Why not use standard panel unit root test for testing PPP

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Abstract

In this paper we show the consequences of applying a panel unit root test when testing for a purchasing power parity relationship. The distribution of the tests investigated, including the IPS test of Im et al (1997), are influenced by a common stochastic trend which is usually not accounted for. The result is that the size tends to one with the number of cross-sections.

JEL: C12; C22; C23

1 Introduction

There is a large amount of literature on testing purchasing power parity (PPP) due to the economic importance of the relationship. PPP states that in the long run the exchange rate adjusted price levels in two countries should be the same. Otherwise it is profitable to export/import goods. The most common way to test the PPP relationship is to apply the standard augmented Dickey-Fuller unit root test (ADF) to the real exchange rate $\varepsilon_t = \ln(P_{it}) - \ln(P_{jt}) + \ln(R_{ijt})$ where P_{it} (P_{jt}) is the price level in country i (j) and R_{ijt} is the exchange rate between country i and country j, all indexed for time period t. Shiller and Perron (1985) show that the power of the ADF test is very low for the number of observations encountered in real world data sets. Hence, PPP is often rejected, subsequently studies use a panel version that increases the power. The most commonly used are the ones of Levin and Lin (1992, 1993) and Im, Pesaran and Shin (1997). Other versions for the test have been proposed by e.g. Quah (1994), Breitung (1997), Hadri (1998), McKoskey and Kao (1998), Maddala and Wu (1999) and Groen (2000). Papers testing PPP with panel unit root test includes Abuaf and Jorion (1990), Frankel and Rose (1996), MacDonald (1996), Oh (1996), Wu

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(1996), Coakley and Fuertes (1997), Papell (1997) and O'Connell (1998), see the surveys of Froot and Rogoff (1995) and Banerjee (1999).

Therefore testing PPP using panel unit root tests are widely used, however, this paper shows that the inference used in these applications are likely to be wrong, i.e. the actual size may be very far from the nominal. The base currency used introduces a common stochastic trend which is not accounted for in the distribution of the test statistics. Most of the papers mentioned use test statistics which have a null of a unit root but the distribution is also effected when the null is an $I(0)$ variable. We can solve the problem by using the panel cointegration method proposed by Jacobson et al (2000). This is a panel version of the multivariate cointegration model of Johansen (1988). Economic theory suggests what the cointegrating vectors should be between prices and exchange rate. Hence we can treat the tests as panel unit root tests instead of panel cointegration tests.

Our paper analytically derives some useful expressions which helps to understand the consequences of the common stochastic trend. Sequential asymptotics are used, i.e. first we let T and then $N \to \infty$, see Phillips and Moon (1999). The Levin and Lin (1992) test is shown to diverge with the number of cross-sections. A Monte Carlo simulation is then carried out to analyze the consequences for some panel unit root tests. The tests investigated in the Monte Carlo are that of Im, Pesaran and Shin (1997) and Groen (2000). The latter two tests have a null of unit root therefore we have a look at McKoskey and Kao (1998) which has $I(0)$ as null. The result is that for very small panels, $N = 2$, the size is approximately correct but for larger panels, $N \geq 10$, the size can be significantly distorted, i.e. the size is much to large.

The paper is organized as follows: The next section introduces the "statistical" PPP model and this PPP specification is used throughout the paper. Section 3 analyzes the consequences for some panel unit root test. The Monte Carlo simulation in Section 4 is used to show how large the consequences can be. Section 5 conclude the paper.

2 Null of unit roots and the PPP

Testing the null of a unit root in a univariate series is often based on the Dickey-Fuller type of equation (or the augmented type):

$$\Delta x_t = \rho x_{t-1} + e_t \tag{1}$$

which under the null of a unit root ($\rho = 0$) becomes

$$\Delta x_t = e_t \tag{2}$$

A panel version may be based on, as in Levin and Lin (1993, 1993) and Im et al (1997),

$$\begin{bmatrix} \Delta x_{1t} \\ \Delta x_{2t} \\ \vdots \\ \Delta x_{Nt} \end{bmatrix} = \begin{bmatrix} \rho_1 x_{1t-1} \\ \rho_2 x_{2t-1} \\ \vdots \\ \rho_N x_{Nt-1} \end{bmatrix} + \begin{bmatrix} e_{1t} \\ e_{2t} \\ \vdots \\ e_{Nt} \end{bmatrix} \tag{3}$$

where N is the number of cross-sections, Δ is the first difference operator and e_{it} are disturbances with finite variance and independent and identically distributed over time. Note that ρ_i might or might not be equal to $\rho_j, i \neq j$. The panel null is $\rho_1 = \rho_2 = ... = \rho_N = 0$. Under the alternative, depending on which test used, some or all ρ_i are less than zero. From (3) it can be shown that there are N random walks in the system under the null. When testing for cointegration x_t is the residual from a regression.

Let $\tilde{p}_i$ denote the log of the price level in country i and r_{iN+1} the log of the exchange rate between country i and $N+1$. The PPP relationship states that $\tilde{p}_{it} - p_{N+1t} + r_{iN+1t} = \varepsilon_t$ should be a cointegrating relationship. To make the notation simpler we let $p_{it} = \ln(P_{it} * R_{iN+1t})$, i.e. the price level in country i is in the currency of country $N+1$. Further, assume that all p_i and p_{N+1} are $I(1)$. There are numerous empirical evidence that prices are $I(1)$, see e.g. Culver and Papell (1997) and Larsson et al (1998). We can also justify it from the same kind of argument that claims that stock prices are $I(1)$. If there are cointegration between p_{it} and p_{N+1} the same stochastic trend drives the two variables. As a consequence, $p_{jt}, i \neq j$, share the same trend, i.e. all prices are driven by the same stochastic trend. If there is no cointegration there is two stochastic trends, one for each price level. In a panel we have

$$\begin{bmatrix} p_{1t} - p_{N+1t} \\ p_{2t} - p_{N+1t} \\ \vdots \\ p_{Nt} - p_{N+1t} \end{bmatrix} = \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \vdots \\ \varepsilon_{Nt} \end{bmatrix} \tag{4}$$

where we test simultaneously if ε_{it} have a non-stationary behavior through a panel unit root test. Under the null of no cointegration the N first prices are generated by

$$\begin{bmatrix} \Delta p_{1t} \\ \Delta p_{2t} \\ \vdots \\ \Delta p_{Nt} \end{bmatrix} = \begin{bmatrix} e_{1t} \\ e_{2t} \\ \vdots \\ e_{Nt} \end{bmatrix} \tag{5}$$

and the price level for country $N+1$ by

$$\begin{bmatrix} \Delta p_{N+1,t} \end{bmatrix} = \begin{bmatrix} e_{N+1,t} \end{bmatrix}. \tag{6}$$

Hence, the variables that are used in the panel unit root test are generated according to

$$\begin{bmatrix} \Delta\varepsilon_{1t} \\ \Delta\varepsilon_{2t} \\ \vdots \\ \Delta\varepsilon_{Nt} \end{bmatrix} = \begin{bmatrix} \Delta p_{1t} - \Delta p_{N+1,t} \\ \Delta p_{2t} - \Delta p_{N+1,t} \\ \vdots \\ \Delta p_{Nt} - \Delta p_{N+1,t} \end{bmatrix} = \begin{bmatrix} e_{1t} - e_{N+1,t} \\ e_{2t} - e_{N+1,t} \\ \vdots \\ e_{Nt} - e_{N+1,t} \end{bmatrix} \tag{7}$$

with covariance matrix

$$E \begin{bmatrix} e_{1t} - e_{yt} \\ e_{2t} - e_{yt} \\ \vdots \\ e_{Nt} - e_{yt} \end{bmatrix} \begin{bmatrix} e_{1t} - e_{yt} \\ e_{2t} - e_{yt} \\ \vdots \\ e_{Nt} - e_{yt} \end{bmatrix}' = \Omega - 2\Phi + \sigma^2 = \Sigma. \tag{8}$$

where Ω is the covariance matrix for the first N price levels and σ^2 is the covariance for the $N+1$. The covariance matrix between the first N and the last price level is Φ. The important thing to note is that each equation of (7) contains one common random walk besides the not common one.

Under the alternative of cointegration the data generating process is

$$\begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \vdots \\ \varepsilon_{Nt} \end{bmatrix} = \begin{bmatrix} p_{1t} - p_{N+1,t} \\ p_{2t} - p_{N+1,t} \\ \vdots \\ p_{Nt} - p_{N+1,t} \end{bmatrix} \tag{9}$$

where $p_{N+1,t}$ is generated according to (6). Note here that there is only one stochastic trend driving all prices.

Some notation: The Brownian motion generated by $\varepsilon_{it} = p_{1t} - p_{N+1,t}$ is denoted $B_i(\Sigma) = W_i(\Sigma) - W(\Sigma)_{N+1}$ and when $B_i(\Sigma)$ is normalized to have unit covariance matrix $B_i = W_i - W_{N+1}$. Note that W_i and W_{N+1} might be dependent. Further, $\rightarrow$ denotes the limit when $T \rightarrow \infty$.

3 Consequences for some test

3.1 Levin and Lin (1992)

The panel unit root test proposed by Levin and Lin (1992) is based on the regression, $i = 1, ..., N$,

$$\varepsilon_{it} = \varepsilon_{it-1} + e_{it}$$

The panel estimator proposed for this simple model is

$$\hat{\rho} = \frac{\sum_{i=1}^{N} \sum_{t=1}^{T} \varepsilon_{it}\varepsilon_{it-1}}{\sum_{i=1}^{N} \sum_{t=1}^{T} \varepsilon_{it-1}^2} \tag{10}$$

with $t-$statistic

$$t_{\rho}=\frac{\frac{1}{\sqrt{N}}\sum_{i=1}^{N}\left[\frac{1}{\sigma^{2}T}\sum_{t=1}^{T}\varepsilon_{it-1}e_{it}\right]}{\frac{\hat{\sigma}}{\sigma}\left[\frac{1}{N}\sum_{i=1}^{N}\left(\frac{1}{\sigma^{2}T^{2}}\sum_{t=1}^{T}\varepsilon_{it-1}^{2}\right)\right]^{1/2}} \tag{11}$$

They showed that the $t-$statistic converges to a standard normal distribution under the assumption of independent random walks. To see the consequences in the PPP case, the three parts of the $t-$statistic is analyzed. First it is obvious that $\hat{\sigma}$ is a consistent estimator of σ, hence $\hat{\sigma}/\sigma \rightarrow 1$ with T. The inner part of the denominator tends, with T, to

$$\begin{aligned}\frac{1}{\sigma^{2}T^{2}}\sum_{t=1}^{T}\varepsilon_{it-1}^{2} &= \frac{1}{\sigma^{2}T^{2}}\sum_{t=1}^{T}\left(p_{it-1}-p_{N+1t-1}\right)^{2}\\ &= \frac{1}{\sigma^{2}T^{2}}\sum_{t=1}^{T}\left(p_{it-1}^{2}-2p_{it-1}p_{N+1t-1}+p_{N+1t-1}^{2}\right)\\ &\rightarrow \int W_{i}^{2}dr-2\int W_{i}W_{N+1}dr+\int W_{N+1}^{2}dr \end{aligned} \tag{12}$$

where W_i and W_{N+1} are Brownian motions with appropriate variances. Considering the N asymptotics, the limits are

$$\frac{1}{N}\sum_{i=1}^{N}\int W_{i}^{2}dr \rightarrow 0.5 \tag{13}$$

$$\frac{1}{N}\sum_{i=1}^{N}\int W_{i}W_{N+1}dr \rightarrow 0 \tag{14}$$

$$\frac{1}{N}\sum_{i=1}^{N}\int W_{N+1}^{2}dr = \int W_{N+1}^{2}dr \tag{15}$$

The numerators limits is

$$\begin{aligned}\frac{1}{\sigma^{2}T}\sum_{t=1}^{T}\varepsilon_{it-1}e_{it} &= \frac{1}{\sigma^{2}T}\sum_{t=1}^{T}\left(p_{it-1}-p_{N+1}\right)\left(e_{it}-e_{yt}\right)\\ &= \frac{1}{\sigma^{2}T}\sum_{t=1}^{T}\left(p_{it-1}e_{it}-p_{it-1}e_{yt}-p_{N+1t-1}e_{it}+p_{N+1t-1}e_{yt}\right)\\ &\rightarrow \int W_{i}dW_{i}-\int W_{i}dW_{N+1}-\int W_{N+1}dW_{i}+\int W_{N+1}dW_{N+1}\end{aligned} \tag{16}$$

It is well known that $\frac{1}{\sqrt{N}}\sum_{i=1}^{N}\int W_{i}dW_{i} \rightarrow N\left(0,0.5\right)$. The quantities $\frac{1}{\sqrt{N}}\sum_{i=1}^{N}\int W_{i}dW_{N+1}$ and $\frac{1}{\sqrt{N}}\sum_{i=1}^{N}\int W_{N+1}dW_{i}$ both have mean 0 and variance 0.5 but with more kurtosis than what would be implied by a normal distribution. The part that influences the statistic the most is the last in equation (16),

$$\frac{1}{\sqrt{N}}\sum_{i=1}^{N}\int W_{N+1}dW_{N+1}=\sqrt{N}\int W_{N+1}dW_{N+1} \tag{17}$$

Because $\int W_{N+1}dW_{N+1}$is either positive of negative (or zero with probability zero) it tends to $-\infty$ or ∞ with N. This implies that the $t-$statistic tend to $-\infty$ or ∞ with N. Defining the new test statistic

$$\tilde{t}_{\rho}=\frac{t_{\rho}}{\sqrt{N}} \tag{18}$$

would have the asymptotic distribution

$$\tilde{t}_{\rho}\rightarrow\frac{\int W_{N+1}dW_{N+1}}{\left[0.5+\int W_{N+1}^{2}dr\right]^{1/2}}. \tag{19}$$

3.2 Im, Pesaran and Shin (1997)

With no lags, the asymptotic version of the Im, Pesaran and Shin (1997) (IPS) test is

$$\Psi_{\bar{t}}=\frac{\sqrt{N}\left(\bar{t}_{N}-E\left[t_{i}|\rho_{i}=0\right]\right)}{\sqrt{Var\left[\bar{t}_{N}|\rho_{i}=0\right]}}$$

When the $t-$statistics are independent $Var\left[\bar{t}_{N}|\rho_{i}=0\right]=\frac{1}{N}\sum_{i=1}^{N}Var\left[t_{i}|\rho_{i}=0\right]$. We know that the expectation of the mean remains the same if the $t-$statistics are dependent as in the case of PPP. A closer look at the individual $t-$statistics reveals

$$t_{i\rho}=\frac{\frac{1}{\sigma^{2}T}\sum_{t=1}^{T}\varepsilon_{it-1}e_{it}}{\frac{\hat{\sigma}}{\sigma}\left(\frac{1}{\sigma^{2}T^{2}}\sum_{t=1}^{T}\varepsilon_{it-1}^{2}\right)^{1/2}} \tag{20}$$

$$\rightarrow\frac{\int W_{i}dW_{i}-\int W_{i}dW_{N+1}-\int W_{N+1}dW_{i}+\int W_{N+1}dW_{N+1}}{\left(\int W_{i}^{2}dr-2\int W_{i}W_{N+1}dr+\int W_{N+1}^{2}dr\right)^{1/2}} \tag{21}$$

The variance of $\bar{t}_{N}$ would be complicated and we have not found an analytical expression.

3.3 Groen (2000)

The panel unit root test of Groen (2000) simultaneously tests $H_0 : \rho_1 = \rho_2 = ... = \rho_N = 0$ in the following system of equations:

$$\begin{bmatrix} \Delta\varepsilon_{1t} \\ \Delta\varepsilon_{2t} \\ \vdots \\ \Delta\varepsilon_{Nt} \end{bmatrix} = \begin{bmatrix} \rho_1 & 0 & & 0 \\ 0 & \rho_2 & & 0 \\ & & \ddots & \\ 0 & 0 & & \rho_N \end{bmatrix} \begin{bmatrix} \varepsilon_{1t-1} \\ \varepsilon_{2t-1} \\ \vdots \\ \varepsilon_{Nt-1} \end{bmatrix} + \begin{bmatrix} e_{1t} \\ e_{2t} \\ \vdots \\ e_{Nt} \end{bmatrix} \tag{22}$$

The major contribution is that he let e_i be correlated with e_j. The likelihood ratio test has asymptotic distribution

$$LR_{\rho_i=0} \rightarrow \sum_{i=1}^{N} \left[\left(\int B_i dB_i \right)^2 \left(\int B_i^2 \right)^{-1} \right] \tag{23}$$

This is the sum of the squared distribution of the individual $t_{i\rho}$ of IPS. For the PPP case where $B_i = W_i - W_{N+1}$ the distribution is

$$LR_{\rho_i=0} \rightarrow \sum_{i=1}^{N} \left[\left(\int W_i dW_i - \int W_i dW_{N+1} - \int W_{N+1} dW_i + \int W_{N+1} dW_{N+1} \right)^2 \right.$$
$$\left. \left(\int W_i^2 dr - 2 \int W_i W_{N+1} dr + \int W_{N+1}^2 dr \right)^{-1} \right] \tag{24}$$

3.4 McKoskey and Kao (1998)

The panel cointegration test of McKoskey and Kao (1998) is easily modified to become a panel test for unit roots. The LM test statistic is

$$LM = \frac{T^{-2} \sum_{i=1}^{N} \sum_{t=1}^{T} S_{it}}{s^2} \tag{25}$$

where S_{it} is the partial sum of the ith variable,

$$S_{it} = \sum_{t=1}^{t} e_{it} \tag{26}$$

and s^2 is a consistent estimator of the long run variance,

$$s^2 = \frac{1}{NT} \sum_{i=1}^{N} \sum_{t=1}^{T} e_{it}^2 \tag{27}$$

The panel test is the standardized LM test statistic,

$$\sqrt{N} \frac{(LM - \mu_{LM})}{\sqrt{s_{LM}^2}} \tag{28}$$

where μ_{LM} and s_{LM}^2 are the expectation and the variance of the LM test statistic. It can be shown, see e.g. Shin (1994), that the LM test statistic is distributed as the quantity $\int W^2$.

As seen from equation (25), in the PPP case the asymptotic distribution would be

$$LM \rightarrow \frac{\sum_{i=1}^{N} \int B(\Sigma)_i^2}{s^2} \tag{29}$$

$$= \frac{\sum_{i=1}^{N} \left(\int W(\Sigma)_i^2 \, dr - 2 \int W(\Sigma)_i \, W(\Sigma)_{N+1} \, dr + \int W(\Sigma)_{N+1}^2 \, dr \right)}{s^2} \tag{30}$$

so variance would be effected. If we assume that all prices have the same variance

$$LM \rightarrow \sum_{i=1}^{N} \left(\int W_i^2 dr - 2 \int W_i W_{N+1} dr + \int W_{N+1}^2 dr \right). \tag{31}$$

4 A Monte Carlo simulation

To evaluate the consequences a small Monte Carlo simulation is carried out. For simplicity we assume that all variables have the same variance but we change the correlation between the base price and the other prices, $\Phi = -0.75, -0.25, 0, 0.25, 0.75$. We choose $N = 2, 5, 10, 50, 100, 200$ and 400. This will allow us to observe what the sizes converge to and how fast. The length of the random walks approximating the Brownian motions is 800 and the number of replicates is 100000. A 5% nominal size is used throughout.

The results of the Monte Carlo simulation is computed in Tables (1), (2) and (3) for IPS, Groen (2000) and Mckoskey and Kao (1998) respectively. The tables show the sizes of the tests when the original test procedure been used. For the IPS test the mean and variance used are asymptotic versions of those presented in Im, Pesaran and Shin (1997). After standardization, the IPS test statistic is compared to the Gaussian distribution. The Levin and Lin (1992) is not simulated as the distribution is shown to be divergent.

Tables (1) – (3) in here

The results from the Monte Carlo simulation are that the size for low values of N is hardly effected however for higher values the size seems very distorted. The size is much bigger than the nominal size. When the correlation decreases from 0.75 the effect on the size becomes further distorted. It seems like the test statistic of Groen (2000) is the one which is effected least, then the one proposed by McKoskey and Kao (1998). The IPS test performs badly with a size of over 50% for $N = 400$ and correlation less than 0.75. For all three tests the size seems to slowly tend to one with the number of cross-sections.

5 Conclusion

In this paper we have shown the consequences to the distribution of some panel unit root test statistics when testing the PPP theory. All the tests investigated are influenced by a large extent. In most cases the size becomes much to large, rarely it is not influenced at all. The size usually increases with the number of cross-sections in the panel and when the correlation between the base price level and the other price levels decreases. The simulation shows that the size tends to one for all the three test statistics although slowly.

For practical purposes the results of this paper have two major implications when testing the PPP hypothesis. firstly, the size of a panel unit root test is likely to be far from the nominal. One reason for using a panel test is to increase the power of the test but the increased size makes it difficult to judge if a rejection of the null depends on increased power or to a to large size. Secondly, as the distribution heavily depends on the correlation between the stochastic trends, these estimates are not available. Therefore in practice it is very difficult to correct the size. It is interesting to note that the results hold irrespectively of tests with a null of unit root or for no unit root null.

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Tables

$\Phi\backslash N$	2	5	10	50	100	200	400
0.75	0.0314	0.0324	0.0351	0.0606	0.0899	0.1395	0.2163
0.25	0.0330	0.0448	0.0652	0.2271	0.3564	0.4719	0.5299
0	0.0350	0.0563	0.0991	0.3347	0.4479	0.5193	0.5535
-0.25	0.0406	0.0791	0.1489	0.4109	0.4826	0.5319	0.5562
-0.75	0.0611	0.1673	0.2808	0.4508	0.4887	0.5134	0.5238

Table 1: Size of the IPS test when testing for PPP.

$\Phi\backslash N$	2	5	10	50	100	200	400
0.75	0.0480	0.0471	0.0488	0.0536	0.0644	0.0744	0.0935
0.25	0.0501	0.0516	0.0550	0.1019	0.1455	0.2076	0.2686
0	0.0506	0.0568	0.0684	0.1428	0.2048	0.2702	0.3171
-0.25	0.0539	0.0640	0.0902	0.1938	0.2584	0.3076	0.3343
-0.75	0.0671	0.1087	0.1634	0.2731	0.3058	0.3303	0.3299

Table 2: Size of the Groen (2000) test when testing for PPP.

$\Phi\backslash N$	2	5	10	50	100	200	400
0.75	0.0436	0.0414	0.0396	0.0715	0.1042	0.1526	0.1764
0.25	0.0507	0.0626	0.0812	0.1621	0.2006	0.2429	0.2537
0	0.0541	0.0747	0.1004	0.1908	0.2248	0.2614	0.2691
-0.25	0.0602	0.0881	0.1195	0.2087	0.2413	0.2705	0.2810
-0.75	0.0712	0.1154	0.1528	0.2352	0.2616	0.2840	0.2934

Table 3: Size of the McKoskey and Kao (1998) LM test when testing for PPP.