Linearity and stationarity of South Asian real exchange rates

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February 2006
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Abstract

The linearity and stationarity of the real exchange rates of India, Nepal, Pakistan and Sri Lanka are investigated using formal linearity and the recently developed nonlinear stationary test procedures. Results obtained show that these real exchange rates are stationary albeit the presence of nonlinearity.

JEL Classification: F31, N15, C52

Key Words: Nonlinearity; Real exchange rates; South Asia; linearity test; nonlinear stationary test

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1. Introduction

Numerous documentations on the findings of nonlinearity in the exchange rates have been recently added to the existing established exchange rate study. Micheal et al. (1997), Sarantis (1999), Taylor and Peel (2000), Baum et al. (2001) and Peel et al. (2001), are among some of the recent articles reporting the existence of nonlinear exchange rate behaviour in the context of developed nations. Earlier on, Peel and Speight (1996) have detected nonlinearities in the exchange rate of East European countries. In a separate endeavour, Ma and Kanas (2000) found nonlinearities from those countries under Exchange Rate Mechanism. Sarno (2000a, b), on the other hand, documented the presence of nonlinearity in the real exchange rates of Middle East and highly inflation countries. Of late, Liew et al. (2003, 2004) and Liew (2004) found strong evidence of nonlinear behaviour of US dollar as well as Japanese yen based real exchange rates in the Asian region. This is followed by Anuruo et al. (2006) complement the literature by offering empirical evidence of nonlinear real exchange rates from the African continent.

One important implication of these documentations is that linear testing frameworks may no longer be taken for granted as adequate tools in the study of exchange rate. Another equally crucial implication is that linearity property of exchange rates, which has been neglected in the past, partially due to ignorance of the plausible presence of nonlinearities and partially due to the unavailability of advance information and computer technology, must be predetermined using formal linearity test prior to the
application any econometric testing and estimation procedures. Otherwise, robustness of the results and relevance of the inference made from these studies are doubtful. Conventionally, it has been a common and formal practice to subject time series including exchange rates to linear testing and estimation procedures with the unjustified assumption that the series under tested is linear in nature. Remarkably, these results are meaningful only if the null hypothesis of linearity has not been rejected by formal linearity test (Liew et al. 2003; Tang et al., forthcoming). In this respect, one easily conducted formal linearity test, which has been adopted in most of the above-mentioned studies to uncover evidence of nonlinearity in the real exchange rates is the Luukkonen-Saikkonen-Teräsvirta (LST) linearity test (Luukkonen et al., 1988). Remarkably, besides exchange rate study, the usefulness of LST test has been extended to the study of, among others, income convergence (Liew and Lim, 2005) and balancing item (Tang et al., forthcoming). Section 2 offers a brief review of this test procedure.

Besides linearity, stationary is another issue in the analysis of time series. As opposed to linearity, stationary has received considerably more attention from economic researchers. In fact, stationary test is conventionally the first test prior to any other econometric testing and estimating procedures. Nonetheless, previous stationary testing procedures like the augmented Dickey-Fuller type (Dickey and Fuller, 1979) and Philips-Perrons (1988) type have implicit assumption of linear time series. Responsive to the plausible presence of nonlinearity in time series, Kapetanious et al. (KSS) (2003) recently developed a stationary test to test the null hypothesis of non-stationary against the alternative of nonlinear stationary. Typically, Liew et al. (2003, 2004, 2005) uncovered 8 (6) US dollar (Japanese yen)-based stationary real exchange
out of 13 selected countries in the Asian region by this KSS test. In complementary, Anuruo et al. (2006) revealed that 11 out of 13 selected US dollar-based African real exchange rates are stationary by the same test. This test will be reviewed shortly in Section 3.

In reviewing the literature, it is observed that study of South Asian exchange rates in the nonlinear perspective is rare and thus more effort is needed in this context. To the best of our knowledge, Chaudhury (2004) remains the sole study in this region that incorporated nonlinear testing frameworks but the author confined their research to Bangladesh only. Earlier on, Liew et al. (2003, 2004) and Liew (2004) conducted a series of research on the Asia region but the Southern part of Asia is not considered in these studies. As such, it would be interesting to know what the South Asian real exchange rates have to say on this context. Motivated by the enthusiasm to put up the shutters on this literature gap, this study is therefore conducted to determine the linearity and stationary properties of South Asian real exchange rates.

The remainder of this paper is structured as follows: Sections 2 and 3 offers a brief review of the Luukkonen et al. (LST) (1988) linearity test and the Kapetanios et al. (KSS) (2003) nonlinear stationary test, which will be applied in this study. Section 3 described the data of study, whereas Section 4 presents the empirical results of the current study and offers related interpretation. The final section concludes this study.
2. Luukkonen et al. (LST) (1988) Linearity Test

To examine whether South Asian real exchange rates are linear or nonlinear in nature, this study adopts the following linearity test procedures suggested in the work of Luukkonen et al. (1988) and Teräsvirta (1994):

\[
y_t = \alpha_0 + \sum_{j=1}^{p} \alpha_j y_{t-j} + \sum_{j=1}^{d} \beta_j y_{t-j} y_{t-d} + \beta_{p+1} y_{t-d}^3 + \epsilon_t, \quad (1)
\]

where \( y_t \) is the real exchange rate, \( p \) and \( d \) are the optimal autoregressive order and delay lag length respectively. As usual, \( \epsilon_t \) is the stochastic errors with zero mean and constant variance under the null hypothesis.

The test procedure as specified in Equation (1) is the augmented first order auxiliary regression in the work of Luukkonen et al. (1988)\(^1\), which have been developed based on the idea of testing the null hypothesis that all \( \beta \)'s in the following framework are simultaneously zero, against the alternative hypothesis that at least one \( \beta \) is not zero.

\[
y_t = \alpha_0 + \sum_{j=1}^{p} \alpha_j y_{t-j} + G(y_{t-d}) \left[ \beta_0 + \sum_{j=1}^{d} \beta_j y_{t-j} \right] + \nu_t, \quad (2)
\]

where \( G(y_{t-d}) \) denotes the transition function which may be specified as exponential or logistic function (see Luukkonen et al., 1988). \( \nu_t \) is the usual stochastic errors.

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\(^1\) See Luukkonen et al. (1988) for other versions of auxiliary regressions.
Equation (2) actually specifies the Smooth Transition Autoregressive (STAR) data generating process, where \( G(y_{t-a}) \left[ \beta_0 + \sum_{j=1}^p \beta_j y_{t-j} \right] \) is the nonlinear component. Note that if \( \beta \)'s =0, Equation (2) would simply reduce to the linear Autoregressive (AR) process. However, as the properties of the transition function, the coefficients of nonlinear terms (\( \beta \)'s) of the variable under estimation are not identified under the null hypothesis, Luukkonen et al. (1988) reparameterized Equation (2) into its auxiliary regression version as in Equation (1) using the basic idea of Taylor expansion approximation. Accordingly, rejection of null hypothesis of all \( b \)'s =0 in the auxiliary Equation (1) against the alternative that at least one \( b \) is non zero implies the presence of nonlinearity in favour of STAR(\( p \)) framework. Hence, the rejection of null hypothesis provides evidence against the adequacy of linear framework. As such, it is reasonable for one to doubt the reliability of econometric testing procedures constructed under the assumption of linear data generating process.

The decision on whether linear or nonlinear framework is appropriate may be based on \( F \)-type and the Lagrange Multiplier-type (\( LM \)) (which has asymptotical chi-squared distribution) test statistics. Note that in conducting this LST test, it has been a common practice to fix the optimal autoregressive order, \( p \) which has to be determined in advance based on partial autocorrelation function (PACF) of the series under tested; see, for instance, Taylor and Peel (2000), Liew et al. (2003, 2004), Liew and Lim (2005), Anuoro et al. (2006) and Tang et al. (forthcoming). As for the optimal delay parameter, \( d \), which also needs pre-determination, this study chooses \( d \in \{1,\ldots,8\} \) from the one that maximizes the LST test statistics. To avoid the use of conventional tabulated critical values, which have various assumptions including
normally distributed, homoscedastic and non-serially correlated errors, this study bootstraps the relevance critical values based on 5000 replicated series using empirical probability distribution and exact sample size (124 observations). Remarkably, unlike simulation, which is based on stochastic distribution, bootstrapping has a disadvantage of case-specific (different series has different empirical probability distribution thereby different bootstrap critical values) and thus cannot be applied to all situations. Nonetheless, it is this unique feature that makes the bootstrap critical values more robust in any individual case than those simulated for general purpose.


Just like a linear series, a given nonlinear series may or may not be stationary. In this perspective, the following stationary test constructed on the nonlinear framework due Kapetanios et al. (KSS) (2003) to may be applied:

$$
\Delta z_t = \sum_{j=1}^{p} \rho_j z_{t-j} + \delta z_{t-1} + \omega_t, \quad (3)
$$

where $z_t$ is the de-meaned and de-trended $y_t$ series and $\omega_t$ denotes the usual stochastic errors.

The testing framework as depicted in Equation (3), which is analogue to the augmented Dickey-Fuller test, is actually a reparameterized version of the following specification:
\[ \Delta x_t = \phi z_{t-1}[1 - \exp(-\theta z_{t-1}^2)] + \epsilon_t, \]  \hspace{1cm} (4)

which is constructed to detect the presence of non-stationarity against nonlinear but globally stationary STAR process, in which the direct testing of null hypothesis,

\[ H_0: \theta^2 = 0 \]

against the alternative \( H_1: \theta^2 > 0 \) is infeasible, since \( \phi \) is not identified under the null.

The null hypothesis, \( H_0: \delta = 0 \) may be tested against the alternative, \( H_1: \delta < 0 \) in Equation (3) based on \( t \)-type statistic of \( \delta \), in which the asymptotical distribution is non-normal and thus decision cannot be based on the conventionally tabulated student-\( t \) table. The critical values obtained via stochastic simulation for a sample size of 1000 observations are available in Kapetanios et al. (KSS) (2003). Nonetheless, for robustness, this study bootstraps the relevance critical values based on 5000 replicated series using empirical probability distribution and exact sample size (124 observations).

4. Data of Study

The U.S. dollar denominated real exchange rates for four selected South Asian economies (India, Nepal, Pakistan and Sri Lanka) in their logarithmic form 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 \( y_t \) and \( s_t \) are, respectively, the logarithm of real and nominal exchange rates (domestic price of US currency) at time \( t \), and \( p_t^* \) and \( p_t \) are the logarithms of U.S. and domestic price
levels respectively. We use the end of period nominal bilateral exchange rate data series, taken from various issues of International Financial Statistics published by IMF. The domestic price is the consumer price index (CPI) of domestic and foreign price is U.S. CPI. Our data spans from the first quarter of the year 1973 to the fourth quarter of the year 2003 (1973:1 to 2003:4). The plots of the real exchange rates series are shown in Figure 1.

4. Empirical Results and Interpretations

As a preliminary exercise, various commonly linear stationary tests including the augmented Dickey-Fuller test (Dickey and Fuller 1979), Dickey-Fuller test with GLS detrending (Elliott et al., 1996), Phillips-Perron test (Phillips and Perron, 1988), Phillips-Perron test with GLS detrending of Ng and Perron (2001) and the Kwiatkowski-Phillips-Schmidt-Shin test of Kwiatkowski et al. (1992). The results are summarized in Table 1.

It is clear from Table 1 that all tests consistently suggest that the real exchange rate is non-stationary for India, whereas for Sri Lanka, stationary. As for the other two rates, results from the linear tests are mixed. In particular, all results except from the NP test indicate that the Nepal real exchange rate is non-stationary. On the other hand, Pakistan real exchange rate is non-stationary based on ERS, NP and KPSS tests, but stationary by the ADF and PP tests. Note that at this moment, it is rather too early to

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2 The selection is based on the availability of completed data set.
draw any conclusion from these stationarity tests, as they are only reliable under the assumption of the linear real exchange rates. In this context, Kapetanios et al. (2003) show via simulation that linear stationary tests have lower power if the data generating process is nonlinear in nature. Moreover, Liew et al. (2004) have empirical demonstrated that linear stationary tests failed to detect any stationary Asian real exchange rates, which contain nonlinearity. Hence, it is important to identify the linearity of the real exchange rate, before the selection of appropriate testing procedures, to avoid misleading statistical inference and implications. To serve this purpose, the current study adopts the formal LST linearity test of Luukkonen et al. (1988).

Prior the application of the LST linearity test, however, the optimum autoregressive order $p$ needs to be empirical determined in advance. In this respect, the partial autocorrelation functions (PACFs) for the South Asian real exchange rates are plotted in Figure 2. It is obvious from Figure 2 that $p$ equals one, in all cases, based on the PACFs criterion.

Having determined the autoregressive order, we then proceed to examine whether the South Asian real exchange rates are linear or nonlinear in nature using the Luukkonen et al. (1988) linearity test. This test result is summarized in Table 2. We know from Table 2 that the null of linearity has been rejected by both the $F$-type and the $LM$-type LST test statistics at standard significance levels in all cases. The rejection of the null hypothesis indicates that the nonlinear parameters are jointly significant by the $LST$
test, thereby suggesting that linear framework is inadequate in characterizing the behaviour of the South Asian real exchange rates. Thus, estimating the linear stationary tests disregarding the presence of nonlinearity will yield deceptive conclusions. Particularly, the above-reported results from the linear testing procedures are neither here nor there and so should be inferred with caution.

This finding is consistent with and complements the earlier findings of nonlinearity in the real exchange rates of industrialised nations (Baum et al., 2001), Asian economies (Liew et al., 2003) and African countries (Anuruo et al., 2006).

The evidence of nonlinearity in the real exchange rates of this study stipulates the application of the nonlinear stationary test. Subsequently, the KSS test is performed and the estimated results are summarized in Table 3.

It is obvious from Table 3 that the null hypothesis of non-stationary has been rejected in favour of nonlinear stationary for the real exchange rates of India, Nepal, Pakistan and Sri Lanka, implying that they are all stationary in the nonlinear sense. This neat result is in sharp contrast to the mixed results from linear tests. The contradicting results are not surprising considering the fact that linear test is not as powerful as nonlinear test in the present of nonlinearity (Kapetanious et al., 2003; and Liew et al. (2003, 2004). Moreover, the current finding provides additional empirical evidence of
nonlinear stationary real exchange rates in the South Asian region to the existing literature; see among others, Baum et al. (2001), Liew et al. (2004), and Anuruo et al. (2006).

5. Conclusions

This study utilizes formal linearity test suggested in the work of Luukkonen et al. (1988) to show that South Asian real exchange rates are nonlinear in movement and so reject the appropriateness of conventional testing and estimating procedures such as stationary test, the order of integration test, the Granger causality test and the cointegration test, which are constructed based on the linear framework—in exchange rate study of this region. These linear procedures are relevance only when formal linearity test result fails to provide evidence on the existence of nonlinearity. By the same principle, exchange rate policy makers can no longer make valid decision upon disregarding the present of nonlinearity in real exchange rates in this region.

Based on the recently formulated nonlinear stationary test due to Kapetanious et al. (2003), it has been shown in this study that South Asian real exchange rates are not only nonlinear but also stationary. Few important implications of this finding are in line. The major one is that stationarity of real exchange rates validates the long run purchasing power parity (PPP), thereby providing fresh evidence to the old PPP literature (see Baum et al. 2001, for instance) from South Asia. More importantly, it signifies that the nominal exchange rates in this region are in equilibrium with their
respective macroeconomic fundamental. For this, credit should be given to the leaders of these economies, which are relatively poor as compare to other Asian economies, for their successfulness in maintaining the macroeconomic equilibrium at least.

Moreover, stationary real exchange rates in the South Asia means that the corresponding nominal exchange rates exhibit long run co-movement with the corresponding CPI-based relative prices. This in turn indicates that the exchange rates forecasters (for the purpose of international trade and investment, etc) may depend on the anticipated relative price to predict the future movement of South Asia nominal exchange rates. From the other perspectives, government policy makers of the region may monitor the movement of nominal exchange rates and intervene at the right time to minimise excessive fluctuation, or to correct mis-adjustment, of nominal exchange rate when deemed necessarily judging from the relative price equilibrium. Nonetheless, attention should be given to nonlinearity when dealing with monitoring and forecasting. Last but not least, stationarity of real exchange rates implies the convergence of prices (in dollar terms) of consumer goods in South Asian countries and US, thereby indicating no arbitrage opportunity of these goods.
References


Figure 1: Plots of real exchange rates by country
Figure 2: The PACFs of real exchange rates by country
Table 1. Result of Linear Stationary Tests.

<table>
<thead>
<tr>
<th>Country</th>
<th>Test Statistic (optimal lag)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ADF</td>
<td>ERS</td>
<td>PP</td>
<td>NP</td>
<td>KPSS</td>
</tr>
<tr>
<td>India</td>
<td>-2.1056 (0)</td>
<td>-1.9432 (0)</td>
<td>-2.4904 (3)</td>
<td>-1.8760 (0)</td>
<td>0.1293 (8)$^X$</td>
</tr>
<tr>
<td>Nepal</td>
<td>-2.0078 (0)</td>
<td>-2.4688 (7)</td>
<td>-3.4031 (6)</td>
<td>-2.7805 (0)$^X$</td>
<td>0.1320 (8)$^X$</td>
</tr>
<tr>
<td>Pakistan</td>
<td>-4.2090 (0)$^I$</td>
<td>-1.1649 (0)</td>
<td>-4.1448 (5)$^I$</td>
<td>-1.0481 (0)</td>
<td>0.1002 (8)</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>-4.8839 (0)$^I$</td>
<td>-4.8667 (0)$^I$</td>
<td>-4.8948 (5)$^I$</td>
<td>-4.0907 (0)$^I$</td>
<td>0.0369 (6)</td>
</tr>
</tbody>
</table>

Critical Values

<table>
<thead>
<tr>
<th>Level</th>
<th>ADF</th>
<th>ERS</th>
<th>PP</th>
<th>NP</th>
<th>KPSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1%</td>
<td>-4.03</td>
<td>-3.55</td>
<td>-4.03</td>
<td>-3.42</td>
<td>0.216</td>
</tr>
<tr>
<td>5%</td>
<td>-3.45</td>
<td>-3.00</td>
<td>-3.45</td>
<td>-2.91</td>
<td>0.146</td>
</tr>
<tr>
<td>10%</td>
<td>-3.15</td>
<td>-2.72</td>
<td>-3.15</td>
<td>-2.62</td>
<td>0.119</td>
</tr>
</tbody>
</table>

Note: ADF, ERS, PP, NP and KPSS are, in that order, the augmented Dickey-Fuller test (Dickey and Fuller 1979), Dickey-Fuller test with GLS detrending (Elliott et al., 1996), Phillips and Perron (1988), PP test with GLS detrending of Ng and Perron (2001) test Kwiatkowski-Phillips-Schmidt-Shin test of Kwiatkowski et al. (1992). The null (alternative) hypothesis of the KPSS test is stationary (non-stationary), whereas the reverse is true for all other tests. Superscripts I, V and X denote statistically significant at 1, 5 and 10% level respectively. The optimal lags in ADF, ERS and NP tests are selected based on modified AIC, whereas the Newey-West bandwidth (Newey and West, 1994) selection method is employed in PP and KPSS tests.
Table 2. Linearity Test Results

<table>
<thead>
<tr>
<th>Country</th>
<th>p</th>
<th>d</th>
<th>LST test statistic</th>
<th>Bootstrap critical values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10%</td>
</tr>
<tr>
<td><strong>F-type</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>1</td>
<td>1</td>
<td>6.8181 X</td>
<td>6.130</td>
</tr>
<tr>
<td>Nepal</td>
<td>1</td>
<td>4</td>
<td>4.412 X</td>
<td>4.274</td>
</tr>
<tr>
<td>Pakistan</td>
<td>1</td>
<td>8</td>
<td>5.701 Y</td>
<td>4.138</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>1</td>
<td>1</td>
<td>50.017 I</td>
<td>6.047</td>
</tr>
<tr>
<td><strong>LM-type</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>1</td>
<td>1</td>
<td>7.431 X</td>
<td>6.720</td>
</tr>
<tr>
<td>Nepal</td>
<td>1</td>
<td>4</td>
<td>4.706 X</td>
<td>4.596</td>
</tr>
<tr>
<td>Pakistan</td>
<td>1</td>
<td>8</td>
<td>6.617 X</td>
<td>4.798</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>1</td>
<td>1</td>
<td>90.204 I</td>
<td>6.623</td>
</tr>
</tbody>
</table>

Note: Superscripts I, V and X denote statistically significant at 1, 5 and 10% level respectively.
Table 3. Nonlinear Test Results

<table>
<thead>
<tr>
<th>Country</th>
<th>$p^*$</th>
<th>KSS statistic</th>
<th>Bootstrap KSS critical values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>India</td>
<td>1</td>
<td>-2.578$^V$</td>
<td>-1.711</td>
</tr>
<tr>
<td>Nepal</td>
<td>1</td>
<td>-3.461$^I$</td>
<td>-1.665</td>
</tr>
<tr>
<td>Pakistan</td>
<td>1</td>
<td>-5.131$^I$</td>
<td>-1.663</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>2</td>
<td>-9.961$^I$</td>
<td>-1.599</td>
</tr>
</tbody>
</table>

Note: Superscripts $V$ and $X$ denote statistically significant at 5 and 10% level respectively.