon a number of periods and demonstrate a smooth transition to a new level. The approach is further extended to circumstances with an unknown break date by Lanne, Saikkonen, and Lütkepohl (2003).

**Methodology**

Let $S_t$ (in logarithm) be the log spot rate and $p^*_t$ and $p_t$ (in logarithm) be the foreign and domestic price levels respectively, the real exchange rate $q_t$ (in logarithm) is as follows:

$$q_t = S_t + p^*_t - p_t$$

(1)

The estimation of $q_t$ is believed to be best relevant for testing PPP. This is because it allows the half-life of a random disturbance to be computed, so that the degree of mean reversion can be measured. To measure the speed of convergence to PPP, one would assume that the deviation of the logarithm of the real exchange rate $q_t$ from its long-run value $q_0$, that is constant under PPP, follows a linear autoregressive process of order one, AR(1):

$$q_t = \rho q_{t-1} + \varepsilon_t$$

(2)

Where $0 < |\rho| < 1$ and $\varepsilon_t$ is a white noise innovation. For annual (monthly) data, the half-life of deviations from PPP($\tau$) is the number of years (months) required for the initial deviation from long-run level to dissipate by half, with no future shocks. At horizon $\tau$, the percentage deviation from equilibrium is $\rho^\tau$. In the long-run PPP level, it is assumed that the starting $q_0$ is zero with ($E[q_t] = 0$) and with an initial shock, $\delta > 0$. Then, from $\delta/2 = |q_t| = |\rho|\delta$, the half-live is given by $\tau = \ln(\frac{1}{2}) / \ln|\rho|$, where the absolute value is introduced to allow oscillation. For instance, if $\rho$ approaches unity, the speed of adjustment $\ln|\rho|$ approaches zero from the left as well. Hence, the half-life $\tau$ approaches infinity, indicating the absence of convergence towards PPP. In reality, the half-lives are estimated by:

$$\hat{\tau} = \frac{\ln(\frac{1}{2})}{\ln|\hat{\rho}|}$$

(3)

Where $\hat{\rho}$ is an OLS estimator of $\rho$. Based on the construction of half-life equation, the speed of adjustment or the half-life, does not rely on the initial level of real exchange rate $q_0$ or the size of deviations (\delta) in the linear AR(1) model.

Although evidence of long run PPP can be justified by the unit root test with the use of real exchange rates data series, a standard test of the unit root—the augmented Dickey-Fuller (ADF) regression will still be carried out. ADF regression is as follows:

$$\Delta q_t = \mu + \beta_t + \varphi_i q_{t-1} + \sum_{i=1}^{k} \gamma_i \Delta q_{t-1} + \varepsilon_t$$

(4)

where, $\Delta q_t$ is the first difference of the real exchange rate, $k$ is the number of lagged which are added to the model to ensure that the residuals, and $\varepsilon_t$ is white noise.

The optimal lag length $k$ is selected using $t$-sig procedure based on Akaike information criterion and Schwarz information criterion, with the maximum value of $k$ equal to 8 (Hall, 1994; Ng & Perron, 1995). For comparison purposes, Phillips-Perron (PP) tests are also performed and the results are reported in addition to
REAL EXCHANGE RATE BEHAVIOR

the general ADF test. In line with the PPP hypothesis, \( q_t \) must display mean reversion behavior devoid of a unit root. The \( \varphi_1 \) term should thereby be significantly less than 0 or else the real exchange rate follows a random walk, indicating that deviations from PPP are permanent. According to Perron (1989), the standard ADF unit root test does not consider the presence of possible structural breaks in estimation of unit roots. Therefore, ADF unit, thus may be distorted as a potential break, i.e., a currency crisis, an oil shock, and a market crash, in the real exchange rate is simply disregarded (Perron, 1989).

Lumsdaine and Papell (1997) furthered Zivot and Andrews’ framework (1992) by including two endogenous structural breaks in the model. In terms of the robustness of the models, enabling two possible structural breaks is much more powerful than allowing for a single structural break. The modification of models can be expressed as follows:

\[
\Delta q_t = \mu + \beta_t + \varphi_t q_{t-1} + \theta DU1_t + \gamma DT1_t + \sigma DU2_t + \nu DT2_t + \sum_{i=1}^{4} \gamma_i \Delta q_{i-1} + \epsilon_t
\]

where, \( DU1_t = 1, \) if \( t > T_{B1} \) and zero otherwise; \( DU2_t = 1, \) if \( t > T_{B2} \) and zero otherwise; \( DT1_t = t - T_{B1}, \) if \( t > T_{B1} \) and zero otherwise; and \( DT2_t = t - T_{B2}, \) if \( t > T_{B2} \) and zero otherwise.

On one hand, \( DU1_t \) and \( DU2_t \) are dummy variables which enable structural changes to take place at \( T_{B1} \) and \( T_{B2}, \) respectively. On the other hand, \( DT1_t \) and \( DT2_t \) are two dummy variables which consider shifts in the trend at \( T_{B1} \) and \( T_{B2}, \) respectively. In this model, it allows for two structural breaks in the intercepts and the slope. With regard to the possible break dates \( (T_{B1} \text{ and } T_{B2}) \), they are selected based on the minimum value of \( t \)-statistic. Briefly speaking, Lumsdaine and Papell’s framework (1997) could find more evidence in rejecting the unit root hypothesis than Zivot and Andrews’ approach (1992) based on the empirical studies.

Another model was suggested by Saikkonen and Lütkepohl (2002) that structural break could occur over a number of periods and then have a smooth transition to a new level. Therefore, when a shift in the level of data generating process (DGP) occurs, testing for a unit root will give more accurate results. Thus, to take into account potential structural breaks, a level shift function indicated by a general nonlinear \( f(\theta)'\gamma \) is added to the deterministic term \( \mu_t \) of the DGP. Saikkonen and Lütkepohl’s model (2002) is as follows:

\[
\Delta q_t = \mu + \mu_t f(\theta)'\gamma + \epsilon_t
\]

where \( \theta \) and \( \gamma \) are parameter vectors and \( \nu_t \) is residual errors generated by an AR\((p)\) process with possible unit root. There are a few possible shift functions. In this study, \( f(\theta)'\gamma \) which can generate sharp one-time shifts at time \( T_B \) for suitable values of \( \theta \) is considered and applied.

\( \square \) An exponential distribution function which allows for a nonlinear gradual shift to a new level starting at time \( T_B \) is as follows:

\[
f_t(\theta) = \begin{cases} 
0, & t < T_B \\
1 - \exp[-\theta(t-T_B+1)], & t \geq T_B
\end{cases}
\]

In the shift term \( f_t^{(2)}(\theta)'\gamma \), both \( \theta \) and \( \gamma \) are scalar parameters, in which value of \( \theta \) is confined to the positive line and \( \gamma \) can take any value. Saikkonen and Lütkepohl’s model (2002) is based on the estimation of the deterministic term with two steps: (1) through a GLS de-trending procedure under the unit root null hypothesis and, (2) then subtracting it from the original series. With the adjusted series, an ADF type test will encompass terms to correct for estimation errors in the parameters of the deterministic part.

As moving toward cointegration test of PPP, it is imperative for the order of all the variables for
cointegration test to be the same in the long run. The order of integration is the number of times in which the time series variables must be differenced for it to become stationary. In line with cointegration method, long-run PPP is deemed to hold if the sum of nominal exchange rate and relative price level of a foreign country (i.e., the United States) in logarithmic form that is \((S_t + p_t^*)\) will be cointegrated with domestic price levels of respective countries \((p_t)\). Let it assume \(y_t = S_t + p_t^*\). Long-run PPP asserts that the relationship exists in a linear combination of the form \(y_t = \alpha_0 + \alpha_1p_t + \epsilon_t\), such that \(\epsilon_t\) is stationary and the cointegration vectors such that \(\alpha_1 = 1\) and \(\epsilon_t\) is the residuals of the regression equation.

The residual based test is deployed based on the Engle-Granger methodology (Engle & Yoo, 1987) which includes test for a unit root on residuals as well as conventional unit root tests. The order of cointegration of the variable is determined through ADF test. If the outcome indicates that the variable is integrated of order one, the long-run equilibrium relation is estimated by regressing \(y_t = S_t + p_t^*\) on, such as:

\[
y_t = \alpha_0 + \alpha_1p_t + \epsilon_t
\]

(8)

Absolute PPP asserts that \(y_t = \alpha_t\) and hence, this requires \(\alpha_0 = 0\) and \(\alpha_1 = 1\).

The test is then carried on by checking the residual of the equilibrium regression for stationary through DF test for unit root. In order to determine that these variables are cointegrated, the residual sequence from the equilibrium equation is denoted by \(\hat{\epsilon}_t\). \(\hat{\epsilon}_t\) is the series of the estimated residuals of the long-run relationship. If the series of the estimated residuals is found to be stationary then \(y_t\) and \(p_t\) series will be cointegrated. The autoregressive equation is estimated in the form of:

\[
\Delta \hat{\epsilon}_t = \beta_1 \hat{\epsilon}_{t-1} + \sum_{i=1}^{n} \beta_{i+1} \Delta \hat{\epsilon}_{t-i} + \epsilon_t
\]

(9)

If \(-2 < \beta_1 < 0\), it can be concluded that the residuals series is stationary. Therefore, \(y_t\) and \(p_t\) are integrated of order one, i.e., \(C(1,1)\).

If both variables (i.e., nominal exchange rates and relative price indices) are presumed to follow a random walk without converging in the long run, a method of error correction model can be pursued. Vector error correction model (VECM) is a restricted vector autoregressive method which encompasses Johansen-Juselius’ multivariate cointegration. VECM restricts the long-run behaviour of endogenous variables to converge to their cointegrating relationship while allowing for short-run adjustment. Johansen’s methodology takes its starting point in the vector autoregression (VAR) of order \(p\) given by:

\[
y_t = \mu + A_1y_{t-1} + \ldots + A_p y_{t-p} + \epsilon_t
\]

(10)

where, \(y_t\) is an \(n \times 1\) vector of variables that are integrated of order one—commonly denoted \(I(1)\)—and is an \(n \times 1\) vector of innovations. In the Johansen test procedure, there are two test statistics. In this study, the trace test is used and displayed as follows:

\[
\hat{\lambda}_{\text{trace}} (r) = -T \sum_{i=1}^{r} \ln(1 - \lambda_i)
\]

(11)

\(T\) denotes the sample size (the number of usable observation) and \(\lambda_i\) is the estimated values of the characteristic roots (also known as Eigen values). The trace statistic tests the null hypothesis that there is at most “\(r\)” cointegration relation against the alternative hypothesis of there are “\(n\)” cointegration relationship (i.e.,
series is stationary), $r = 0, 1, 2, ..., m - 1$. If the trace statistic is greater than the given critical value, then the null hypothesis is rejected and concludes that the series is stationary.

The construction of CPI-based real exchange rate consists of US dollar-based nominal exchange rates for Malaysia, Singapore, and Thailand and their respective consumer price indices. All the data are directly sourced from International Financial Statistics (IFS) of the International Monetary Fund (IMF) and cross-checked with the data sources from Bloomberg Terminal in order to ensure the consistency and reliability of the data.

**Findings**

In this section, the authors study CPI-based real exchange rates of three Southeast Asian economies—Malaysia, Singapore, and Thailand—are studied over the time period January 1980 to December 2014. US dollar is treated as the numeraire, since the United States has long been one of the major trading partners and its currency plays a dominant role in international trade (Goldberg & Tille, 2008).

*Figure 1*. CPI-based real exchange rates (in natural logarithms) of Malaysia, Singapore, and Thailand over a period of January 1980 to December 2014.

Figure 1 shows CPI-based real exchange rates of Malaysia, Singapore, and Thailand (in natural logarithms). As shown in Figure 1, potential structural breaks experienced by these economies occur in three different time zones: (1) 1983-1984, (2) 1997-1998, and (3) 2007-2008. Unexpected and drastic upsurge in real
exchange rates during 1997-1998 Asian financial crisis noticeably dominates the scene, indicating a potential structural shift in the mean and trend of the time series after 1997. It is an inevitable fact that figuring out another potential break with naked eyes without hesitation is barely possible, and thus this suggests that allowing the breaks to be endogenously determined is a sensible implementation.

The empirical analysis begins with a discussion of the results of ADF and PP unit root tests, in which an assumption of no structural changes exists. ADF and PP unit root tests are run firstly at levels (i.e., constant and trend) and and secondly at first differences of CPI-based real exchange rates series that serves as a benchmark for comparison.

The obtained results are displayed in Table 1. As shown in Table 1, both ADF and PP tests, conducted at levels, fail to reject the null hypothesis of a unit root for the three countries’ time series at the 1% significance level. This implies that the CPI-based real exchange rates of three nations (Malaysia, Singapore, and Thailand) in this study are non-stationary at levels. Therefore, to detect one endogenous structural break over a long period for the sample time series data, Zivot-Andrews’ model (Zivot & Andrews, 1992) is used and results are presented in Table 2 below.

Table 1
Results of Conventional Linear Unit Root Tests for a Period of January 1980 to December 2014

<table>
<thead>
<tr>
<th>Country</th>
<th>ADF test</th>
<th></th>
<th>PP test</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Level (constant and trend)</td>
<td>1st difference</td>
<td>Result</td>
<td>Level (constant and trend)</td>
</tr>
<tr>
<td>Malaysia</td>
<td>-1.8962</td>
<td>-16.2853**</td>
<td>I(1)</td>
<td>-1.7903</td>
</tr>
<tr>
<td>Singapore</td>
<td>-1.5331</td>
<td>-16.3957**</td>
<td>I(1)</td>
<td>-1.3669</td>
</tr>
<tr>
<td>Thailand</td>
<td>-2.1129</td>
<td>-15.3013**</td>
<td>I(1)</td>
<td>-1.8576</td>
</tr>
</tbody>
</table>

Notes. * and ** denote 5% and 1% levels of significance, respectively; for the ADF test, lags are selected automatically with the use of Schwarz Info Criterion.

Table 2
Results of Linear Unit Root Test With One Endogenous Structural Break (Zivot-Andrews (1992) Test) for a Period of January 1980 to December 2014

<table>
<thead>
<tr>
<th>Country</th>
<th>Level (constant and trend)</th>
<th>Break point</th>
<th>Level (constant)</th>
<th>Break point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malaysia</td>
<td>-5.9447**</td>
<td>August 1997</td>
<td>-3.5189</td>
<td>July 1997</td>
</tr>
<tr>
<td>Singapore</td>
<td>-4.0159</td>
<td>July 1997</td>
<td>-3.7741</td>
<td>July 1997</td>
</tr>
<tr>
<td>Thailand</td>
<td>-5.9362**</td>
<td>July 1997</td>
<td>-4.3568</td>
<td>July 1997</td>
</tr>
</tbody>
</table>

Notes. * and ** denote 5% and 1% level of significance, respectively; the 5% and 1% critical values in level with constant and trend are -5.08 and -5.57, respectively; in level without trend only they are -4.93 and -5.43, respectively; and lag selection is automatic on the basis of t-test.

Results obtained for CPI-based real exchange rates of Malaysia and Thailand show that null hypothesis of a unit root is rejected at level (with trend and constant), while results obtained for Singapore fail to reject the null hypothesis of a unit root. At level without trend, results obtained for the three countries’ data fail to reject the null hypothesis of a unit root for CPI-based real exchange rates. Based on the results obtained by Zivot-Andrews test (1992), the results consistently report a single break in July-August 1997. The 1997 structural break occurred was associated with the Asian financial crisis in 1997-1998, which triggered off a general meltdown of Asian currencies and was followed by financial turmoil. Among the three countries,
Malaysia and Thailand are the two countries that were affected the most.

Although allowing for structural breaks, Zivot-Andrews test (1992) does support PPP for Singapore as the $t$-statistics does not allow the null hypothesis to be rejected at the 1% level of significance. This may imply that mean reversion may not exist with the Singapore dollar/USD real exchange rate series, as when linear level shifts are allowed, the PPP puzzle may remain unsolved. According to Lumsdaine and Papell (1997), Zivot-Andrews test (1992) may lead to biased results as more than one break may actually exist.

Table 3
Results of Linear Unit Root Test (Lumsdaine-Papell (1997) Test) with Two Endogenous Structural Breaks for a Period of January 1980 to December 2014

<table>
<thead>
<tr>
<th></th>
<th>Level (constant and trend)</th>
<th>Break points</th>
<th>Level (constant)</th>
<th>Break points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>July 1997</td>
<td></td>
<td>July 1997</td>
</tr>
<tr>
<td>Singapore</td>
<td>-4.8160</td>
<td>October 1985</td>
<td>-4.5850</td>
<td>June 1997</td>
</tr>
<tr>
<td></td>
<td></td>
<td>July 1997</td>
<td></td>
<td>October 2009</td>
</tr>
<tr>
<td></td>
<td></td>
<td>June 1997</td>
<td></td>
<td>December 2005</td>
</tr>
</tbody>
</table>

Notes. * and ** denote 5% and 1% level of significance, respectively; the 5% and 1% critical values in level with constant and trend are -6.75 and -7.19 (in level with constant and trend) and -6.16 and -6.74 (in level without trend), respectively; and lag selection is automatic on the basis of $t$-test.

Table 4
Results of SL Test With Exponential Shift for a Period of January 1980 to December 2014

<table>
<thead>
<tr>
<th></th>
<th>Break point</th>
<th>Lag</th>
<th>Coefficients</th>
<th>SL-statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$d$ (const)</td>
<td>$d$ (trend)</td>
</tr>
<tr>
<td>Malaysia</td>
<td>Feb. 1998</td>
<td>1</td>
<td>0.6490</td>
<td>0.0022</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(854.12)</td>
<td>(0.1422)</td>
</tr>
<tr>
<td>Singapore</td>
<td>Jan. 1998</td>
<td>1</td>
<td>0.3278</td>
<td>-0.0004</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(512.68)</td>
<td>(-0.0319)</td>
</tr>
<tr>
<td>Thailand</td>
<td>Feb. 1998</td>
<td>1</td>
<td>3.2050</td>
<td>0.0018</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(3,189.61)</td>
<td>(0.0859)</td>
</tr>
</tbody>
</table>

Critical values for SL-statistics

<table>
<thead>
<tr>
<th></th>
<th>1%</th>
<th>5%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-3.55</td>
<td>-3.03</td>
<td>-2.76</td>
</tr>
</tbody>
</table>

Notes. ***, **, and * denote the statistical significance at 99%, 95%, and 90% confidence levels, respectively; critical values are sourced from Lanne et al. (2002); and the $t$-statistics of each coefficient are in parentheses.

Lumsdaine-Papell test (1997) allowing for two possible structural breaks is proven to be more robust than Zivot-Andrews test (1992) as more significant results are found for Malaysia and Thailand from Lumsdaine-Papell test (1997) as shown in Table 3, as compared to those obtained from Zivot-Andrews test (1992) (see Table 2). However, with the real exchange rate time series of Singapore, the null hypothesis of a unit root is not rejected, suggesting that PPP may not hold for Singapore in the long run. Despite that the real exchange rates fail to demonstrate mean-reverting behavior, it is worth to take note that possible break dates based on the minimum value of $t$-statistic (Table 3) could provide a clearer picture with major events, such as the commodity crisis (1985-1886), the Asian crisis (1997-1998), and the energy shock (2005), that have
permanent effects on the exchange rates series.

As pointed out by recent studies that unit root tests may be biased once nonlinearities in the deterministic components exist, an alternative approach—the Saikkonen and Lütkepohl test (2002), that considers structural breaks with a smoother functional form for the transition period could be much more informative than the linear endogenous break tests. The Saikkonen and Lütkepohl test (2002) test with the optimal lag length \( k = 1 \) being determined by the standard Akaike Info Criterion has been displayed in Table 4. The estimated coefficient of \( \Delta q(t-1) \) represents \( \Delta q(t-1) \); \( d(\text{const}) \) represents \( Z_1 = [1, 0, ..., 0] \), the regressor for initial estimation of the constant; \( d(\text{trend}) \) represents \( Z_2 = [1, 1, ..., 1] \), the regressor for the initial estimation of the trend; and \( d(\text{shift}) \) represents \( Z_3 = [f_1(\theta) : f_2(\theta) : \ldots : f_r(\theta)] \), the regressor for initial estimation of the exponential shift parameter.

Based on the findings from unit root test with exponential shift, the parameters of exponential shift \( d(\text{shift}) \) are significant to take the non-linear shift during 1997-1998, which is consistent with results obtained from Zivot-Andrews test (1992) and Lumisdaine-Papell test (1997) (see Table 2 and Table 3). This may suggest that the impact of the Asian financial crisis is present. During the crisis, the USD was appreciating against most Asian currencies (including Ringgit Malaysia, Sing dollar, and baht), suggesting that bilateral trade adjustments due to the volatility of exchange rates existed. However, Saikkonen-Lütkepohl test (2002) is unable to reject the null hypothesis of a unit root for all three countries, contradicting with results obtained from Saikkonen-Lütkepohl test (2002) linear tests. This may suggest that the non-linear behavior of the three currencies and US dollar-based real exchange rates is rather weak.

<table>
<thead>
<tr>
<th>Country</th>
<th>CPI-based real exchange rate</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malaysia</td>
<td>Jan. 1980-Dec. 2014</td>
<td>-0.0089</td>
</tr>
<tr>
<td></td>
<td>Jan. 1986-Dec. 1998</td>
<td>0.0118</td>
</tr>
<tr>
<td></td>
<td>Jan. 1999-Dec. 2014</td>
<td>-0.0091</td>
</tr>
<tr>
<td>Singapore</td>
<td>Jan. 1980-Dec. 2014</td>
<td>-0.0051</td>
</tr>
<tr>
<td></td>
<td>Jan. 1986-Dec. 1998</td>
<td>-0.0112</td>
</tr>
<tr>
<td></td>
<td>Jan. 1999-Dec. 2014</td>
<td>-0.0005</td>
</tr>
<tr>
<td>Thailand</td>
<td>Jan. 1980-Dec. 2014</td>
<td>0.0123</td>
</tr>
<tr>
<td></td>
<td>Jan. 1986-Dec. 1998</td>
<td>-0.0348</td>
</tr>
<tr>
<td></td>
<td>Jan. 1999-Dec. 2014</td>
<td>0.0035</td>
</tr>
</tbody>
</table>

Notes. The coefficient of mean reversion (\( \phi \)) is taken account such that \( \hat{\rho} = \ln(\frac{1}{\hat{\phi}})/\ln|\hat{\rho}| \), where \( \phi = (\hat{\rho} - 1) \); \( S_e \) represents the standard errors of estimated \( \hat{\rho} \); and \( t \) denotes the estimated monthly half-life with CI denotes confidence interval.

Pertaining to the detected break dates on the series, the half-life estimations are performed to determine the magnitude of real exchange rate adjustment towards long-run PPP. The full sample estimations of half-life are displayed in Table 5. As shown in Table 5, the half-life estimations of each country show that the degree of the CPI-based real exchange rate adjustment towards PPP varies against each other upon the duration of the
study. For Malaysia, the full sample estimations of half-life are reported to be approximately 77.5 months with the 95% confidence interval of 0.32 month to 154.68 months. For Singapore and Thailand, the half-life estimations for CPI-based real exchange rates (full sample) are 135.6 months and 56.0 months respectively. These reported that half-life estimates are far greater than the estimates of three to five years as suggested in Rogoff (1996). After converting, the findings demonstrate that the number of years required for the initial shock from the long-run level to dissipate by half is longer than usual.

Particularly, the sub-sample estimations display that the exchange rate misalignment is more evident after 1997 (the Asian financial crisis). The half-lives for real exchange rates which are longer than three years suggest that the PPP-hypothesis is found to be operationally less relevant. Evidence of lengthy half-lives for real exchange rates in the presence of high degree volatility may be biased due to the presence of cumulative effects of the shocks. This is particularly relevant as the period of study is featured by great adjustments in Asian exchange rates and the major change in terms of the flexibility of their exchange rate arrangements.

As mixed evidences of long-run PPP are found for Malaysia, Singapore, and Thailand through the three unit root tests and half-life estimations, further cointegration tests are carried out. Based on results of the ADF and PP tests (Table 1), consumer price indices as well as the nominal exchange rates of Malaysia, Singapore, and Thailand are found to be integrated of order one, i.e., I(1), as first differences of these variables are found to be stationary. Since the condition to apply a cointegration test has been fulfilled, the cointegration analysis is therefore performed.

Table 6
Results of Full-Sample Equilibrium Regression Test for Three Countries for a Period of January 1980 to December 2014

<table>
<thead>
<tr>
<th></th>
<th>Estimated</th>
<th>Standard error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malaysia</td>
<td>1.5888</td>
<td>0.0217</td>
</tr>
<tr>
<td>Singapore</td>
<td>0.7494</td>
<td>0.0302</td>
</tr>
<tr>
<td>Thailand</td>
<td>1.2565</td>
<td>0.0195</td>
</tr>
</tbody>
</table>

As shown in Table 6, the estimated coefficient for Malaysia, Thailand, and Singapore are higher from unity: near to unity and lower than unity, respectively. In order to examine the residual of the equilibrium regression of each country for the period of January 1980 to December 2014, Dickey-Fuller (DF) test statistics will be estimated and then compared with the critical values for the Engle-Granger cointegration test (Engle & Yoo, 1987). The null hypothesis of “no integration” is established against its alternative hypothesis.

Table 7
Results of Engle-Granger Test for a Period of January 1980 to December 2014

<table>
<thead>
<tr>
<th></th>
<th>Dickey-Fuller test statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malaysia</td>
<td>-1.9100</td>
</tr>
<tr>
<td>Singapore</td>
<td>-1.8432</td>
</tr>
<tr>
<td>Thailand</td>
<td>-2.1413</td>
</tr>
</tbody>
</table>

Critical values for Engle-Granger cointegration test (2 variables)

<table>
<thead>
<tr>
<th></th>
<th>1%</th>
<th>5%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-3.921</td>
<td>-3.350</td>
<td>-3.054</td>
</tr>
</tbody>
</table>

Note. The DF t-statistics of the residuals of the equilibrium regression for three countries fail to reject unit root null.
As shown in Table 7, the DF test statistics estimated for Malaysia, Singapore, and Thailand are greater than the critical value of -3.921 at the 1% level of significance, suggesting that the null hypothesis of no integration cannot be rejected at the 1% level of significance. This implies that $y_t$ and $p_t$ are not cointegrated during the period of January 1980 to December 2014. This indicates that the residuals obtained from the DF test may not be stationary and the real exchange rate of these three chosen countries may be driven by stochastic trends.

To confirm the relatively weak evidence of PPP found for the real exchange rates of Malaysia, Singapore, and Thailand above, another common cointegration test—Johansen cointegration test, is carried out. Based on the time of breaks obtained for Malaysia, Singapore, and Thailand from Lumsdaine-Papell test (1997) (see Table 3), Johansen cointegration test is performed. After allowing for structural breaks in the CPI-based real exchange rate series, relatively strong evidence of cointegration can be found for Malaysia, Singapore, and Thailand (see Table 8). This suggests that PPP relationship for these three nations has been affected greatly by the crises. In addition, when the two breaks are allowed to jointly take place in the series, results obtained for the three countries suggest strongly that the null hypothesis of a unit root should be rejected at the 5% level of significance, implying that cointegration among relative prices and exchange rates among the three countries’ currencies and the US dollar exist in the long-run. In short, significantly strong evidence of PPP are found for Malaysia, Singapore, and Thailand in relation to the US.

Table 8
Results of Johansen Cointegration Tests ($\lambda_{\text{trace}}$ Statistic) Which Allows for Structural Break(s) for a Period of January 1980 to December 2014

<table>
<thead>
<tr>
<th>Null hypothesis</th>
<th>$T_{B_1}$</th>
<th>$T_{B_2}$</th>
<th>$T_{B_1}$ and $T_{B_2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malaysia</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>30.11</td>
<td>88.01*</td>
<td>115.78*</td>
</tr>
<tr>
<td>$r = 1$</td>
<td>6.39</td>
<td>7.39</td>
<td>29.25</td>
</tr>
<tr>
<td>Singapore</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>84.79*</td>
<td>58.68*</td>
<td>84.50*</td>
</tr>
<tr>
<td>$r = 1$</td>
<td>28.70</td>
<td>8.29</td>
<td>29.23</td>
</tr>
<tr>
<td>Thailand</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>116.16*</td>
<td>41.85*</td>
<td>117.18*</td>
</tr>
<tr>
<td>$r = 1$</td>
<td>11.01</td>
<td>11.86</td>
<td>14.76</td>
</tr>
</tbody>
</table>

Notes. $T_B$ stands for time of break; * denotes rejection of the null hypothesis of a unit root at the 5% significance level; and all the values of $t$-tests for $\lambda_{\text{trace}}$ statistics for the three countries reject the null hypothesis of no cointegration between $y_t$ and $p_t$ ($r = 0$) after $T_{B_1}$ and $T_{B_2}$ are considered.

Conclusions

This study re-examines the mean-reversion hypothesis for the real exchange rates in the US dollar terms of three countries, i.e., Malaysia, Singapore, and Thailand over a period of January 1980-2014. Using linear and non-linear unit root tests to detect possible endogenous break(s), real exchange rates for currencies of the three countries are examined for the long-run purchasing power parity (PPP) during the study period. Results obtained from ADF and PP unit root tests show that no structural changes taken place and all CPI-based
exchange rates series of the three countries consistently contain a unit root. Subsequently, different endogenous break unit root tests, i.e., Zivot-Andrews test (1992) and Lumsdaine-Papell test (1997) were conducted and results showed that the time series of Malaysia and Thailand are trend-stationary, when breaks are considered. However, Saikkonen and Lütkepohl test (2002) failed to show any evidence of mean-reversion behavior for the real exchange rates of all three countries. Moreover, short-run volatility of real exchange rates is found to be very high in nature and speed of adjustment to PPP is found to be very low. This suggests that half-life measures may be operationally less applicable towards the countries studied. In terms of cointegration tests, although Engle-Granger test failed to find any significant evidence of integration of PPP for all the three countries, Johansen cointegration test provides results with a higher degree of mean reversion for the real exchange rates of all the three countries, once break points are considered. Hence, the results suggest that if structural breaks exist and are ignored, the conventional Johansen procedure may lead to erroneous results. In other words, real exchange rates in Malaysia, Singapore, and Thailand are found to be affected greatly by a series of shocks. Therefore, allowing for multiple breaks is vindicated when testing the validity of long-run PPP for these three countries. The findings shed lights on the importance of relationship between exchange rates and prices and also their implication to future policy making and forecasting decisions.

References


Lothian, J. R., & Taylor, M. P. (1996). Real exchange rate behaviour: The recent float from the perspective of the last two


