Asymmetric Adjustment and Long-Run Purchasing Power Parity in BRICs

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ABSTRACT

The purpose of this study is to investigate whether the purchasing power parity (PPP) theory holds true for Brazil, Russia, India, and China (BRICs). We use the newly developed momentum threshold cointegration tests advanced by Enders and Siklos (2001) to investigate if there is any asymmetric adjustment for BRICs. We show that while Engle-Granger test assumes only symmetric adjustment does not obtain the results of the cointegration relationship for BRICs, the threshold cointegration test provides clear evidence of the long-run PPP with asymmetric adjustment for BRICs (except for China). In contrast to symmetric error correction model, it is found that asymmetric adjustment of nominal exchange rates play an important role in eliminating deviations from long-run PPP.

Keywords: Purchasing Power Parity, Threshold Cointegration Tests, Threshold Error Correction Model, Asymmetric Adjustment, BRICs

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1. Introduction

The recent studies of long-run purchasing power parity (PPP) have utilized conventional unit root tests in real exchange rates and cointegration between various measures of domestic and foreign prices and nominal exchange rates. The conclusions drawn in these studies are primarily based on linear tests for stationary or cointegration. Moreover, as pointed out by Balke and Fomby (1997), the power of linear cointegration tests fall under an asymmetric adjustment process. For example, in international monetary economics the regular finding of unit root in real exchange rates causes discomfort to economists who wish to build models around a long run PPP relationship (e.g., Taylor et al., 2001). Therefore, it is possible that linear adjustment leads to poor results of the equilibrium relationship because conventional cointegration tests do not take into account asymmetric adjustment. However, ample evidence of asymmetries in key economic variables has been established in recent years. As shown by Madsen and Yang (1998) and Ramsey and Rothman (1996), such as inflation rate have asymmetric adjustment process. Many other literatures have attempted to address similar issues in the context of a threshold autoregressive (TAR) model. Ender and Granger (1998), Caner and Hansen (2001) and Lo and Zivot (2001) all form part of the growing literature that examines the interplay between nonstationary, cointegration and nonlinearity.

When we mentioned earlier, one possible explanation for the inconsistency in the empirical evidence on PPP hypothesis is that earlier study implicitly assume that exchange rate behavior is linear in nature. Taylor and Peel (2000) and Sarno (2000) illustrate that the adoption of linear stationarity tests is inappropriate in detecting mean reversion if true data generating process of exchange rate is in fact a stationary non-linear process. Besides, the importance of allowing for non-linear adjustment of the exchange rate towards their long-run PPP equilibrium has been stressed in a number of past studies. For instance, Hsieh (1989) observes that exchange rate changes may be non-linearly dependent. Boothe and Glassman (1987) point out that exchange rate is not linearly predictable. Sarno (2000) provides strong evidence that real exchange rate of Middle East countries non-linearly towards their long-run PPP equilibrium. Sarno and Taylor (2002) arrive at the main conclusions that exchange rate-relative price relation holds in the long-run among major industrialized countries, and that mean reversion in real exchange rate displays significant nonlinearities. These findings of the existence of non-linear relationship between exchange rates and they imply that exchange rate researchers could no longer take for granted that exchange rate movements are linearly dependent.

The standard unit root and cointegration test are that assume symmetric adjustment. Nevertheless, official intervention in the foreign exchange market means that nominal exchange rate movements are asymmetric. Under a managed float, one of the monetary authorities might be willing to tolerate currency appreciation and depreciation. In the 1980s, empirical studies commonly failed to support PPP, as the hypothesis of mean reversion for the real exchange rate was outperformed by the random walk hypothesis (Enders, 1988; Taylor, 1988; Patel, 1990). The asymmetric adjustment of real exchange rate is explained by the stickiness of national price level. Rhee and Rich (1995) and Madsen and Yang (1998) provide evidence that if prices are sticky in the downward direction, and that means the real exchange rate adjustment is nonlinear.

BRICs are terms used to refer to the combination of Brazil, Russia, India, and China. The BRICs report is Global Economics Paper No. 99, brought out by Goldman Sachs (Wilson & Purushothaman, 2003). The main point of research was to argue that the economies of the BRICs are rapidly developing and by the year 2050 will eclipse most of the current richest countries of the world. BRICs have become more generic marketing terms to refer to these emerging markets,
and they would be the largest entity on the global stage. The relative importance of the BRICs as an engine of new demand growth and spending power may shift more dramatically and quickly than expected. Higher growth in these economies could offset the impact of graying (old age) populations and slower growth in the advanced economies. Higher growth may lead to higher returns and increased demand for capital. The weight of the BRICs in investment portfolios could rise sharply, and BRIC countries could experience greater capital inflows.

The purpose of this study is to investigate whether the PPP theory holds true for BRICs. We use the newly developed momentum threshold cointegration tests advanced by Enders and Siklos (2001) to investigate if there is any asymmetric adjustment for BRICs. This present empirical study contributes significantly to this field of research. First, it determines whether a long-run PPP holds true in the BRICs for which we use the threshold cointegration test of Enders and Siklos (2001). Although empirical studies have previously been conducted for developed countries and Asian countries and African countries, but this is not the case for BRICs, and this study fills this gap in the literature. Second, this study is the first of its kind to utilize the threshold cointegration test for long-run PPP in BRICs. Precisely what we find is that a long-run PPP holds for BRICs but that adjustment mechanism is asymmetric.

The remainder of this study is organized as follows. Section 2 presents theoretical background of purchasing power parity, Section 3 describes the methodologies including kinds of the non-linear cointegration tests and error-correction models. Section 4 presents the data and our empirical results. Section 5 concludes this study.

2. Theoretical Background of Purchasing Power Parity (PPP)

The hypothesis of the purchasing power parity (PPP) postulates that nominal exchange rate adjust to reflect differences in price levels across countries. By this hypothesis, the exchange rate between countries of any two economics should equalize the relative price levels in these economics, provided that the effects of trade barrier and transaction costs are negligible. In fact, the market is not free after all and it has been generally accepted that PPP is not likely to hold true in the short run. Short-run PPP is almost never an economically relevant proposition, so empirical investigation has focused on long-run PPP. During much of the past few decades, a plethora of studies has centered on the investigation of the validity of long-run PPP. This usually involves testing for unit roots in real exchange rates. If the test rejects the unit root hypothesis, the real exchange rate reverts to its mean and long-run PPP holds. A stationary real exchange rate indicates that any long-run relationship between the nominal exchange rate and domestic and foreign prices is virtually existent, therefore validating the theory of PPP.

The rationality behind the PPP is a simple arbitrage hypothesis: If two identical goods are traded at different prices in different countries, a profitable arbitrage opportunity arises and the arbitrageurs can buy the good cheaply in one location and sell it at a higher price in the other. In the absence of arbitrage costs, this process leads to convergence of the deviations from PPP towards zero. Under this version of the PPP theory, we would expect stationary in real exchange rate dynamics. One major policy implication of this is that PPP can be used to determine the equilibrium exchange and imply is that making unbounded gains from arbitrage in traded goods is indeed impossible in those countries.
3. Methodology
3.1 Threshold Cointegration Tests (TAR and MTAR)

In this study, we employ the threshold cointegration technique advanced by Enders and Siklos (2001) to test for long-run PPP with asymmetric adjustment in BRICs. This test involves a two-stage process. In the first stage, we estimate a long-run equilibrium relationship of the form:

\[ e_t = \alpha_0 + \alpha_1 p_t^* + \alpha_2 p_t + u_t \] (1)

where \( e_t \) is the logarithm of foreign exchange in the domestic currency, \( p_t^* \) and \( p_t \) represent the logarithm of foreign and domestic price levels respectively, and \( u_t \) is the stochastic disturbance term. The second stage focuses on the OLS estimates of \( \rho_1 \) and \( \rho_2 \) in the following regression:

\[ \Delta u_t = I_t \rho_2 u_{t-1} + (1 - I_t) \rho_2 u_{t-1} + \sum_{j=1}^{l} \gamma_j \Delta u_{t-j} + \varepsilon_t \] (2)

where \( \varepsilon_t \) is a white-noise disturbance and the residuals, \( u_t \), in equation 1 are extracted to equation 2 to be further estimated. \( I_t \) is the Heaviside indicator function such that:

\[ I_t = \begin{cases} 1 & \text{if } u_{t-1} \geq \tau \\ 0 & \text{if } u_{t-1} < \tau \end{cases} \]

where \( \tau \) is the threshold value. A necessary condition for \( \{ u_t \} \) to be stationary is: \(-2 < (\rho_1, \rho_2) < 0\). If the variance of \( \varepsilon_t \) is sufficiently large, it is also possible for one value of \( \rho_j \) to be between \(-2\) and \(0\) and for the other value to equal zero. Although there is no convergence in the regime with the unit-root (i.e., the regime in which \( \rho_j = 0 \)), large realization of \( \varepsilon_t \) will switch the system into the convergent regime. Enders and Granger (1998) and Enders and Siklos (2001) both point out in either case, under the null hypothesis of no convergence, the \( F \)-statistic for the null hypothesis \( \rho_1 = \rho_2 = 0 \) has a nonstandard distribution. The critical values for this non-standard \( F \)-statistic are tabulated in their paper. Enders and Granger (1998) also show that if the sequence is stationary, the least squares estimates of \( \rho_1 \) and \( \rho_2 \) have an asymptotic multivariate normal distribution.

Model using equation 2 is referred to as Threshold Autoregression Model (TAR), where the test for threshold behavior of the equilibrium error is termed threshold cointegration test. Assuming the system is convergent, \( \mu_t = 0 \) can be considered as the long-run equilibrium value of the sequence. If \( \mu_t \) is above its long-run equilibrium, the adjustment is \( \rho_1 \mu_{t-1} \) and if \( \mu_t \) is below its long-run equilibrium, the adjustment is \( \rho_2 \mu_{t-1} \). The equilibrium error therefore behaves like a threshold autoregression. The null hypothesis of \( \rho_1 = \rho_2 = 0 \) tests for the cointegration relationship and the rejection of this null implies that the existence of cointegration between variables. The finding of \( \rho_1 = \rho_2 = 0 \) put it valuable to further test for symmetric adjustment (i.e., \( \rho_1 = \rho_2 \)) by using a standard \( F \)-test. When adjustment is symmetric as \( \rho_1 = \rho_2 \), equation 2 converges the prevalent augment DF test (Dickey & Fuller, 1981). Rejecting both the null hypotheses of \( \rho_1 = \rho_2 = 0 \) and \( \rho_1 = \rho_2 \) imply the existence of threshold cointegration and the asymmetric adjustment.
According to Enders and Granger (1998), this model is especially valuable when adjustment is asymmetric such that the series exhibits more ‘momentum’ in one direction than the other. Instead of estimating equation 2 with the Heaviside indicator depending on the level of $\mu_{t-1}$, the decay could also be allowed to depend on the previous period’s change in $\mu_{t-1}$. The Heaviside indicator could then be specified as $I_t = 1$ if $\Delta \mu_{t-1} \geq \tau$ and $I_t = 0$ if $\Delta \mu_{t-1} < \tau$, where $\tau$ is the threshold value. This model is termed Momentum-Threshold Autoregression Model (M-TAR). The TAR model can capture ‘deep’ cycle process if, for example, positive deviations are more prolonged than negative deviations. The M-TAR model allows the autoregressive decay to depend on $\Delta \mu_{t-1}$. As such, the M-TAR representation can capture ‘sharp’ movements in a sequence.

In the most general case, the value of $\tau$ is unknown, it needs to be estimated along with the value of $\rho_1$ and $\rho_2$. By demeaning the $\{ \mu_t \}$ sequence, the Enders and Granger (1998) test procedure employs the sample mean of the sequence as the threshold estimate of $\tau$. However, the sample mean is a biased threshold estimator in the presence of asymmetric adjustments. For instance, if autoregressive decay is more sluggish for positive deviations of $\mu_{t-1}$ from $\tau$ than for negative deviations, the sample mean estimator will be biased upwards. A consistent estimate of the threshold $\tau$ can be obtained by using Chan’s (1993) method of searching over possible threshold values to minimize the residual sum of squares from the fitted model.

Enders and Siklos (2001) apply Chan’s methodology to a Monte Carlo study to obtain the $F$-statistic for the null hypothesis of $\rho_1 = \rho_2 = 0$ when the threshold $\tau$ is estimated using Chan’s procedure. The critical values of this non-standard $F$-statistic for testing the null hypothesis of $\rho_1 = \rho_2 = 0$ are also tabulated in their paper. As there is generally no presumption as to whether to use TAR or M-TAR model, the recommendation is to select the adjustment mechanism by a model selection criterion such as the Akaike information criterion (AIC) or Schwartz Bayesian information criterion (SBC).

### 3.2 Threshold Error-Correction Model (TECM)

After having found evidence supporting asymmetric adjustment of threshold cointegration, an asymmetric error-correction model can be used to investigate the movement adjustment process of variables to the long-run equilibrium relationship. The conventional error-correction models do not represent whether the value of threshold exists true, above or under fundamental value $\tau$, which will have different adjustment process. We estimate the following system of asymmetric error-correction models for each country:

\[
\Delta \varepsilon_t = \alpha_1 + \sum_{i=1}^{K} \alpha_i \Delta \varepsilon_{t-i} + \sum_{i=1}^{K} \beta_i \Delta p_{t-i}^* + \sum_{i=1}^{K} \gamma_i Z_{t-i}^* + \gamma_2 Z_{t-i} + \varepsilon_{ct} \tag{3}
\]

\[
\Delta p_{t}^* = \alpha_2 + \sum_{i=1}^{K} \alpha_i \Delta \varepsilon_{t-i} + \sum_{i=1}^{K} \beta_i \Delta p_{t-i} + \sum_{i=1}^{K} \gamma_i Z_{t-i}^* + \gamma_2 Z_{t-i} + \varepsilon_{p^*t} \tag{4}
\]

\[
\Delta p_t = \alpha_3 + \sum_{i=1}^{K} \alpha_i \Delta \varepsilon_{t-i} + \sum_{i=1}^{K} \beta_i \Delta p_{t-i} + \sum_{i=1}^{K} \gamma_i Z_{t-i}^* + \gamma_2 Z_{t-i} + \varepsilon_{pt} \tag{5}
\]

where $Z_{t-i}^* = I_{t-1} \mu_{t-1}$ and $Z_{t-i} = (1-I_{t}) \mu_{t-1}$. $\mu_{t-1}$ is residual from equation (3), (4) and (5),

\[
I_t = \begin{cases} 
1 & \text{if } \Delta u_{t-1} \geq \tau \\
0 & \text{if } \Delta u_{t-1} < \tau 
\end{cases}
\]
Moreover, \( Z^+_{t-1} \) and \( Z^-_{t-1} \) are represent the shock adjustment for \( u_{t-1} \geq \tau \) and \( u_{t-1} < \tau \), respectively. The estimated coefficients of \( Z^+_{t-1} \) and \( Z^-_{t-1} \), \( \gamma_1 \) and \( \gamma_2 \), determine the speed of adjustment for positive and negative deviations from long-run PPP, respectively. The choice of the appropriate lag length is based on the multivariate AIC. The choice of non-zero threshold follows the same procedure outlined earlier.

### 4. Empirical Results

#### 4.1 Data

The empirical period starts with July 1992 and ends with December 2006. The reason for starting the empirical period with July 1992 is to after Soviet Union disorganization on December 25, 1991, the independent Russia inherited an original Soviet Union, so that our data can not early in 1992. The data begin from July since nominal exchange rate data of Russia are available from this period. Variables for the Brazil, Russia, India, and China are obtained from the International Monetary Fund’s International Financial Statistics (IFS) database. In general, the real exchange rate is related to the nominal exchange rate and to prices in countries, and then variables include the nominal exchange rate of the Brazil, Russia, India, and China, the consumer price indices for the BRICs and the United States. The exchange rate is the amount of domestic currency per US dollar, and the logarithmic transformations are required to achieve stationarity in variance.

#### 4.2 Cointegration Test

Table 1 report the application of the Engle-Granger procedure and for each country the lag length was selected using the AIC. Engle-Granger cointegration test results indicate that the null of no cointegration can not be rejected. The absence of long-run relationship between the nominal exchange rate and the domestic price index and the foreign price index in these initial tests might be attributable to the employment of linear tests for mean reversion whereas there are in fact asymmetries in any adjustment toward fundamental values with respect to positive and negative shocks. Moreover, these tests for symmetric cointegration have low power against a background of asymmetric adjustment.

<table>
<thead>
<tr>
<th>Country</th>
<th>( \rho )</th>
<th>AIC/SBC</th>
<th>Lags</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symmetric adjustment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Brazil</td>
<td>-0.054931</td>
<td>2.2233 / 8.5414</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>(-2.118679)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Russia</td>
<td>-0.042152</td>
<td>-35.7488 / -29.4307</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>(-2.370824)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. India</td>
<td>-0.047771</td>
<td>-574.1698 / -564.7273</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>(-2.112854)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. China</td>
<td>-0.062587</td>
<td>-320.1411 / -313.8229</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>(-2.799093)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: 1. The critical values of t-statistics for the null hypothesis with three variables in the cointegrating relationship are -4.73, -4.11, and -3.83 at the 1%, 5% and 10% significance levels respectively.
2. AIC = T*ln(RSS)+2*n; SBC = T*ln(RSS)+n*lnT, where n = number of regressors and T = number of usable observations. RSS is the residual sum of squares.
Therefore, we go for threshold cointegration tests. The AIC was used to determine whether the adjustment mechanism is best captured as a TAR or M-TAR process. The results of the threshold cointegration test with zero thresholds shown in Table 2. The null hypothesis of $\rho_1 = \rho_2 = 0$ cannot be rejected for any country. These results indicate that PPP fails assuming linear adjustment or allowing for asymmetric adjustment using a threshold value of zero. Given the presence of measurement errors and adjustment costs, there is no reason to presume that the threshold is equal to zero.

Table 2. The estimated adjustment equations using threshold cointegration test with zero threshold

<table>
<thead>
<tr>
<th>Country</th>
<th>$\rho_1$</th>
<th>$\rho_2$</th>
<th>$\Phi_\mu$ or $\Phi_\mu^*$</th>
<th>$\rho_1 = \rho_2$</th>
<th>AIC/SBC</th>
<th>Flag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>-0.0527</td>
<td>-0.0114</td>
<td>1.4556</td>
<td>0.8800</td>
<td>-60.1486/-41.3692</td>
<td>TAR</td>
</tr>
<tr>
<td>Russia</td>
<td>-0.0688</td>
<td>-0.0038</td>
<td>4.6977</td>
<td>5.4914</td>
<td>-138.0838/-119.3044</td>
<td>M-TAR</td>
</tr>
<tr>
<td>India</td>
<td>-0.0306</td>
<td>-0.0759</td>
<td>2.7470</td>
<td>0.9819</td>
<td>-567.6782/-524.5385</td>
<td>TAR</td>
</tr>
<tr>
<td>China</td>
<td>-0.0173</td>
<td>-0.0884</td>
<td>5.1443</td>
<td>2.3693</td>
<td>-317.7372/-308.2947</td>
<td>M-TAR</td>
</tr>
</tbody>
</table>

Note: 1.*, **, *** indicate significance levels at 10%, 5% and 1% respectively.
2. Entries in this column are the $F$-statistics for the null hypothesis $\rho_1 = \rho_2 = 0$. This test follows non-standard distribution so the test statistics are compared with critical values reported by Enders and Dibooglt (2001).
3. The numbers reported in this column are $F$-statistics of symmetric adjustment.
4. The $\rho_1$ and $\rho_2$ determine the speed of adjustment for positive and negative deviations respectively.
5. AIC=T*$\ln$(RSS)+2*n; SBC=T*$\ln$(RSS)+n*lnT, where n=number of regressors and T= number of usable observations. RSS is the residual sum of squares.

As shown in Table 3, widespread support the theory is found in Chan’s method that is used to obtain a consistent estimate of threshold and the M-TAR model uses the AIC for select criterion. We find there is a strong evidence for the null hypothesis of no cointegration is rejected (the alternative hypothesis that PPP holds is accepted) for Brazil, Russia and India at the 10% level. The major difference from the results previously reported in Table 1 is the case for cointegration that is substantially strengthened when asymmetries are allowed for. In addition, whenever long-run PPP holds and the null hypothesis of symmetric adjustment is also rejected. Because of China government's control to exchange rate, so that the price level in China are underestimated seriously, and PPP fails. That should be noted in this regard that in the literature, PPP is reportedly more likely to hold in countries with higher inflation (Rogoff, 1996). True that we would have expected that PPP should hold true for most of the BRICs under study, and our results are consistent with this expectation. Our results are also consistent with those found in Enders and Dibooglu (2001) and Enders and Chumrusphonlert (2004). They found long-run PPP with asymmetric adjustments for both European and Asian countries. Besides, the Brazil and China out of all countries, there is evidence that $|\rho_1| < |\rho_2|$ implying that the speed of adjustment toward fundamental values is faster in the case of a negative shock with respect to $\mu_\mu$. For example, the real rate of the Brazil converges to its fundamental value $\tau$ at the rate of 3.98% for a positive deviation and 55.72% for a negative deviation. In addition, the null hypothesis of symmetric adjustment is rejected at the 10% significance level.
Table 3. The estimated adjustment equations using threshold cointegration test with consistent estimate of the threshold

<table>
<thead>
<tr>
<th>Country</th>
<th>$\rho_1$</th>
<th>$\rho_2$</th>
<th>$\Phi_\mu$ or $\Phi_{\mu}^{-1}$</th>
<th>$\rho_1 = \rho_2$</th>
<th>AIC/SBC</th>
<th>Flag</th>
<th>$\tau$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>-0.0398</td>
<td>0.5572</td>
<td>7.1289*</td>
<td>12.0878***</td>
<td>-71.3284/-52.5491</td>
<td>M-TAR</td>
<td>-0.1517</td>
</tr>
<tr>
<td>Russia</td>
<td>-0.3953</td>
<td>-0.0228</td>
<td>7.6355*</td>
<td>12.3144***</td>
<td>-164.5633/-124.4245</td>
<td>M-TAR</td>
<td>0.0530</td>
</tr>
<tr>
<td>India</td>
<td>1.1262</td>
<td>-0.0569</td>
<td>7.3697*</td>
<td>10.7008***</td>
<td>-581.9941/-575.6759</td>
<td>M-TAR</td>
<td>0.0324</td>
</tr>
<tr>
<td>China</td>
<td>-0.0164</td>
<td>-0.0962</td>
<td>5.6261</td>
<td>2.8627</td>
<td>-320.4726/-314.1661</td>
<td>M-TAR</td>
<td>-0.0021</td>
</tr>
</tbody>
</table>

Note: 1. *, **, *** indicate significance levels at 10%, 5% and 1% respectively.
2. Entries in this column are the F-statistics for the null hypothesis $\rho_1 = \rho_2 = 0$. This test follows non-standard distribution so the test statistics are compared with critical values reported by Enders and Dibooglt (2001).
3. The numbers reported in this column are F-statistics of symmetric adjustment.
4. The $\rho_1$ and $\rho_2$, determine the speed of adjustment for positive and negative deviations, respectively.
5. AIC=T*ln(RSS)+2*n; SBC=T*ln(RSS)+n*lnT, where n=number of regressors and T= number of usable observations.
6. $\tau$ is the threshold value.

4.3 Error-Correction Models

The asymmetric error-correction models with consistent estimate of thresholds with the USA as the base country is shown in Table 4. For instance, in the case of the USA and India, OLS was used to find estimate the long-run relationship as

$$e_i = 1.12 p_i - 1.32 p^*_i + 4.67$$ (6)

where $e_i = \log$ of the India/USA exchange rate, $p_i = \log$ of the India price level, and $p^*_i = \log$ of the USA price level. Using Equation 6, the estimated error-correction equation using consistent estimates of threshold are (with t-statistics in parentheses)

$$\Delta e_i = A_{11}(L)\Delta p_{i,-1} + A_{21}(L)\Delta p^*_i + A_{31}(L)\Delta e_{i,-1} - 0.1636Z_{i,-1}^+ - 0.0390Z_{i,-1}^-$$ (7)

$$\Delta p_i = A_{22}(L)\Delta p_{i,-1} + A_{22}(L)\Delta p^*_i + A_{32}(L)\Delta e_{i,-1} - 0.0151Z_{i,-1}^+ + 0.0748Z_{i,-1}^-$$ (8)

$$\Delta p^*_i = A_{33}(L)\Delta p_{i,-1} + A_{32}(L)\Delta p^*_i + A_{33}(L)\Delta e_{i,-1} + 0.3237Z_{i,-1}^+ - 0.0129Z_{i,-1}^-$$ (9)

where $A_q(L)$ is a 7th order polynomial in the lag operator L

$$Z_{i,-1}^+ = (1-I_i)[e_{i,-1} - 1.12 p_{i,-1} + 1.32 p^*_i - 4.67]$$

$I_i$ is the momentum threshold Heaviside indicator function found by applying Chan’s (1993) method to each equation.

In Equation 7, the India—the USA rate falls (rises) whenever it lies above (below) its long-run PPP level. The estimates imply that the nominal exchange rate adjusts by 16.36% of a positive gap and 3.9% of a negative gap from long-run PPP. The t-value imply that coefficients are significant at conventional levels. Whereas Equation 8 indicates that the India price level responds to positive, but not negative deviations from long-run PPP. Moreover, Equation 9
indicates that the USA price level responds to negative, but not positive deviations from PPP. For comparison purposes, the symmetric error-correction model for India-USA is

\[
\Delta e_t = A_{11}(L)\Delta p_{t-1} + A_{12}(L)\Delta p_{t-1}^* + A_{13}(L)\Delta e_{t-1} - 0.0377Z_{t-1} \\
(2.7129)
\]

\[
\Delta p_t = A_{21}(L)\Delta p_{t-1} + A_{22}(L)\Delta p_{t-1}^* + A_{23}(L)\Delta e_{t-1} + 0.0025Z_{t-1} \\
(0.2852)
\]

\[
\Delta p_{t}^* = A_{31}(L)\Delta p_{t-1} + A_{32}(L)\Delta p_{t-1}^* + A_{33}(L)\Delta e_{t-1} - 0.0035Z_{t-1} \\
(-1.0836)
\]

where \( Z_{t-1} = e_{t-1} - 1.12p_{t-1} + 1.32p_{t-1}^* - 4.67 \).

In the case of symmetric adjustment, the error-correction term on the nominal exchange rate is significant at conventional levels. The model implies that the nominal exchange rate adjusts to eliminate deviations from PPP. However, in contrast to the threshold model, the nominal exchange rate adjusts by 3.77\% of the discrepancy from long-run PPP.

### Table 4. The estimated asymmetric error-correction models

<table>
<thead>
<tr>
<th>Country</th>
<th>Linear ECM</th>
<th>Threshold ECM</th>
<th>Flag</th>
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<td>( \gamma )</td>
<td>( \gamma_1 )</td>
<td>( \gamma_2 )</td>
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<td>-0.0484*</td>
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<td>(4.1135)</td>
<td>(-1.6777)</td>
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<td>(0.1494)</td>
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<td>(0.0206)</td>
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<td>(6.5109)</td>
<td>(-4.5253)</td>
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Note: 1. \( t \)-Statistics are in parentheses. *, **, *** indicate significance levels at 10\%, 5\% and 1\% respectively.

2. \( \gamma_1 \) and \( \gamma_2 \) determine the speed of adjustment for positive and negative deviations, respectively.

3. \( \tau \) is the threshold value.
Whenever long-run PPP holds, an asymmetric error-correction model can be used to investigate the movement of variables to the long-run equilibrium relationship. Having found evidence supporting asymmetric adjustment, the estimated asymmetric error-correction models with consistent estimate of thresholds are shown in Table 4. We find that negative deviations from PPP are eliminated more quickly than positive deviations and that the exchange rate (not the price levels) is responsible for Brazil of the adjustment. On the contrary, we find that positive deviations from PPP are eliminated quicker than negative deviations and that the exchange rate (not the price levels) is responsible for Russia and India of the adjustment. The results reported in Table 4 highlight more general role played by nominal exchange rate adjustment. Furthermore, we find that the speed of adjustment coefficients on price levels tend to be small in magnitude and statistically insignificant.

These results are similar to those found in Enders and Dibooglu (2001) and Enders and Chumrusphonlert (2004) for European and Asian countries, respectively. For comparison purposes, we also estimate symmetric error-correction models for each country. Results reported in Table 4 further indicate that the exchange rate (not the price levels) is responsible for most of the adjustment.

5. Conclusions

We show that while Engle-Granger test assumes only symmetric adjustment does not obtain the results of the cointegration relationship for all of BRICs, the threshold cointegration test provides clear evidence of the long-run PPP with asymmetric adjustment for most of BRICs, except for China. Apparently our empirical results strongly support the long-run PPP with asymmetric adjustments for most of the countries studied here (except for China). In contrast to conventional cointegration model and symmetric error-correction model, the relation of nominal exchange rate and price level is more suitable using nonlinear model to describe, and it is found that asymmetric adjustment of nominal exchange rates play an important role in eliminating deviations from long-run PPP. Another major policy implication of our study is that PPP can be used to determine the equilibrium exchange for BRICs we examine, and what this implies is that making unbounded gains from arbitrage in traded good is indeed impossible in all countries.

