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Purchasing power parity in OECD countries: nonlinear unit root tests revisited

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Abstract

The aim of this paper is to provide additional evidence on the purchasing power parity empirical fulfillment in a pool of OECD countries. We apply the Harvey et al. (2008) linearity test and the Kruse (2010) nonlinear unit root test. The results point to the fact that the purchasing power parity theory holds in a greater number of countries than has been reported in previous studies.

JEL classification: C32, F15
Keywords: Real exchange rates, purchasing power parity, nonlinearities, unit root tests.

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1. Introduction

The purchasing power parity (PPP) theory has probably been one of the more controversial topics in international finance given that its empirical validity is still subject to analysis. Following the more general trend in time series Econometrics to the initial papers testing for a unit root using the Augmented Dickey Fuller and Phillips-Perron alike tests, new studies have incorporated panel and nonlinear unit root tests.

The PPP theory has important implications from a theoretical perspective because it is the basic building block of a number of open economy macroeconomic models. In addition, its empirical validity can be understood as a measure of economic integration amongst countries, as well as a way of assessing the degree of misalignment of currencies. In its absolute version, the PPP theory establishes that prices in different countries should be the same when converted into a common currency. This relationship can be expressed mathematically as follows:

$$E_t = \frac{P_t^*}{P_t} \qquad (1)$$

where E_t is the nominal exchange rate, defined as the price in foreign currency of a unit of the domestic currency, and P_t and P_t^* are the average prices of the basket of goods of a representative consumer in the home and foreign country. Equation (1) implies that the real exchange rate should be equal to 1. However, it is well known that PPP does not hold in the short run because in the short run, prices are relatively inflexible in response to changes in the nominal exchange rate. Thus if PPP holds at all, it is expected to hold in the long run.

In order to empirically analyse the fulfilment of PPP, unit root testing has become a very popular approach. If the real exchange rate contains a unit root, the shocks should have permanent effects and the variable will never return to its long run equilibrium. However, if the real exchange rate is stationary, shocks tend to die out in the long run and the equilibrium is achieved some time after the shock has occurred.

In a recent contribution, Bahami-Oskooee et al (2007) applied Kapetanios et al (2003), which controls for the possibility of nonlinearities in the data generation process, to a set of OECD countries. Their results are more favourable towards the stationarity of the real exchange rate than in previous studies, which mostly focus on linear unit root tests. However, the authors do not test for the presence of nonlinearities in the data and include a linear time trend, which is not compatible with the absolute or relative version of the PPP theory.

In this paper we contribute to the empirical analysis of PPP by first using panel data unit root tests in order to explore the cross-section and time series properties of the data jointly (Levin, Lin and Chu, 2002; Im, Pesaran and Shin, 2003; Maddala and Wu, 1999; and Choi, 2001). Second, we apply the recently developed Kruse (2010) unit root test, which is an upgraded version of the Kapetanios et al (2003) test in order to distinguish which series are stationary. Prior to the Kruse (2010) test, we check the adequacy of the nonlinear behaviour under the alternative hypothesis by testing the hypothesis of linearity vs. nonlinearity by means of the Harvey et al. (2008) test.

The remainder of the paper is organised as follows. In the next section we summarise the methods applied in this empirical research and present our results. The last section concludes.

2. Methodology and results

The real exchange rates used in this empirical analysis are real effective exchange rates (REER) for a pool of OECD countries (see table 2). We have used monthly observations from January 1972 to January 2010, obtained from the *OECD Economic Indicators* database.

We apply a group of panel unit root tests, that is, Levin, Lin and Chu (2002), Im, Pesaran and Shin (2003), Maddala and Wu (1999) and Choi (2001). Levin, Lin and Chu (2002) suppose a common unit root under the null hypothesis against the alternative of stationarity of all individuals, whereas the other tests allow for individual unit roots under the alternative hypothesis. The latter supposes a less restrictive framework since in the former the assumption of a common unit root under the null, or general stationarity under the alternative, may be too strong.

Alternatively, Im, Pesaran and Shin (2003) base their test on the assumption of different autoregressive parameter for every individual. A different approach is followed by Maddala and Wu (1999) and Choi (2001), who combine the different p-values of the individual auxiliary regressions, either for the ADF or Phillips-Perron tests, to obtain the following Fisher (1932)-type test

$$-2\sum_{i=1}^{N}\ln p_i \rightarrow \chi^2_{2N} \tag{2}$$

where p_i are the asymptotic p-value of a unit root test for individual *i*. Additionally, Choi (2001) proposes the following test, based on the combination of individual p-values:

$$Z = \frac{1}{\sqrt{N}} \sum_{i=1}^{N} \Phi^{-1}(p_i) \rightarrow N(0,1) \quad (3)$$

where Φ is the standard normal cumulative distribution function.

If the PPP hypothesis does not hold for the pool of countries, it is still possible that it might hold for some of the countries. In order to distinguish the countries for which this hypothesis holds, we apply individual unit root tests which take into account the possibility of nonlinear behaviour of the real exchange rate.

According to Taylor et al (2001), amongst others, real exchange rates might follow a nonlinear path over time. If that is the case, as stated by many authors such as Kapetanios et al (2003), traditional (linear unit root tests) may suffer from power problems, i.e. they tend to over accept the null hypothesis. Thus, Kapetanios et al (2003) propose a unit root test against the alternative of globally stationary exponential smooth transition autoregression (ESTAR).

$$y_t = \beta y_{t-1} + \phi y_{t-1} F(\theta; y_{t-1}) + \varepsilon_t \quad (4)$$

where ε_t is $iid(0,\sigma^2)$ and $F(\theta; y_{t-1})$ is the transition function, which is assumed to be exponential,

$$F(\theta; y_{t-1}) = 1 - exp\{-\theta(y_{t-1} - c)^2\} \quad (5)$$

with $\theta > 0$. However, Kapetanios et al (2003) assume that *c=0.*

In practice, it is common to reparameterise equation (3) as

$$\Delta y_t = \alpha y_{t-1} + \gamma y_{t-1}(1 - exp\{-\theta y_{t-1}^2\}) + \varepsilon_t. \quad (6)$$

in order to apply the test. This equation implies the existence of two regimes, i.e. an inner or central regime and an outer regime, where the transition bewteen the regimes is smooth. Kapetanios et al (2003) impose *α=0*, implying that the variable is a unit root in the central regime. The null hypothesis $H_0 : \theta = 0$ is tested against the alternative $H_1 : \theta > 0$, i.e. we test whether the variable is an I(1) process in the outer regime. From an economic viewpoint and in the context of exchange rates, this implies that the further the real exchange rate deviates from equilibrium, the faster the speed of mean reversion towards the fundamental equilibrium. In addition, the existence of trade barriers may create a central threshold where transactions are not profitable and arbitrage does not clear the market (a unit root process in the inner regime), whereas for large deviations, the profits from arbitrage are greater than the cost, and the arbitrage mechanism brings the exchange rate to the inner regime. Moreover, according to Taylor and Peel (2000), among others, an ESTAR function is appropriate to model exchange rates, given that this type of equation assumes that the effects of the shock on the variable are symmetric in the sense that these effects do not depend on the sign of the shock.

The idea of Kapetanios et al (2003) of imposing *c=0* may be too restrictive for variables where the threshold value may be different from 0. In the case of the REER, allowing for a threshold different from zero makes it possible to test for the relative version of PPP, where real exchange rates may revert to an equilibrium value different from 0. Hence, in this paper we apply Kruse's (2010) test, which is an extension of the Kapetanios et al (2003) unit root test, which relaxes the assumption of a zero location parameter *c*. Kruse (2010) considers the following modified ADF regression

$$\Delta y_t = \alpha y_{t-1} + \gamma y_{t-1}(1 - exp\{-\theta(y_{t-1} - c)^2\}) + \varepsilon_t . \tag{7}$$

Following Kapetanios et al (2003), it is possible to obtain a first order Taylor approximation of equation (7)

$$\Delta y_t = \delta_1 y^3{}_{t-1} + \delta_2 y^2{}_{t-1} + \varepsilon_t \tag{8}$$

In addition, equations (6)-(8) may incorporate lags of the dependent variable to control for autocorrelaton. In order to test the null hypothesis of unit root $H_0 : \delta_1 = \delta_2 = 0$ against a globally stationary ESTAR process, $H_0 : \delta_1 \neq 0, \delta_2 < 0$. Kruse (2010) proposes a τ test, which is a version of the Abadir and Distaso (2007) Wald test.

However, linearity needs to be tested in order to have an insight into the best specification of the model otherwise, the most commonly used linear unit root tests may be more appropriate. To test the null hypothesis of linearity against the alternative of a nonlinear model, we apply Harvey et al. (2008). These authors propose a test with the same limiting distribution regardless of whether the variable is I(0) or I(1). The new test is called W_{λ}, and is distributed as a $\chi^2(2)$. This test performs better in terms of size and power than those proposed by Harvey and Leybourne (2007).

Table 1 displays the results of the panel unit root tests. With the Levin, Lin and Chu (2002) test, it is not possible to reject the hypothesis that all the REER are non-stationary. However, the alternative hypothesis may be too restrictive. As shown in table 1, the rest of the tests reject the null hypothesis in favour of the alternative that there are some REER which are stationary.

In table 2, we display the results of the individual unit root tests and linearity test. In order to decide whether to introduce nonlinearities under the alternative hypothesis, we first apply the linearity test by Harvey et al. (2008). The hypothesis of linearity is, hence, rejected in 14 cases up to 27. We have applied the Ng and Perron (2001) linear unit root tests, along with the Kruse (2010) test. When the linearity hypothesis is rejected we find that using the Kruse (2010) test, PPP holds in the euro zone, Australia, Germany, Iceland, Italy, Korea, Mexico, New Zealand and Norway. Performing the Ng and Perron (2001) tests among the remaining countries, PPP holds in France, the Netherlands and the UK. Therefore, our preferred results provide evidence that support the PPP theory in seven EU countries, the Euro area and six non EU countries.

The Bahmani-Oskooee (2007) study on OECD countries provides a useful comparison[1] since the unit root tests are similar. The results are more favourable to the PPP hypothesis than most previous studies. Since a trend is not consistent with the PPP hypothesis, the comparison only considers the results for demeaned data. If we use the same criterion and select KSS for those countries where we have evidence against the linearity hypothesis[2], our results provide evidence in favour of stationarity for an additional four countries; Korea, Mexico, Netherland and the UK. However, we cannot reject the hypothesis that there is a unit root for Ireland and Switzerland.

Interestingly, there are some additional results in favour of PPP. In Belgium, although the linearity hypothesis is rejected, it is possible to reject the null with the Ng and Perron (2001) test. Also, for Austria, Japan, Switzerland and Turkey, the hypothesis of linearity is not rejected and it is possible to reject the null of unit root with the Kruse (2010) test.

[1] In addition to their 15 EU and 8 non EU countries, our sample includes 3 extra Non EU countries: Korea, Mexico and Turkey.

[2] The authors do not perform any diagnostic test of nonlinearity and present results for both ADF and KSS tests.

3. Conclusions

There are a large number of unit root tests available. When using panel unit root tests, we cannot reject nonstationarity for all countries except if the alternative hypothesis is that all the series are stationary. However, alternative tests show the null of unit root may be rejected if the alternative hypothesis is that some of the countries show a stationary REER. One possible interpretation of these results is that the former alternative hypothesis is too restrictive. If only some of the countries are I(1), it may be a good idea to look for a unit root in each country.

Therefore, we look at countries separately to expand our analysis. The study of the individual series may give further evidence in favour or against the PPP hypothesis. To do this, we use a linearity test to decide whether the standard unit root or a unit root test which allows for a nonlinear deterministic component is more appropriate. We find that introducing a nonlinear component seems more appropriate in roughly half of the cases. Following this procedure, we find that PPP holds for twelve of the REER series. This is a relatively large proportion with respect to previous studies.

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Table 1: Panel unit root tests results

Method	Statistic	Probability
Levin, Lee and Chu	-1.01559	0.1549
PP - Fisher Chi-square	99.1112	0.0002
ADF - Fisher Chi-square	98.2839	0.0002
Im, Pesaran and Shin W-stat	-4.08224	0.0000

Note: The order of lags has been determined by the MAIC (Ng and Perron, 2001). Probabilities for Fisher tests are computed using an asymptotic Chi-square distribution. All other tests assume asymptotic normality.

Table 2: Linearity tests and individual unit root tests results

Country	Wλ	MZa	MZt	MSB	MPT	Kruse	Kruse(c)
Euro	8.2356**	-11.6952**	-2.40948**	0.20602**	2.13001**	6.83448	13.40905**
Australia	21.3149**	-4.35769	-1.47269	0.33795	5.62852	5.06794	9.07081*
Austria	1.9862	0.10974	0.10710	0.97593	55.1143	10.0976**	13.10506**
Belgium	14.4795**	-6.49715*	-1.79151*	0.27574	3.80953*	2.84490	5.312460
Canada	3.3105	-1.54017	-0.85237	0.55343	15.4028	4.29029	3.807584
Denmark	0.3883	0.31487	0.21053	0.66862	30.8564	4.46988	5.377654
Finland	8.3452**	-4.40434	-1.47919	0.33585	5.57184	2.40440	3.005024
France	0.7897	-16.4391**	-2.85034**	0.17339**	1.55394**	7.96875*	3.389046
Germany	7.6893**	-11.4602**	-2.36978**	0.20678**	2.23447**	7.44727	23.06839**
Greece	9.3189**	-2.09124	-0.75756	0.36225	9.58126	0.96444	1.586086
Iceland	20.9535**	-14.7338**	-2.52125**	0.17112**	2.39263**	11.1783**	15.83559**
Ireland	5.3136**	-1.59962	-0.57284	0.35811	10.4029	1.32200	6.390756
Italy	25.4014**	-4.97535	-1.56767	0.31509	4.94919	4.50917	14.30809**
Japan	1.5544	-0.93371	-0.54927	0.58827	19.4279	7.00095*	6.855110
Korea	8.5481**	-3.19966	-1.10036	0.34390	7.49356	9.94479**	27.59870**
Luxemburg	0.9246	-2.61026	-1.13154	0.43350	9.34048	2.99080	5.595345
Mexico	5.6653**	-13.5001**	-2.58830**	0.19172**	1.85367**	7.68538	12.919473**
N. Zealand	9.0132**	-10.5378**	-2.28270**	0.21662**	2.37642**	5.85096	15.89702**
Netherlands	3.2306	-7.44038*	-1.83936*	0.24721*	3.62721*	6.82171	7.890458
Norway	10.3758**	-6.42246*	-1.63792*	0.25503*	4.33640*	7.536154	19.05137**
Portugal	1.1269	-0.56414	-0.29812	0.52844	18.4673	2.22007	1.772414
Spain	4.0642	-0.12318	-0.07463	0.60583	24.3375	4.70903	8.378290
Sweden	4.8584*	-0.01167	-0.00658	0.56400	22.5196	3.95568	5.615036
Switzerland	0.5721	-0.30880	-0.21100	0.68327	27.8469	15.39618**	8.553954
Turkey	0.6932	-3.71786	-1.35983	0.36576	6.59190	8.067539*	22.790801
UK	2.5621	-13.6050**	-2.47206**	0.18170**	2.32770**	6.897512	7.591917
US	3.4896	-1.92106	-0.80923	0.42124	10.9175	4.490706	5.721585

Note: The order of lag to compute the tests has been chosen using the Akaike Information Criterion. The Ng and Perron tests include an intercept, whereas the Kruse test has been applied to the raw and demeaned data, Kruse and Kruse (c) respectively. The symbols * and ** mean rejection of the null hypothesis of unit root at the 10% and 5% respectively. The critical values for the Ng and Perron tests have been taken from Ng and Perron (2001), whereas those for the Kruse test have been obtained from Kruse (2010).

	$\chi^2(2)$	MZa	MZt	MSB	MPT	Kruse	Kruse(c)
5%	5.99	-8.10000	-1.98000	0.23300	3.17000	9.53	10.17
10%	4.60	-5.70000	-1.62000	0.27500	4.45000	7.85	8.60

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