E c o n o m i c s   B u l l e t i n

Nonlinear unit root tests of PPP using long-horizon data

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Abstract

The Kapetanios, Shin, and Snell (KSS, 2003) test for a nonlinear unit root is used to study purchasing power parity using Taylor's extensive data set, updated to include recent exchange rate and price level data. The results i) indicate that PPP holds with respect to the US dollar for most countries and ii) are more supportive of PPP than those from standard linear unit root tests.

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1. **Introduction**

As a long run equilibrium condition of open economy macro models, the hypothesis of purchasing power parity (PPP) has been the focus of much empirical work. The absolute version of PPP indicates that the price of a market basket of (traded) goods is the same everywhere in terms of a common currency. Deviations from PPP are corrected by goods arbitrage. A partial list of techniques used in such empirical work includes single equation unit root tests, variance ratio tests, cointegration studies, and panel unit root tests. The voluminous empirical evidence is mixed. Sarno and Taylor (2002) provide a thorough review of the PPP literature.

In an influential paper, Taylor (2002) concludes that long run purchasing power parity held during the past century in the sample of countries he studied and suggests that it is time to focus attention on short-run, real exchange rate adjustment rather than PPP. His findings are particularly important because his data set includes more than one hundred years of annual observations ending in 1996, hence provides a long horizon perspective lacking in most other studies. Subsequently, numerous researchers have applied different econometric methods to Taylor's data set. Lopez, Murray, and Papell (LMP, 2005) criticize Taylor's approach for the use of suboptimal lag length selection in the unit root tests. Employing unit root tests with optimally selected lags to Taylor's data, LMP find support for PPP in the data for just nine of sixteen developed countries.[1]

Bahmani-Oskooee, Kutan, and Zhou (BKZ, 2007) apply the Kwiatkowski, Phillips, Schmidt, Shin (KPSS, 1992) test for stationarity to Taylor's data and conclude that the evidence supports PPP for eighteen of the twenty countries in the data set. They base their conclusions on two different versions of the KPSS test, one in which the null is a stationary real exchange rate (RER) and the other in which the RER is trend stationary. Furthermore they use these two versions with two different real rates, one with respect to the US dollar and the other against a world basket of currencies. Thus data for each country are subject to four different tests. If any one of these produces results indicating a stationary series, BKZ cite this as evidence supportive of PPP. Indeed, for five of the eighteen countries they mention as displaying results supportive of PPP, only one of the four test versions supports PPP. A skeptic of purchasing power parity using the same criterion could interpret their evidence as not indicating PPP because stationarity is rejected for fifteen countries at least one of the four empirical specifications.

In other work with the Taylor data Bahmani-Oskooee, Kutan, and Zhou (2006) apply the nonlinear unit root test of Kapetanios, Shin, and Snell (2003) to the Taylor data. They find rejections of the unit root null, that is, evidence in favor of purchasing power parity, for sixteen of nineteen countries when the US dollar is the numeraire currency. Instead of relying on unit root tests Wallace and Shelley (2006) apply the Fisher-Seater test with bootstrapped errors to the Taylor data and conclude that PPP holds for at least twelve of nineteen countries with respect to the United States.

In this study, as in that of BKZ (2006) the Kapetanios, Shin, and Snell (KSS) nonlinear unit root test is used to study purchasing power parity in the Taylor data. But there are three important differences from the BKZ study. First, the Taylor data are updated to 2007 (2006 in the case of Argentina). The BKZ study is through 1996 as in Taylor's original study. Second, Taylor's data set actually includes information for three additional countries, Chile, Greece, and New Zealand although results for these countries were not published in his study, presumably because there are fewer than one

[1] They eliminate Argentina, Brazil and Mexico (included in Taylor) from their study.

hundred years of observations.[2] Findings for these three countries are reported in this paper. Finally, the results of the KSS tests are compared to those from three linear unit root tests; the augmented Dickey-Fuller (ADF), the Elliott, Rothenberg, and Stock (ERS, 1996) test which Taylor applied, and the KPSS test as used in BKZ.

2. Data and Methodology

The Taylor data set consists of annual observations on logged nominal exchange rates and logged price indexes (consumer price index) for the twenty-three countries listed in Table I. For most countries the data set is updated through 2007 using IMF, OECD, and Federal Reserve Board data. Recent data for Chile are from the country's Central Bank. In the case of Argentina, the data for 1997-2006 from the country's statistical agency are added to the data set. The nominal exchange rate is measured as units of foreign currency per US dollar. For each country except Chile, Greece, and New Zealand the data span more than 100 years.

KSS begin with a univariate, smooth transition autoregressive model of order one in which the transition function is exponential. Using a Taylor series approximation, they derive their test equation given by

$$\Delta y_t = \delta y_{t-1}^3 + \sum_{i=1}^{j} \phi_i \Delta y_{t-i} + u_t \qquad (1)$$

In this study, y_t is the demeaned (or demeaned and detrended) log real exchange rate. The coefficient of interest for the unit root test is δ. As shown in equation (1) lags of the dependent variable may be included to eliminate serial correlation. Under the null of a (nonlinear) unit root, $\delta=0$ while the alternative of a stationary series is $\delta<0$. As with linear unit root tests, failure to reject the null implies a nonstationary real exchange rate thus does not support PPP. Rejection of the null suggests a stationary real exchange rate and evidence in favor of PPP.[3]

It is fairly common to conduct one set of unit root tests on the real exchange rate including only a constant in the estimations and then another including a constant and trend in the estimations. The possibility of Balassa-Samuelson effect is usually cited as justification for the inclusion of a trend. For comparability to other studies this practice is followed in this paper although a theoretical justification for why the Balassa-Samuelson effect would yield a trended real exchange rate is lacking in the literature.

3. Results

To address serial correlation in the ADF and ERS tests lags of Δy_t are added (if needed) with the Schwarz information criterion used to determine lag length. In the nonlinear versions Lagrange multiplier tests are used to fix the lag length. Each nonlinear unit root test is estimated with zero to eight lags of the dependent variable. The shortest lag length which yields an obs.R^2 statistic having a marginal significance level of .2 or better is selected as the number of lags to use in the estimation. For a few countries this criterion was not satisfied and the nonlinear tests were conducted with additional, nine to twelve lags. The added lags eliminated autocorrelation in the case of Norway with nine lags used in the nonlinear test on the demeaned real exchange rate.

However, in the case of tests on both the demeaned and demeaned-detrended real exchange rate for Germany, not a single specification using from zero to twelve lags

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[2] Table I lists the countries and the period for which data are available. Although the earliest observations are for England in 1850, use of the dollar as numeraire implies that all empirical estimations begin no earlier than 1870.

[3] Strictly speaking rejection of the null implies that the real exchange rate is mean reverting, evidence supportive of the relative version of PPP but not sufficient for absolute PPP. In the absence of models in which relative, but not absolute, PPP holds in the long run, most macroeconomists, however, probably regard evidence of stationarity as indicative of absolute PPP.

resolved the problem. In this instance, inspection of the graphs of residuals from estimating equation (1) with different lags revealed exceptionally large (absolute) errors during the years immediately following World War I. During this period, of course, Germany experienced several years of hyperinflation. Restricting the sample period to 1928-2007 and again estimating equation (1) with zero to eight lags produces a much better behaved specification that satisfies the criterion described above. For Germany, this means one lag of the dependent variable eliminates serial correlation in the nonlinear unit root test. The same problem occurs in tests using the demeaned and detrended real exchange rates for Denmark, Japan, and Norway. Inspection of residual graphs is used to select restricted sample periods and the above described criterion again applied to search for a specification free of serial correlation. In the case of Japan, the period from 1941-1948 (World War II and its immediate aftermath) display relatively large (in absolute terms) residuals. No specification free of serial correlation could be found which included the post WW II period. Consequently, only results for 1885-1940 are reported for Japan.[4]

Table II reports the t-statistics for the nonlinear tests on demeaned real exchange rates, that is estimation of equation (1) for each country with sufficient lags to eliminate autocorrelation. For comparison, the results from the ADF, ERS, and KPSS linear tests are also provided. The final row of the table shows the number of statistics indicating stationarity, thus evidence of PPP, of the real exchange rates. Critical values for the nonlinear tests are from Table I of KSS. As can be observed from the table, the nonlinear test results are supportive of purchasing power parity for eighteen of the twenty-two countries in the study. The linear test results show fewer significant t-stats (insignificant t-stats in the case of the KPSS test) thus indicate less support for PPP. In some cases, the linear tests present conflicting results. For example, in the case of Sweden both the ADF and ERS tests indicate rejection of the unit root null hence are supportive of PPP but the KPSS test statistic indicates rejection of the stationarity null, thus is not supportive of PPP.

Results are not notably different when the nonlinear tests are carried out on demeaned and detrended data (Table III). The only differences are for Denmark and Switzerland which do not display evidence of PPP with demeaned data but do for demeaned and detrended data; and Germany and Japan whose real exchange rates appear stationary when demeaned but not so when demeaned and detrended. But, note that the sample periods for Japan are different in the two versions of the nonlinear tests as previously explained. Again, the linear tests which include a constant and trend in the estimation equations present mixed results and weaker evidence for PPP than observed in the nonlinear estimations.

4. Conclusions

The Taylor data are the most extensive long horizon data available on exchange rates and price levels with more than a century of annual observations for most included countries. Long span data are important for testing long run propositions such as PPP, particularly if mean reversion is slow as discussed in Rogoff (1996). When applied to the real exchange rates constructed from the Taylor data, the linear unit root tests yield mixed results but the nonlinear, KSS tests produce strong evidence in favor of purchasing power parity. The results of this study reinforce Taylor's conclusion; PPP has generally held over the twentieth century for the countries in the sample.

[4] As mentioned previously, there is no theoretical justification for including a trend in PPP tests. Absent such a rationale, one should probably have greater confidence in the results with demeaned data.

Table I-Countries and Period Coverage

Country	Taylor data-years of coverage	Updated to
Argentina	1884-1996	2006
Australia	1870-1996	2007
Belgium	1870-1996	2007
Brazil	1880-1996	2007
Canada	1870-1996	2007
Denmark	1880-1996	2007
Finland	1881-1996	2007
France	1880-1996	2007
Germany	1880-1996	2007
Italy	1880-1996	2007
Japan	1885-1996	2007
Mexico	1886-1996	2007
Netherlands	1870-1996	2007
Norway	1870-1996	2007
Portugal	1890-1996	2007
Spain	1880-1996	2007
Sweden	1880-1996	2007
Switzerland	1892-1996	2007
UK	1850-1996	2007
US	1870-1996	2007
Additional countries in the data set but for which results are not reported in Taylor (2002)		
Chile	1913-1996	2007
Greece	1948-1996	2007
New Zealand	1948-1996	2007

Table II-Unit Root Tests for Mean Stationary Real Exchange Rates

Country	KSS demeaned	ADF constant	ERS constant	KPSS constant
Argentina	-8.242**	5.035**	-4.900**	.107
Australia	-1.804	-2.027	-2.143*	.745**
Belgium	-10.274**	-4.745**	-2.810*	.793**
Brazil	-5.223**	-2.637	-2.248*	.154
Canada	-1.907	-2.531	-1.733	.798**
Denmark	-1.420	-2.148	-2.066	.695**
Finland	-7.587**	-6.259**	-6.109**	.164
France	-3.564**	-4.048**	-2.028*	.896**
Germany[a]	-3.324*	-2.892	-2.489*	.173
Italy	-4.843**	-4.116**	-4.130**	.077
Japan	-3.225*	-2.405	-1.006	1.127**
Mexico	-12.592**	-6.021**	-3.148**	.868**
Netherlands	-3.162*	-2.862	-2.501*	.501*
Norway	-3.581**	-3.632**	-2.271**	.509*
Portugal	-6.020**	-2.976*	-1.897	.362
Spain	-4.276**	-3.342*	-2.906**	.281
Sweden	-5.098**	-4.008**	-3.165**	.551*
Switzerland	-2.887	-1.632	-0.802	.981**
UK	-4.279**	-3.243*	-2.800**	.335
Additional Countries				
Chile	-3.073*	-1.735	-1.076	1.092**
Greece	-8.808**	-7.665**	-0.585	.218
New Zealand	-4.301**	-3.827**	-3.941**	.596*
# stationary	18	11	14	9

* Significant at 5%
** Significant at 1%

Table III-Unit Root Tests for Trend Stationary Real Exchange Rates

Country	KSS detrended	ADF constant, trend	ERS constant, trend	KPSS constant, trend
Argentina	-8.262**	-5.014**	-5.010**	.105
Australia	-2.636	-3.080	-2.851	.174*
Belgium	-9.705**	-5.603**	-5.641**	.070
Brazil	-4.245**	-2.695	-2.704	.091
Canada	-2.569	-3.606*	-2.067	.211*
Denmark[a]	-3.411*	-3.495*	-2.926	.160*
Finland	-7.531**	-6.357**	-6.408**	.056
France	-7.123**	-4.989**	-4.924**	.212*
Germany[b]	-3.067	-2.916	-2.895	.119
Italy	-4.824**	-4.120**	-4.143**	.062
Japan[c]	-3.049	-2.502	-2.556	.204*
Mexico	-11.676**	-7.038**	-7.014**	.065
Netherlands	-3.583*	-3.441	-3.481*	.176*
Norway[a]	-4.755**	-3.349	-3.325	.193*
Portugal	-5.689**	-2.923	-2.811	.251**
Spain	-4.471**	-3.273	-3.232*	.219**
Sweden	-4.905**	-4.546**	-4.562**	.064
Switzerland	-5.056**	-3.911*	-3.912**	.130
UK	-4.620**	-3.328	-3.013*	.130
Additional Countries				
Chile	-4.039**	-3.459*	-3.416*	.185*
Greece	-8.736**	-7.436**	-0.858	.161*
New Zealand	-3.645*	-4.519**	-4.512**	.035
# stationary	18	13	13	11

* Significant at 5%

** Significant at 1%

[a] Estimation period 1915-2007

[b] Estimation period 1928-2007

[c] Estimation period 1885-1940

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