Economics Bulletin

Volume 30, Issue 3

Are Real Exchange Rates Nonlinear with a Unit Root? Evidence on Purchasing Power Parity for China: A Note

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Abstract

This article applies the threshold autoregressive model proposed by Caner and Hansen (2001) to examine both linearity and stationarity of China's real exchange rate vis-à-vis her 9 trading partner countries over the period of January 1986 to October 2009. Two main conclusions are drawn. Firstly, the empirical results indicate that China's real exchange is a nonlinear process. Secondly, a unit root in real exchange rate was found for most of the cases under study. This result provides no support for purchasing power parity for China relative to their major trading partner countries.

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Citation: Tsangyao Chang and Su-yuan Lin and Horng-jinh Chang, (2010) "Are Real Exchange Rates Nonlinear with a Unit Root? Evidence on Purchasing Power Parity for China: A Note", *Economics Bulletin*, Vol. 30 no.3 pp. 1897-1905.
Submitted: May 23 2010. **Published:** July 19, 2010.

1. Introduction

Purchasing power parity (hereafter, PPP) is a cornerstone of many theoretical models in international finance. PPP states that the exchange rates between currencies are in equilibrium when their purchasing power is the same in each of the two countries. This means that the exchange rate between any two countries should equal the ratio of two currencies¡ price level of a fixed basket of goods and services. The basic idea behind the PPP hypothesis is that since any international goods market arbitrage should be traded away over time, we should expect the real exchange rate to return to a constant equilibrium value in the long run. Studies on this issue are critical not only for empirical researchers but also for policymakers. In particular, a non-stationary real exchange rate indicates that there is no long-run relationship between nominal exchange rate and domestic and foreign prices, thereby invalidating the PPP. As such, PPP cannot be used to determine the equilibrium exchange rate, and an invalid PPP also disqualifies the monetary approach from exchange rate determination, which requires PPP to hold true.

Empirical evidence on the stationarity of real exchange rates is abundant but inconclusive thus far. For details on previous studies, please refer to the works of Taylor (1995), Rogoff (1996), MacDonald and Taylor (1992), Taylor and Sarno (1998), Sarno and Taylor (2002), Taylor and Taylor (2004), and Lothian and Taylor (2000, 2008), who have provided in-depth information on the theoretical and empirical aspects of PPP and the real exchange rate.

Recently, there has been a growing consensus that the real exchange rate exhibits nonlinearities, and consequently, conventional unit root tests such as the Augmented Dickey Fuller (ADF) test have low power in detecting the mean reversion of exchange rate. A number of studies have provided empirical evidence on the nonlinear adjustment of exchange rate.[1] However, the finding of nonlinear adjustment does not necessarily imply nonlinear mean reversion (stationarity). As such, stationarity tests based on a nonlinear framework must be applied.

This empirical study contributes to this line of research by determining whether PPP holds for China¡s real exchange rate relative to a sample of her major trading partner countries (Hong Kong, Indonesia, Japan, Korea, Malaysia, Philippines, Singapore, Taiwan, and Thailand), using the threshold autoregressive (hereafter, TAR) model and the test statistics proposed by Caner and Hansen (2001). The major advantage of this approach is that it allows us to simultaneously investigate nonstationarity and nonlinearity. With this,

[1] Reasons for the nonlinear adjustment are the presence of transactions costs that inhibit international goods arbitrage and official intervention in the foreign exchange market may be such that nominal exchange rate movements are asymmetric (see Taylor, 2004; Taylor and Peel, 2000; Juvenal and Taylor, 2008; Reitz and Taylor, 2008). Kilian and Taylor (2003) also suggest that nonlinearity may arise from the heterogeneity of opinion in the foreign exchange market concerning the equilibrium level of the nominal exchange rate: as the nominal rate takes on more extreme values, a great degree of consensus develops concerning the appropriate direction of exchange rate moves, and traders act as accordingly

the current research hopes to fill the existing gap in the literature. We find that China¡s bilateral real exchange rate is a nonlinear process characterized by a unit root, not consistent with PPP, relative to most of the trading partner countries (seven out of nine), with the exception of Taiwan/China and South Korea/China two cases.

China provides an interesting arena to research for several reasons. First, China has made remarkable economic progress over the past two decades. China¡s average annual economic growth rate over the past two decades (1990-2009) is 9.76%. In 2009, per capita GDP in China was US$ 3,566. Second, China has become the world¡s first and largest trading country with the foreign exchange reserves estimated at US$ 2,400 billion at the end of 2009. Third, China started its open policy in the late 1970s, thus sufficient data are available for researchers to evaluate the effect of economic liberalization on economic phenomena.

This paper is organized as follows. Section 2 presents the data used in our study. Section 3 briefly describes the TAR unit test and our empirical results. Section 4 concludes the paper.

2. Data

Our empirical analysis covers a sample of nine East Asian countries: Hong Kong, Indonesia, Japan, Korea, Malaysia, Philippines, Singapore, Taiwan, and Thailand. Monthly data are employed in this study, and the time span is from January 1986 to October 2009. All consumer price indices, CPI (based on 2000 = 100), and nominal exchange rates relative to the China RMB yen data are taken from the International Monetary Fund¡s International Financial Statistics CD-ROM.[2] Testing for PPP against the China is based on the argument that China has become one of the fast growing countries in the whole world and China is also the major trading partners for these nine East Asian countries for the past decade.

3. Methodology and Empirical Results

3.1. Caner and Hansen¡s (2001) Threshold Unit Root Test

Following the work of Caner and Hansen (2001), we adopt a two regime TAR(*k*) model with an autoregressive unit root as follow:

$$\Delta r_t = \theta_1' x_{t-1} I_{\{Z_t<\lambda\}} + \theta_2' x_{t-1} I_{\{Z_t\geq\lambda\}} + e_t, \qquad t = 1, ¡ \, , T \qquad (1)$$

Where r_t is the real exchange rate for $t = 1,2....,T$, $x_{t-1} = (r_{t-1}, v_t', \Delta r_{t-1}, \ldots, \Delta r_{t-k})'$, $I_{\{\bullet\}}$ is the indicator function, e_t is an i.i.d. disturbance, $Z_{t-1} = r_{t-1} - r_{t-m}$ is the threshold variable, *m*

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[2] The real exchange rate series of a country at time *t* is define as $(S_t \times P_t^{China}) / P_t^H$, where S_t is the nominal exchange rate of home country per China RMB , P_t^{China} and P_t^H denote the consumer price indices of home country and the China, respectively.

represents the delay parameter and $1 \le m \le k$, v_t is a vector of exogenous variables including an intercept and possibly a linear time trend. The threshold value λ is unknown and takes the values in the compact interval $\lambda \in \Lambda = [\lambda_1, \lambda_2]$, where λ_1 and λ_2 are selected according to $P(Z_t \le \lambda_1) = 0.15$ and $P(Z_t \le \lambda_2) = 0.85$.[3] The components of θ_1 and θ_2 can be partitioned as follows:

$$\theta_1 = \begin{pmatrix} \rho_1 \\ \beta_1 \\ \alpha_1 \end{pmatrix}, \qquad \theta_2 = \begin{pmatrix} \rho_2 \\ \beta_2 \\ \alpha_2 \end{pmatrix} \tag{2}$$

where ρ_1 and ρ_2 are scalar terms. β_1 and β_2 have the same dimensions as v_t, and α_1 and α_2 are *k*-vectors. Thus (ρ_1, ρ_2) are the slope coefficients on r_{t-1}, (β_1, β_2) are the slopes on the deterministic components, and (α_1, α_2) are the slope coefficients on $(\Delta r_{t-1}, \ldots, \Delta r_{t-k})$ in the two regimes.

The threshold effect in Equation (1) has the null hypothesis of $H_0 : \theta_1 = \theta_2$, which is tested using the familiar Wald statistic: $W_T = W_T(\hat{\lambda}) = \sup_{\lambda \in \Lambda} W_T(\lambda)$.[4] The stationarity of the process r_t can be established in two ways. The first is when there is a unit root in both regimes (a complete unit root). . Here the null hypothesis is of the form $H_0 : \rho_1 = \rho_2 = 0$, which is tested against the unrestricted alternative $\rho_1 \ne 0$ or $\rho_2 \ne 0$ using the Wald statistic. The parameters of ρ_1 and ρ_2 from the Equation (1) will control the regime-dependent unit root process of the real exchange rate. If $\rho_1 = \rho_2 = 0$ holds, the real exchange rate has a unit root can be described as a rejection of PPP. This statistic is:

$$R_{2T} = t_1^2 + t_2^2 \tag{3}$$

where t_1 and t_2 are the *t* ratios for $\hat{\rho}_1$ and $\hat{\rho}_2$ from the ordinary least squares estimation. However, Caner and Hansen (2001) claim that this two-sided Wald statistic may have less power than a one-sided version of the test. As a result, they propose the following one-sided Wald statistic as follows:

$$R_{1T} = t_1^2 I_{\{\hat{\rho}_1 < 0\}} + t_2^2 I_{\{\hat{\rho}_2 < 0\}} \tag{4}$$

To distinguish between the stationary case given as H_1 and the partial unit root case given as H_2, Caner and Hansen (2001) suggest using individual t statistics t_1 and t_2. If only one of $-t_1$ and $-t_2$ is statistically significant, this will be consistent with the partial unit root case H_2. This means real exchange rate behaves like a ¡nonstationary process¡ in one regime; but

[3] According to Andrews (1993), this division provides the optimal trade-off between various relevant factors, which include the power of the test and the ability of the test to detect the presence of a threshold effect.

[4] $W_T = W_T(\hat{\lambda}) = \sup_{\lambda \in \Lambda} W_T(\lambda) = T\left(\frac{\hat{\sigma}_0^2}{\hat{\sigma}^2(\lambda)} - 1\right)$, where $\hat{\sigma}_0^2$ and $\hat{\sigma}^2$ are residual variances from least squares estimation of the null linear and TAR models, respectively.

exhibits a ¡stationary process¡ in the other regime, vice versa. Caner and Hansen (2001) show that both tests R_{1T} and R_{2T} will have power against both alternatives.[5] To obtain maximum power form these tests, critical values are generated using bootstrap simulations with 10,000 replications, as suggested by Caner and Hansen (2001).

3.2. Empirical Results

For the sake of comparison, we also incorporate the Augmented Dickey-Fuller (ADF), PP (Phillips and Perron, 1988), and KPSS (Kwiatkowski et al., 1992) tests into our study. The results of these three conventional unit root tests -- ADF, PP, and the KPSS tests, as shown in Table I, indicate that the real exchange rates are non-stationary for China. As stated earlier, there is a growing consensus that the real exchange rate exhibits nonlinearities, and consequently, conventional unit root tests such as the ADF test, have low power in detecting the mean reversion of exchange rate. A number of studies have also provided empirical evidence on the nonlinear adjustment of exchange rate. Therefore, we proceed to test the real exchange rate by using Caner and Hansen¡s (2001) nonlinear TAR unit root tests.

First, we use the Wald test W_T to examine whether or not we can reject the linear autoregressive model in favor of a threshold model. The results of the Wald test along with the bootstrap critical values generated at conventional levels of significance are reported in Table II. The bootstrap *p*-value for threshold variables of the form $Z_{t-1} = r_{t-1} - r_{t-m}$ for delay parameters *m* varies from 1 to 12. Since the parameters *m* is generally unknown, there is no reason to think the optimal delay parameter will be the same across countries. To circumvent this, Caner and Hansen (2001) suggest making *m* endogenous by selecting the least squares estimate of *m* that minimizes the residual variance. This amounts to selecting *m* at the value that maximizes the W_T statistic. We find that the W_T statistic is maximized for China-Hong Kong, China-Indonesia, China-Philippines, and China-Singapore when $m = 2$, for China-Malaysia when $m = 4$, for China-Taiwan and China-Thailand when $m = 5$, for China-Japan when $m = 7$, and for China-South Korea when $m = 10$. Taken together, these results imply strong statistical evidence against the null hypothesis of linearity at least at the 10% significance level for all the cases indicating that simple linear models are inappropriate and the TAR model is our preference.

Next, we explore the threshold unit root properties of real exchange rate based on the R_{1T} statistic for each delay parameter *m*, ranging from 1 to 12, paying particular attention to the results obtained for our preferred model. The R_{1T} test results, together with the bootstrap critical value at the conventional levels of significance and the bootstrap *p*-value, are reported in Table III. We are able to reject the unit root null hypothesis for only two cases at the 5% significance level and they are Taiwan-China and South Korea-China. However, we are unable to reject the threshold unit root hypothesis for most of the cases.

[5] As stated by Caner and Hansen (2001) that R_{1T} has more power than that of R_{2T}, here we only report the results of R_{1T} in our study.

Taken together our results provide no support for PPP for most of the China¡s trading partner countries and point that the real exchange rates of these countries are non-linear nonstationary, implying that deviations of exchange rate is no mean reverting towards the PPP equilibrium. As we mentioned earlier that trade barriers, transaction costs, as well as interventions in the exchange market, could be behind this nonlinear behavior.

The one-sided test statistic of R_{1T}, however, is not able to distinguish the complete and partial unit root in real exchange rate, we examine further evidence on the unit root hypothesis (partial unit root) by examining the individual t statistics, t_1 and t_2. The results are reported in Table IV. Also, with the exception of the Taiwan-China and South Korea-China, the statistics for both t_1 and t_2 are smaller than the critical value at the 5% level of significance, and this leads us to the conclusion that real exchange rates in most of the China¡s trading partner countries are nonlinear process that are characterized by a unit root process, not consistent with the PPP. These results might source from several factors such as differences in technology/productivity and preferences, different factor endowments, trade barriers, transportation costs and differences in price index formations. It should also be noted that the share of government activities in China are still large which makes the prices to be administrated. The administrated prices might be an important source of deviation from the PPP in China. Therefore, it is possible to claim that deviations in the short-run form the PPP are prolonged for China and there are no forces which are capable of bringing the exchange rate back to its PPP values in the long-run.

The major policy implication that emerges from our study is that the government in China can not use PPP to determine the equilibrium exchange rate and the unbounded gains from arbitrage in traded good are possible in China.

4. Conclusions

This study applies the TAR model proposed by Caner and Hansen (2001) to examine both linearity and stationarity of China¡s real exchange rate vis-a-vis her 9 trading partner countries over the period of January 1986 to October 2009. Two main conclusions are drawn. Firstly, the empirical results indicate that China¡s real exchange is a nonlinear process. Secondly, a unit root in real exchange rate was found for most of China¡s trading partner countries under study. This provides no support for purchasing power parity for China relative to their major trading partner countries.

Acknowledgement: We are grateful to Bruce Hansen for making available his MATLAB codes for the TAR model, which were modified for the present exercise. However, any remaining errors are my own. The authors are also indebted to an anonymous reviewer, whose comments had improved the readability of this article substantially. Any remaining errors are our own.

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Table I. Univariate unit root tests

	Level			1st difference		
	ADF	**PP**	**KPSS**	**ADF**	**PP**	**KPSS**
Hong Kong	-2.312(12)	-1.990(11)	0.951[14]**	-13.591(11)**	-12.07(11)***	0.097[11]
Indonesia	-1.863(0)	-1.787(6)	1.057[14]***	-14.782(0)**	-17.86(2)***	0.074[2]
Japan	-1.702(0)	-2.621(8)	0.835[14]***	-13.184(0)***	-15.82(14)***	0.142[12]
Malaysia	-1.640(0)	-1.633(2)	1.461[14]***	-12.196(0)***	-15.598(1)***	0.137[1]
Philippine	-1.419(1)	-1.532(6)	0.569[14]**	-13.073(0)***	-16.115(5)***	0.124[6]
Singapore	-1.232(0)	-1.258(5)	0.463[14]*	-14.168(0)***	-15.519(8)***	0.194[6]
South Korea	-2.170(2)	-2.214(3)	0.495[14]*	-13.145(1)***	-13.142(3)***	0.095[1]
Taiwan	-1.214(1)	-1.171(5)	0.559[14]**	-11.123(1)***	-12.231(2)***	0.084[1]
Thailand	-1.543(0)	-1.16(5)	0.994[14]***	-12.128(0)***	-13.231(3)***	0.101[4]

Note: ***, ** and * indicate significance at the 0.01, 0.05 and 0.1 level, respectively. The number in parenthesis indicates the lag order selected based on the recursive t-statistic, as suggested by Perron (1989). The number in the brackets indicates the truncation for the Bartlett Kernel, as suggested by the Newey-West test (1987).

Table II. Threshold test

Countries	Wald Statistic	Bootstrap p-value	Optimal delay parameter m	Threshold parameter $\hat{\lambda}$	Number of observations in Regime 1 and its percentage
Hong Kong	96.346	0.004	2	0.0106	220(80.58%)
Indonesia	153.261	0.008	2	0.0413	231(84.61%)
Japan	72.893	0.052	7	0.0727	228(83.51%)
Malaysia	87.602	0.031	4	0.0215	231(84.61%)
Philippine	97.093	0.023	2	-0.043	40(14.65%)
Singapore	85.665	0.045	2	0.020	231(84,61%)
South Korea	79.067	0.038	10	0.054	231(84.61%)
Taiwan	44.186	0.042	5	-0.0275	100(36,63%)
Thailand	66.009	0.098	5	0.042	231(84.61%)

Following much of the existing empirical literature on monthly real exchange rates and PPP, we set a maximum lag of 12 and base all our bootstrap tests on 10,000 replications. Most of the statistics are significant, which supports the presence of threshold effects

Table III. One sided unit root tests

Countries	Optimal delay parameter m	R_{1T} Statistic	Bootstrap critical values			Bootstrap p-value
			10%	5%	1%	
Hong Kong	2	14.839	16.375	22.870	41.840	0.117
Indonesia	2	3.045	13.382	18.556	34.949	0.598
Japan	7	7.614	11.161	14.885	25.458	0.219
Malaysia	4	5.854	12.211	15.978	28.099	0.334
Philippine	2	9.766	12.467	16.736	29.743	0.161
Singapore	2	10.714	13.719	18.710	32.524	0.156
South Korea	10	59.808	12.019	15.959	27.394	**0.000**
Taiwan	5	25.508	13.205	18,024	33.467	**0.022**
Thailand	5	4.764	12.185	15.892	27.915	0.417

Table IV. Partial unit root results

Countries	Optimal delay parameter m	t_1^2 Statistic	Bootstrap p-value	t_2^2 Statistic	Bootstrap p-value
Hong Kong	2	2.179	0.170	3.176	0.106
Indonesia	2	0.842	0.538	1.528	0.350
Japan	7	1.935	0.205	1.967	0.247
Malaysia	4	2.419	0.125	-1.048	0.958
Philippine	2	3.072	0.071	0.572	0.666
Singapore	2	1.998	0.203	2.592	0.147
South Korea	10	1.768	0.256	7.528	**0.000**
Taiwan	5	5.050	**0.012**	-0.054	0.837
Thailand	5	2.182	0.174	-0.108	0.839