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A Monte Carlo Comparative Simulation Study for Identification of the Best Performing Panel Cointegration Tests

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Abstract

In this paper the performance of nine panel cointegration tests, having the null hypothesis of no cointegration, with respect to weighted average rank scores under the whole space of alternative using Monte Carlo simulations have been carried out. Our results indicate that PdPtp, PAWS and PdP_V tests are the only three best performing tests among all panel cointegration tests whether time and cross sectional dimensions are small, medium or large. However, PDFTstar, PDFTrhostar and PdGtp panel cointegration tests have also identified as best performer at large cross sectional dimensions.

Keywords: Panel Cointegration Tests, Rank Scores, Best Performer, Mediocre Tests.

Introduction

A revolutionary stage started in the field of economics three decade earlier when (Engle and Granger, 1987) introduced the concept of cointegration in time series to describe the long run relationship between the integrated variables. If there are variables integrated of order *d* then a linear combination of these variables must be less than of order *d* to find the long run relationship between these variables. For example, if Z_t with components of p-dimensional process is $Z_t \sim I(1)$ then these variables are said to be cointegrated if their linear combination is stationary i.e. $\gamma' Z_t \sim I(0)$ for $\gamma \neq 0$. According to (Lütkepohl, 2005) it is not necessary that all components of Z_t may have the same order but at least one of them must be of order *d* to define cointegration as linear combination of variables.

In panel data the concept of cointegration is a little complicated as compared to time series data. This complication occurs due to unbalanced panel, heterogeneity, cross-sectional and time dependence models. A lot of panel cointegration tests have been developed in literature to describe the phenomena of cointegration. These tests are different from each other due to their mathematical structure and assumptions. Some of the tests developed assume the assumption of cross-section independence or cross-section dependence while other tests are derived on the basis of homogeneity or heterogeneity. First panel cointegration tests developed by (Pedroni, 1999), (Kao, 1999) and (Pedroni, 2004) based on residuals of the model using Dickey Fuller (DF) and Augmented Dickey Fuller (ADF) statistics. After that, a lot of panel cointegration tests developed in different studies of literature, like McCoskey and (Kao, 1998), (Pedroni, 1999), (Westerlund, 2007) etc., based on different assumptions.

In literature different Monte Carlo comparative studies have been carried out to evaluate the size and power performance of panel cointegration tests. (Kao, 1999) carried out first simulation study by comparing five panel cointegration tests through Monte Carlo simulations. He analyzed size distortion at small time and cross section units due to which power, at one alternative, of tests produced poor results. (McCoskey and Kao, 1998) also conducted a simulation study by comparing five panel cointegration tests developed by them. Their study showed mix results for the tests having the null hypothesis of no cointegration and tests having the null hypothesis of cointegration from size and power properties point of view. (Pedroni, 2004) also developed and compared the same number (i.e. five) of panel cointegration tests and he also observed size distortion issue at small dimensions. (Pedroni, 2004) considered three alternatives to analyze power properties of tests. (Gutierrez, 2003) also carried out a comparative study by considering the tests of (Kao, 1999), (Pedroni, 1999) and (Larsson et al., 2001) through Monte Carlo simulations. (Gutierrez, 2003)'s study shows mix results, in certain situations all these three type tests beat each other from power point of view. All these studies provide different results in order to identify the best and worst performer test. In almost all previous studies the comparison of panel cointegration tests are made for one, two or very few alternatives to analyze the size and power performance of these tests. Also, in these studies asymptotic critical value has been used to investigate the size and power properties. Moreover, in these comparative studies a serious size distortion is observed for majority of the tests under asymptotic critical value which makes power comparison doubtful because a test with high size distortion will have less power and a test with less size distortion will have high power.

To tackle these problems, our study investigates the power behavior of panel cointegration tests under all alternatives rather than a few. We have used simulated critical value instead of asymptotic critical value to avoid size distortion problem and stabilize the size of all tests around nominal size of 5%. In order to contribute in literature this study uses rank scores of 10 panel cointegration tests. Our study helps the researchers and practitioners to pick a best tests for applied analysis and avoid to use worst performing test.

Panel Cointegration Tests to be Compared

In this study we have considered panel cointegration tests developed in (Pedroni, 1999), (Kao, 1999), (Westerlund, 2007) and (Hoang, 2006). These test-statistics are explained below,

Pedroni's Tests

(Pedroni, 1999) developed panel cointegration tests mention in Eq (1), Eq (2) and Eq (3) based on the following regression model,

$$y_{it} = \alpha_{0i} + \alpha_{1i} t + x_{it}^{'} \beta_i + e_{it}, \text{ where } \quad i = 1, 2, 3, \ldots\ldots\ldots, N \quad , \quad t = 1, 2, 3, \ldots\ldots\ldots, T$$

First two test-statistic given in Eq (1) and Eq (2) represent the dimension based test-statistics by summing up the all the quantities over cross section N (see (Pedroni, 1999) for more detail). While the third test-statistic mentioned in Eq (3) is based on Augmented Dickey Fuller (ADF) parametric grouping procedure.

$$T^2 N^{3/2} Z_{\hat{v}N,T} = T^2 N^{3/2} \left(\sum_{i=1}^{N} \sum_{t=1}^{T} \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^{2} \right)^{-1} \text{ -------------------- Eq (1)}$$

$$Z_{tN,T}^{*} = \left(\tilde{s}_{NT}^{*2} \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^{2} \right)^{-1/2} \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{L}_{11i}^{-2} \hat{e}_{i,t-1} \Delta \hat{e}_{it} \text{ ------------ Eq (2)}$$

$$N^{-1/2}\widetilde{Z}^{*}_{tN,T} = N^{-1/2}\sum_{i=1}^{N}\left[\left(\hat{s}_i^{*2}\sum_{t=1}^{T}\hat{e}^2_{i,t-1}\right)^{-1/2}\sum_{t=1}^{T}\hat{e}_{i,t-1}\Delta\hat{e}_{it}\right] \text{-------------- Eq (3)}$$

Westerlund's Tests

(Westerlund, 2007) also developed different test-statistics to contribute in panel cointegration literature. (Westerlund, 2007) used structural dynamic instead of residual to develop his test-statistics, given in Eq (4) and Eq (5) based on generalized version procedure proposed by Banerjee et al. (1998). These tests are derived using the following error correction model,

$$\Delta y_{it} = \delta_i^{'} d_t + \alpha_i (y_{i,t-1} - \beta_i^{'} x_{i,t-1}) + \sum_{j=1}^{p_i}\alpha_{ij}\Delta y_{i,t-j} + \sum_{j=-q_i}^{p_i}\gamma_{ij}\Delta x_{i,t-j} + e_{it}$$

$$G_T = \frac{1}{N}\sum_{i=1}^{N}\frac{\widehat{\alpha}_i}{SE(\widehat{\alpha}_i)} \text{ ------------------ Eq (4)}$$

$$P_T = \frac{\widehat{\alpha}}{SE\left(\widehat{\alpha}\right)} \text{ -------------------- Eq (5)}$$

Kao's Tests

(Kao, 1999) introduced parametric residual panel cointegration tests, given in Eq (6), Eq (7) and Eq (8), which are the extension of panel unit root tests. (Kao, 1999) used the following model based on DF and ADF procedure to develop his test-statistics,

$$y_{it} = \alpha_i + x_{it}'\beta + e_{it}$$

$$DF^*_{\rho} = \frac{\sqrt{N}\,T(\hat{\rho}-1) + \frac{3\sqrt{N}\,\hat{\sigma}^2{}_v}{\hat{\sigma}^2{}_{ov}}}{\sqrt{3+\frac{36\,\hat{\sigma}^4{}_v}{5\,\hat{\sigma}^4{}_{ov}}}} \text{ ------------ Eq (6)}$$

$$DF^*_{t} = \frac{t_\rho + \frac{\sqrt{6N}\hat{\sigma}_v}{2\hat{\sigma}_{ov}}}{\sqrt{\frac{\hat{\sigma}^2{}_{ov}}{2\hat{\sigma}^2{}_v}+\frac{3\hat{\sigma}^2{}_v}{10\hat{\sigma}^2{}_{ov}}}} \text{ ---------------- Eq (7)}$$

Where $\hat{\sigma}^2_v = \hat{\Sigma}_u + \hat{\Sigma}_{u\varepsilon}\Sigma_\varepsilon^{-1}$, $\hat{\sigma}^2_{ov} = \hat{\Omega}_u - \hat{\Omega}_{u\varepsilon}\hat{\Omega}_\varepsilon^{-1}$, $w_{it} = (u_{it},\varepsilon_{it})'$, $w_{it} = (u_{it},\varepsilon_{it})'$

$$\hat{\Sigma} = \begin{pmatrix}\hat{\sigma}^2_u & \hat{\sigma}_{u\varepsilon}\\ \hat{\sigma}_{\varepsilon u} & \hat{\sigma}^2_\varepsilon\end{pmatrix} = \frac{1}{NT}\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{w}_{it}\hat{w}_{it}' \quad , \quad \hat{\Omega} = \begin{pmatrix}\hat{\sigma}^2_{0u} & \hat{\sigma}_{0u\varepsilon}\\ \hat{\sigma}_{0\varepsilon u} & \hat{\sigma}^2_{0\varepsilon}\end{pmatrix}$$

$$\hat{\Omega} = \frac{1}{N}\sum_{i=1}^{N}\left\{\frac{1}{T}\sum_{t=1}^{T}\hat{w}_{it}\hat{w}_{it}' + \frac{1}{T}\sum_{\tau=1}^{l}\bar{\omega}_{\tau l}\sum_{t=\tau+1}^{T}\left(\hat{w}_{it}\hat{w}_{i,t-\tau}' + \hat{w}_{i,t-\tau}\hat{w}_{it}'\right)\right\}$$

$$\mathrm{t}_{\mathrm{ADF}} = \frac{\left(\sum_{i=1}^{N} e_i' Q_{xp} v_i\right)}{s_v \left(\sum_{i=1}^{N} e_i' Q_{xp} e_i\right)^{1/2}} \text{ -------------- Eq (8)}$$

Where $Q_{xp} = I + X_p \left(X_p' X_p\right)^{-1} X_p'$ and $s_v^2 = \frac{1}{T}\sum_{t=1}^{T} \hat{v}_{itp}^2$.

Hoang's Tests

(Hoang, 2006) introduced panel cointegration tests, also called average weighted symmetric tests, based on the idea of averaging the test statistics of each cross section. (Hoang, 2006) used the following model to develop test-statistic given in Eq (9).

$$y_{it} = \alpha_{0i} + x_{it}^{'} \beta_i + u_{it}$$

$$\bar{t}_{ws} = \frac{1}{N}\sum_{i=1}^{N} t_{iws} \text{ ------------ Eq (9)}$$

where $t_{iws} = \left(\sigma_{e_i}^2 \left(\sum_{t=2}^{T-1} \hat{u}_{it}^2 + \frac{1}{T}\sum_{t=1}^{T} \hat{u}_{it}^2\right)^{-1}\right)^{-\frac{1}{2}} \left(\widehat{\rho}_i - 1\right)$, $\widehat{\sigma}_i^2 = \frac{1}{T}\sum_{t=2}^{T}\left(\hat{u}_{it} - \hat{u}_{i,t-1}\right)^2$

Hereafter, test-statistics mention from Eq (1) to Eq (9) are abbreviated as PdP_V, PdPtp, PdGtp, W_Gt, W_Pt, PDFTrhostar, PDFTstar, PADF and PAWS respectively.

Methodology

This study considers the following heterogeneous panel data generating process for two series x_{it} *and* y_{it}, where $i \in N$ *and* $t \in T$, to make comparison of panel cointegration tests.

$$y_{it} = \alpha_i + \beta_i x_{it} + e_{it}, \qquad e_{it} = \rho e_{it-1} + v_{it} \quad \text{where} \quad v_{it} \sim N(0,1)$$

and $\quad x_{it} = x_{it-1} + \varepsilon_{it} \quad$ where $\quad \varepsilon_{it} \sim N(0, \sigma_i^2)$

Here $\alpha_i \sim U(0,10)$, $\beta_i \sim U(0,2)$ and $\sigma_i^2 \sim U(.5,1.5)$, under the null hypothesis of no cointegration $\rho = 1$ while under the alternative hypothesis of cointegration $0 \le \rho < 1$. However, under the alternative hypothesis we take the values of ρ as $\{0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0\}$ to observe the power of tests at each alternative.

Rank Scores of Test

The following test statistics are used of rank scores to identify the best, mediocre and worst performer tests,

$$\Psi^{\tau} = \frac{\sum_{T} \frac{1}{T} \times \Im^{\tau}(T)}{\sum_{T} \frac{1}{T}} \text{ and --------- (1)}$$

$$\Im^{\tau}(T) = \frac{\sum_{l=1}^{\kappa} \Re_l^{\tau}(T)}{\kappa} \text{ ----------- (2)}$$

Where $\Re_l^\tau(T) = \underset{l=1,2,\ldots\ldots\kappa}{Rankings}\left(\pi_l^\tau(T)\right)_{(Descending\ Order)}$ denotes the rank of a power $\pi_l^\tau(T)$ of a test τ at a specific point alternative hypothesis l corresponding to time series *T*. Statistics mentioned in *Eq (1)* and *Eq (2)* are called weighted average rank scores and rank scores, respectively. Both of these test statistics are used to categorize panel cointegration tests into worst, mediocre and best performer tests. A test is classified as worst performer if its rank score lies greater than 10%. Similarly, if a test has rank score greater than 5% and less than or equal to 10%, and below or equal to 5% is identified to be mediocre and best performer tests respectively.

Results and Discussion

In this comparative study a time series length (T) of 10, 25, 50 and 100, cross section length (N) of 2, 8, 16 and 32 while Monte Carlo size of 10000 are taken to rank tests according to their power performance. In this study we have calculated and used simulated critical values to keep the size of all panel cointegration tests stable around nominal size of 5%.

Table 1. Rank Scores of Panel Cointegration Tests, at N=2

N=2					
Tests / RS	$\Im^\tau(10)$	$\Im^\tau(25)$	$\Im^\tau(50)$	$\Im^\tau(100)$	Ψ^τ
PDFTstar	3.7**	6.1*	6.3*	8.3*	4.84**
PDFTrhostar	6.7*	6.8*	6.9*	8.7*	6.86*
PADF	3.8**	5.1*	5**	5.6*	4.35**
PdGtp	7.3*	3**	2.1**	1.5**	5.34*
PdPtp	5.3*	3.2**	2.8**	1.8**	4.31**
PdP_V	2.6**	2.8**	1.7**	1.1**	2.45**
PAWS	1.1**	1**	1.1**	1.1**	1.08**
W_Gt	8.3*	8.4*	8.1*	5.7*	8.15*
W_Pt	5.8*	8.6*	8.7*	6.7*	6.85*

Note: '*' and '**' indicate mediocre and best performing tests respectively.

Table 1 shows the rank scores and weighted average rank scores of panel cointegration tests having the null hypothesis of no cointegration when the number of cross section units are 2. It is evident that all tests have either categorized into mediocre or best performing tests according to their assigned rank scores. There are only two tests (i.e. PdP_V and PAWS) having rank scores less than 5% and are identified as best performing tests whether time series dimension is small, medium or large. While, PDFTrhostar, W_Gt and W_Pt tests are detected as mediocre performer tests at all time series units. However, PdGtp and PdPtp tests have categorized into best performing tests corresponding to time series 25, 50 and 100 but at T=10 both tests are ranked into mediocre category. Similarly, PDFTstar test has a reverse ordering behavior as compared to ordering behavior of PdGtp and PdPtp tests, that is PDFTstar lies in best performing category at T=10 but this test lost its best performing position at time series 25 and onwards and shifts into mediocre category. Moreover, there is only single test (PADF) which is identified as best performing at T=10 and T=50 while at time series 25 and 100 this test ranks into mediocre category.

Overall analysis corresponding to weighted average rank scores (mentioned in last column of Table 1) indicates that PDFTstar, PADF, PdPtp, PdP_V and PAWS tests are identified as best performing test while all other tests rank into mediocre performing tests when the number of cross sectional units are 2.

When the number of cross section units increases from 2 to 8 the Table 2 shows that performance of all tests have been improved throughout all time dimension. Again, PdP_V and PAWS tests with previously best performing status of their rank scores for N=2 remain in same position corresponding to cross sectional dimension 8 as well. A similar same status behavior of rank scores have been observed for PDFTstar, PdGtp, PdPtp and W_Pt tests when number of cross sectional units are 8. While, PDFTrhostar test at T=10, PADF and W_Gt tests at T=100 have managed their position from mediocre to best category according to their assigned rank scores when number of cross section dimension is 8 as compared their rank scores at N=2.

Table 2. Ranking Scores of Panel Cointegration Tests, at N=8

N=8					
Tests / RS	$\Im^{\tau}(10)$	$\Im^{\tau}(25)$	$\Im^{\tau}(50)$	$\Im^{\tau}(100)$	Ψ^{τ}
PDFTstar	3.20**	6.60*	7.30*	8.80*	4.81**
PDFTrhostar	3.40**	5.80*	6.70*	7.70*	4.61**
PADF	5.00**	5.30*	2.70**	1.40**	4.59**
PdGtp	8.00*	2.70**	1.60**	1.30**	5.61*
PdPtp	6.20*	2.10**	1.40**	1.20**	4.38**
PdP_V	2.40**	1.20**	1.00**	1.00**	1.87**
PAWS	1.00**	1.20**	1.10**	1.00**	1.06**
W_Gt	8.20*	8.10*	7.10*	3.70**	7.78*
W_Pt	7.40*	8.90*	8.80*	7.30*	7.91*

Note: '*' and '**' indicate mediocre and best performing tests respectively.

However, the weighted average rank scores of tests (last column of Table 2) shows that PDFTrhostar test has also managed its place in best performer tests beside other five tests (PDFTstar, PADF, PdPtp, PdP_V and PAWS) at N=8. While, only three (PdGtp, W_Gt and W_Pt) tests are identified as mediocre.

Table 3. Ranking Scores of Panel Cointegration Tests, at N=16

N=16					
Tests / RS	$\Im^{\tau}(10)$	$\Im^{\tau}(25)$	$\Im^{\tau}(50)$	$\Im^{\tau}(100)$	Ψ^{τ}
PDFTstar	5.20*	6.50*	7.80*	8.80*	6.02*
PDFTrhostar	4.10**	5.30*	6.30*	7.80*	4.86**
PADF	7.00*	5.90*	2.30**	1.40**	5.86*
PdGtp	3.90**	2.40**	1.60**	1.00**	3.11**
PdPtp	3.50**	1.70**	1.20**	1.00**	2.66**
PdP_V	3.20**	1.00**	1.00**	1.00**	2.29**
PAWS	1.10**	1.20**	1.10**	1.00**	1.12**
W_Gt	9.00*	8.00*	7.20*	2.90**	8.19*
W_Pt	8.00*	9.00*	8.10*	3.40**	7.98*

Note: '*' and '**' indicate mediocre and best performing tests respectively.

Table 3 shows the rank scores and weighted average rank scores of tests when the number of cross sections is 16. Table 3 indicates that all tests lie either in mediocre category or best category. It is evident that PdGtp and PdPtp tests have also ranked into best performing tests category according to their rank scores beside PdP_V and PAWS tests when the number of cross sections increases from 8 to 16 at all considered time dimension. While, PDFTrhostar and W_Gt tests remain in the same category (mediocre tests) at N=16 as compared to their position at N=8. PDFTstar test has identified to be the mediocre category test at all level of time units. However, PADF test is recognized in mediocre category at T=10 and T=25 but as the time dimension gets larger this test manages its position in bets performing tests with respect to its rank scores. While, W_Pt test with rank scores 3.40 at T=100 shifts its position from mediocre performer category at T=10, 25 and 50 to best performer category.

According to weighted average rank scores of tests (last column of Table 3) it is investigated that PDFTrhostar, PdGtp, PdPtp, PdP_V and PAWS tests are identified as best performing tests while other four remaining tests lie in mediocre category when the number of cross section units are 16.

Table 4. Ranking Scores of Panel Cointegration Tests, at N=32

N=32					
Tests / RS	$\Im^{\tau}(10)$	$\Im^{\tau}(25)$	$\Im^{\tau}(50)$	$\Im^{\tau}(100)$	Ψ^{τ}
PDFTstar	4.00**	5.70*	7.30*	6.40*	4.93**
PDFTrhostar	3.10**	3.50**	3.90**	5.60*	3.44**
PADF	6.70*	5.10*	2.10**	1.40**	5.47*
PdGtp	3.80**	2.20**	1.30**	1.00**	2.96**
PdPtp	1.90**	1.50**	1.20**	1.00**	1.67**
PdP_V	2.00**	1.00**	1.00**	1.00**	1.59**
PAWS	4.30**	1.10**	1.00**	1.00**	2.96**
W_Gt	8.90*	7.50*	6.20*	1.80**	7.84*
W_Pt	8.10*	8.80*	4.40**	2.30**	7.49*

Note: '*' and '**' indicate mediocre and best performing tests respectively.

When the number of cross section units increases from 16 to 32 then Table 4 shows that all tests lie either in mediocre category or best category according to their assigned rank scores or weighted average rank scores whether time dimension is small, medium or large. Again, four best performer tests (PdGtp, PdPtp, PdP_V and PAWS) with respect to their assigned rank scores dominate other tests. While, PADF and W_Gt tests achieve a similar status of their rank scores as have been observed for the previous number of cross section units (i.e. N=16) corresponding to each time dimension. Moreover, the rank scores performance of PDTstar test matches its performance when the number of cross section dimension is 8 throughout all time series. W_Pt test has improved its performance at T=50 and has ranked as best performer test at that time series while its rank scores status remains same at T=10, 25 and 100 as has been observed for N=16.

From weighted average rank scores point of view (last column of Table 4) when N=32, it is evident that PDFTstar test has also managed its place in best performing tests category alongside the previously assigned five best performer tests (PDFTrhostar, PdGtp, PdPtp, PdP_V and PAWS) at N=16. Whereas PADF, W_Gt and W_Pt tests have remained in the mediocre tests category with respect to their assigned weighted average rank scores when N=32.

Conclusion and Recommendation

Overall, it is observed that PdPtp, PdP_V and PAWS panel cointegration tests are detected as best performing tests whether time or cross sectional dimensions are small, medium or large. However, when the number of cross sectional units increases then PDFTstar, PDFTrhostar and PdGtp tests also become best performer beside PdPtp, PdP_V and PAWS tests while three tests (PADF, W_Gt and W_Pt) have remained in the category of mediocre performer tests. Among these three mediocre tests, W_Gt and W_Pt tests are identified as mediocre tests throughout all time and cross sectional dimensions. However, PADF test with irregular status (shifts from mediocre to best and vice versa) has also been placed in mediocre tests class rather than best performing.

Hence, it is recommended to use PdPtp, PAWS and PdP_V panel cointegration tests having better performance as compared to other tests whether time and cross section dimensions are small, medium or large. However, at large time and cross section (considered in this study) dimensions PDFTstar, PDFTrhostar and PdGtp panel cointegration tests are also recommended to be used beside PdPtp, PAWS and PdP_V tests.

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