APPENDIX

A) Unit root testing

In time series and panel data econometrics, one of the concepts that have attracted increasing attention is the characteristic of stationarity.

"A stochastic process is said to be stationary if its mean and variance are constant over time and the value of covariance between the two time periods depends only on the distance or gap or lag between the two time periods and not the actual time at which the covariance is computed" (Gujarati, 2003:797).

It is highly significant to specify whether a series is stationary or not before continuing. Although there are various tests which have been used to test for stationarity, it was decided to use the most commonly used test in panel data analysis: the Levin, Lin and Chu (2002) test.

The null hypothesis is as follows:

Eq. 0.1

$$\Delta y_{it} = \rho y_{i,t-1} + \sum_{L=1}^{P_i} \theta_{iL} \Delta y_{i,t-L} + \alpha_{mi} d_{mt} + \varepsilon_{it}\ , m = 123$$

Where dmt is the vector of deterministic variables and αmt the corresponding vector of coefficients for model m =1,2,3.

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Step 1: Individual augmented Dickey-Fuller (ADF) regressions for each cross-section

Eq. 0.2

$$\Delta y_{it} = \rho_i y_{i,t-1} + \sum_{L=1}^{P_i} \theta_{iL} \Delta y_{i,t-L} + \alpha_{mi} d_{mt} + \varepsilon_{it}\ , m = 123$$

For a given T, choose the maximum lag order pmax and then use the t-statistic of $\widehat{\theta_{\iota L}}$ to determine if a smaller lag can be chosen instead. Once the lag is determined, two auxiliary regressions should be run:

Eq. 0.3

$$\Delta y_{it}\ on\ \Delta y_{i,t-L}\ (L = 1, \ldots .p_i) and\ d_{mt} to\ get\ the\ residual\ \widehat{e_{\iota t}}$$

And

Eq. 0.4

$$\mathbf{y_{i,t-1}\ on\ \Delta y_{i,t-L}\ (L = 1, \ldots .p_i) and\ d_{mt} to\ get\ the\ residual\ \widehat{v_{\iota,t-1}})}$$

Then, standardise these residuals to account for different variances where $\widehat{\sigma_{e\iota}}$ is the standard error for each ADF regression (2).

Eq. 0.5

$$\widetilde{\mathbf{e_{\iota t}}} = \widehat{\mathbf{e_{\iota t}}}/\widehat{\boldsymbol{\sigma_{\varepsilon\iota}}}\ \mathbf{and}\ \tilde{\mathbf{v}}_{\mathbf{i,t-1}} = \hat{\mathbf{v}}_{\mathbf{it}}/\hat{\boldsymbol{\sigma}}_{\boldsymbol{\varepsilon}\mathbf{i}}$$

Step 2: Estimation of the ratio of long-run to short-run standard deviations

Under the null hypothesis (1), the long-run variance can be estimated as follows:

Eq. 0.6

$$\hat{\sigma}_{yi}^2 = \frac{1}{T-1}\sum_{t=2}^{T}\Delta y_{it}^2 + 2\sum_{L=1}^{\overline{K}} w_{\overline{K}L}\left[\frac{1}{T-1}\sum_{t=2+L}^{T}\Delta y_{it}\Delta y_{i,t-L}\right]$$

Where $\overline{K}$ is a truncation lag that can be dependent on the data.

For each cross-section, the ratio of long-run to short-run deviation is $\hat{s}_i = \hat{\sigma}_{yi}/\hat{\sigma}_{\varepsilon i}$ and the average standard deviation is estimated by $\hat{S}_N = \frac{1}{N}\sum_{i=1}^{N}\hat{s}_i$.

Step 3: Computation of the panel test statistics

Run the pooled regression:

Eq. 0.7

$$\tilde{\mathbf{e}}_{\mathbf{it}} = \boldsymbol{\rho}\tilde{\mathbf{v}}_{\mathbf{i,t-1}} + \tilde{\boldsymbol{\varepsilon}}_{\mathbf{it}}$$

The conventional t-statistic is $t_\rho = \frac{\hat{\rho}}{\hat{\sigma}(\hat{\rho})}$ where

Eq. 0.8

$$\hat{\boldsymbol{\rho}} = \sum_{i=1}^{N}\sum_{t=2+p_i}^{T}\tilde{\mathbf{v}}_{\mathbf{i,t-1}}\tilde{\mathbf{e}}_{\mathbf{it}}/\sum_{i=1}^{N}\sum_{t=2+p_i}^{T}\tilde{\mathbf{v}}_{\mathbf{i,t-1}}^2$$

Eq. 0.9

$$\hat{\boldsymbol{\sigma}}(\hat{\boldsymbol{\rho}}) = \hat{\boldsymbol{\sigma}}_{\tilde{\varepsilon}}/\left[\sum_{i=1}^{N}\sum_{t=2+p_i}^{T_i}\tilde{\mathbf{v}}_{\mathbf{i,t-1}}^2\right]^{1/2}$$

And the estimated variance of $\tilde{\varepsilon}_{it}$ is

Eq. 0.10

$$\hat{\sigma}_{\tilde{\varepsilon}}^2 = \frac{1}{N\tilde{T}} \sum_{i=1}^{N} \sum_{t=2+p_i}^{T} (\tilde{e}_{it} - \hat{\rho}\tilde{v}_{i,t-1})^2$$

The adjusted t-statistic is computed as follows:

Eq. 0.11

$$t_\rho^* = \frac{t_\rho - N\tilde{T}\hat{S}_N \hat{\sigma}_{\tilde{\varepsilon}}^{-2} \hat{\sigma}(\hat{\rho}) \mu_{m\tilde{T}}^*}{\sigma_{m\tilde{T}}^*}$$

Where $\mu_{m\tilde{T}}^*$ and $\sigma_{m\tilde{T}}^*$ are the mean and standard deviations given in Levin, Lin and Chu (2002).

B) Hausman test for misspecification

In general, it is assumed that there is exogeneity of the regressors ($E(u_{it}|X_{it})=0$) in panel data models. But the residuals may include individual and time effects possibly correlated with X_{it} ($E(u_{it}|X_{it})\neq 0$). Therefore Hausman (1978) proposed and constructed a test to identify this endogeneity or misspecification.

Null hypothesis H_0: No misspecification or $E(u_{it}|X_{it})=0$

Alternative hypothesis H_1: Misspecification or $E(u_{it}|X_{it})\neq 0$

The test is based on two estimators ($\hat{\beta}_{GLS}$ *and* $\tilde{\beta}_{within}$) that are both consistent with H_0 but have a different distribution under H_1.

Eq. 0.12

$$\hat{q}_1 = \hat{\beta}_{GLS} - \tilde{\beta}_{within}$$

The Hausman test is defined as

Eq. 0.13

$$\mathbf{m_1} = \hat{\mathbf{q}}_1[\mathbf{var}(\hat{\mathbf{q}}_1)]^{-1}\hat{\mathbf{q}}_1 \sim \chi^2_K$$

Where K is the dimension of $\hat{q}$ (the number of regressors or slope coefficients). However, Hausman and Taylor (1981) mentioned that there are other equivalent tests that are asymptotically distributed χ^2_K under H_0.

Eq. 0.14

$$\hat{\mathbf{q}}_1 = \hat{\boldsymbol{\beta}}_{GLS} - \tilde{\boldsymbol{\beta}}_w$$

Eq. 0.15

$$\hat{\mathbf{q}}_2 = \hat{\boldsymbol{\beta}}_{GLS} - \tilde{\boldsymbol{\beta}}_B$$

Eq. 0.16

$$\hat{\mathbf{q}}_3 = \tilde{\boldsymbol{\beta}}_w - \hat{\boldsymbol{\beta}}_B$$

Where the vector of slope coefficients is $m_i = \hat{q}_i V_i^{-1}\hat{q}_i$ where $V_i = var(\hat{q}_i)$ for i=1,2,3.

To avoid the estimation of the GLS estimator for simplicity purposes, we prefer the computation of m_3:

Eq. 0.17

$$\hat{\mathbf{q}}_3 = \tilde{\boldsymbol{\beta}}_w - \hat{\boldsymbol{\beta}}_B \text{ and } \mathbf{m}_3 = \hat{\mathbf{q}}_3\mathbf{V}_3^{-1}\hat{\mathbf{q}}_3 \text{ where } \mathbf{V}_3 = \mathbf{var}(\hat{\mathbf{q}}_3)$$

The comparison of m_3 to $\chi^2(2)$ will provide us with the information to know whether we should accept the null hypothesis of heterogeneity of the X regressors or not: if $m_3 > \chi^2(2)$, we reject the null hypothesis.

C) Testing for heteroskedasticity

A correct panel data regression assumes homoskedastic disturbances with similar variances across time and individuals. However, when cross-sectional units are of varying size and different variances then this assumption may not hold and the standards errors will be biased.

The general test for heteroskedasticity is adopted from Greene (econometric analysis).

Null hypothesis: H_0: $\sigma_i^2 = \sigma^2$ for all i or homoskedasticity

Alternative hypothesis: H1: $\sigma_i^2 \neq \sigma^2$ for all i or heteroskedasticity

The LM test statistic is defined as follows:

Eq. 0.18

$$\mathbf{LM} = \frac{\mathbf{T}}{\mathbf{2}}\sum_{\mathbf{i=1}}^{\mathbf{N}}[\frac{\hat{\boldsymbol{\sigma}}_{\mathbf{i}}^{\mathbf{2}}}{\hat{\boldsymbol{\sigma}}} - \mathbf{1}]\mathbf{^\wedge 2} \sim \boldsymbol{\chi}_{\mathbf{N-1}}^{\mathbf{2}}$$

Where $\hat{\sigma}_i^2$ is the individual regression's RSS/NT while $\hat{\sigma}$ is the pooled regression's RSS/NT. If the LM $> \chi_{N-1}^2$ then the null hypothesis can be rejected and it can be concluded that the model suffers from heteroskedasticity.

D) Testing for serial correlation

In a panel data analysis context, the classical error component disturbances $(u_{it} = \mu_{it} + v_{it})$ assume correlation within a cross-section due to individual effects. The correlation coefficient then becomes:

Eq. 0.19

$$\mathbf{Correl(u_{it}, u_{is}) = \frac{\sigma_{\mu}^{2}}{(\sigma_{\mu}^{2}+\sigma_{v}^{2})}, for\ t \neq s}$$

However, we might observe serial correlation where the unobserved shock in a given period will affect the relationship for a few periods. To test for serial correlation, we assume the following: $y_{it} = Z_{it}'\,\delta + u_{it}$ where δ is (K+1) x1 and $u_{it} = \mu_{it} + v_{it}$ for i=1,...N and t=1,....N, and $\mu_i{\sim}IIN(0, \sigma_{\mu}^{2}), v_{it}$ is either AR(1) or MA(1). The proposed test checks for serial correlation together with individual effects.

Null hypothesis: H_0: $\sigma_{\mu}^{2} = 0;\ \lambda = 0$ (No random effects and No serial correlation)

$v_{it} = \varepsilon_{it} - \lambda\varepsilon_{i,t-1}$

Alternative hypothesis H_1: $\sigma_{\mu}^{2} = 0;\ \rho = 0$ (Random effects and serial correlation)

$v_{it} = \ \rho v_{i,t-1} + \varepsilon_{it}$

If the LM $>\chi_{2}^{2}$ then the null hypothesis can be rejected and it can be concluded that the model suffers from serial correlation.

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