2. DOES INCOME CONVERGE AMONG EU MEMBER COUNTRIES FOLLOWING THE POST-WAR PERIOD? EVIDENCE FROM THE PANKPSS TEST

Burcu OZCAN[1]

Abstract

In this study, we examine both stochastic and deterministic convergence in the logarithm of the relative per capita income of eighteen EU countries. The panel stationary test developed by Carrion-i Silvestre et al. (2005) is employed over the period 1950-2010. The univariate results attained from the stochastic convergence test provide that convergence does hold for sixteen countries except for Bulgaria and Ireland. In addition, the findings of the deterministic convergence test render the evidence favourable to convergence in sixteen EU countries as well, except for Austria and Greece. In other words, the individual results from panel stationarity tests are mostly in support of income convergence among EU members. Furthermore, both types of convergence appear to hold for the entire EU panel set. Therefore, shocks to relative per capita income levels of EU countries appear to be temporary.

Keywords: catch-up, stochastic convergence, deterministic convergence, structural breaks, panel stationarity test

JEL Classification: C23, O40, O47, R11

1. Introduction

Economic convergence is of great interest in growth theory and development economics. In other words, the long-term trend in relative regional income levels is an important issue in assessing regional economic performance (Carlino and Mills, 1996). Therefore, testing for convergence within regions in a country and between international economies has led to a surge of interest and debate (Fleissig and Strauss, 2001). If growth rates in per capita income across different countries converge over time, poor countries have a tendency to grow faster than rich ones and ultimately catch up with them. Therefore, as stated by Carrion-i Silvestre and German-

[1] Firat University, Faculty Of Economics And Administrative Sciences, Department Of Economics, 23200, Elazig, Turkey. Email: bozcan@firat.edu.tr

Soto (2007), economic growth differentials between countries have been tackled from different perspectives and extensively discussed in the economic literature for both developed and developing countries. Regarding the definition of convergence, many proposals have been made by scholars in the literature. For instance, Michelis *et al.* (2004) assert that *"convergence of two or more economic series, such as per capita output in different regions, is said to occur if the difference between the series becomes arbitrarily small or tends to some constant as time elapses."* In addition, Drennan *et al.* (2004) suggest that *"income convergence means that income growth will tend to be slower in areas with higher than average income and faster in areas with lower than average income."* In other words, convergence occurs when countries with relatively low initial levels of income grow faster than countries with relatively high initial levels of income.

There are two competing approaches in the growth literature: the neo-classical growth model and the endogenous growth model. The neo-classical growth model predicts economic convergence, whereas the endogenous growth model rejects it. The income convergence hypothesis is based on the original neo-classical growth model proposed by Solow (1956). Solow (1956) indicates that countries should converge to a balanced growth path, where poorer countries grow faster than richer ones. Countries with more capital per worker have a lower return on capital than other countries. This situation leads to an incentive for capital to flow from richer countries to poorer ones (Holmes, 2002). Convergence appears to be a natural result of exogenous technical change, which migrates across countries with similar preferences and technology (Michelis *et al.*, 2004). In other words, the Solow (1956) growth model assumes that economies will converge absolutely to the same per capita income level in the long-run steady-state due to identical saving rates, population growth, and technology. In addition, as stated by Strazicich *et al.* (2004), the Solow model predicts that incomes will ''converge conditionally'' to their own steady state or ''compensating differential'' due to persistent heterogeneous characteristics among countries.

Contrary to the neo-classical growth model, the new endogenous growth literature derived from the seminal studies of Romer (1986, 1990) and Lucas (1988) suggests that positive externalities associated with inputs such as technology and education may lead to increasing returns to scale and thus prevent any tendency towards convergence. The endogenous growth literature implies that richer countries may grow at a faster rate because they are able to allocate more resources to research and development (Holmes, 2002). As a result, convergence does not hold.

Early empirical studies in the convergence literature employed cross-country regressions. This strand of research includes the seminal studies of Baumol (1986), Barro (1991), Barro and Sala-i-Martin (1992), and Mankiw *et al.* (1992). In these studies, average per capita output growth rates are regressed on initial output levels. A negative correlation between the average growth rate and initial output provides evidence of convergence. However, over time, cross-country growth regressions have been criticised. For instance, based on Galton's fallacy, Friedman (1992) and Quah (1993, 1996) criticised cross-country growth regressions and suggested the use of time-series properties of the cross-country variances. In a similar fashion, Bernard and Durlauf (1995, 1996) asserted that cross-section growth regressions cannot discriminate between the hypotheses of global or local convergence and proposed a stronger alternative, called the time-series approach. They also showed that cross-section tests tend to spuriously reject the null of no convergence when economies have different long-run steady states. In addition, Evans and Karras (1996) suggested that the cross-sectional approach leads to incorrect inferences due to inconsistent convergence rate estimates. Therefore, they proposed the notion of time series convergence.

There are three notions of convergence mentioned in the literature. The first type, β convergence, was introduced by Baumol (1986) and Barro and Sala-i-Martin (1991, 1992). Indicating that poorer economies grow faster than richer ones, this type of convergence is examined by using cross-sectional Barro-Baumol growth regressions in which average per capita output growth rates are regressed on initial income levels for a range of economies (Cook, 2008). A negative coefficient of initial income level provides evidence of β convergence. The second type, σ (sigma) convergence, implies that the variation of income among countries has a diminishing tendency over time (Quah, 1993). This type is measured by the standard deviation of per capita income for countries over time. A persistent decline in the annual standard deviations provides evidence in support of sigma convergence (Drennan *et al.*, 2004). The last type, stochastic convergence, requires that the log per capita income of a country relative to the average income of a group of countries follows a trend stationary process (Costantini and Sen, 2012).

The convergence types mentioned above have two versions: absolute and conditional convergence. In the case of absolute convergence, economies are assumed to have the same steady-state levels, and the only difference across countries is attributed to their initial levels of capital. In this case, poor economies grow faster because they are further away from their steady-state levels. However, as stated by Galvão Jr and Gomes (2007), in the conditional convergence case, the assumption that all economies have the same parameters and institutions, and thus, the same steady-state positions are ignored. Therefore, economies are convergent only after their steady-state levels are controlled for. For instance, absolute (unconditional) β convergence is tested by a cross-section regression in which the growth rate of per capita income over a long period is regressed on the initial per capita level. As stated previously, a negative and significant coefficient represents evidence of convergence. However, in the case of conditional β convergence, initial values, which may not be in equilibrium, may differ among countries because of differences in skills and the industry mix (Drennan *et al.*, 2004). Therefore, a test of conditional β convergence includes other variables that change across countries, such as population growth, the capital depreciation rate, and technological progress. Regarding stochastic convergence, the absolute version is tested by unit root tests without fixed individual effects, whereas the conditional version is tested by implementing unit root tests with fixed individual effects (Charles *et al.*, 2012).

In this study, we aim to test for both stochastic and deterministic convergence types for eighteen EU countries by employing the panel stationarity test (PANKPSS) developed by Carrion-i Silvestre *et al.* (2005). Our contributions to the literature are two-fold. First, to our knowledge, there are no studies applying Carrion-i Silvestre *et* *al.*'s (2005) test in analysing income convergence in EU countries. Additionally, there are only two studies applying the PANKPSS test while testing for income convergence. First, Carrion-i Silvestre and German Soto (2009) employed the PANKPSS test for Mexican federal entities. Second, Elmi and Ranjbar (2012) used this test for selected Organisation of the Islamic Conference (OIC) countries. Our second contribution is the testing of both types of convergence, namely, deterministic and stochastic. Studies in the related literature generally consider stochastic convergence.

The rest of the paper is organised as follows. Section 2 includes a brief literature review. In Section 3, we present the data and methodology. In Section 4, empirical results are reported, and in Section 5, we conclude the study and suggest some policy implications.

2. Literature Review

Studies generally employ regression analyses or unit root tests to search for the validity of different versions of convergence mentioned previously. Earlier studies in the literature were based extensively on the application of econometric models using cross-sectional data to test for the β convergence. This strand includes the seminal studies of Baumol (1986), Barro (1991), Barro and Sala-i-Martin (1991, 1992), Mankiw *et al.* (1992), and Sala-i Martin (1996), among others. In particular, income convergence has been a debated topic in the economics discipline since the studies of Barro (1991) and Barro and Sala-i-Martin (1991, 1992). Among these scholars, Baumol (1986) found evidence of β convergence in a sample of 16 developed countries, whereas Barro and Sala-i Martin (1992), using the neo-classical growth model, tested income convergence across 48 contiguous US states over various periods from 1840 to 1988 and found evidence of convergence. In another study, using the Solow growth model, Mankiw *et al.* (1992) investigated income convergence for a cross-section of countries. They found that convergence among countries is possible when population growth and capital accumulation are held constant. Finally, Sala-i-Martin (1996) examined σ convergence and β convergence across a large sample of countries consisting of the United States, Japan, and five European nations. The results provided strong evidence for both convergence types.

Over time, the time series notion of convergence evolved. Following its introduction, the notion of stochastic convergence has been a popular issue debated in the empirical literature thanks to the seminal study of Carlino and Mills (1993) for US states. In this strand, studies employing univariate unit root tests with breaks generally obtained results in support of convergence. See, among others, Li and Papell (1999) for 16 OECD countries, Loewy and Papell (1996) for the 7 regions of the US, Cellini and Scorcu (2000) for G7 countries, Vogelsang and Tomljanovich (2002) for a sample of US states, Strazicich *et al.* (2004) for 15 OECD countries, Brüggemann and Trenkler (2005) for the Czech Republic, Hungary, and Poland, DeJuan and Tomljanovich (2005) for a sample of Canadian provinces, Galvao Jr and Gomes (2007) for 19 Latin American countries, Carrion-i Silvestre and German Soto (2007) for Mexican states, Dawson and Sen (2007) for 19 countries, Dawson and Strazicich (2010) for 29 OECD and non-OECD countries, and Escobari (2011) for 19 Latin American countries. However, some time series studies have obtained little or no evidence of convergence. For instance, Carlino and Mills (1993) found evidence of convergence for only three regions of the US, and studies obtaining little or no evidence of convergence include Bernard and Durlauf (1995) on a sample of 15 OECD countries, Cunado (2011) on OPEC countries, Lim and McAleer (2004) on ASEAN-5 countries, and Costantini and Sen (2012) on a sample of 29 countries.

Some of the studies mentioned above also tested σ and β convergence types in addition to stochastic convergence. For instance, Carlino and Mills (1993), Michelis *et al.* (2004), Drennan *et al.* (2004), DeJuan and Tomljanovich (2005), Galvao Jr and Gomes (2007), and Dawson and Sen (2007).

In another research strand, stochastic convergence is tested via panel unit root tests. As in the time series approach, studies applying panel unit root tests with breaks generally obtain evidence of stochastic convergence. This strand includes studies by Evans and Karras (1996) for the 48 contiguous US states, Fleissig and Strauss (2001) for the OECD and a European subsample, Cheung and Pascual (2004) for G7 countries, Guetat and Serranito (2007) for MENA countries, Lima and Resende (2007) for Brazilian states, Reza and Zahra (2008) for 10 new members of the European Union, Carrion-i Silvestre and German Soto (2009) for Mexican federal entities, Aslan and Kula (2011) for Turkish provinces, Wang (2012) for ASEAN countries, Lin *et al.* (2013) for 28 Chinese provinces. Most of these studies obtained evidence in support of convergence. However, among them, some studies attained little or no evidence of income convergence. Example studies include those by Charles *et al.* (2012) on the Common Market for Eastern and Southern Africa (COMESA), Elmi and Ranjbar (2012) on the selected Organisation of the Islamic Conference (OIC) countries, Costantini and Arbia (2006) on Italian regions, McCoskey (2002) on Sub-Saharan African countries, Lima and Resende (2007) for Brazilian states, and Holmes (2002) on OECD countries, with the last applying the SURADAF test developed by Breuer *et al.* (2002).

The last research strand includes studies applying non-linear unit root tests in the framework of panel data or time series data. For instance, Lau (2010a) obtained results supporting convergence for the continental US. In another study, Lau (2010b) found that divergence does hold for the provinces of China. Liew and Lim (2005) found that China, Indonesia, Malaysia, Thailand and the Philippines exhibit divergence, whereas Hong Kong, Korea, Taiwan and Singapore show convergence. In addition, Christopoulos and Tsionas (2007) obtained overwhelming evidence of convergence among US regions, whereas Tunali and Yilanci (2010) obtained evidence of divergence for 19 MENA countries. Finally, Kalita and Tiwari (2012) found evidence against convergence among Indian states.

3. Data and Methodology

We use per capita GDP data from Maddison's (2010) database for the following eighteen EU countries over the period 1950-2010: Austria, Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Sweden, UK, Bulgaria, Greece, Hungary, Ireland, Poland, Portugal, Romania, and Spain. Our time period and sample are dictated by data availability.

We test for not only stochastic convergence but also deterministic convergence based on the studies of Li and Papell (1999) and Romero-Avila (2008). Li and Papell (1999) suggested two convergence types. The first is stochastic convergence, a weaker definition of convergence in the time-series context, proposed by Carlino and Mills (1993). This type assumes convergence if the log of relative output is trend stationary. In other words, according to Carlino and Mills (1993), stochastic convergence is valid when the per capita income of one region relative to that of the economy as a whole is stationary. However, deterministic convergence predicts convergence if the log of relative output is level stationary and thus requires the elimination of the deterministic and stochastic trend (Li and Papell, 1999).

A common test for stochastic and deterministic convergence is a unit root testing procedure in the log of relative per capita income. A unit root in the log of relative per capita income would imply that shocks to the income series have permanent effects, thus making the series diverge from the sample mean. However, stationarity in the log of relative income indicates that shocks exert only temporary effects. Therefore, each country's per capita GDP series converges stochastically or deterministically towards the sample average.

In addition, we follow Carlino and Mills (1993) in designing a precise examination indicator in the unit root testing procedure. We thus need to compute the log of the ratio of per capita income relative to the average per capita income levels for the sample of 18 EU countries. We obtain the following relative income variable for the unit root testing procedure. $y_{it} = \ln(Y_{it} / \bar{y}_t)$, where Y_{it} represents per capita GDP, and $\bar{y}_t$ is the yearly sample average per capita GDP level, whereas $i = 1,...,N$ and $t = 1,...,T$ denote the number of countries and time periods, respectively. In this study, N equals 18, and T equals 61.

Based on the above explanations, we search for a unit root in y_{it} series.

3.1. Panel Stationarity Test of Carrion-i Silvestre et al. (2005)

In general, due to the low power of univariate unit root tests, the rejection of the null hypothesis of no convergence fails. Therefore, panel unit root tests are employed to test for convergence in recent studies. Panel data allow us to use information from both cross-section and time series dimensions of the data. Furthermore, as stated by Romero-Avila (2008), we are able to control conditional convergence through the inclusion of country-specific effects that proxy for time-invariant compensating differentials among economies due to panel data. In addition, allowing for structural breaks in the unit root testing procedure is crucial. As stated by Li and Papell (1999), it is important to develop an economic framework that incorporates structural breaks in the deterministic component of the trend function. Otherwise, ignoring structural breaks may lead to a bias towards the acceptance of no convergence and to an erroneous interpretation of output movements.

Based on the above explanations, we seek the validity of stochastic and deterministic convergence types by allowing for breaks in the panel data framework. For this purpose, we employ the panel stationarity (PANKPSS) test developed by Carrion-i Silvestre *et al.* (CBL hereafter, 2005).

CBL (2005) suggest a panel stationarity test, which is the panel extension of the time series KPSS (Kwiatkowski *et al.*, 1992) test. It considers several structural breaks in the level and/or the slope of the individual time series. Furthermore, cross-sectional dependence is allowed for. In this case, under the null hypothesis of stationarity, the data-generating process (DGP) for the variable is as

$$y_{it} = \alpha_i + \sum_{k=1}^{m_i} \theta_{i,k} DU_{i,k,t} + \beta_i t + \sum_{k=1}^{m_i} \gamma_{i,k} DT^{*}_{i,k,t} + \varepsilon_{i,t} \tag{1}$$

where: y_{it} is the log of relative per capita GDP, α_i represents country-specific time invariant compensating differentials allowing for conditional convergence.

ε_{it} is assumed to be stationary. $DT^{*}{}_{i,k,t}$ and $DU_{i,k,t}$ denote the dummy variables for the changes in slope and level, respectively, and are defined as follows: $DT^{*}{}_{i,k,t} = t - T^{i}_{b,k}$ for $t \succ T^{i}_{b,k}$ and 0 elsewhere, with $T^{i}_{b,k}$ denoting the kth break location for the ith individual, for $k = 1,........, m_i$, $m_i \geq 1$, and $i = 1,..., N$. $DU_{i,k,t} = 1$ for $t \succ T^{i}_{b,k}$ and 0 otherwise. $\beta_i t$ denotes country-specific linear time trends.

The specification in equation (1) is general enough to allow for structural breaks to have different effects (effects are measured by $\theta_{i,k}$ and $\gamma_{i,k}$) on each individual time series and to be located at different dates, as the dates of breaks are not restricted to satisfy $T^{i}_{b,k} = T_{b,k} \quad \forall i \in \{1,..., N\}$. Furthermore, a different number of structural breaks are allowed for each individual. In other words, $m_i \neq m_j$, $\forall i \neq j, \quad i, j \in \{1,..., T\}$.

To test the deterministic convergence, we exclude from equation (1) both country-specific time trends and slope shifts, leading to the obtaining of the following equation (2).

$$y_{it} = \alpha_i + \sum_{k=1}^{m_i} \theta_{i,k} DU_{i,k,t} + \varepsilon_{i,t} \tag{2}$$

In equations (1) and (2), rejection of the null hypothesis renders evidence against convergence for at least one country, whereas non-rejection of the null hypothesis provides evidence in support of stochastic or deterministic convergence for the entire panel set. The test of the panel stationarity null hypothesis follows Hadri's (2000) test statistic, which is simply the average of the univariate stationarity test of KPSS. The $LM(\lambda)$ test statistic has the following general expression:

$$LM(\lambda) = N^{-1}\sum_{i=1}^{N}\left(\hat{\omega}_i^{-2}T^{-2}\sum_{t=1}^{T}S_{i,t}^2\right) \quad (3)$$

where: $S_{i,t} = \sum_{j=1}^{t}\hat{\varepsilon}_{i,j}$ represents the partial sum process that is obtained with the estimated OLS residuals of equation (1).

An autocorrelation- and heteroskedasticity-consistent estimate of the long-run variance of $\varepsilon_{i,t}$ is represented by $\hat{\omega}_i^2$. In this case, equation (3) allows for heterogeneity in the estimation of long-run variances across individuals. However, homogeneity may also be imposed according to CBL (2005). The test is dependent on the location of breaks, which are represented by λ. For each individual i, each break is expressed as the vector $\lambda_i = (\lambda_{i,1},.........,\lambda_{i,m_i})' = (T_{b,1}^i / T,................,T_{b,m_i}^i / T)'$, which indicates the location of the breaks relative to the entire time period, T. The normalised test statistic under the null hypothesis of panel stationarity is expressed as

$$Z(\lambda) = \frac{\sqrt{N}(LM(\lambda) - \bar{\xi})}{\bar{\zeta}} \rightarrow N(0,1) \quad (4)$$

where: $\bar{\xi}$ and $\bar{\zeta}$ are the arithmetic averages of expected values and variances, respectively, for each cross-sectional unit.

In addition, the limited distribution of the $Z(\lambda)$ test is standard normal. Therefore, computing a new set of critical values is not necessary. However, the computations of the Z(λ) statistic require the cross-sectionally independent individual series along with asymptotic normality. When we tested for cross-sectional dependence in this study, we obtained results against the independence. We thus computed the bootstrap distribution of the panel stationarity test to control for cross-sectional dependence and finite sample-bias. To that end, Maddala and Wu's (1999) bootstrap procedure was used.

In addition, the PANKPSS test follows the procedure outlined by Bai and Perron (1998) that computes the global minimisation of the sum of squared residuals (SSR) as an estimation of the number of structural breaks and their position. Once the dates for all possible $m_i \leq m^{\max}$ for each i are estimated, the suitable number of structural breaks is obtained via Bai and Perron's (1998) procedures. The first procedure depends on the use of the Bayesian information criterion (BIC) and the modified Schwarz information criterion (LWZ) of Liu *et al.* (1997). The second procedure is based on the sequential computation of structural breaks with the application of *pseudo* F-type test statistics. In this study, based on the suggestion of Bai and Perron (1998), we used the sequential procedure when the model under the panel stationarity null hypothesis does not include trending regressors. However, in the presence of trending regressors, we applied the LWZ information criterion, given Bai and Perron's (1998) suggestion that the LWZ criterion performs better than the BIC criterion.

3.2. Cross-sectional Dependence Test

We used Breusch and Pagan's (1980) and Pesaran's (2004) LM tests to analyse cross-sectional dependence. Breusch and Pagan's (1980) LM test is based on the average of the squared pair-wise correlation of residuals and LM statistic (CD_{LM1}) and is constructed as

$$CD_{LM1} = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij} \tag{5}$$

where: $\hat{\rho}_{ij}$ denotes the sample estimate of the cross-sectional correlation among residuals.

With the null hypothesis of cross-sectional independence, the $CDLM_1$ statistic is distributed as χ^2 with N (N-1)/2 degrees of freedom for fixed N and $T \to \infty$.

Apart from the $CDLM_1$ test statistic, in the case of large N and T, the following CD_{LM2} statistic, which is asymptotically distributed as standard normal under the null of no cross-sectional dependence, was developed by Pesaran (2004):

$$CD_{LM2} = \sqrt{\frac{1}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}(T\hat{\rho}_{ij} - 1) \tag{6}$$

Due to the problem of size distortions, it is not appropriate to use the CD_{LM2} statistic when N is large relative to T, as suggested by Pesaran (2004). In this case, a new cross-sectional dependence test, namely, the CD test, was suggested by Pesaran (2004). This test is based on the sum of the coefficients of correlation among cross-sectional residuals, with the CD test statistic identified as follows:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}\right) \tag{7}$$

The CD test is distributed as standard normal for N and T tending to infinity in any order with the null hypothesis of no cross-sectional dependence. The results of these tests are reported in the following sub-section.

4. Empirical Results

Table 1

The Results of Cross-Sectional Dependence Test

	Intercept		Intercept and Trend	
	Test statistics	probability	Test statistics	probability
$CDLM_1$	294.730	0.000	316.052	0.000
$CDLM_2$	8.102	0.000	9.321	0.000
CD	-4.988	0.000	-4.893	0.000

As shown in Table 1, all cross-sectional dependence tests reject the null hypothesis of cross-sectional independence under both intercept and intercept and trend cases.[2] Therefore, we must consider cross-sectional dependence via the bootstrap procedure. Tables 2 and 3 provide the results of stochastic and deterministic convergence tests.

Table 2

The Results of Panel KPSS Stationarity Test (Stochastic Convergence)

Panel a: The dates of structural breaks and the results of individual KPSS tests										
Countries	KPSS	m	Tb,1	Tb,2	Tb,3	Tb,4	Tb,5	Critical values (%)		
								90	95	99
Austria	0.081	3	1958	1969	1990			0.117	0.147	0.212
Belgium	0.049	2	1961	1990				0.110	0.134	0.174
Denmark	0.038	3	1958	1981	1996			0.119	0.146	0.198
Finland	0.088	2	1979	1990				0.125	0.151	0.209
France	0.075	1	1990					0.131	0.15	0.186
Germany	0.030	3	1958	1975	1990			0.074	0.099	0.149
Italy	0.020	2	1970	1994				0.066	0.088	0.129
Netherlands	0.050	2	1989	2001				0.089	0.121	0.166
Sweden	0.023	2	1976	1992				0.133	0.158	0.203
UK	0.043	3	1970	1982	1998			0.088	0.116	0.167
Bulgaria	0.133 ^{c}	3	1967	1984	1996			0.115	0.147	0.203
Greece	0.060	3	1959	1971	2001			0.117	0.144	0.198
Hungary	0.031	2	1969	1990				0.120	0.147	0.206
Ireland	0.126 ^{c}	4	1958	1976	1985	2001		0.115	0.147	0.200
Poland	0.015	2	1973	1989				0.126	0.154	0.205
Portugal	0.021	5	1961	1974	1983	1992	2001	0.044	0.053	0.091
Romania	0.030	3	1980	1989	1998			0.119	0.145	0.198
Spain	0.058	4	1961	1978	1989	2001		0.116	0.142	0.191

Panel b: Panel stationarity (PANKPSS) Tests		
Model	Test statistics	Probability value *
LM (λ) (hom)	5.497	1.921
LM (λ) (het)	14.098	1.931

Panel c: Bootstrap critical values (%)								
Model	1	2.5	5	10	90	95	97.5	99
LM(λ) (hom)	2.209	2.659	3.136	3.660	8.746	9.675	10.606	11.975
LM(λ) (het)	5.112	5.886	6.731	7.979	19.127	20.936	22.347	24.459

Notes: * denotes asymptotic probability values. ^{a}, ^{b}, ^{c} indicate significance at the 1%, 5%, and 10% levels, respectively. m and Tb denote the number and dates of breaks, respectively. $m^{\max}$ is set at five. Break dates were obtained through the LWZ information criterion. hom and

[2] We also employed the bias-adjusted Lagrange Multiplier test (*adj LM)* of Pesaran *et al.* (2008) and obtained cross-sectional dependence result as in other tests.

het indicate that the test statistic was computed under the assumptions of homogeneity and heterogeneity of long-run variance, respectively. The finite sample critical values were obtained through Monte Carlo simulations with 20,000 replications.

As shown in Table 2, the individual KPSS test results indicate that stochastic convergence does hold for sixteen countries, except for Bulgaria and Ireland. For these sixteen countries, shocks to relative per capita income series appear to have only temporary effects. Log relative income levels in these sixteen countries are converging to the group average. However, for Bulgaria and Ireland, shocks to relative per capita income have permanent effects. For the entire panel, under the presence of cross-sectional dependence, stochastic convergence does hold at all significance levels (i.e., 1%, 5%, and 10% levels) under both assumptions of homogeneity and heterogeneity in long-run variance.[3] Concerning the break dates, the first break dates correspond to the late 1950s and early 1960s for 8 out of 18 countries, namely Austria, Belgium, Denmark, Germany, Greece, Ireland, Portugal, and Spain. In particular, it appears that the establishment of the European Economic Community and the European Atomic Energy Community in 1958 led to crucial effects on the log relative per capita income series of EU countries. With respect to the second and third break dates, aside from 1958, the first (1972-1973) and second oil crises (1978-1979), the fall of Berlin Wall in 1990, the collapse of communism in 1989 in Eastern Europe and, finally, the European currency crisis between 1992-1993 appear to be the main events creating significant breaks in the trend paths of relative per capita income series of EU countries. For instance, three break dates in Germany correspond to the establishment of the European Economic Community and the European Atomic Energy Community in 1958, the period after the first oil crisis, and the collapse of Berlin Wall in 1990, respectively.

Table 3

The Results of Panel KPSS Stationarity Test (Deterministic Convergence)

Panel a: The dates of structural breaks and the results of individual KPSS tests										
Countries	KPSS	m	Tb,1	Tb,2	Tb,3	Tb,4	Tb,5	Critical values (%)		
								90	95	99
Austria	0.174 *b*	3	1958	1976	1989			0.109	0.133	0.202
Belgium	0.065	3	1958	1989	2000			0.143	0.179	0.261
Denmark	0.052	4	1962	1972	1984	2001		0.141	0.157	0.198
Finland	0.069	2	1980	1997				0.097	0.125	0.195
France	0.090	1	2001					0.119	0.146	0.245
Germany	0.038	3	1958	1967	2001			0.158	0.194	0.279
Italy	0.038	5	1958	1967	1978	1987	2001	0.203	0.218	0.240
Netherlands	0.061	5	1960	1971	1980	1990	2001	0.126	0.134	0.154
Sweden	0.048	3	1958	1967	1976			0.163	0.207	0.297

[3] Asymptotic probability values cannot be used under the presence of cross-sectional dependence. Thus, we compared the tests statistics in Panel b to bootstrap critical values in Panel c.

Panel a: The dates of structural breaks and the results of individual KPSS tests										
Countries	KPSS	m	Tb,1	Tb,2	Tb,3	Tb,4	Tb,5	Critical values (%)		
								90	95	99
UK	0.073	3	1960	1969	1987			0.115	0.137	0.209
Bulgaria	0.060	3	1958	1989	2001			0.138	0.170	0.241
Greece	0.427 [a]	3	1960	1969	2001			0.149	0.194	0.261
Hungary	0.069	4	1969	1978	1990	2001		0.163	0.175	0.204
Ireland	0.048	3	1958	1989	1998			0.147	0.178	0.251
Poland	0.029	4	1961	1979	1988	1997		0.071	0.078	0.093
Portugal	0.045	4	1967	1979	1989	2001		0.189	0.207	0.241
Romania	0.063	1	1989					0.111	0.133	0.226
Spain	0.064	3	1962	1972	1989			0.108	0.128	0.201

Panel b: Panel stationarity (PANKPSS) tests		
Model	Test statistics	Probability value [*]
LM (λ) (hom)	0.255	0.399
LM (λ) (het)	3.059	0.001

Panel c: Bootstrap critical values (%)								
Model	1	2.5	5	10	90	95	97.5	99
LM (λ) (hom)	0.808	1.098	1.343	1.652	4.384	4.824	5.228	5.714
LM (λ) (het)	1.218	1.541	1.788	2.053	4.750	5.207	5.708	6.188

Notes: [*] denotes asymptotic probability values. [a], [b], [c] indicate significance at the 1%, 5%, and 10% levels, respectively. m and Tb denote the number and dates of breaks, respectively. $m^{\max}$ is set at five. Break dates were obtained through the sequential pseudo F-type test. hom and het indicate that the test statistic was computed under the assumptions of homogeneity and heterogeneity in long-run variance, respectively. The finite sample critical values were obtained through Monte Carlo simulations with 20,000 replications.

As seen in Table 3, deterministic income convergence does hold for sixteen countries, except for Austria and Greece. Convergence is valid for Austria at the 1% significance level, whereas it is rejected for Greece at all significance levels. Furthermore, for the entire panel set, under the existence of cross-sectional dependence, deterministic convergence does hold at the 10% significance level or better. In addition, most countries generally have three breaks. Concerning the break dates, the first break dates correspond to the late 1950s and early 1960s. In particular, as in the stochastic convergence case, the establishment of the European Economic Community and the European Atomic Energy Community in 1958 had significant impacts on the log relative per capita income levels of the EU countries under study. Regarding the second and third break dates, the first and second oil crises, the Merger Treaty that came into force in 1967, and the Single European Act in 1987 led to crucial shifts in the relative per capita income levels of EU countries.

5. Conclusion and Policy Implications

We tested for stochastic and deterministic convergence types among selected eighteen EU members following the post-war period. For this purpose, the PANKPSS test of CBL (2005) was employed. We thereby allowed for structural breaks and cross-sectional dependence in our testing procedure. We also included country-specific effects in the unit root testing procedure; therefore, conditional convergence was tested. The results generally supported both convergence types, namely stochastic conditional convergence and deterministic conditional convergence. For stochastic convergence, the results presented evidence favourable to divergence for only Bulgaria and Ireland. However, for the deterministic convergence case, divergence was attained for only Austria and Greece. In addition, stochastic and deterministic convergence held for the entire panel set under the assumption of heterogeneous as well as homogeneous long-run variance.

Our findings have important policy implications as well. The evidence of convergence suggests that the members of European Union have strong connections to each other through international trade, globalization, and financial links. Due to migration of capital, labor and knowledge among EU members, the major differences between their economic structures fall each day. In particular, the migration of capital from the most developed members to the least developed ones may lead to convergence as proposed by Solow (1956). In other words, there is a strong and fast technologic spillover among European Union along with the high degree of movement of production factors. Besides, the institutions of European Union, such as the European Central Bank, support all members and help them in case of necessity. All these factors lead to diminish in differences of their economic structures. Therefore, our result in favor of convergence is not an unexpected result. There are only four countries, i.e. Bulgaria and Ireland in the case of stochastic conditional convergence, and Austria and Greece in the case of deterministic convergence, diverging from the sample mean. Austria and Ireland diverge from the sample with upward trends, whereas Bulgaria and Greece diverge from the sample mean with downward trends. In particular, Greece has been severely affected from the last global economic crisis. In this context, as a policy tool, to catch up with other EU members, the governments of Greece and Bulgarian should design policies to increase per capita income level, such as tax benefit, and to decrease unemployment level. Besides, the monetary supports from the European Union's institutions may be a remedy for Greece and Bulgaria. As regards Austria and Ireland, the high level of per capita income appears to cause divergence. In this case, Austria and Ireland may help other members, e.g. via capital transfer by making more investment in other members of EU. Besides, economic shocks derived from macroeconomic policies will have permanent effects on relative real output levels of these four non-convergent markets. Policymakers need to design alternative macroeconomic policy tools to revert their per capita income levels to sample mean. Despite the small evidence of divergence, convergence does hold for the whole panel set. Thus, for the whole panel set and fourteen EU members; except for Austria, Ireland, Greece and Bulgaria, monetary, fiscal and technology shocks on relative per capita income levels will have transitory effects. Instruments of macroeconomic policy have only limited impacts on relative real output levels of these convergent markets. Based on these results, it could be asserted that a catching-up process is valid for the panel of EU countries under consideration.

Over all, it could be suggested that there is a certain harmony despite economic and financial diversity among EU countries (Reza and Zahra, 2008). In addition, shocks to relative per capita income series of EU members appear to be temporary. In other words, following a shock, income levels of EU countries converge to the average income of the group. Therefore, monetary and fiscal policy shocks to per capita real income do not permanently affect international income gaps, and economies move together in the long run (Fleissig and Strauss, 2001). Additionally, allowing for structural breaks and cross-sectional dependence in the framework of panel data unit root tests yields strong evidence of convergence among EU countries.

References

Aslan A. and Kula, F., 2011. Is there Really Divergence Across Turkish Provinces?. Evidence From the Lagrange Multiplier Unit Root Tests. *European Planning Studies*, 19(3), pp. 539-549.

Bai J. and Perron, P., 1998. Estimating and testing linear models with multiple structural changes. *Econometrica*, 66, pp. 47–78.

Barro, R.J., 1991. Economic growth in a cross-section of countries. *Quarterly Journal of Economics*, 106, pp. 407–43.

Barro, R. and Sala-i-Martin, X., 1991. Convergence across states and regions. *Brookings Papers on Economic Activity*, 1, pp. 107–82.

Barro, R.J. and Sala-i-Martin, X., 1992. Convergence. *Journal of Political Economy*, 100(2), pp. 223-251.

Baumol, W., 1986. Productivity growth, convergence and welfare: what the long-run data show. *American Economic Review*, 76, pp. 1075–1085.

Bernard, A. and Durlauf, S.N., 1995. Convergence in International Output. *Journal of Applied Econometrics*, 10(2), pp. 97-108.

Bernard, A.B. and Durlauf, S.N., 1996. Interpreting tests of the convergence hypothesis. *Journal of Econometrics,* 71 (1-2), pp. 161-173.

Breuer, B. McNown, R. and Wallace, M., 2002. Series specific unit root test with panel data. *Oxford Bulletin of Economics and Statistics*, 64, pp. 527-546.

Breusch, T. and Pagan, A., 1980. The Lagrange multiplier test and its application to model specifications in econometrics. *Reviews of Economics Studies*, 47, pp. 239–253.

Brüggemann, R. and Trenkler, C., 2005. Are *Eastern European Countries Catching Up? Time Series Evidence for Czech Republic, Hungary, and Poland*, SFB 649 Discussion Paper 2005-014, Humboldt University, Berlin.

Carlino, G. and Mills, L., 1993. Are US regional incomes converging?. *Journal of Monetary Economics*, 32(2), pp. 335–346.

Carlino, G. and Mills, C., 1996. Convergence and the US States: A Time-Series Analysis. *Journal of Regional Science*, 36(4), pp. 597-616.

Carrion-i-Silvestre, J.L., del Barrio, T. and López-Bazo, E., 2005. Breaking the panels. An application to the GDP per capita. *Econometrics Journal*, 8, pp. 159–175.

Carrion-i-Silvestre, J.L. and German-Soto, V., 2007. Stochastic Convergence amongst Mexican States. *Regional Studies*, 41(4), pp. 531-541.

Carrion-i-Silvestre, J.L. and German-Soto, V., 2009. Panel data stochastic convergence analysis of the Mexican regions. *Empirical Economics*, 37, pp. 303–327.

Cellini, R. and Scorcu, A. E., 2000. Segmented stochastic convergence across the G-7 countries. *Empirical Economics*, 25, pp. 463-474.

Charles, A., Darne, O., and Hoarau, J.F., 2012. Convergence of real per capita GDP within COMESA countries: A panel unit root evidence. *The Annals of Regional Science,* 49(1), pp. 53-71.

Cheung, Y.W. and Pascual, A.G., 2004. Testing for output convergence: a re-examination. *Oxford Economic Papers*, 56, pp. 45–63.

Christopoulos, D.K. and Tsionas, E.G., 2007. Are US regional incomes converging? A nonlinear perspective. *Regional Studies*, 41(04), pp.525-530.

Cook, S., 2008. An alternative perspective on the stochastic convergence of incomes in the United States. *Applied Economics Letters*, 15(12), pp. 929-934.

Costantini, M. and Arbia, G., 2006. Testing the stochastic convergence of Italian regions using panel data. Applied *Economics Letters*, 13(12), pp. 775-783.

Costantini, M. and Sen, A., 2012. New evidence on the convergence of international income from a group of 29 countries, *Applied Economics Letters*, 19(5), pp. 425-429.

Cunado, J., 2011. Structural Breaks and Real Convergence in OPEC Countries. *Journal of Applied Economics*, 14(1), pp.101-117.

Dawson, J.W. and Sen, A., 2007. New evidence on the convergence of international income from a group of 29 countries. *Empirical Economics*, 33(2), pp.199–230.

Dawson, J.W. and Strazicich, M.C., 2010. Time-series tests of income convergence with two structural breaks: evidence from 29 countries. *Applied Economics Letters*, 17(9), pp. 909-912.

DeJuan, J. and Tomljanovich, M., 2005. Income convergence across Canadian provinces in the 20th century: Almost but not quite there. *The Annals of Regional Science*, 39, pp. 567– 592.

Drennan, M.P., Lobo, J. and Strumsky, D., 2004. Unit root tests of sigma income convergence across US metropolitan areas. *Journal of Economic Geography*, 4(5), pp. 583-595.

Elmi, Z. and Ranjbar, O., 2012. Which OIC countries are catching up? Time Series Evidences with Multiple Structural Breaks. *Iranian Journal of Economic Studies,* 1(1), pp. 13-28.

Escobari, D., 2011. Testing for Stochastic and Beta-convergence in Latin American Countries. *Applied Econometrics and International Development*, 11(2), pp. 123-138.

Evans, P. and Karras, G., 1996. Do Economies Converge? Evidence from a Panel of U.S. States. *The Review of Economics and Statistics*, 78(3), pp. 384-388.

Fleissig, A. and Strauss, J., 2001. Panel Unit-Root Tests of OECD Stochastic Convergence. *Review of International Economics*, 9(1), pp. 153–162.

Friedman, M., 1992. Do old fallacies ever die?. *Journal of Economic Literature,* 30(4), pp. 2129-2132.

Galvão Jr, A.F. and Gomes, F.A.R., 2007. Convergence or divergence in Latin America? A time series analysis. *Applied Economics*, 39(11), pp. 1353-1360.

Guetat, I. and Serranito, F., 2007. Income convergence within the MENA countries: A panel unit root approach. *The Quarterly Review of Economics and Finance*, 46, pp. 685– 706.

Hadri K., 2000. Testing for unit roots in heterogeneous panel data. *The Econometrics Journal*, 3, pp. 148–161.

Holmes, M.J., 2002. Convergence in International Output: Evidence from Panel Data Unit Root Tests. *Journal of Economic Integration*, 17(4), pp. 826 838.

Kalita, M. and Tiwari, A.K., 2012. Testing Income Convergence: Evidence from Indian States Using Panel Linear and Nonlinear Unit Root Tests. *The Economic Research Guardian*, 2(1), pp. 60-69.

Kwiatkowski, D., Phillips, P.C.B., Schmidt, P.J. and Shin, Y., 1992. Testing the null hypothesis of stationarity against the alternative of a unit root: How sure are we that economic time series have a unit root. *Journal of Econometrics*, 54, pp.159–178.

Lau, C.K.M., 2010a. Convergence across the United States: Evidence from Panel ESTAR Unit Root Test. *International Advances in Economic Research*, 16, pp. 52–64.

Lau, C.K.M., 2010b. New evidence about regional income divergence in China. *China Economic Review*, 21, pp. 293–309.

Li, Q and Papell, D., 1999. Convergence of international output Time series evidence for 16 OECD countries. *International Review of Economics and Finance*, 8, pp. 267–280.

Liew, V.K.S. and Lim, K.P., 2005. Income Divergence? Evidence of Non-linearity in the East Asian Economies. *Economics Bulletin*, 15(1), pp. 1-7.

Lim, L.K. and McAleer, M., 2004. Convergence and catching up in ASEAN: a comparative analysis. *Applied Economics*, 36(2), pp. 137-153.

Lima, M.A.M and Resende, M., 2007. Convergence of per capita GDP in Brazil: an empirical note. *Applied Economics Letters*, 14(5), pp. 333-335.

Lin, P.C., Lin, C.H. and Ho, I.L., 2013. Regional convergence or divergence in China? Evidence from unit root tests with breaks. *The Annals of Regional Science*, 50 (1), pp. 223-243.

Liu, J., Wu, S. and Zidek, J.V., 1997. On segmented multivariate regressions, *Statistica Sinica,* 7, pp. 497–525.

Loewy M.B. and Papell, D.H., 1996. Are U.S. regional incomes converging? Some further evidence. *Journal of Monetary Economics*, 38, pp. 587–598.

Lucas, R.E., 1988. On the mechanics of economic development. *Journal of Monetary Economics*, 22 (1), pp. 3-42.

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

Maddison Database. [online] Available at: http://www.ggdc.net/maddison (Accessed in January 2013).

Mankiw, N.G., Romer, D. and Weil, D.N., 1992. A Contribution to the Empirics of Economic Growth. *Quarterly Journal of Economics*, 107(2), pp. 407-437.

McCoskey, S.K., 2002. Convergence in Sub-Saharan Africa: a nonstationary panel data approach. *Applied Economics*, 34(7), pp. 819-829.

Michelis, L., Papadopoulos, A.P. and Papanikos, G.T., 2004. Regional convergence in Greece in the 1980s: an econometric investigation. *Applied Economics*, 36(8), pp. 881- 888.

Pesaran, H., 2004. *General diagnostic tests for cross-section dependence in panels*. Working Paper No. 0435, University of Cambridge.

Pesaran, M.H., Ullah, A. and Yamagata, T., 2008. A Bias-Adjusted LM Test of Error Cross- Section Independence. *Econometrics Journal*, 11, pp. 105-127.

Quah, D., 1993. Galton's fallacy and tests of the convergence hypothesis. *Scandinavian Journal of Economics*, 95, pp. 427–43.

Quah, D. 1996, Empirics for growth and convergence. *European Economic Review*, 40, pp. 1353–1375.

Reza, R. and Zahra, K.T., 2008. Evaluation of the Income Convergence Hypothesis in Ten New Members of the European Union: A Panel Unit Root Approach. *Panoeconomicus*, 2, pp. 157-166.

Romer, P.M., 1986. Increasing returns and long-run growth. *The Journal of Political Economy,* 94 (5), pp. 1002-1037.

Romer, P.M., 1990. Endogenous technological change. *Journal of Political Economy,* 98 (5), pp. 71-102.

Romero-Ávila, D., 2008. Convergence in carbon dioxide emissions among industrialised countries revisited. *Energy Economics*, 30, pp. 2265–2282.

Sala-i-Martin, X., 1996. Regional cohesion: Evidence and theories of regional growth and convergence. *European Economic Review*, 40(6), pp. 1325–1352.

Solow, R., 1956. A contribution to the theory of economic growth. *Quarterly Journal of Economics*, 70, pp. 65–94.

Strazicich, M.C., Lee, J. and Day, E., 2004. Are incomes converging among OECD countries? Time series evidence with two structural breaks. *Journal of Macroeconomics*, 26, pp. 131–145.

Tunali, C.B. and Yilanci, V., 2010. Are per capita incomes of MENA countries converging or diverging?. *Physica A*, 389, pp. 4855-4862.

Vogelsang, T. and Tomljanovich, M., 2002. Are U.S. regions converging? Using new econometric methods to examine old issues. *Empirical Economics*, 27 (1), pp. 49-62.

Wang, M.S., 2012. Income convergence within ASEAN, ASEAN+3: a panel unit root approach. *Applied Economics Letters*, 19(5), pp. 417-423.

Yavuz, N.C. Yilanci, V., 2012. Testing For Nonlinearity in G7 Macroeconomic Time Series. *Romanian Journal of Economic Forecasting*, 15(3), pp. 69-79.