Economics Bulletin

Volume 32, Issue 4

Exports and FDI: A Granger causality analysis in a heterogeneous panel

Chaido Dritsaki
Technological University of Western Macedonia

Melina Dritsaki
Brunel University

Abstract

This paper investigates the heterogenous panels Granger causality between exports and Foreign Direct Investment (FDI) for the twelve new EU countries from 1995 until 2010. The cointegration test by Pedroni (1999) shows a long run heterogenous relationship. A two-stage Engle and Granger procedure (1987), allowing for testing of heterogeneity of panel data on dynamic models, shows a bilateral causal relationship between exports and foreign direct investment both in the long and short run for the examined countries.

We would like to thank the editor and an anonymous referee for useful suggestions
Citation: Chaido Dritsaki and Melina Dritsaki, (2012) "Exports and FDI: A Granger causality analysis in a heterogeneous panel", *Economics Bulletin*, Vol. 32 No. 4 pp. 3128-3139.
Contact: Chaido Dritsaki - dritsaki@yahoo.com, Melina Dritsaki - Melina.dritsaki@brunel.ac.uk.
Submitted: June 13, 2012.   **Published:** November 19, 2012.

1. Introduction

The aim of this paper is to evaluate the causal relationship between export of goods and services and foreign direct investment (FDI) for a panel of twelve new EU countries using a new framework for Granger causality analysis in heterogeneous panel.

According to theory there are two viewpoints as far as exports and foreign direct investment are concerned. The first viewpoint support that foreign direct investment from multinationals in a country replace exports, reducing employment and economic growth in this country in the long run. The second viewpoint suggests that exports and FDI operate supplementary resulting is a positive relationship between them. Many studies support the fact that causality can be run both ways. However, they tend to find out that higher growth leads to more FDI rather than vice versa.

Granger causality method (1969) is considered the most popular method for the evaluation of causal relationship between two variables in most papers. Recently, econometricians have started to modify the Granger tests, employing them for the evaluation in the causal relations of dynamic panel data. So, the common method used in time-series variables cannot be implemented for a panel data analysis. The expansion of Granger methodology on panel data gives the opportunity to improve the conventional Granger analysis making it preferable on panel data. However, a disadvantage that is observed on Granger causality testing for panel data is the assumption of causal heterogeneity. This assumption is ignored from a large number of researchers leading to wrong conclusions for the causal relationship of the examined variables and a rejection of causal relationship for a number of observations or a sub-sample. This paper adopts the two-step Engle and Granger (1987) procedure. This procedure allows dynamic models to control for panel heterogeneity.

The study is organised as follows. In section 2, we perform a literature review of a sample of both theoretical and empirical studies. The econometric methodology is presented in section 3, and the description of the data follows in section 4. The empirical results are shown in part 5. Finally, Section 6 concludes.

2. Literature review

2.1 Theoretical background

The classical trade theories like those of Ricardo and Heckscher-Ohlin do not identify with clarity which is the relationship between foreign direct investment and trade, given the fact that production parameters are internationally immobile. In his study, Mundell (1957) investigating the relationship between FDI and trade and based on the assumptions of the neoclassical Heckscher-Ohlin and Samuelson theory, concluded that flows of FDI depend largely on the differences between prices and financing of each country. With the rapid mobility of capital these differences become smaller. Therefore, Mundell concludes that capital mobility driven by FDI constitutes a perfect substitute for exports for each country.

Schmitz and Helmberger (1970) show that trade increases when capital mobility is imported in a country thus a complementary relationship between FDI and trade is possible.

Markusen (1984) and Helpman (1984) are among the first who incorporate the theory of the multinational enterprise (MNEs) in their trade models (theory of the multinational enterprise (MNEs). Specifically, in his study, Markusen (1984) presents a general equilibrium model incorporating horizontal MNEs. Also, he presents various models demonstrating that moving factors can lead to increased trade. Markusen's models show how conditions such as external economies of scale and different production technologies can operate as a basis for trade. On the contrary, in his paper Helpman (1984) presents a model of vertical MNEs and FDI. Helpman develops a general equilibrium trade model based on various factors of financing.

The distinction between horizontal and vertical FDI formed by Markusen (1984) and Helpman (1984) has important implications in the relationship between FDI and trade. In case of horizontal FDI, a substitutional relationship is expected whereas for the case of vertical FDI, FDI is expected to have a complementary relationship with trade.

2.2 Empirical studies

If in the empirical literature, a substitution in the relationship between exports and foreign direct investment is confirmed, then exports are at least partially displaced by local sales at the foreign market. This result could be detrimental to the production and employment of the country where investments take place. If foreign direct investment and exports have a complementary link, then foreign direct investment benefit the country in which they occur. However, the majority of studies predict a positive relationship between foreign direct investment and exports.

Eaton and Tamura (1994) analyze the relationship of exports and foreign direct investment and control the determinants which influence these variables, like income per capita, population and the endowment of human capital. They find a strong complementary relationship between the examined variables. On the contrary, Andersen and Hainaut (1998) find a complementary relationship for USA, Japan and Germany but not for United Kingdom.

Lin (1995) finds a positive and significant influence of foreign direct investment of Taiwan in the exports of four ASEAN Countries (Indonesia, Malaysia, Philippines and Thailand).

On his paper, Pfaffermayr (1996) analyze the complementary relationship between foreign direct investment and exports for Austria. Adopting the Granger-causality procedure, he proved a significant positive causal relationship in both directions.

Clausing (2000) investigated the operations of US MNEs in 29 countries from 1977 – 1994 and finds a strong positive influence of FDI on exports.

Yao (2006) investigates the effect of exports and foreign direct investment (FDI) on economic performance of China. Using a large panel data set encompassing 28 Chinese provinces over the period 1978–2000 established that both exports and foreign direct investment have a strong and positive effect on economic growth.

Türkan (2006) identifies a strong complementary relation between American trade and foreign direct investment of intermediate exporting goods while he finds a slight negative relation between foreign direct investment and trade on final goods.

Falk and Hake (2008) using a panel of industries and seven EU countries for the period 1973-2004, investigate the relationship of exports and foreign direct investment. Estimates used show that exports cause FDI but not vice versa.

Finally, Chiappini (2011) investigates the causal relationship between Foreign Direct Investment and exports of goods and services using the new heterogeneous method Hurlin and Venet for panel data in 11 European countries from 1996 to 2008.

The results of this research shown that there is a homogeneous causal relationship from FDI to exports, while the causal relationship from exports found to be heterogeneous.

This paper will investigate the Granger causality between outward Foreign Direct Investment (FDI) and the exports of goods and services in 11 European countries from 1996 to 2008. Using a new method to evaluate causality in a heterogeneous panel, we find that the causal relationship from FDI to exports is homogeneous among the panel. However, we find strong evidence of heterogeneity of the causal relationship from exports to FDI in our sample.

The investigation conducting for the relationship between foreign direct investment and trade is diversified for each country or the destination country. Researchers that examine the relationship between FDI and exports from developed to developing countries find it complementary. The same relation is found to be substitution between developed countries.

3. The Econometric Methodology

In order to examine the causal relationship between Foreign Direct Investment and trade for the twelve new members of European Union we follow the two-step Engle and Granger (1987) procedure. This procedure allows dynamic models to control for panel heterogeneity.

In pursuit of this objective, stationarity tests are conducted initially as well as the Pedroni tests of panel cointegration (1999). In addition, to estimate the relationship between Foreign Direct Investment and exports via a “group-mean” panel data we use the fully modified Ordinary Least Squares (FMOLS) estimator developed by Pedroni (2000, 2001) which not only generates consistent estimates of the parameters in relatively small samples, but also controls for potential endogeneity of the regressors and serial correlation. (Ramirez 2006).

Thus, the first stage is to make the panel unit root tests and to find if there is a cointegrated vector. Afterwards, we should estimate the long run relationship in order to receive the estimated residuals, continuing with the estimation of Granger causality model using the dynamics of error correction. The long and short run causal relationship testing consists of the error correction parameters’ testing.

4. Data

The sample consists of annual data for twelve new members of European Union such as Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Lithuania, Latvia, Malta, Poland, Romania, Slovenia and Slovakia. The sample covers the period from 1995 until 2010 for all countries. All data derived from Eurostat Luxembourg: Economy and Finance (ECB). The variables used are Foreign Direct Investment (FDI) on constant prices of 2005 as well as exports of goods and services (EX) on constant prices of 2005. Natural logarithms of those variables are symbolized as lnFDI and lnEX.

5. Empirical Results

5.1 Panel Unit-Root Tests

Before starting with causality procedure we should examine if exports of goods and services as well as FDI are stationary. In other words we should determine if both panel series are stationary (don't show unit root). In this test, four different tests are employing aiming at detecting the presence of unit roots on panel data. The most famous ones are those suggested by Levin, Lin and Chu (LLC) (2002), Im, Pesaran and Shin (IPS) (2003) and Maddala and Wu (MW) (1999).

Levin, Lin, and Chu (2002) on their paper assume that the autoregressive root is homogeneous for all the individuals of the panel. Afterwards, Phillips and Sul (2003) proved that the above hypothesis is incorrect leading to the rejection of null hypothesis of the presence of unit root in many cases. Therefore, Im, Pesaran and Shin (2003) have suggested a new framework for the unit root testing on panel data allowing the heterogeneity on the lagged level term.

Finally, Maddala and Wu (1999) suggest two different panel unit root tests directly comparable with Im, Pesaran and Shin (2003) test. The first test is based on the Augmented Dickey-Fuller (MW-ADF) test and the second one on Phillips-Perron (MW-PP) test. So, we apply four different panel unit root tests presented on table 1.

Table 1: Panel unit root tests

Panel level series				
	lnEX		lnFDI	
	Individual intercept	Individual trend and intercept	Individual intercept	Individual trend and intercept
LLC(t*)	-1.2648 (0.103)	-1.194 (0.115)	-1.026 (0.152)	-0.927 (0.176)
IPS(W_{tbar})	-0.4992 (0.308)	-0.960 (0.168)	-1.287* (0.098)	-1.493* (0.067)
MW-ADF	25.989 (0.353)	28.531 (0.238)	32.160 (0.123)	33.281 (0.117)
MW-PP	31.696 (0.134)	29.057 (0.218)	16.234 (0.879)	19.930 (0.700)
Panel first difference series				
	ΔlnEX		ΔlnFDI	
	Individual intercept	Individual trend and intercept	Individual intercept	Individual trend and intercept
LLC(t*)	-5.829*** (0.000)	-4.556*** (0.000)	-4.065*** (0.000)	-3.668*** (0.000)
IPS(W_{tbar})	-5.189*** (0.000)	-2.917*** (0.001)	-3.242*** (0.000)	-1.965** (0.032)
MW-ADF	71.035*** (0.000)	47.202*** (0.003)	51.430*** (0.000)	35.458* (0.061)
MW-PP	130.86*** (0.000)	106.46*** (0.000)	80.835*** (0.000)	61.188*** (0.000)

Notes:
1. Panel data include all countries

2. The variables are expressed in a logarithmic form)
3. The numbers in parentheses denote p-values
4. ***, **, * denotes rejection of null hypothesis at the 1%, 5% and 10% level of significance, respectively.
5. Null hypothesis for all tests for panel data is that there is unit root (series are non stationary)
6. Δ denote first differences

The results of table 1 show that variables are non stationary on their levels. This result indicates the presence of a unit root in model variables. The first differences of the variables are stationary. This means that all variables are integrated I(1). Therefore, we can construct a model on the levels of variables examining if there is a cointegrated vector between the examined variables.

5.2 Panel Cointegration

In the next step we use a panel cointegration test developed by Pedroni (1999) which used a residual–based ADF test. Pedroni proposed several tests for cointegration that allow for heterogeneous slope coefficients across cross sections.

This consists of seven component tests: the panel v-statistic, panel ρ-statistic, panel t-statistic (non-parametric PP), panel t-statistic (parametric ADF), group ρ-statistic, group t-statistic (non-parametric PP), and group t-statistic (parametric ADF) (for details, see appendix 1).

Cointegration test is occurred in the following models in heterogeneous panels.

$$\ln EX_{it} = \alpha_0 + \alpha_1 YEAR_t + \alpha_2 \ln FDI_{it} + u_{it} \quad (1)$$

$$\ln FDI_{it} = \beta_0 + \beta_1 YEAR_t + \beta_2 \ln EX_{it} + e_{it} \quad (2)$$

where i and t denote province i (i = 1, 2, …,12) in year t (t = 1995, 1996,…, 2010). The error term u_{it} and e_{it} are assumed to be a stochastic white noise.

Equations (1) and (2) estimate only the long-run relationship. The estimated residuals u_{it} and e_{it} are the deviation from the modelled long-run relationship. If the series are cointegrated then u_{it} and e_{it} residuals for the two equations will be stationary variables. They do not make assumptions about the direction of causality between EX and FDI. The test results are given in Table 2

Table 2. Panel Cointegration Statistics (Individual Intercept & Individual Trend)

	Equation (1) for lnEX	**Equation (2) for lnFDI**
Panel cointegration statistics		
Panel v - Statistic	-0.158 (0.561)	0.392 (0.347)
Panel ρ - Statistic	-0.387(0.349)	1.582(0.943)
Panel t-statistic (non-parametric PP)	-3.437 (0.000)***	1.021(0.710)
Panel t-statistic (parametric ADF)	-2.421 (0.007)***	-1.771(0.038)**
Group-mean panel cointegration statistics		
Group ρ-statistic	1.288 (0.901)	2.608 (0.995)
Group t-statistic (non-parametric PP)	-1.985 (0.023)**	0.210 (0.583)

Group t-statistic (parametric ADF)	-1.504 (0.066)*	-3.449 (0.000)***

Notes:
1. The critical value is -1.96 to reject the null hypothesis of no cointegration at the 5% significance level as all the statistics are left-tailed tests.
2. ***, ** and * denote significance respective at the 1%, 5% and 10% level.

Table 2 reports these seven statistics for the relationship between exports and Foreign Direct Investment. As it can easily be understood from the table, there is no strong cointegrating relationship between two variables in equation (1), since four out of seven statistical criteria reject the null hypothesis of no cointegration. On the other hand, table 2 points out a remarkable non cointegrating relationship between two variables for equation (2).

Having established that there is a linear combination on equation (1) that keeps the pooled variables in proportion to one another in the long run, we can proceed to generate individual long-run estimates for equation (1).

In view of the fact that the OLS estimator is a biased and inconsistent estimator when applied to cointegrated panels, we utilize the “group-mean” panel fully modified OLS estimator (FMOLS) developed by Pedroni (2000, 2001). The FMOLS estimator method not only generates consistent estimates of the β parameters in small samples, but also controls for the likely endogeneity of the regressors and serial correlation. The panel FMOLS estimator for the coefficient β is given in appendix 2. (see Dritsaki and Dritsaki 2012).

Table 3 below presents the estimation of the cointegrating vector and t-ratios for equation (1).

Table 3. Panel Group FMOLS Results

	YEAR	lnFDI
lnEX	0.027 (3.247)***	1.400 (67.23)***

Notes:
1. Panel data include all countries
2. The variables are expressed in a logarithmic form)
3. The numbers in parentheses denote t-ratios
4. ***, **, * denotes rejection of null hypothesis at the 1%, 5% and 10% level of significance, respectively.

From the results of table 3 we observe that FDI have a positive effect on exports in the long run. More specific, an increase of FDI by 1% will cause an increase of exports by 1.4% in the long run.

5.3 Testing for Granger causality in heterogeneous panels

While EX and FDI variables are cointegrated in equation (1), we estimate Granger causality using an error correction model in order to examine the long run relationship using the two-step Engle and Granger procedure (1987). This procedure allows dynamic models to control for panel heterogeneity.

The first step is the estimation of long-run relationship from equation (1) in order to get the estimated residuals u_{it}. The second step is to estimate Granger’s causality model with the dynamics of error correction. Causality testing consists of the logarithmic relationship between EX and FDI variables on the following equations:

$$\Delta \ln EX_{jt} = \alpha_{1j} + \beta YEAR_t + \gamma_{1i} \sum_{i=1}^{i=k} \Delta \ln EX_{jt-i} + \delta_{1i} \sum_{i=1}^{i=k} \Delta \ln FDI_{jt-i} + \lambda_{1j} e_{1jt-1} + u_{1jt} \quad (3)$$

$$\Delta \ln FDI_{jt} = \alpha_{2j} + \beta YEAR_t + \gamma_{2i} \sum_{i=1}^{i=k} \Delta \ln EX_{jt-i} + \delta_{2i} \sum_{i=1}^{i=k} \Delta \ln FDI_{jt-i} + \lambda_{2j} e_{2jt-1} + u_{2jt} \quad (4)$$

where Δ is a difference operator; j signifies the country, t the time period and k is the lag length, (taking into account the relatively short time period covered by the data we shall assume that k = 1 in the analysis that follows). e_{jt-1} is the lagged error-correction term derived from the long-run cointegrating relationship; coefficients a_j, β, γ_i, δ_i and λ are parameters to be estimated. The error correction term e_{jt-1} corresponds to the residual u_{jt} from the long run relationship in equation (1)

There are several parameters of interest in the error correction model
Testing for long run causality involves testing whether $\lambda = \delta_i = 0$.
λ is long-run effect of innovations in FDI on EX.
δ_i is short-run Granger causality from FDI on EX
For long-run Granger causality, hypotheses are:
FDI to EX

$$H_0 : \lambda_{1j} = 0 \quad \forall j$$

$$H_1 : \lambda_{1j} \neq 0 \quad for \ \ at \ \ least \ \ 1 \ \ j$$

EX to FDI

$$H_0 : \lambda_{2j} = 0 \quad \forall j$$

$$H_1 : \lambda_{2j} \neq 0 \quad for \ \ at \ \ least \ \ 1 \ \ j$$

For short-run Granger causality, hypotheses are:
FDI to EX

$$H_0 : \delta_{1i} = 0 \quad \forall j, k$$

$$H_1 : \delta_{1i} \neq 0 \quad for \ \ at \ \ least \ \ 1 \ \ j, k$$

EX to FDI

$$H_0 : \delta_{2i} = 0 \quad \forall j, k$$

$$H_1 : \delta_{2i} \neq 0 \quad for \ \ at \ \ least \ \ 1 \ \ j, k$$

Table 4. Panel Causality Tests

Short-run		**Long-run**	
H_0:No causality	**F**	**H_0:No causality**	**t-stat**
FDI to EX (δ_{1i})	4.475 (0.001)***	FDI to EX (λ_{1j})	-2.374 (0.018)**
EX to FDI (δ_{2i})	10.956 (0.000)***	EX to FDI (λ_{2j})	-4.376 (0.000)***

Note:
The number inside the parenthesis represents p-value

***, ** and * denote significance at 1%, 5% and 10% level respectively.

As it is obvious from table 4, the coefficients λ_{1j} and λ_{2j} of e_{1jt-1} and e_{2jt-1} in equations (3) and (4) are significant. So, there is a long-run Granger causality running from exports to Foreign Direct Investment (FDI) but also from Foreign Direct Investment (FDI) to exports (bilateral long run causal relationship). Also, coefficients δ_{1i} and δ_{2i} on equations (3) and (4) are significant. This means that there is also a short-run bilateral causal relationship between the examined variables. Consequently, we can see that there is a bilateral causal relationship both in the short and long run for exports and Foreign Direct Investment (FDI) for the examined countries.

6. Conclusions

The purpose of this study was to test for panel Granger causality between export and FDI for twelve new EU countries during the period 1995-2010. The concept of heterogeneous panels Granger causality is introduced where the null hypothesis is that there is no causal relationship in any panel against the alternative where there is causality in at least one time series. Afterwards, cointegration test by Pedroni (1999) present a cointegrated vector in exports' equation showing a long run heterogeneous relationship. Furthermore, the paper generates consistent estimates by employing the Pedroni FMOLS procedure and finds that Foreign Direct Investment has a positive and significant effect on exports in the long-run. Finally, the paper presents a bilateral causal relationship both in the long and short run level.

One main conclusion of this study is that exports and Foreign Direct Investment (FDI) are two important factors for the economic development of the twelve new countries of EU. The steady growth of exports and Foreign Direct Investment (FDI) on these countries of EU can be achieved by adopting a policy with the most suitable economic reforms. Currency devaluation for the countries not joining the Euro zone yet is a first step. The second step is the attraction of FDI. These two important steps adopt a steady basis for a rapid increase of exports leading to new investments. Export-push, Foreign Direct Investment (FDI) and a stable exchange rate are three important elements of openness which can create a favourable external environment for high and sustainable output growth.

References

Andersen, P. S. and Hainaut, P. (1998). Foreign Direct Investment and Employment in the Industrial Countries', Bank for International Settlements Working Paper, 61.

Chiappini, P. (2011). FDI and trade: A Granger causality analysis in a heterogeneous panel, *Economics Bulletin*, 31(4), pp. 2975-2985.

Clausing, K. A. (2000). Does Multinational Activity Displace Trade, *Economic Inquiry*, 38(2), pp. 190-205.

Dritsaki, M. and Dritsaki, C. (2012). A Panel Data Approach to the Demand for Money in the Bulgaria and Romania, Applied Economics Letters, 19(8), pp. 705-710.

Eaton, J. and Tamura, A. (1994). Bilateralism and Regionalism in Japanese and US Trade and Direct Foreign Investment Patterns', NBER Working Paper, No. 4758, Cambridge, MA.

Engle, R.F., and Granger C. W.J. (1987). Cointegration Error Correction: Representation, Estimation and Testing, *Econometrica*, 2, pp. 251-276.

Falk, M. and Hake, M. (2008). A Panel Data Analysis on FDI and Exports, Austrian Institute of Economic Research (WIFO).

Granger, C. W.J. (1969). Investigating Causal Relations by Econometric Models and Cross-Spectral Methods. *Econometrica*, 37(3), pp. 424-438.

Helpman, E. (1984). A simple theory of international trade with multinational corporations, *Journal of Political Economy*, 92(3), pp. 451-471.

Hurlin, C. and Venet, B. (2001). Granger Causality Tests in Panel Data Models with Fixed Coefficients. Working Paper Eurisco 2001-09, University of Paris Dauphine.

Im, K.S., Pesaran, M.H. and Shin, Y. (2003). Testing for unit roots in heterogeneous panels, *Journal of Econometrics* 115(1), pp. 53-74.

Levin, A., Lin, C.F. and Chu, C.S.J. (2002). Unit root test in panel data: Asymptotic and finite sample properties, *Journal of Econometrics*, 108(1), pp. 1-24.

Lin, A. (1995). Trade effects of foreign direct investment: Evidence for Taiwan with four ASEAN countries, *Weltwirtschaftliches Archiv* 131, pp. 737-747.

Maddala, G.S. and Wu, S. (1999). A comparative study of unit root tests with panel data and a new simple test, *Oxford Bulletin of Economics and Statistics*, 61, pp. 631-652.

Markusen, J. R. (1984). Multinationals, multiplant economies and the gains from trade, *Journal of International Economics*, 16(3-4), pp. 205-226.

Mundell, R. (1957). International trade and factor mobility, *American Economic Review*, 47, pp. 321-335.

Pedroni, P. (1999). Critical values for cointegration tests in heterogeneous panels with multiple regressors, *Oxford Bulletin of Economics and Statistics* (Special Issue), pp. 653– 669.

Pedroni, P. (2000). Fully modified OLS for heterogeneous cointegrated panels *Advances in Econometrics*, 15, pp. 93–130.

Pedroni, P. (2001). Purchasing power parity tests in cointegrated panels, *Review of Economics and Statistics*, 83, pp. 727–731.

Pedroni, P. (2004). Panel cointegration: Asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. *Econometric Theory*, 20, pp. 597–625.

Pfaffermayr, M. (1996). Foreign outward direct investment and exports in Austrian manufacturing: Substitutes or complements?, *Weltwirtschaftliches Archiv* 132, pp. 501-522.

Phillips, P.C.B. and Sul, D. (2003). Dynamic panel estimation and homogeneity testing under cross section dependence, *Econometrics Journal*, 6(1), pp. 217-259.

Ramirez, M.D. (2006). A Panel Unit Root and Panel Cointegration Test of the Complementarity Hypothesis in the Mexican Case, 1960-2001, Economic Growth Center Yale University, Center Discussion Paper, No. 942.

Schmitz, A. and Helmberger, P. (1970). Factor mobility and international trade: the case of complementarity, *American Economic Review*, 60, pp. 761-767.

Türkan, K. (2006). Foreign Outward Direct Investment and Intermediate Goods Exports: Evidence from USA, Paper presented on the ETSG 2006, http://www.etsg.org/ETSG2006/papers/Turkcan.pdf

Yao, S. (2006). On economic growth, FDI and exports in China, *Applied Economics*, 38, pp. 339–351.

Appendix 1: Pedroni Panel Cointegration Test: Various Test Statistics

1. Panel v-statistic

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

2. Panel ρ-statistic

$$T\sqrt{N} Z_{\hat{\rho}N,T} \equiv T\sqrt{N} \left(\sum_{i=1}^{N} \sum_{t=1}^{T} \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^{2} \right)^{-1} \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{L}_{11i}^{-2} \left(\hat{e}_{i,t-1} \Delta \hat{e}_{i,t} - \hat{\lambda}_i \right)$$

3. Panel t-statistic (non-parametric)

$$Z_{tN,T} \equiv \left(\tilde{\sigma}_{N,T}^{2} \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^{2} \right)^{-1/2} \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{L}_{11i}^{-2} \left(\hat{e}_{i,t-1} \Delta \hat{e}_{i,t} - \hat{\lambda}_i \right)$$

4. Panel t-statistic (parametric)

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

5. Group ρ-statistic

$$TN^{-1/2} \tilde{Z}_{\tilde{\rho}N,T-1} \equiv TN^{-1/2} \sum_{i=1}^{N} \left(\sum_{t=1}^{T} \hat{e}_{i,t-1}^{2} \right)^{-1} \sum_{t=1}^{T} \left(\hat{e}_{i,t-1} \Delta \hat{e}_{i,t} - \hat{\lambda}_i \right)$$

6. Group t-statistic (non-parametric)

$$N^{-1/2} \tilde{Z}_{tN,T-1} \equiv N^{-1/2} \sum_{i=1}^{N} \left(\hat{\sigma}_i^{2} \sum_{t=1}^{T} \hat{e}_{i,t-1}^{2} \right)^{-1/2} \sum_{t=1}^{T} \left(\hat{e}_{i,t-1} \Delta \hat{e}_{i,t} - \hat{\lambda}_i \right)$$

7. Group t-statistic (parametric)

$$N^{-1/2} \tilde{Z}_{tN,T}^{*} \equiv N^{-1/2} \sum_{i=1}^{N} \left(\sum_{t=1}^{T} \hat{S}_i^{*2} \hat{e}_{i,t-1}^{*2} \right)^{-1/2} \sum_{t=1}^{T} \left(\hat{e}_{i,t-1}^{*} \Delta \hat{e}_{i,t}^{*} \right)$$

Appendix 2: Fully Modified Ordinary Least Squares (FMOLS)

Consider a panel cointegration framework as:

$Y_{it} = \alpha_{it} + \beta X_{it} + \varepsilon_{it}$

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

$Z_{it} = (Y_{it,} X_{it})' \sim I(1)$ and

$\varpi = (\varepsilon_{i,t}, \mu_{i,t})' \sim I(0)$ with long run covariance matrix

$\Omega_i = L_i L_i' . L_i$ is the lower triangular decomposition of Ω_i which can be decomposed

as $\Omega_i = \Omega_i^0 + \Gamma_i + \Gamma_i'$

where

Ω_i^0 is the contemporaneous covariance and

Γ_i is a weighted sum of autocovariances.

The panel FMOLS estimator for the β is:

$$\beta_{NT}^* = N^{-1} \sum_{i=1}^{N} \left(\sum_{t-1}^{T} (X_{it} - \overline{X}_i)^2 \right)^{-1} \left(\sum_{t=1}^{T} (X_{it} - \overline{X}_i) Y_{it}^* - T\widehat{\tau}_i \right)$$

where

$$Y_{it}^* = (Y_{it} - \overline{Y}_i) - \frac{\widehat{L}_{21i}}{\widehat{L}_{22i}} \Delta X_{it} \quad and \quad \widehat{\tau}_i = \widehat{\Gamma}_{21i} + \widehat{\Omega}_{21i}^0 - \frac{\widehat{L}_{21i}}{\widehat{L}_{22i}} (\widehat{\Gamma}_{22i} + \widehat{\Omega}_{22i}^0)$$