Panel Unit Root and Cointegration Tests
Methods and Applications Using EViews

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Panel Unit Root Tests

Background

- The unit root testing in the panel data context is very similar to that employed in the context of using time series data.

- Panel data are used to overcome one important limitation of DF/ADF and PP types of unit root tests, which is that they have low power, especially for modest sample sizes.

- The above is the key motivation for using panel data.

- It is hoped that more powerful versions of the tests can be applied when time series and cross-sectional information are combined as a result of which the sample size increases.

- Of course, the sample size may be increased by increasing the length of the time period. However, the problem is that for many time series variables, it may not be easy to get data for extended time periods. Further, even if available, long time series may be of limited use because of structural breaks in the time series.
Important Points to Remember

✓ Although the single time series and panel data approaches to unit root testing appear to be very similar on the surface, a valid construction and application of the test statistics in the panel data context is much more complex compared to that for single time series.

✓ One important complication in the panel data context arises from the fact that the test statistics may have different asymptotic distributions depending on whether \( N \) is fixed and \( T \) tends to infinity, or vice versa, or both \( T \) and \( N \) increase simultaneously in a fixed ratio.

✓ Issues that need special attention in the panel data context are:

(i) The design and interpretation of the null and alternative hypotheses

(ii) The problem of cross-sectional dependence in the errors across the unit root testing regressions

✓ Some early unit root tests that assumed cross-sectional independence in the errors are called ‘first generation’ panel unit root tests, while the more recent tests that allow for some form of cross-sectional dependence are termed ‘second generation’ panel unit root tests.
First-Generation Panel Unit Root Tests

❖ Levin-Lin-Chu (LLC) (2002) test

- This test is an extension of ADF test in the context of panel data.

- It assumes that individual processes are cross-sectionally independent.

The LLC test equation takes the following form:

$$\Delta Y_{i,t} = \alpha_i + \theta_t + \delta_i t + \rho_i Y_{i,t-1} + \sum_{k=1}^{n} \phi_k \Delta Y_{i,t-k} + u_{i,t}$$ .... (1)

This equation is very general as it allows for two-way fixed effects, one coming from $\alpha_i$ (representing unit-specific fixed effect) and the other from $\theta_t$ (unit-specific time effects). It also includes separate deterministic trends in each series through $\delta_i t$, and the lag structure ($\Delta Y_{i,t-k}$) to remove autocorrelation in $\Delta Y_{i,t}$. 
The null and alternative hypotheses of this test are:

\[ H_N : \rho_i = \rho = 0 \quad \forall i \]
\[ H_A : \rho_i < 0 \quad \forall i \]

Under the assumption that the individual processes are cross-sectionally independent, the test derives conditions for which pooled OLS estimator of \( \rho \) will follow a standard normal distribution under the null hypothesis.

Thus, the LLC test may be viewed as a pooled ADF test, potentially with different lag lengths across the different sections in the panel.
Im-Pesaran-Shin (2003) test

- The major limitation of the LLC test is that it restricts $\rho$ to being homogeneous across all $i$.

- To remove above limitation, Im, Pesaran and Shin (IPS) proposed an alternative approach where, given equation (1) above, the null and alternative hypotheses are considered to be:

  $H_N : \rho_i = 0 \quad \forall i$

  $H_A : \rho_i < 0 , i = 1, 2, ..., N_1$;

  $\rho_i = 0, i = N_1 + 1, N_2 + 1, ..., N$

- So, the null hypothesis still specifies all series in the panel as non-stationary, but under the alternative, a proportion of the series $\binom{N_1}{N}$ are stationary, and the remaining proportion $\binom{N-N_1}{N}$ are non-stationary. No restriction that all of the $\rho$ are identical is imposed in this test.
The statistic for the panel unit root test here is constructed by conducting separate unit root tests for each series in the panel, calculating the ADF $t$-statistic for each one in the standard fashion, and then taking their cross-sectional average.

This average is then transformed into a standard normal variate under the null hypothesis of a unit root in all the series.

IPS developed an LM-test approach as well as the more familiar $t$-test.

If the time series dimension ($T$) is sufficiently large, it is then possible to run separate unit root tests on each series to determine the proportion for which the individual tests cause a rejection of null hypothesis, and thus how strong is the weight of evidence against the joint null hypothesis.
It should be noted that while IPS’s heterogeneous panel unit root tests are superior to the homogeneous case of LLC when \( N \) is modest relative to \( T \), they may not be sufficiently powerful when \( N \) is large and \( T \) is small, in which case the LLC approach may be preferable.

- **Maddala-Wu (1999) test**

- An advantage of this test is that it can be applied to examine stationarity of an unbalanced panel.

- It is a variant of the IPS test where unit root tests are conducted separately on each series in the panel, and the \( p \)-values associated with the test statistics are then combined.
If we call these $p$-values $p_i(i = 1, 2, \ldots, N)$, then under the null hypothesis of a unit root in each series, each $p_i$ will be distributed uniformly over the $[0,1]$ interval and hence the following will hold for given $N$ as $T \to \infty$:

$$\lambda = -2 \sum_{i=1}^{N} \ln(p_i) \sim \chi^2_{2N}$$

It is to be noted that the number of observations per series can differ in this case as the regressions are run separately for each series and then only their $p$-values are combined in the test statistic.

Also note that the cross-sectional independence assumption is crucial here for this sum to follow a $\chi^2$ distribution.
Second-Generation Panel Unit Root Tests

- The first-generation panel unit root tests such as LLC and IPS are based on the assumption of cross-sectional independence. This assumption appeared to be quite restrictive in many empirical applications of macroeconomics.

- For instance, non-stationarity in the GDP series of a particular country may appear because of the persistence of international shocks, and the cross-section units (countries) are not independent.

- The first-generation unit root tests for panel data cannot incorporate the effects of international shocks or international dependence.

- O’Connell (1998) showed that considerable size distortions may arise when such cross-sectional dependencies are present but ignored. In that situation, the $H_N$ gets rejected far too frequently when it is correct.
Thus, the second-generation panel unit root tests have been developed to take care of cross-sectional dependency.

There are two approaches here – one that imposes some restrictions on the covariance matrix of the residuals (e.g., O’Connell, 1998) and the other is related to low-dimensional common factor model (e.g., Bai and Ng, 2004).

O’Connell was the first scholar to devise a method to deal with the problem of cross-sectional dependence in panel data. He considered covariance matrix of the error term and used a feasible GLS estimator for $\rho$ for the homogeneous panel. This approach is valid when the number of cross section units (N) is limited.
On the other hand, in the factor structure approach of Bai and Ng (2004), the cross-sectional dependence is allowed by taking some common factors which have differential effects on different cross section units. This test separated the data into a common factor component that is highly correlated across the series and a specific part that is idiosyncratic, i.e., largely cross-section specific.

Concluding Observations

✓ Satisfactorily dealing with cross-sectional dependence is not easy. In the presence of such dependencies, the test statistics are affected in a non-trivial way by the nuisance parameters ($\alpha_i$ and $\theta_t$).

✓ For above reason, despite their inferiority in theory, the first generation approaches that ignore cross-sectional dependence are still widely employed by the empirical researchers.
Panel Cointegration Tests

- Testing for cointegration in panel data is a rather complex issue, since one must consider the possibility of cointegration across groups of variables (termed as ‘cross-sectional cointegration’) as well as within the groups.

- It is also possible that the parameters in the cointegrating series and the number of cointegrating relationships could differ across the panel.

- Most of the work so far has relied upon a generalisation of the single equation methods of the Engle–Granger type following the pioneering work by Pedroni (1999, 2004).
Pedroni’s approach is very general and allows for separate intercepts for each group of potentially cointegrating variables and separate deterministic trends.

For a set of variables $Y_{i,t}$ and $X_{mi,t}$ that are individually integrated of order one and thought to be cointegrated

$$Y_{i,t} = \alpha_i + \delta_i t + \beta_{1i} X_{1i,t} + \beta_{2i} X_{2i,t} + \ldots + \beta_{Mi} X_{Mi,t} + u_{i,t} \quad \ldots \quad (1)$$

where $m = 1, 2, \ldots, M$ are the explanatory variables in the potentially cointegrating regression; $t = 1, 2, \ldots, T$ and $i = 1, 2, \ldots, N$.

The estimated residuals from this regression $(\hat{u}_{i,t})$ are then subjected to separate ADF-type test for each group of variables to determine whether they are $I(0)$. 


The test equation is

\[ \Delta \hat{u}_{i,t} = \rho_i \hat{u}_{i,t-1} + \sum_{j=1}^{p} \phi_{i,j} \Delta \hat{u}_{i,t-j} + \nu_{i,t} \quad \text{.... (2)} \]

and the null hypothesis is that the residuals from all of the test regressions are unit root processes \( (H_N : \rho_i = 0) \), which indicates absence of cointegration.

Pedroni proposes two possible alternative hypotheses:

(i) All of the autoregressive dynamics are the same stationary process \( (H_A : \rho_i = \rho < 0 \ \forall \ i) \)

(ii) The dynamics from each test equation follow a different stationary process \( (H_A : \rho_i < 0 \ \forall \ i) \)

Hence, in the first case no heterogeneity is permitted, while in the second it is permitted.
Based on standardised versions of the usual $t$-ratio from equation (2), Pedroni then constructed seven different test statistics which are:

- panel $v$-statistic,
- panel $\rho$-statistic,
- panel PP-statistic,
- panel ADF-statistic,
- group $\rho$-statistic,
- group PP-statistic, and
- group ADF-statistic

The standardisation required is a function of whether an intercept or trend is included in (2), and the value of $M$.

These standardised test statistics are each asymptotically standard normally distributed.
Kao (1999) developed a restricted version of Pedroni’s approach, where the slope parameters in equation (1) are assumed to be fixed across the groups but the intercepts are allowed to vary. Then the ADF test regression is run on the estimated residuals obtained from first-stage regression to test the validity of the null hypothesis of no cointegration.

In contrast to above tests, Larsson et al. (2001) developed a test that is basically a generalisation of Johansen’s maximum likelihood based cointegration test in the context of heterogenous panels.
Panel Unit Root Tests

- EViews 10 provides a range of four tests for unit roots within a panel structure, but all are based on the assumption of cross-sectional independence.

- We can apply different tests in one go using EViews and compare the results.

- We consider data given in Excel file named ‘GDP-CON_BRICS’. This file contained data on GDP and final consumption expenditure (CONEXP) [both in constant 2010 US$, and millions] for five BRICS countries for the period 1995 to 2018.

Data source: www.worldbank.org/indicator
Steps in EViews for Panel Unit Root tests

1. Transform the variables in log. The log-transformed variables are named as LGDP and LCONEXP, respectively.

2. Import the data in EViews. Once the data are imported, the following window opens:
3. To examine the stationarity of LGDP series, double click on the variable that opens the following window:
4. Click **View/Unit Root Test...** to have the following window opened:

As regards ‘Test Type’, we continue with ‘Summary’ to have results of all tests at one place, as regards ‘Lag Length’, we choose ‘Automatic selection’, and conduct the unit root test in ‘Level’ to begin with.
It is found that the LGDP series has unit root (non-stationary) in ‘Level’ form based on all four panel unit root tests (the $p$-values for the test statistics are greater than 0.10).
6. If we run the test again considering first-difference form of LGDP, the following output is obtained:

<table>
<thead>
<tr>
<th>Method</th>
<th>Statistic</th>
<th>Prob.**</th>
<th>Cross-sections</th>
<th>Obs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Null: Unit root (assumes common unit root process)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Levin, Lin &amp; Chu t*</td>
<td>-4.37805</td>
<td>0.0000</td>
<td>5</td>
<td>110</td>
</tr>
<tr>
<td>** Probabilities for Fisher tests are computed using an asymptotic Chi-square distribution. All other tests assume asymptotic normality.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It is clear that the first-difference of LGDP series doesn’t have unit root and is stationary (the $p$-values for all the test statistics are less than 0.01).

If we repeat the exercise for the LCONEXP series, the same conclusion emerges. Thus, LCONEXP is also non-stationary in ‘Level’ form but stationary in ‘first difference’ form.
Panel Cointegration Tests

- We want to check whether cointegration exists between the variables LCONEXP and LGDP.

- For this purpose, we shall apply tests of Pedroni and Kao.

- One prerequisite to run the conintegration test is that the variables are \( I(1) \) so that their linear combination is \( I(0) \) – this condition is fulfilled by the two variables, confirmed by applying the panel unit root test.
Steps in EViews

1. Select the two variables (LCONEXP and LGDP) from the workfile window and open those only ‘as Group’ to have the following window:
2. Click **View/Cointegration Test/Panel Cointegration Test** to have the following ‘Panel Cointegration Test’ window:

Here, to begin with, we choose Pedroni (Engle-Granger based) as ‘Test type’ and prefer ‘Automatic selection’ for ‘Lag length’.
It is found that all seven statistics to examine the validity of the ‘H_N: no cointegration’, are statistically insignificant as their p-values are above 0.10.

So, we accept the H_N and conclude that there is no cointegration between LCONEXP and LGDP as per Pedroni-test.
However, if we choose the Kao (Engle-Granger based) as ‘Test type’, the following results are obtained:

<table>
<thead>
<tr>
<th>Kao Residual Cointegration Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Series: LCONEXP GDP</td>
</tr>
<tr>
<td>Date: 04/25/20 Time: 11:12</td>
</tr>
<tr>
<td>Sample: 1985-2010</td>
</tr>
<tr>
<td>Included observations: 120</td>
</tr>
<tr>
<td>Null Hypothesis: No cointegration</td>
</tr>
<tr>
<td>Trend assumption: No deterministic trend</td>
</tr>
<tr>
<td>Automatic lag length selection based on SIC with a max lag of 5</td>
</tr>
<tr>
<td>Newey-West automatic bandwidth selection and Bartlett kernel</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>t-Statistic</th>
<th>Prob</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADF</td>
<td>-3.843059</td>
<td>0.0001</td>
</tr>
<tr>
<td>Residual variance</td>
<td>0.000316</td>
<td></td>
</tr>
<tr>
<td>HAC variance</td>
<td>0.000418</td>
<td></td>
</tr>
</tbody>
</table>

**Augmented Dickey-Fuller Test Equation**
Dependent Variable: D(RESID)
Method: Least Squares
Date: 04/25/20 Time: 11:12
Sample (adjusted): 2000-2018
Included observations: 95 after adjustments

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>t-Statistic</th>
<th>Prob</th>
</tr>
</thead>
<tbody>
<tr>
<td>RESID(1)</td>
<td>-0.147321</td>
<td>0.038160</td>
<td>-4.074177</td>
<td>0.0001</td>
</tr>
<tr>
<td>D(RESID)(1)</td>
<td>0.412568</td>
<td>0.085110</td>
<td>4.848499</td>
<td>0.0000</td>
</tr>
<tr>
<td>D(RESID)(2)</td>
<td>-0.057310</td>
<td>0.081757</td>
<td>-0.649658</td>
<td>0.5174</td>
</tr>
<tr>
<td>D(RESID)(3)</td>
<td>0.224365</td>
<td>0.086135</td>
<td>2.604912</td>
<td>0.0108</td>
</tr>
<tr>
<td>D(RESID)(4)</td>
<td>0.174661</td>
<td>0.091416</td>
<td>1.910610</td>
<td>0.0592</td>
</tr>
</tbody>
</table>

| R-squared    | 0.286810    | Mean dependent var | 0.002258 |
| Adjusted R-squared | 0.255112 | S.D. dependent var | 0.019791 |
| S.E. of regression | 0.144492 | Akaike info criterion | -5.757230 |
| Sum squared resid | 0.018901 | Schwarz criterion | -5.448776 |
| Log likelihood | 270.0163   | Hannan-Quinn criter | -5.24976 |
| Durbin-Watson stat | 2.319586 |                             |         |

Here the ADF test statistic is statistically significant at 0.01 percent level.

So, we reject the $H_N$ and conclude that there is cointegration between these variables.

The researcher in this situation of contrasting results would obviously go in for reporting the result based on Kao test.
References


4. EViews Help_ Panel Unit Root Testing
   [To be downloaded from http://www.eviews.com/help/helpintro.html#page/content/advtime-
   ser-Panel_Unit_Root_Testing.html]

5. EViews Help_ Panel Cointegration Testing
   [To be downloaded from http://www.eviews.com/help/helpintro.html#page/content/coint-
   Panel_Cointegration_Testing.html]