Associate Professor, SIYUE LIU, PhD
Department of Finance, Wuhan University, China
E-mail: syliu4856@yahoo.com.cn
Professor TSANGYAO CHANG, PhD
Department of Finance, Feng Chia University, Taiwan
E-mail: tychang@fcu.edu.tw

PURCHASING POWER PARITY IN LATIN AMERICAN COUNTRIES: LINEAR AND NONLINEAR UNIT ROOT TESTS WITH STATIONARY COVARIATES

Abstract. *We apply both linear and nonlinear unit root tests with stationary covariates, proposed Hansen (1995) and Tsong (2011), respectively to test the validity of long-run Purchasing Power Parity (PPP) for a sample of Latin American countries over January 1995 to February 2010. Empirical results from both linear and nonlinear unit root test with different stationary covariates indicate that PPP holds true for all of the Latin American countries. Our results have important policy implications for the Latin America countries under study.*
Keywords: *Purchasing Power Parity; Latin American Countries; Linear and Nonlinear Unit Root Tests; Stationary Covariates.*

JEL Classification: C22, F31

1. Introduction

Whether the Purchasing power parity (hereafter, PPP) holds true remains one of the most active and controversial issues in international macroeconomics. 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 to 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 (RER) 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 RER 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. Some references in the field are Taylor and Peel (2000), Taylor *et al.*, (2001), Lothian and Taylor (2008), and Taylor and Taylor (2004) who have provided in-depth information on the theoretical and empirical aspects of PPP and the RER.

As for methodology, recent studies of long-run PPP have mostly utilized conventional unit root tests such as the Augmented Dickey Fuller (1981, ADF) and Phillips and Perron (1988, PP) tests– fail to reject the unit root hypothesis of the RER. While numerous studies support a unit root in the RER, critics have claimed that the drawing of such conclusions may be attributed to the lower power of the conventional unit root tests employed. Including stationary covariates in the regression equation is one promising approach for improving the power of unit root tests, as proposed by Hansen (1995)[1]. He showed that additional information contained in stationary covariates that are correlated with the series can be exploited to obtain the covariate ADF (hereafter, CADF) test that has higher power than the ADF test.

Recently, there has been a growing consensus that the RER exhibits nonlinearities, and consequently, conventional unit root tests such as the ADF test has 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. However, the finding of nonlinear adjustment does not necessarily imply nonlinear mean reversion (stationarity). As such, stationary tests based on a nonlinear framework must be applied. The Exponential Smooth Transition Autoregressive (ESTAR) time series model has proved to be popular in economics for the analysis of time series data, such as data on RERs. The presence of transaction costs suggests that while large deviations of RERs from their equilibrium values will be corrected by arbitrage, small deviations may not be corrected, and the globally stationary ESTAR model with a unit root central regime is able to capture this type of nonlinearity (see, e.g. Baum *et al.*, 2001; Taylor *et al.*, 2001; Sollis, 2009). A number of tests of the unit root hypothesis against stationary ESTAR nonlinearity have recently been proposed (see, e.g. Kapetanios *et al.*, 2003; Park and Shintani, 2005). Therefore, in our study we use both linear (ADF) and nonlinear (Kapetanios *et al.*, 2003, hereafter, KSS) unit root tests with stationary covariates to test the validity of long-run PPP for a sample of Latin American countries over January 1995 to February 2010. As we know that these countries share some characteristics as high inflation, nominal shocks, and trade openness which might have led to quicker adjustment in relative prices and contributed for long-run PPP to hold. To the best of our knowledge, this study is the first of its kind to utilize the stationary test with stationary covariateso test the long-run PPP in Latin American countries. Empirical results from both linear and nonlinear unit root tests with different stationary covariates indicate that PPP holds true for all of the Latin American countries under study.

The plan of this paper is organized as follows. Section II presents the data used in our study. Section III first briefly describes the linear and nonlinear unit

[1] This idea is based on the notion that a particular time series to be tested in rarely observed in isolation.

root tests with stationary covariates, proposed by Hansen (1995) and Tsong (2011), respectively, and then presents our empirical results. Section IV concludes the paper.

2. Data

Our empirical analysis covers the 15 Latin American countries: Argentina, Bolivia, Brazil, Chile, Columbia, Costa Rica, Dominica, Ecuador, Haiti, Honduras, Mexico, Paraguay, Peru, Uruguay, and Venezuela. Monthly data are employed in our empirical study, and the time span is from January 1995 to February 2010. All consumer price indices, CPI (based on 2005 = 100), and nominal exchange rates relative to the USA dollar data, respectively, are taken from the Datastream. Each of the consumer price index and nominal exchange rate series was transformed into natural logarithms before performing the econometric analysis. Testing for the PPP against the USA is based on the argument that internal foreign exchange markets are mostly dollar dominated. In addition, funds for economic reconstructions are being provided by US sponsored institutions.

3. Methodology and Empirical Results

3.1. ADF Test with Covariates (CADF)

To improve the power of univariate tests, Hansen (1995) developed the CADF test by incorporating related stationary covariates with relevant information into the regression. This approach leads to a new regression error variance that is smaller than that in the conventional regression used to compute the ADF test. Because the regression parameters are more precisely estimated, the test statistic is more powerful. For our empirical purpose, the CADF test is the *t*-statistic for $\lambda = 0$ in the following regression with an intercept:

$$\Delta y_t = \alpha_0 + \lambda y_{t-1} + \sum_{i=1}^{k} \beta_i \Delta y_{t-i} + \sum_{j=-r}^{p} \alpha'_j x_{t-j} + \varepsilon_t \qquad (1)$$

which is an autoregression of Δy_t augmented by its lagged level y_{t-1} and the leads and lags of *m* stationary covariates in x_t. In fact, it can be considered as an augmentation of the ADF regression.

3.2. KSS Test with Covariates (CKSS)

Tsong (2011) proposes a new procedure for testing the unit root null against stationary but nonlinear alternatives. This test can be viewed as a generalization of the one developed by Kapetanios *et al.* (2003) by incorporating stationary covariates. The KSS unit root test is based on detecting the presence of non-stationarity against a nonlinear but globally stationary ESTAR process and the model is given by

$$\Delta y_t = \gamma y_{t-1}\{1-\exp(-\theta y_{t-1}^2)\} + \nu_t, \qquad (2)$$

where y_t is the data series of interest, ν_t is an *i.i.d.* error with zero mean and constant variance, and $\theta \geq 0$ is the transition parameter of the ESTAR model and governs the speed of transition. Under the null hypothesis y_t follows a linear unit root process, but y_t follows a nonlinear stationary ESTAR process under the alternative. One shortcoming of this framework is that the parameter γ is not identified under the null hypothesis. Kapetanios *et al.* (2003) have used a first-order Taylor series approximation for $\{1-\exp(-\theta y_{t-1}^2)\}$ under the null hypothesis $\theta = 0$ and have then approximated Equation (2) by using the following auxiliary regression:

$$\Delta y_t = \xi + \delta y_{t-1}^3 + \sum_{i=1}^{k} \theta_i \Delta y_{t-i} + \nu_t \quad t = 1,2,....,T \qquad (3)$$

In this framework, the null hypothesis and alternative hypotheses are expressed as $\delta = 0$ (non-stationarity) against $\delta < 0$ (non-linear ESTAR stationarity). For our empirical purpose, the CKSS test is the *t*-statistic for $\delta = 0$ in the following regression with an intercept:

$$\Delta y_t = \alpha_0 + \delta y_{t-1}^3 + \sum_{i=1}^{k} \alpha_i \Delta y_{t-i} + \sum_{j=-r_1}^{r_2} \alpha'_j x_{t-j} + \varepsilon_t \qquad (4)$$

which is an autoregression of Δy_t augmented by its lagged level y_{t-1}^3 and the leads and lags of *m* stationary covariates in x_t. In fact, it can be considered as an augmentation of the KSS test[2].

3.3. Empirical results

For comparison, we first apply several conventional unit root tests to examine the null hypothesis of a unit root in the RER of each country. We select the lag order of the test on the basis of the recursive *t*-statistic, as suggested by Perron (1989). The three tests ADF, PP and KPSS (Kwiatkowski *et al.*, 1992) without a trend function are reported in Tables 1. In our study, we only consider a specification with a constant but without a time trend because time trend in RERs is not consistent with the long-run PPP. Results from Tables 1 clearly indicate that the ADF and PP tests fail to reject the null hypothesis of non-stationary RERs for all of the 15 Latin American countries, with the exception of Mexico and Venezuela (when the ADF test are conducted). The KPSS test also yields similar

[2] Since the distributions of both CADF and CKSS tests are not standard, the asymptotic *p*-values for both tests are computed by means of Bootstrap simulations using 5000 replications.

results indicating that the RERs in Latin American countries are non-stationary, with the exception of Ecuador.

Table 1. Univariate unit root tests

	Level			**1st difference**		
	ADF	**PP**	**KPSS**	**ADF**	**PP**	**KPSS**
Argentina	-1.455(2)	-1.350(8)	1.342[10]***	-6.51(1)***	-10.83(7)***	0.079[8]
Bolivia	-1.546(6)	-0.741(8)	1.641[11]**	-2.55(5)*	-9.42(6)***	0.596[8]**
Brazil	-1.508(1)	-1.342(4)	0.480[10]**	-10.21(0)***	-10.24(1)***	0.301[4]
Chile	-1.614(1)	-1.562(3)	0.533[10]**	-10.82(0)***	-10.82(0)***	0.157[3]
Colombia	-1.012(0)	-1.215(3)	0.388[10]*	-11.52(0)***	-11.52(1)***	0.243[2]
Costa Rica	-0.591(0)	-0.798(4)	0.369[10]*	-12.72(0)***	-12.75(4)***	0.409[5]*
Dominica	-1.208(4)	-0.959(9)	1.588[10]***	-4.13(3)***	-13.52(9)***	0.067[9]
Ecuador	-2.073(6)	-2.067(8)	0.255[10]	-4.94(5)***	-14.61(8)***	0.109[7]
Haiti	-2.319(0)	-2.321(3)	1.168[10]***	-13.72(0)***	-13.72(4)***	0.224[4]
Honduras	-1.718(0)	-1.616(6)	1.580[10]***	-10.99(0)***	-10.99(0)***	0.159[5]
Mexico	-3.114(2)**	-2.278(6)	0.741[10]***	-10.24(1)***	-18.23(2)***	0.072[12]
Paraguay	-0.984(0)	-1.184(7)	0.582[10]**	-12.59(0)***	-12.87(6)***	0.402[7]*
Peru	-1.271(0)	-1.349(4)	0.599[10]**	-11.56(0)***	-11.52(2)***	0.627[4]**
Uruguay	-1.030(1)	-1.180(7)	0.788[10]***	-10.11(0)***	-10.33(4)***	0.351[8]*
Venezuela	-2.640(0)*	-2.461(3)	0.454[10]*	-14.89(0)***	-15.08(6)***	0.083[8]

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).*

Before we go on our CADF and CKSS tests, the most important issue concerning these covariate tests is the determination of appropriate covariates, which has a great impact on the test power and therefore the empirical results. Unfortunately, no econometric theory is available for the selection of a particular set of covariates that can produce the highest power among a number of covariates. In the related literature, the commonly used approach is to select the stationary covariates in the study according to economic theory (e.g., Amara and Papell, 2006; Elliot and Pesavento, 2006). Here, we use dp (domestic inflation rate), dp^* (foreign inflation rate), and (dp^*, dp) (both domestic and foreign inflation rates) as the covariates for each country during the test. Tables 2 and 3 report the results of CADF and CKSS tests. With a few exceptions, empirical results from our CADF and CKSS tests using different stationary covariates indicate that PPP holds true for all of the 15 Latin American countries.

Table 2. Results of CADF tests for Latin countries

Covariate	dp^*	dp	$\left(dp^*, dp\right)$
Argentina	-1.641** (0.999)[0.031]	-7.719*** (0.041)[0.000]	-7.605*** (0.034)[0.000]
Bolivia	-2.549*** (0.505)[0.007]	-2.479*** (0.110)[0.006]	-4.300*** (0.067)[0.000]
Brazil	-1.556* (0.934)[0.053]	-2.486*** (0.578)[0.003]	-2.226** (0.524)[0.014]
Chile	-1.864** (1.000)[0.039]	-2.406*** (0.590)[0.009]	-1.792** (0.170)[0.032]
Colombia	-1.433* (0.993)[0.083]	-2.198** (0.824)[0.017]	-1.870** (0.768)[0.030]
Costa Rica	-1.606* (0.611)[0.044]	-2.135** (0.637)[0.015]	-1.706** (0.061)[0.049]
Dominica	-1.217 (0.960)[0.117]	-1.710* (0.861)[0.058]	-1.931** (0.832)[0.025]
Ecuador	-2.888*** (0.898)[0.002]	-4.857*** (0.261)[0.000]	-4.827*** (0.131)[0.000]
Haiti	-2.359** (0.922)[0.012]	-2.596*** (0.740)[0.006]	-2.707*** (0.731)[0.003]
Honduras	-1.516* (0.806)[0.077]	-0.690 (0.713)[0.246]	-1.149 (0.293)[0.125]
Mexico	-5.001*** (0.745)[0.000]	-3.974*** (0.415)[0.000]	-3.907*** (0.524)[0.001]
Paraguay	-1.500* (0.821)[0.071]	-1.689** (0.765)[0.037]	-1.577* (0.627)[0.064]
Peru	-1.970** (0.778)[0.019]	-3.238*** (0.739)[0.000]	-3.785*** (0.727)[0.000]
Uruguay	-1.518* (0.984)[0.062]	-1.707** (0.394)[0.034]	-1.731** (0.837)[0.030]
Venezuela	-2.713*** (0.966)[0.010]	-3.124*** (0.769)[0.001]	-3.248*** (0.641)[0.000]

*Notes: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively. The number in parenthesis indicates the value of* $\hat{\rho}^2$*. The asymptotic p-values are computed by means of Bootstrap simulations using 1000 replications.*

Table 3. Results of CKSS tests for Latin countries

Covariate	dp^*	dp	(dp^*, dp)
Argentina	-2.162*** (0.999)[0.003]	-8.014*** (0.054)[0.000]	-7.848*** (0.042)[0.000]
Bolivia	-2.480*** (0.508)[0.004]	-2.455*** (0.110)[0.013]	-4.223*** (0.067)[0.000]
Brazil	-1.433* (0.979)[0.087]	-2.399*** (0.601)[0.008]	-2.060** (0.523)[0.022]
Chile	-1.865** (1.000)[0.042]	-2.414*** (0.591)[0.005]	-1.810** (0.169)[0.039]
Colombia	-1.411 (0.993)[0.076]	-2.172** (0.826)[0.009]	-1.854** (0.768)[0.041]
Costa Rica	-1.589** (0.611)[0.060]	-2.117** (0.637)[0.009]	-1.684** (0.061)[0.046]
Dominica	-1.515* (0.960)[0.062]	-2.046** (0.852)[0.030]	-2.284** (0.825)[0.012]
Ecuador	-2.973*** (0.971)[0.001]	-4.959*** (0.252)[0.000]	-4.916*** (0.126)[0.000]
Haiti	-2.516*** (0.922)[0.008]	-2.706*** (0.755)[0.003]	-2.823*** (0.748)[0.001]
Honduras	-1.644** (0.806)[0.053]	-0.767 (0.698)[0.219]	-1.281 (0.263)[0.095]
Mexico	-5.319*** (0.745)[0.000]	-4.288*** (0.328)[0.000]	-4.182*** (0.429)[0.000]
Paraguay	-1.524* (0.820)[0.064]	-1.700** (0.765)[0.046]	-1.595** (0.628)[0.049]
Peru	-1.979** (0.775)[0.025]	-3.172*** (0.750)[0.000]	-3.709*** (0.744)[0.000]
Uruguay	-1.650* (0.921)[0.063]	-1.746** (0.859)[0.038]	-1.779** (0.839)[0.042]
Venezuela	-2.730*** (0.826)[0.001]	-3.413*** (0.596)[0.000]	-3.506*** (0.460)[0.000]

*Notes: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively. The number in parenthesis indicates the value of* $\hat{\rho}^2$ *. The asymptotic p-values are computed by means of Bootstrap simulations using 1000 replications.*

As we know that Latin American countries share important similarities in their economic history, which might lead to co-movements in their RERs. Our results do not come as a surprise because most of the Latin American countries have experienced periods of high inflation and processes of trade openness in the post-1980 period. As argued by Alba and Park (2003), those country-specific characteristics ensure parity and can decisively contribute to empirical evidence of PPP. The major policy implication that emerges from this study is that that PPP can be used to determine the equilibrium exchange rate for these 15 Latin American countries. The governments of these Latin American countries can use the PPP to predict the exchange rate that determine whether a currency is over or undervalued, as well as if the country is experiencing difference between domestic and foreign inflation rates. Nevertheless, reaping unbounded gains from arbitrage in traded goods is not possible in these 15 Latin American countries under study.

4. Conclusions

This study applies both linear and nonlinear unit root tests with stationary covariates, proposed by Hansen (1995) and Tsong (2011), respectively to test the validity of long-run PPP for a sample of Latin American over January 1995 to February 2010. Empirical results from both linear and nonlinear unit root test with different stationary covariates indicate that PPP holds true for all of the Latin American countries. Our results have important policy implications for the Latin American countries under study.

REFERENCES

[1] **Alba, J. D., Park, D. (2003),** ***Purchasing Power Parity in Developing Countries: Multi-period Evidence under the Current Float***; *World Development*, 31(12), 2049-2060;

[2] **Amara, J., Papell, D. H. (2006),** ***Testing for Purchasing Power Parity Using Stationary Covariates***; *Applied Financial Economics*, 16(11), 29-39;

[3] **Baum, C. F., Barkoulas, J. T., Caglayan, M. (2001),** ***Nonlinear Adjustment to Purchasing Power Parity in the Post-Bretton Woods***; *Journal of International Money and Finance*, 20, 379–399;

[4] **Dickey, D. A., Fuller, W. A. (1981),** ***Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root***; *Econometrica*, 49, 1057-1072;

[5] **Elliott, G., Pesavento, E. (2006),** ***Higher Power Tests for Bilateral Failures of PPP after 1973,*** *Journal of Money, Credit and Banking.*, 38(6), 1405-1430;

[6] **Hansen, B. E. (1995),** ***Rethinking the Univariate Approach to Unit Root Testing,*** *Econometric Theory*, 11, 1148-1171;

[7] **Kapetanios, G., Shin, Y., Snell, A. (2003),** ***Testing for a Unit Root in the Nonlinear STAR Framework,*** *Journal of Econometrics*, 112, 359-379;

[8] **Kwiatkowski, D., Phillips, P., Schmidt, P., Shin, Y. (1992),** ***Testing the Null Hypothesis of Stationarity against the Alternative of a Unit Root: How Sure Are We that Economic Time Series Have a Unit Root?*** *Journal of Econometrics*, **54**, 159–178;

[9] **Lothian, J. R., Taylor, M. P. (2008),** ***Real Exchange Rates over the Past Two Centuries: How Important is the Harrod-Balassa-Samuelson Effect?*** *Economic Journal*, 118(532), 1742-1763;

[10] **Newey, W., West, K. (1994),** ***Automatic Lag Selection in Covariance Matrix Estimation,*** *Review of Economic Studies*, **61**, 631–653;

[11] **Park, J. Y., Shintani, M. (2005),** ***Testing for a Unit Root against Transitional Autoregressive Models;*** *Working Papers No. 05-W10*, Department of Economics, Vanderbilt University, Nashville, TN;

[12] **Perron, P. (1989),** ***The Great Crash, the Oil Price Shock and the Unit Root Hypothesis;*** *Econometrica*, 57, 1361–1401;

[13] **Phillips, P. C. B., Perron, P. (1988),** ***Testing for a Unit Root in Time Series Regression***; *Biometrika*, 75, 335–346;

[14] **Sollis, R. (2009),** ***A Simple Unit Root Test against Asymmetric STAR Nonlinearity with an Application to Real Exchange Rates in Nordic Countries,*** *Economic Modelling*, 26, 118–125;

[15] **Taylor, A. M., Taylor, M. P. (2004),** T***he Purchasing Power Parity Debate,*** *Journal of Economic Perspectives*, 18(4), 135-158;

[16] **Taylor, M. P., Peel, D. A. (2000),** ***Nonlinear Adjustment, Long-Run Equilibrium and Exchange Rate Fundamentals;*** *Journal of International Money and Finance*, 19(1), 33-53;

[17] **Taylor, M. P., Peel, D. A., Sarno, L. (2001)**, ***Nonlinear Mean-reversion in Real Exchange Rates: Towards a Solution to the Purchasing Power Parity Puzzles;*** *International Economic Review*, 42, 1015–1042;

[18] **Tsong, C. C. (2011),** ***Testing for a Unit Root with Covariates against Nonlinear Alternatives,*** *Economic Modelling*, 28(3), 1226-1234.