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A Century of PPP: Supportive Results from non-Linear Unit Root Tests

ABSTRACT

Testing for stationarity of the real exchange rates is a common practice to validate the purchasing power parity (PPP) theory. In this paper, we test PPP by applying a new unit root test that allows for nonlinearity in the data to the real exchange rates constructed with a century of data of 20 countries from Taylor (*Review of Economics and Statistics*, 2002). The problem of lag selection has been taken into account in testing as recommended by Lopez *et al*. (*Journal of Money, Credit and Banking*, 2005) who challenged Taylor's conclusion that PPP holds well over the twentieth century. The results support PPP in 16 out of 19 cases when the U.S. dollar is used as base currency, a result much closer to Taylor (2002) than Lopez *et al.* (2005) and in line with recent studies.

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1. Introduction

The issue of whether PPP holds has been subject to substantial controversy. It is well known that PPP holds better, among other things, for long span data. One way to test for the validity of PPP is to test whether real exchange rate is mean reverting or not. Perhaps, the strongest evidence for PPP in this sense is provided by Taylor (2002), who employed a century of real exchange rate data for 20 countries against the US dollar and a "world" basket of currencies, and concluded that "PPP has held in the long run over the twentieth century for my sample of 20 countries" (p. 144). Taylor reached this conclusion by using a more powerful test, namely, Dickey-Fuller (DF)-Generalized-Least-Squares (GLS) test of Elliott, Rothenberg and Stock (1996), rather than the standard augmented DF (ADF) tests. His results were not sensitive to using a different base currency (the U.S. dollar or the "world" basket) either. Taylor's findings were also robust to employing either industrial countries or developing countries.[1] As a result, Taylor stated that "If PPP holds in the long run, it is no longer productive to devote further the attention to the stationarity question" (p. 144).

However, Taylor's evidence is recently challenged by Lopez, Murray and Papell (2005). Extending the Taylor (2002) data set for two more years through 1998 and using the data of industrial countries only, Lopez *et al.* (2005) checked the sensitivity of Taylor's results to employing different lag specifications by proposing the use of a general-to-specific method of Hall (1994) for ADF tests and a modified Akaike information criterion of Ng and Perron (2001) for DF-GLS tests. When they performed the tests using these procedures, they found evidence in favor of PPP only in 9 of 16 real exchange rates of industrial countries relative to the U.S. dollar. They also found that the DF-GLS test does not appear to be more powerful than the ADF test

[1] The industrial countries include Australia, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the U.K., and the U.S. while Argentina, Brazil and Mexico are the developing countries.

when using proper lag selection procedures. These findings made them to conclude that "We do not see how finding evidence of PPP for one more than half of the countries justifies describing the 20th century as a 'A Century of Purchasing Power Parity' (Lopez *et al*., 2005, p. 362)".

The tests employed by Taylor (2002) and Lopez *et al*. (2005) assume that adjustment of real exchange rates is in a linear fashion. More recent studies, however, have pointed out possibility of the adjustment being non-linear in nature. When non-linear unit-root testing procedure is applied to determine mean-reverting properties of real exchange rates, relatively more evidence is found in support of PPP. Examples include Michael, Nobay and Peel (1997), Sarantis (1999), Taylor, Peel and Sarno (2001), Sarno and Taylor (2002), Taylor (2003), and Sarno, Taylor and Chowdhury (2004).[2]

In this paper, we test PPP one more time by using a century of data from Taylor (2002) and by allowing for nonlinearity in the data after taking the problem of lag selection into account as recommended by Lopez *et al* (2005) who challenged Taylor. In doing so we use an alternative testing procedure suggested by Kapetanios, Shin and Snell (hereafter, KSS) (2003) who developed a new technique for the null hypothesis of a unit root against an alternative of nonlinear stationary smooth transition autoregressive (STAR) process. They argued that, under the assumption that the real exchange rates follow nonlinear stationary processes, the alternative hypothesis of linear stationarity in the standard ADF tests would be misspecified. Using quarterly bilateral real exchange rates with the US dollar and real interest rates for the 1957-1998 and 1957-2000 period, respectively, for some selected OECD countries, KSS (2003) have illustrated that their tests are more powerful than the standard ADF tests. Chortareas and Kapetanios (2004), Hasan (2004) and Liew, Baharumshah, and Chong (2004) have applied the

[2] Such non-linearity in real exchange rates may be caused by transactions costs in international arbitrage, which create a band of no arbitrage for the real exchange rate. For different transaction costs see Bahmani-Oskooee and Das (1985).

KSS tests to the bilateral real exchange rates of Japan, India, and a group of Asian countries, respectively. More recently, Bahmani-Oskooee, Kutan and Zhou (2006a and 2006b) apply the KSS tests to the real effective exchange rates of 88 developing countries and 23 OECD countries (respectively), and found more support for PPP than the linear ADF tests.

However, these relatively few recent studies focus on shorter sample periods, such as the post-floating period. A direct application of nonlinear unit root tests to longer data sets over a century is lacking. In this paper, we fill this gap in the literature. In doing so, we also attempt to shed some light on the conflicting findings in Taylor (2002) and Lopez *et al*. (2005). Looking forward, we find more support for PPP than reported in Lopez *et al.* (2005). While the latter study finds evidence in support of PPP only in 9 out of 16 real exchange rates of industrial countries relative to the U.S. dollar, KSS tests reject the null in favor of PPP in 14 out of the same 16 real exchange rates. We also conduct the tests for the three developing countries included in Taylor (2002) but missing in Lopez *et al.* (2005). We find that KSS tests support long-run PPP for 2 out of these 3 real exchange rates. Overall, the evidence suggests that PPP has *mostly* held in the long run over the twentieth century. To support our findings, we review the KSS (2003) test in section 2 and report the results in section 3. Our summary is provided in section 4.

2. Methodology[3]

We utilize the tests developed by KSS (2003) to incorporate non-linearity in time series movement in testing for the stationarity of real exchange rates. KSS (2003) have expanded the standard ADF test by keeping the null hypothesis as nonstationarity in a time series variable

[3] This section draws on Bahmani-Oskooee, Kutan and Zhou (2006b) who apply the KSS methodology to the real effective exchange rates of 23 OECD countries for the floating exchange rate period.

against the alternative of a nonlinear but globally stationary process. Their new test is based on the following exponential smooth transition autoregressive (ESTAR) specification:

$$\Delta y_t = \gamma y_{t-1}[1 - \exp(-\theta y_{t-1}^2)] + \varepsilon_t, \qquad \theta \geq 0 \qquad (1)$$

where y_t is the de-meaned or de-trended series of interest, ε_t is an i.i.d. error with zero mean and constant variance, and $[1 - \exp(-\theta y_{t-d}^2)]$ is the exponential transition function adopted in the test to present the nonlinear adjustment. The null hypothesis of a unit root in y_t (i.e., $\Delta y_t = \varepsilon_t$) implies that $\theta = 0$ (thus $[1 - \exp(-\theta y_{t-d}^2)] = 0$). If θ is positive, it effectively determines the speed of mean reversion.

The null hypothesis of nonstationarity with the KSS test procedure is H_0: $\theta = 0$ against the mean-reverting nonlinear alternative hypothesis H_1: $\theta > 0$. Because γ in (1) is not identified under the null, we cannot directly test H_0: $\theta = 0$. To deal with this issue, KSS suggest to reparameterize (1) by computing a first-order Taylor series approximation to specification (1) to obtain the auxiliary regression expressed by (2) below:

$$\Delta y_t = \delta y_{t-1}^3 + \text{error} \qquad (2)$$

For a more general case where the errors in (2) are serially correlated, regression (2) is extended to

$$\Delta y_t = \sum_{j=1}^{p} \rho_j \Delta y_{t-j} + \delta y_{t-1}^3 + \text{error} \qquad (3)$$

with the p augmentations, which are used to correct for serially correlated errors. The null hypothesis of nonstationarity to be tested with either (2) or (3) is H_0: $\delta = 0$ against the alternative H_1: $\delta < 0$. KSS show that the t-statistic for $\delta = 0$ against $\delta < 0$, i.e., t_{NL}, does not have an

asymptotic standard normal distribution. They tabulate the asymptotic critical values of the t_{NL} statistics via stochastic simulations.

In this study, we apply both the ADF and KSS tests to Taylor's (2002) data to test for the stationarity of the real exchange rates. Following the suggestions of KSS (2003, p. 365) and Lopez *et al* (2005), the number of augmentations p for either the ADF tests or the KSS tests is selected using the general-to-specific procedure of Hall (1994) and Ng and Perron (1995).

3. Data and test results

The data set employed in Taylor (2002) consists of annual nominal exchange rates and price levels, each for over 100 years, through 1996 for 20 countries.[4] They are Argentina, Australia, Belgium, Brazil, Canada, Denmark, Finland, France, Germany, Italy, Japan, Mexico, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the U.K., and the U.S. The exchange rates, E_{it}, are measured as domestic currency units per U.S. dollar and the price levels, P_{it}, are consumer price deflators or, if not available, GDP deflators. Following the instruction of Taylor (2002), 19 real exchange rates relative to the U.S. dollar are generated as $q_{it} = r_{it} - r_{US,t}$, where $r_{it} = \log P_{it} - \log E_{it}$. Twenty real exchange rates relative to the "world" basket of currencies are constructed by $q_{it}^W = r_{it} - r_{it}^W$, where $r_{it}^W = \sum_{j \neq i} r_{jt} / (N-1)$ and $N = 20$.

Both the ADF tests and the KSS tests are applied to these real exchange rates (RERs) with the number of augmentations p for either tests being selected using the general-to-specific procedure. The test results are reported in Tables 1 and 2 for the RERs relative to the U.S. dollar and to the "world" basket, respectively. In these tables, four statistics are reported. The test statistic of the standard ADF that only includes a constant in the model for testing is denoted by

[4] We are grateful to Alan Taylor for providing us his data set.

t_{ADF1}, and the one that includes both a constant and a time trend is denoted by t_{ADF2}. The KSS test statistics based on regression (3) are denoted by t_{NL1} for de-meaned data and t_{NL2} for de-trended data. To obtain the de-meaned or de-trended data, we first regress each series on a constant or on both a constant and a time trend, respectively, and then we save the residuals.

The results in Table 1 for the RERs relative to the U.S. dollar reveal that t_{ADF1} statistics reject the null for 10 out of 19 cases at the 5% significance level. By allowing a time trend in the model, t_{ADF2} statistic indicates two additional 5% rejections for the Australian/U.S. and Canadian/U.S. real exchange rates. Together, the ADF tests reject the null of nonstationarity in favor of the alternative of linear stationarity for 12 of 19 RERs relative to the U.S. dollar at the 5% significance level. The results are consistent with the finding in Lopez *et al.* (2005) who reject the null in only 9 cases out of 16 RERs of industrial countries relative to the U.S. dollar, and seem to be "*not sufficient* to conclude the long-run PPP has held over the last century" (Lopez *et al.* 2005, p. 369).

However, once we take the non-linearity in real exchange rate movement into account, the KSS tests reject the null of nonstationary RER for 14 cases for the de-meaned data and add two more 5% rejections for the Canadian/U.S. and Swiss/U.S. real exchange rates with the de-trended data. These total 16 rejections at the 5% significance level out of 19 RERs relative to the U.S. dollar provide strong support for long-run PPP over the 20th century.

The KSS test results for the RERs relative to the "world" basket also show the support for long-run PPP. Whereas the ADF tests reject the null for only 9 out of 20 cases by t_{ADF1} and/or t_{ADF2}, the KSS tests reject the null of nonstationarity at the 5% significance level in favor of the alternative of non-linear stationarity for 14 out of total 20 RERs for the de-meaned and/or de-trended series. Although, these results support the earlier findings that the selection of numeraire

currency is critical for inferences on PPP [5], nevertheless, the non-linear tests provide more support for PPP as compared to the linear tests.

4. Summary and Conclusion

Since the purchasing power parity theory is a long-run theory of exchange rate determination, in testing the theory the longer the time dimension of the data, the better. This was recently demonstrated by Taylor (2002) who collected data for a group of twenty countries over 100 years. By applying the well-known ADF test and more powerful DF-GLS test Taylor concluded that "PPP has held in the long run over the 20th century for my sample of 20 countries". This finding, however, was recently challenged by Lopez, Murray and Papell (2005) who demonstrated that if Taylor had used a proper lag selection criterion in the testing procedure, support for PPP would have been reduced to no more than 9 out of 16 cases (with the U.S. as numeraire and without including three developing countries).

The standard ADF or DF-GLS test assumes the adjustment of a time series variable such as a real exchange rate is in a linear fashion. More recent studies of the behavior of real exchange rates, however, have argued that the mean reverting properties of the real rates could follow a non-linear path. Therefore, in this paper we try to arbitrate and resolve the conflicting results reported by Taylor (2002) and Lopez *et al*. (2005) by allowing non-linearity in the mean reverting process of real exchange rates of all 20 countries. The results could be best summarized by saying that using non-linear unit root test, we are able to support PPP in 16 out of 19 cases when the U.S. dollar is used as base currency, a result much closer to Taylor (2002) than Lopez *et al.* (2005) and in line with recent studies.

[5] See, for example, Papell and Theodoridis (2001) and Lopez and Papell (2005).

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Table 1.
Unit root test results for the real exchange rates relative to the U.S. dollar

	t_{ADF1}	p		t_{NL1}	p		t_{ADF2}	p		t_{NL2}	p
Argentina	-3.28*	7		-7.98**	8		-3.15	7		-8.14**	8
Australia	-2.79	1		-3.23*	1		-3.48*	1		-3.80*	1
Belgium	-4.12**	1		-8.93**	4		-5.05**	1		-9.65**	1
Brazil	-3.08*	4		-4.53**	8		-3.02	4		-4.53**	8
Canada	-2.59	0		-2.23	0		-3.76*	0		-3.85*	0
Denmark	-0.99	6		-0.78	6		-1.72	6		-1.94	6
Finland	-5.94**	1		-6.42**	2		-6.14**	1		-6.35**	2
France	-3.54**	1		-4.53**	1		-4.18**	1		-5.60**	1
Germany	-2.96*	1		-3.73**	1		-3.28	1		-3.65*	1
Italy	-4.23**	2		-5.03**	2		-4.23**	2		-5.02**	2
Japan	-1.13	1		-1.38	7		-2.03	7		-3.26	7
Mexico	-1.87	6		-2.02	6		-2.75	6		-2.61	6
Netherlands	-2.76	1		-2.95*	1		-3.13	1		-3.49*	1
Norway	-3.54**	1		-4.27**	1		-3.85*	1		-4.05**	1
Portugal	-2.25	5		-4.67**	5		-2.20	5		-4.08**	5
Spain	-3.20*	1		-4.15**	1		-3.19	1		-4.49**	1
Sweden	-3.54**	1		-4.83**	1		-4.48**	1		-4.47**	1
Switzerland	-1.35	2		-1.74	2		-2.68	2		-3.77*	2
UK	-2.60	4		-3.36*	1		-2.77	4		-4.94**	3

Notes: t_{ADF1} and t_{ADF2} are the standard ADF test statistics for the null of nonstationarity of the variable in the study without and with a time trend, respectively, in the model for testing. t_{NL1} and t_{NL2} are the KSS test statistics for the de-meaned and the de-trended data, respectively. p are the selected numbers of augmentations using the general-to-specific procedure of Hall (1994) and Ng and Perron (1995). The 5% and 1% asymptotic critical values are -2.86 and -3.43 for t_{ADF1} respectively, and are -3.41 and -3.96 for t_{ADF2} respectively. The 5% and 1% asymptotic critical values for t_{NL1} are -2.93 and -3.48 respectively, and those for t_{NL2} are -3.40 and -3.93 respectively, taken from Kapetanios et al. (2003, p. 364). * and ** denote rejection of the null hypothesis at the 5% and 1% significance levels, respectively.

Table 2.
Unit root test results for the real exchange rates relative to the "world" basket

	t_{ADF1}	p		t_{NL1}	p		t_{ADF2}	p		t_{NL2}	p
Argentina	-3.26*	7		-6.80**	8		-3.82*	8		-6.40**	8
Australia	-2.05	3		-1.97	3		-3.71*	5		-4.10**	1
Belgium	-3.98**	1		-8.41**	4		-4.80**	1		-7.42**	4
Brazil	-3.14*	4		-4.61**	4		-3.05	4		-4.55**	4
Canada	-2.45	1		-1.22	3		-3.18	1		-3.73*	1
Denmark	-2.68	4		-3.73**	4		-3.55*	4		-3.60*	4
Finland	-6.19**	1		-5.57**	2		-6.17**	1		-5.58**	2
France	-3.14*	1		-4.21**	1		-4.94**	1		-3.77*	1
Germany	-2.47	1		-3.70**	1		-2.47	1		-3.59*	1
Italy	-3.80**	2		-5.09**	2		-3.78*	2		-5.11**	2
Japan	-1.45	1		-1.69	1		-2.99	1		-2.56	1
Mexico	-0.62	6		-1.18	6		-2.51	6		-1.81	6
Netherlands	-2.25	7		-3.89**	7		-2.77	7		-2.64	7
Norway	-1.91	7		-2.34	7		-2.01	7		-1.99	7
Portugal	-1.73	4		-3.50**	4		-1.98	5		-3.47*	4
Spain	-2.03	0		-2.20	0		-2.30	0		-2.58	0
Sweden	-2.67	0		-3.19*	0		-2.54	0		-2.33	0
Switzerland	-0.82	5		-1.64	0		-2.75	0		-2.42	0
UK	-1.48	4		-2.00	4		-2.88	4		-2.24	0
US	-3.52**	1		-5.50**	1		-3.67*	1		-5.52**	1

See notes to Table 1.