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## Shortfalls of panel unit root testing

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### Abstract

This paper shows that (i) magnitude and variation of contemporaneous correlation are important in panel unit root tests, and (ii) demeaning across the panel usually does not eliminate these problems.

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Panel unit root procedures such as the Im, Pesaran and Shin (IPS; Im et al., 1997) have become popular in recent years to analyze issues such as convergence and PPP. IPS procedures address the low power associated with single series ADF tests by averaging the test statistics across the panel ( $N$  series) and assuming i.i.d. errors. When this assumption is violated and residuals are contemporaneously correlated, IPS suggests demeaning across  $N$  to remedy a size distortion. Our contribution is to demonstrate that the extent of size distortion generated by contemporaneous correlations depends on the magnitude of cross-correlation coefficients, their variability and the number of series in the panel. We show that demeaning will not eliminate the size problem caused by the variation of cross correlations, and lead to false inference.

The IPS test possesses substantially more power than single-equation ADF test by averaging  $N$  independent ADF regressions:

$$\Delta y_{it} = \alpha_i + \rho_i y_{i,t-1} + \sum_{j=1}^p \theta_{ij} \Delta y_{i,t-j} + v_{it} \quad (1)$$

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for  $i=1, \dots, N$  series. The procedure allows for heterogeneity in  $\rho$  and  $\alpha$ . The null hypothesis is that  $\rho_i=0$  and the alternative is that certain percentage of the series has a value of  $\rho$  significantly less than zero. The limiting distribution is given as:

$$\sqrt{N} \frac{(\bar{t}_{ADF} - \mu_{ADF})}{\sqrt{\sigma_{ADF}^2}} \rightarrow N(0, 1) \quad (2)$$

where the moments  $\mu_{ADF}$  and  $\sigma_{ADF}^2$  are from Monte Carlo simulations, and  $\bar{t}_{ADF}$  is the average estimated ADF  $t$ -statistics from the sample. The power to reject the null increases by the  $\sqrt{N}$ . The IPS test is derived assuming that the series are independently generated, and they suggest subtracting cross-sectional means to remove common time-specific or aggregate effects. This assumes that the error term from Eq. (1) consists of two random components,  $v_{it} = \theta_t + \zeta_{it}$ , where  $\zeta_{it}$  is the idiosyncratic random component, and  $\theta_t$  is a stationary time-specific (aggregate) effect that accounts for common correlation in the errors across economies. However, subtracting cross-sectional means will only partially reduce the correlation in the data if there is heterogeneity (correlation between  $\zeta_{it}$ ) in the cross-sectional correlation, and hence a substantial size distortion may still remain.

In Table 1, we report how different levels and variation of cross-sectional dependence along with the number of series in the panel affect the size distortion and size-adjusted critical values. After generating cross-correlated  $N$  series with a  $T=50$  (number of time series observations), we ran 5000 Monte Carlo

Table 1  
Critical values for common and heterogeneous contemporaneous correlation

	$N=10$		$N=25$		$N=50$		$N=100$	
	5% Critical value	Size distortion	5% Critical value	Size distortion	5% Critical value	Size distortion	5% Critical value	Size distortion
<i>Homogenous correlation <math>\rho_{ij} =  \rho_{ij}  =</math></i>								
0	-1.679	0.050	-1.683	0.050	-1.622	0.050	-1.591	0.050
0.25	-2.038	0.084	-2.285	0.116	-2.572	0.161	-3.229	0.235
0.5	-2.742	0.176	-3.791	0.261	-4.947	0.342	-6.564	0.428
0.75	-4.927	0.319	-7.301	0.395	-9.673	0.458	-13.78	0.484
<i>Heterogeneous correlation <math>\rho_{ij} = 0,  \rho_{ij}  =</math></i>								
0.1	-1.688	0.055	-1.688	0.054	-1.744	0.060	-1.721	0.057
0.2	-1.864	0.072	-1.785	0.066	-1.927	0.079	-2.036	0.098
0.3	-1.903	0.077	-1.999	0.093	-2.163	0.110	-2.492	0.142
0.4	-2.055	0.094	-2.235	0.119	-2.577	0.152	-3.007	0.203
0.5	-2.377	0.136	-2.638	0.148	-2.973	0.197	-3.662	0.246

$N$  represents the number of series in the panel. The top half of the table possesses data with homogenous correlation across the panel. The bottom half assumes the data have a mean correlation of zero (e.g., demeaned data), but both positive and negative correlation exists that sums to zero but whose absolute value varies between 0 and 0.5. Hence, contemporaneous correlation varies across the sample but has mean zero. Thus, the bottom half includes the effects of only heterogeneity on the panel. Number of observations ( $T$ ) is chosen as 50 since Im et al. (1997) show that critical values are going to be independent of  $T$ . These values have been obtained with 5000 iterations. Simulations are carried out using the software Gauss® on a 1.4-GHz PC. The random seed used in the simulations is ( $5^{13}$ ). We discard the random number additions that generate non-positive definite correlation matrices.

Table 2  
Power of panel unit root test with cross correlation

Variation in $\rho_i$	$N=25$	$N=50$	$N=100$
0	0.462	0.735	0.958
0.1	0.440	0.721	0.924
0.2	0.410	0.614	0.838
0.3	0.362	0.538	0.699
0.4	0.300	0.454	0.570
0.5	0.251	0.350	0.415

The table illustrates the power for different  $N$  and heterogeneous correlations. The number of time series observations is fixed at 25 in each series and the autoregressive coefficient used in the simulation studies is 0.9.

simulations to test the IPS null hypothesis of a unit root process.<sup>1</sup> The top half of Table 1 displays contemporaneously (and homogeneously) correlated series (similar to the DGP in Maddala and Wu, 1999), which are generated with equal cross-sectional correlation  $\rho_{ij}=\rho$  for all  $i$  and  $j$  ( $i\neq j$ ). Homogeneous correlation in the panel assumes that all series in the panel are identically correlated (e.g.,  $\rho_1=\rho_2=0.4$ ). Such homogeneous correlation will be completely removed after demeaning of the data, implying  $\rho_{ij}=|\rho_{ij}|=0$ .

The bottom half of Table 1 reports a second DGP with mean  $\rho_{ij}=0$ ,  $|\rho_{ij}|>0$ . The purpose of this exercise is to simulate a demeaned data set (so the average correlations equal zero) with heterogeneous positive and negative correlations. This approach isolates the effects of heterogeneity on the critical values and size distortion. The variations (or heterogeneity) in cross correlations are generated by  $\rho_{ij}=k$ , where  $k$  is a uniformly distributed random variable in the interval  $[-m,m]$  and  $m=0.1, 0.2, 0.3, 0.4, 0.5$ . We discard the random number additions that generate non-positive definite correlation matrices. Our choice of differing  $k$ 's is conservative in terms of representing the heterogeneity of cross-sectional correlations. Three well-known data sets (see Table 3) have average variations between 0.55 and 0.65.

Results clearly show that the greater the magnitude and heterogeneity of contemporaneous correlation, the higher is the size distortion and more negative are the size-adjusted critical values. Further, the size distortions increase with  $N$ . For variation levels around 0.5, the size distortion is substantial for  $N=25$  or higher. Thus, demeaning data do not eliminate the size distortions in the data if the original DGP had heterogeneous correlation, and hence false inference can occur.

Table 2 shows that adjusting the critical values for heterogeneity of the cross correlation also results in lower power as the lack of independence implies that this value does not increase by the square root of  $N$ . The results in the first row for zero variation case represent demeaned series with homogeneous correlation, in which the correlation matrix used is the identity matrix; in this case, an  $N=100$  has double the power of  $N=25$ , and hence is consistent with Eq. (2). The subsequent results display the decrease in power following the size adjustment. In the case of  $N=100$ , for instance, the power declines from 0.958 to 0.415 using the size-adjusted critical values; furthermore, the power increased only 65% instead of 100% from  $N=25$ .

Table 3 applies our simulation studies to three widely used data sets (Maddison, 1995 data set which Evans and Karras, 1996) examined, the BLS data of Fleissig and Strauss, 2001, and an IFS data set of PPP that is extensively used (e.g., Mark, 2001) to illustrate that demeaning typically does not remove all of the contemporaneous correlation (see Appendix A for data description). To adjust for the size problem, we use the actual covariance

<sup>1</sup> The panel data are constructed as follows. The  $N$  cross-correlated series are generated by taking the Choleski decomposition of a given  $N\times N$  correlation matrix (e.g.,  $10\times 10$ , or  $25\times 25$ ) and multiplying it by  $N$  series of size  $5000+T$  to generate the cross correlation between our error terms. Next, we add these error terms to a random walk series again of size  $5000+T$  and finally throw away the initial 5000 observations to eliminate the effects of initial values. We use the same procedure in 5000 Monte Carlo simulations to test the IPS null hypothesis of a unit root process. The simulations use Gauss 3.2 on a 1.4-GHz PC. The random seed was  $5^{13}$ .

Table 3  
Critical values and size distortion on demeaned data

	Convergence Maddison	Convergence, BLS Wage	PPP
Test statistic	– 2.105	– 2.267	– 2.203
Size adjusted			
1% Critical value	– 3.996	– 2.797	– 3.339
5% Critical value	– 2.812	– 2.036	– 2.442
10% Critical value	– 2.249	– 1.620	– 1.945
Size distortion	0.181	0.096	0.144

Critical values and test statistics for real data examples from convergence studies. For Maddison,  $N=15$  and  $T=123$ , the BLS wage data set has  $N=48$  and  $T=65$  and PPP data set has  $N=17$  and  $T=96$ . Critical values are derived from 5000 iterations using the actual (historical) covariance matrix.

matrix in our Monte Carlo simulations (which use the actual  $N$  and  $T$ ) to calculate size-adjusted critical values and the size distortion. We report these statistics in Table 3 for the demeaned data. For both the OECD and PPP data, demeaned ADF statistics reject the null hypothesis of a unit root process at the 1% level, while critical values adjusting for variation in the cross correlations indicate that we cannot reject a unit root process at even the 10% level. The size distortion hence produces incorrect inference and a Type I error.

## 1. Conclusion

Our paper demonstrates that the greater the extent of cross correlations and their variation, the higher is the size distortion and more negative are the size-adjusted critical values. This implies that demeaning does not eliminate the problem of contemporaneous correlation. We show that its imposition induces false inference in several commonly used panel data sets given the extensive heterogeneous cross-sectional dependence that exists in these panels. Further, the power of the panel tests to reject the null hypothesis does not increase by the square root of  $N$ , and hence larger panels possess a greater size distortion.

## Appendix A

The PPP data set is from the IFS CD and includes quarterly data from 1974.1 to 1999.4 for Australia, Austria, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Netherlands, New Zealand, Spain, Sweden, Switzerland and the UK. We use the US as the benchmark and CPI prices. The Maddison data include annual per capita income data from 1870 to 1994 for Australia, Austria, Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, New Zealand, Spain, Sweden, UK and US. The US states include per capita wage data from the BLS website for 48 states from 1926 to 1995; two states were dropped due to data unavailability.

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