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1. Introduction. 2. Literature Review. 3. Methodology. 4. Empirical Results. 5. Concluding Remarks

Abstract: In this paper we test the convergence hypothesis by using a revised 4-step procedure of panel unit root test suggested by Evans and Karras (1996). We use data on output for 24 OECD countries over 40 years long. Whether the convergence, if any, is conditional or absolute is also examined. According to a proposition by Baltagi, Bresson, and Pirotte (2005), we incorporate spatial autoregressive error into a fixed-effect panel model to account for not only the heterogeneous panel structure, but also spatial dependence, which might induce lower statistical power of conventional panel unit root test. Our empirical results indicate that output is converging among OECD countries. However, convergence is characterized as conditional. The results also report a relatively lower convergent speed compared to conventional panel studies.

Keywords: Convergence *Hypothesis, Panel Unit Root Test, Spatial Dependence.*

Abstract: En este documento probamos la hipótesis de convergencia usando un procedimiento revisado de cuatro pasos del test de raíces unitarias de panel sugerido por Evans y Karras (1996). Usamos datos de la producción de 24 países de la OCDE para un periodo de 40 años. Se examinará también si la convergencia es condicional o absoluta. De acuerdo con una proposición de Baltagi, Bresson y Pirotte (2005), incorporamos el error espacial auto-regresivo en un modelo de panel de efectos fijos para estimar no solamente la estructura heterogénea de panel, sino también la dependencia espacial, la cual podría inducir un más bajo poder estadístico del test convencional de raíces unitarias. Nuestros resultados empíricos indican que la producción es convergente entre los países de la OCDE. Sin embargo, la convergencia es caracterizada como condicional. Los resultados también reportan una menor velocidad de convergencia, en términos relativos, comparada con estudios convencionales de panel.

Palabras clave: Hipótesis de convergencia, Test de raíces unitarias de panel, dependencia espacial.

Clasificación JEL: O40, C21, C23.

Convergence Hypothesis: Evidence from Panel Unit Root Test with Spatial Dependence

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1. Introduction

Stemming from the neoclassical Solow growth model (Solow 1956) of long-run growth, convergence hypothesis has been extensively studied. The issue fires the imagination that policy might be able to influence economic growth. From a theoretical point of view, standard neoclassical models assume economic growth to be an inexorable, exogenous process and the gaps of output per capita among countries, due to differences of initial capital, would vanish sooner or later.

The convergence process thus is characterized as absolute convergence, which means that groups of countries would share the same steady-state characteristics, and therefore converge to the same long-run growth path. However, recent endogenous growth theories (i.e. Romer 1986, 1990, Rebelo 1991, and Lucas 1988) believe that economic growth is endogenous and that institutional factors could have profound impacts. That is, two countries may have identical long-run growth rates but different output levels, which is referred to as conditional convergence.

This paper proposes an empirical analysis to test the convergence hypothesis among 24 OECD countries over the 1953-2000 period. We revise a panel unit root test proposed by Evans and Karras (1996) to empirically test for the convergence hypothesis. Whether the possible convergence process

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is conditional or absolute is further examined. In particular, our analysis concentrates on the cross-sectional correlation among the countries, which, according to Baltagi, Bresson, and Pirotte (2005), makes conventional panel unit root tests lose statistical power and suffer size distortion.

Although previous empirical studies in spatial econometrics show that economic growth engines are affected by spatial factors， studies that use panel unit root tests to test convergence hypothesis under a spatial dependence context still remain scarce. Motivated by the 4-step procedure proposed by Evans and Karras (1996) and further refined by Gaulier, Hurlin and Jean-Pierre (1999), this study revises their procedure by explicitly taking into account not only the heterogeneity in the sample, but also the cross-sectional dependence that is generally ignored in related studies. A fixed-effect panel is estimated and the effect of spatial dependence is captured by spatial dependent error structure. The convergence, according to Evans and Karras (1996), is defined as whether the series of the output per capita difference between a sample country and the international average converges to a constant value and the convergence type is of absolute if the constant value is zero

Our empirical results show that there is output convergence among OECD countries and the convergence is characterized as a conditional one. The results also report a relatively lower convergent speed compared to conventional panel studies without considering possible spatial dependence. Hence, this study provides more robust evidence of conditional convergence among OECD countries. The paper proceeds as follows: section 2 briefly reviews related literature. A revised panel unit root test is proposed in section 3; section 4 presents the results; and section 5 concludes.

2. Literature Review

For more than a decade, a large number of theoretical and empirical studies have investigated the origins of economic growth and convergence. Convergence hypothesis is implied by neoclassical theories. However, endogenous growth theories reject the absolute convergence hypothesis. The well-known neoclassical Solow model (Solow 1956) treats technology as an exogenous source of long-run economic growth. Accordingly, countries with different initial capital converge to the same long run steady state, characterized as absolute convergence. In contrast, endogenous growth theories believe that the sources of long-run economic growth such as knowledge spillovers (Romer 1986), incomplete market competition of R&D product (Romer 1990), non-diminishing marginal return of "core capital" (Rebelo 1991), or human capital accumulation (Lucas 1988), are endogenous. These models suggest that policy can adjust the engine of economic growth and hence convergence is not likely to happen or it is conditional. The discrepancies among theories spark a large number of empirical studies focusing on the convergence hypothesis.

Several empirical techniques to test for convergence have been developed based on the neoclassical growth model and mixed evidence is found. The most common approach is to use cross-sectional data to test β -convergence, which means poor countries grow faster than rich ones and σ -convergence, which is characterized by the diminishing income variance between poor and rich countries. The typical literature of this sort includes Baumol (1986) and Barro and Sala-I-Martin (1995), both of which support the convergence hypothesis. The other branch of literature, first introduced by Bernard and Durlurf (1995), considers a stochastic convergence process (from a time-series point of view) and proposes that convergence is true if the series of output difference between two countries is stationary. Therefore, the convergence test can be interpreted as testing unit root in the series. In addition, a zero long-run mean value of the series indicates absolute convergence while a nonzero mean value implies conditional convergence. Contrary to cross sectional studies, most time series literature tends to accept that there is a unit root in the output difference series, which means no convergence.

Due to advances in the econometric techniques, some panel data approaches have been adopted to address the convergence hypothesis. Among those methods, the extensions of variant panel unit root tests have been proposed as a more powerful alternative test than those based on individual time series (unit roots tests). These panel unit root tests, such as Levin, Lin and Chu (2002), Im, Pesaran and Shin (2003), and so on, increase the power of the test for convergence by the square root of the cross sectional units.

Evans and Karras (1996) propose a 4-step procedure to test convergence based on time series interpretation of convergence and they find strong evidence of conditional convergence for U.S. states and a sample of 54 countries.

One major criticism of the conventional unit root tests is their insufficiency of modeling cross-sectional dependence and heterogeneity among data. If the iid and homogeneity assumptions are violated, these techniques suffer from significant size distortions that do not disappear with simple demeaning. Recent literature is attempting to address these problems. Barro (1991) and Armstrong (1995) include continent dummies into their model to control for differences among country group. Gaulier, Hurlin and Jean-Pierre (1999), consider the heterogeneous nature among countries and extends Evans and Karras's method by using a fixed-effect dynamic panel model. The heterogeneity among countries is captured by the country specific parameters. They find absolute convergence among European countries and conditional convergence among OECD countries, as well as no convergence among the world countries. However, the iid error assumption still holds in most studies that have already taken the heterogeneity of sample into account.

Pesaran (2004) tests the cross-sectional correlation among countries.[3] He finds strong cross-sectional dependence among countries within the same continent and weaker but significant dependence among continents (except Middle East and African countries). Given that the cross-section correlation and interactions, which in particular are common among countries, conventional panel unit root tests are misspecified. A simulation studied by Baltagi, Bresson, and Pirotte (2005) has shown that the test power and size can be on average worsened up to about 15% by the presence of cross-sectional correlation.

Recent econometric advances have proposed two new approaches to release the restrictive homogeneity and iid error assumption. One of them, proposed by Pesaran (2005), assumes an unobservable common factor in error term to capture the cross-sectional correlation. He suggests that an international average can be used as a proxy to capture the unobservable common factor. Alternatively, Baltagi *et al.*(2005) suggests that we can use spatial econometric model to address the problem and this is adopted by the present paper.

In spatial econometric empirical papers, it has been found that the engine of economic growth is affected by the spatial factors. Coe and Helpman (1995), and Keller (2002) find that, for OECD countries, the R&D spillover effect is huge and depends on the geographic distance. Lall and Yilmaz (2001) find that human capital levels are spatially interdependent. These results are crucial because they indicate that the generally accepted iid error structure

[3] Pesaran (2004) uses Penn World table data, 1971-2000.

assumption is actually invalid and the conventional regression models are possibly misspecified. It will be more appropriate that we take the spatial effect into account in testing convergence hypothesis.

3. Methodology

Evans and Karras (1996) propose a general 4-step procedure to test the convergence hypothesis primarily based on time series representation of convergence process. Nevertheless, when contemporaneous cross-sectional correlation appears the procedure is problematic from both economic and econometric standpoints. Simulation results of Baltagi, Bresson, and Pirotte (2005) suggest that spatial specification significantly decreases the power and size of panel unit root tests under cross-sectional correlation context. Therefore, we introduce a spatial autoregressive error process into Evans and Karras' model to capture the effect of spatial dependence.[4]

Despite the fact that spatial models are not new in convergence literature, especially in regional growth studies, they are only applied to cross-sectional representation of convergence process and limited in regional data.[5] The present paper represents the first attempt to apply panel unit root test with spatially correlated error to the problem of output convergence in country level data. This section describes the methodological issues: subsection 3.1 briefly introduces the 4-step procedure proposed by Evans and Karras (1996); subsection 3.2 discusses the spatial model used in the study and its economic implications; the revised 4-step procedure is summarized in subsection 3.3; a preliminary pre-test of cross-sectional dependence and data issue are given in subsection 3.4 and 3.5, respectively.

3.1 Conventional Four-step Procedure (Evans and Karras(1996))

Mapping the time series interpretation of convergence process into a panel context, Evans and Karras (1996) develop a four-step procedure of panel unit root test. Gaulier, Hurlin and Jean-Pierre (1999), by introducing fixed-effect parameters, extend this approach to consider the heterogeneous

[4] In this paper, we do not consider the autocorrelation among error terms in time dimension because it can be eliminated by including sufficient lag length.

[5] Kosfeld and Lauridsen (2004) use panel unit root test with spatial model. However, they consider unit root in spatial dimension, which is different with time dimension unit root in this paper.

nature among countries. In this paper, we further extend Gaulier, Hurlin and Jean-Pierre's approach by introducing spatial model to capture the cross-sectional correlation.

The convergence, according to Evans and Karras (1996), is defined as the deviation of output per capita of a sample country from the international average approaches a constant value as time goes to infinity. Hence, under panel context, N economies converge if and only if the expected GDP per capita cross economies differences are stationary:

$$\lim_{p\to\infty} E_t(y_{it+p} - \bar{y}_{t+p}) = \mu_i \quad ,$$

where y_{it} is GDP per capita for country i at time t, $\bar{y}_t$ is the international average at time t, p is the lag length, i =1, 2, …, N. Convergence to be absolute or conditional depends on whether $\mu i = 0$ for all i or $\mu i \neq 0$ for some i.

Hence, the data generating process for N countries can be assumed as:

$$(1) \quad \Delta(y_{it} - \bar{y}_t) = \alpha_i + \rho_i(y_{it-1} - \bar{y}_{t-1}) + \sum_{j=1}^{p_i} \gamma_{ij} \Delta(y_{it-j} - \bar{y}_{t-j}) + u_{it} \, ,$$

where α_i is the time-invariant parameter for individual country, p_i is the lag length, ρ_i and γ_{ij} are parameters to be estimated, and u_{it} is the iid error term of country i at time t. Equation (1) essentially is a typical function form for Augmented Dickey-Fuller test under panel context. The existence of unit root can now be characterized by testing the null that all parameters ρ_i's are equal to zero. So the N economies are said to be convergent if all the parameters, ρ_i's, are less than zero. The type of the convergence process, if any, is characterized by testing the individual-specific parameters, α_i's, which are pertaining to the unconditional mean value of the series, are equal to zero.

The following 4-step procedure of panel unit root test for convergence is proposed by Evans and Karras(1996) :

(1) Apply ordinary least squares to the equation (1) to obtain, $\hat{\sigma}_i$, the estimate of standard deviation. To control for the heterogeneity across individuals, the series is normalized by dividing the estimated standard error.

(2) Using ordinary least squares, obtain the parameter estimate $\hat{\rho}$ and its t-ratio, t (ρ) by estimating

$$\Delta(y_{it} - \bar{y}_t)/\hat{\sigma}_i = \alpha_i/\hat{\sigma}_i + \rho(y_{it-1} - \bar{y}_{t-1})/\hat{\sigma}_i + \sum_{j=1}^{p} \gamma_{ij} \Delta(y_{it} - \bar{y}_t)/\hat{\sigma}_i + u_{it}/\hat{\sigma}_i$$

as a panel.

(3) If the t-ratio exceeds an appropriately chosen critical value, reject H_0: $\hat{\rho}_i = 0$ in favor of H_a: $\hat{\rho}_i < 0$. If not, H_0 may hold.

(4) If Ho can be rejected, calculate the F-ratio

$$\Phi(\hat{\alpha}_i) = 1/(N-1) \times \sum_{i=1}^{N} t(\hat{\alpha}_i)^2,$$

where $t(\hat{\alpha}_i)$ is the t-ratio of the estimator of α_i, obtained by applying ordinary least squares to equation(1) for economy i. Evans and Karras (1996, p263) derive the F-ratio based on the standard joint hypothesis test approach in least square estimation. If the F-ratio exceeds an appropriately chosen critical value, infer that convergence is conditional. If not, convergence may be absolute.

3.2 Spatial Effect

However, for both econometric and economic theory, it is too restrictive to assume no cross-sectional dependence in testing convergence hypothesis. The restriction implies that the economies are closed, which is obviously inappropriate to understand convergence process, considering the continuing process of globalization around world in recent decades. We consider first the impact of spatial effect on the economic growth engines identified in literature: human capital and technology. Specifically, the convergence process would be accelerated when human capital and physical capital move among countries in response to differentials in remuneration rates.

Under an open economy context, another possibility for poor countries to converge towards richer ones is through technology diffusion or knowledge spillover. Today's global economy has shown strong trend of globalization and barriers to international trade and factor mobility have been significantly reduced. Indeed, the integration of financial market and the tighter connections among countries produce higher rate of factor exchanging, larger trade volume, and faster knowledge diffusion. Econometrically, the presence of cross-sectional dependence leads to non-spherical error structure that results invalid statistical inferences.

According to Baltagi, Bresson, and Pirotte (2005), the power and size of panel unit root tests without considering cross-sectional dependence will be greatly impaired. As a matter of fact, previous studies have suggested that the OECD country group is cross-sectional dependent when conducting simple OLS estimation (Pesaran 2004, for example). In order to establish more robust results, it is necessary to consider cross-sectional dependence.

Modeling the cross-sectional dependence by taking advantage of spatial econometric technique is appealing because the dependence among countries is related to location and distance.[6] In this paper, the cross-sectional dependence therefore can be called spatial effect: technology, factor mobility, culture, and institutions- factors emphasized by both neoclassical and endogenous theories are correlated according to geographical locations. Generally, barriers to trade, to technology spillover, to capital mobility, and to migration are set up in country level and their free mobility is confined within a country. A commonly observable phenomenon is that those barriers appear stronger among inter-continental countries than those among countries located within the same continent. Distance also affects the degree of interactions among countries. In addition, cross sections unit in the data are generally defined in location.

In order to capture the spatial effect, following suggestion by Baltagi, Bresson, and Pirotte (2005), I assume the error structure to be spatially autoregressive:

(2) $\boldsymbol{u}_t = \lambda W_n \boldsymbol{u}_t + \varepsilon_t$,

where $\boldsymbol{u}_t$ is the N x 1 error vector in period t=1,…,T, λ is the spatial autoregressive parameter, ε_t is an N 1 iid error with zero mean and σ^2 variance[7]. Equation (2), called spatial autoregressive error, is widely used in spatial studies. This specification implies that the innovations of all country containing unmodeled factors that influence current output are interrelated according to the orders of contiguity.

Note that this error structure makes some traditional panel unit root tests, which are based on the combination of the individual unit root tests, can not

6 Pesanran(2005) propose an alternative way to capture the cross-sectional dependence. We prefer the spatial error model because the dependence channels among countries implied by theory are strongly spatially related. In addition, his method assumes a random common factor in data, which would be eliminated by demeaning the series.

7 Baltagi, Bresson, and Pirotte (2005) investigate three different types of spatial error specification. In practice, there is no general rule to determine which one is the best. We choose the spatial autoregressive specification since it is the most widely adopted approach in spatial empirical work.

be conducted, for example IPS test and Evans and Karras's approach, because estimating single series fails to account spatial effect and will produce incorrect standard errors. The model should be jointly estimated to avoid incorrect standard error.

The N x N W matrix, referred as spatial weight matrix in literature, has to be pre-specified due to identification problem. Choice of the W matrix is always subject to disputation. The pre-specified weights matrix should be exogenous and invariant over time, which precludes using variable such as trade or FDI（Foreign Direct Investment）as spatial weights. The most popular way is to assign the weight value based on simple contiguity check. Specifically, I specify the weight matrix in the following way:

$W_{ij} = 1$ if the two countries are within the same continent;

$W_{ij} = 0$, otherwise.

As a common technique in spatial econometrics, the final weight matrix, to ensure the result is spatial stationary, has been row-standardized in estimation.

In specifying the weight matrix, continent location of countries is served as selection criteria. The idea is that countries within continents are similar to each other in terms of variables such as social status, culture, technology, and climate. Pesaran (2004) has found weak, though significant, correlations across continents but strong cross sectional dependence among countries located within the same continent. A commonly observable phenomenon is that the integration barriers appear stronger among inter-continental countries than among countries in the same continent.

The fact that countries within the same continent have strong trend of integration has been confirmed in huge amount of literature: European countries have formed European Union; North American countries have market integration agreement (NAFTA); Australia and New Zealand are well known to be close related; similar agreement can also be found in the Asian countries. Empirical evidence has also indicated the existence of growth clubs or clusters and those clubs and clusters are generally confined within a continent. (Durlauf and Johnson 1995; Quah 1997).

3.3 A Revised Four-step Procedure

The test procedure follows Evans and Karras (1996) and Gaulier, Hurlin and Jean-Pierre (1999). However, since they fail to consider the non-iid error structure, we extend their models by incorporating spatial dependences. Due to the presence of spatial effect, we correspondingly modify the Evans and Karras's 4-step procedure in following perspectives: (1) we abandon the normalization procedure in the first step since the OLS estimate cannot provide correct standard error; (2) we jointly estimate the fixed-effect dynamic panel by maximum likelihood other than OLS estimation which produces biased estimator; (3) instead of the F-statistics suggested by Evans and Karras, we use standard F-test in the model because the retrieved fixed-effect parameters from demeaned equation are biased.

We first determine the lag length here by estimating equation (1) for each country with OLS. This is essentially the ADF unit root test, given the function form of equation (1). The lag length is chosen based on SIC standard. In contrast to Evans and Karras (1996) that collect the estimated standard error of u to normalize the original series, we directly use the true series in following steps. The OLS residuals cannot be used to correctly estimate the variance-covariance matrix due to the presence of spatial correlation.

Second, we jointly estimate the dynamic panel model:

$$(3)\quad \Delta(y_{it}-\bar{y}_t)=\alpha_i+\rho(y_{it-1}-\bar{y}_{t-1})+\sum_{j=1}^{p}\gamma_{ij}\Delta(y_{it}-\bar{y}_t)+u_{it}$$

$$u_i=\lambda W_n u_t+\varepsilon_t.$$

The presence of the α_i's parameters, isolating the effect of the omitted variable, indicates the different structural characteristics of the economies. The contemporaneous cross-sectional dependence across countries is properly captured by the spatial error specification.

Evans and Karras (1996) show that the test H_0: $\hat{\rho}_i = 0$ against H_a: $\hat{\rho}_i < 0$ in (1), which indicates that there is a unit root in the series, is equivalent to test $\rho < 0$ against not all of them are zeros. Here we impose the same lag length for the panel, which is the largest length found in individual series tests. Although it seems more efficient to estimate with different lag length, differences in lag length naturally generate an unbalanced panel structure of the model, which makes the estimation step greatly complicated.[8] Allowing longer lag length does not pose too much trouble in that we are focusing on the coefficient ρ and α, while using parsimonious model may suffer omitted variable bias.

Given the first order spatial autoregressive error specification, OLS method is inappropriate. The true full (NT x NT) variance-covariance matrix is

$$(4)\quad \Omega = \sigma^2 (I_T \otimes ((I_N - \lambda W_{N\times N})^{-1} (I_N - \lambda W'_{N\times N})^{-1})) \quad .$$

As shown in Elhors(2003), it is possible to estimate equation (3) by maximum likelihood with sufficient long T, based on the variance-covariance matrix. To remove the country specific fixed effect, we first demean the series of the variable. The log likelihood function, after the equation is demeaned, can be derived as

$$-NT\frac{Ln(2\pi\sigma^2)}{2} + T\sum_{i=1}^{N} Ln(1-\lambda\omega_i) - \frac{1}{2\sigma^2}\sum_{t=1}^{T} e_t' e_t$$
$$e_t = (I - \lambda W)[(z_t - \bar{z}) - (X_t - \bar{X})\theta]$$

where $z_t = \Delta(y_{.,t} - \bar{y}_t)$, X_t is vector of all right hand side explanatory variables and θ is coefficient vector, $\bar{X}$ and $\bar{z}$ are the average of X and Z over time for each country, and ω's are the characteristic roots of the standardized weight matrix.

Third, we conduct t-test of ρ to determine whether the process is convergent or not. We can draw the conclusion that the convergence happens based on the rejection of the null hypothesis that all ρ's are zero without identifying if the convergence is absolute or conditional.

Fourth, using F-test to test the restrictions that the fixed effects, α_i's, jointly are equal to zero. If they are zero, then all country's output per capita will converge to an international long run level, which supports the absolute convergence hypothesis. If not, conditional convergence is expected. Evans and Karra(1996) derive a F-statistic based on the t-value of the fixed-effect parameters. The fixed-effect parameters can be retrieved from the demeaned

[8] Gaulier, Hurlin and Jean-Pierre (1999) estimate this panel by LSDV (Least Square Dummy Variable) estimator without imposing lag length. Estimating such an unbalanced dynamic panel with LSDV method will produce inconsistent estimates and they use simulation method to find the correct critical value.

equation, but these estimates are biased and estimated standard errors are incorrect due to spatial error. Hence associated t-values are incorrect.

Instead of using the F-statistic suggested by Evans and Karras, we use the standard F-statistic in fixed-effect panel model. The pooled panel model can be treated as a restricted fixed-effect model. The test statistics is derived based on comparison between restricted and unrestricted model. We use the following F ratio to test the null hypothesis that all fixed-effect parameters are equal to zero:

$$F(N-1, NT-N-K) = \frac{(RRSS - URSS)/(N-1)}{URSS/(NT-K-N)},$$

where K is the number of regressors, RRSS is the restricted residual sum of squared computed from a spatial error model without fixed effect, URSS is the unrestricted residual sum of squared calculated from the original fixed-effect model with spatial error. Under the conditional convergence hypothesis, all fixed-effect parameters will be different from zeros. Therefore, rejection of the null hypothesis can be viewed as an evidence of conditional convergence.

3.4 Preliminary test

To statistically confirm the existence of spatial effect in our sample, we conduct a LM test proposed by Breusch and Pagan (1980). The test statistics is

$$LM = \sqrt{\frac{1}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} (T\hat{\delta}_{ij}^{2} - 1),$$

where $\hat{\delta}_{ij}$ is the sample estimate of correlation coefficient of the residuals:

$$\hat{\delta}_{ij} = \frac{\sum_{t=1}^{T} e_{it} e_{jt}}{\sqrt{\sum_{t=1}^{T} e_{it}^{2} \sum_{t=1}^{T} e_{jt}^{2}}}$$

and e_{it} is the LSDV estimate of the error term u_{it}.

Under the null hypothesis that there is no cross-sectional dependence, the test statistic is asymptotically standard normal distributed. The value of the LM test equals 18.97, which is strongly significant, suggests that OLS errors are cross-sectionally correlated. This preliminary test confirms that we should take spatial effect into account.

3.5 The Data

The data used in this study are drawn from the latest Penn World Tables (PWT), Summers and Heston. We use annual time series data from 1953-2000 of per capita GDP-adjusted PPP with 1996 constant price- to conduce the empirical research. We take logarithm before conducting the empirical study. The sample includes the following countries: Australia, Austria, Belgium, Canada, Switzerland, Denmark, Spain, Finland, France, United Kingdom, Greece, Ireland, Iceland, Italy, Japan, Korea, Republic of Mexico, Netherlands, Norway, New Zealand, Portugal, Sweden, Turkey, and United States.

4. Empirical results

We conduct ADF test for the individual series and the SIC's show that each series has lag length no more than two. So we choose 2 as the lag length for the panel study. Due to the initial condition for estimation, the sample period for regression is adjusted to 1956-2000.

Table 1 reports results in fixed-effect model with spatial error. We obtain significant spatial autocorrelation parameter at 10 percent level, which again confirms that there is notable spatial effect among OECD countries. Thus inference from previous studies might not be reliable.

The t-statistic value associated with the coefficient of $(y_{it-1} - \bar{y}_{t-1})$ is significantly less than zero at 5% level, indicating that the process characterized by equation (1) does not have a unit root. The rejection of null hypothesis enables us to conclude that there is convergence. However, we cannot characterize that the convergence is conditional or absolute.

In the fourth step, we estimate pooled panel model with spatial error and calculate the F-statistics to find out the type of the convergence indicated in the t-test. The calculated F-statistics value is 2.43, which is greater than related critical F value, so we reject the null hypothesis that all fixed-effect parameters are zeros. Then we conclude to conditional convergence in the sample. That is, the OECD countries have different individual steady state. Although the growth rates among the country group could be the same in the long run, output levels of the countries are permanently different.

Combining the two test results, we conclude that in the OECD countries sample, conditional convergence happens. Most empirical studies of OECD countries have concluded that there is output convergence among the OECD countries sample, even they don't consider the cross-sectional correlation. The result is consistent with the intuition. The sample includes some countries that have experienced rapid growth when their GDP per capita level is low, for example, Korea and Mexico during the past decades, Japan after WW II. Given the strong convergence behavior of these countries, convergence is expected.

On the other hand, countries in the sample also have great structural disparity, including very different culture, institutional setup, as well as structural breaks. And there are subgroups of the sample closely related and interacted, for instance, European Union, North American countries. Because of such great heterogeneity and spatial correlation among these countries, the convergence is expected to be conditional.

Another result of remark is that the study shows a relatively slower global common convergence speed, 2.2%, compared to the value, 4.3%, reported in Evans and Karras, and 8.39%, in Gaulier, Hurlin and Jean-Pierre. In terms of the "half life" measure[9] in literature, the global convergence speed in present study is 32 years, much higher than 16.5 years (Evans and Karras) and 8.7 years (Gaulier, Hurlin and Jean-Pierre). For comparison purpose, we also consider a model without introducing spatial dependence term. Equation (3) is re-estimated with Least Square Dummy Variable (LSDV) method and Table 3 shows the estimated speed of convergence is 3.7%, or equivalently, 19 years in terms of the half-life measure, which is still higher than the estimated convergence speed under spatial dependence context.

[9] The half- life means the half time for a country to converge to its steady state. It can be calculated as $-\ln(2)/\ln(1+\rho)$.

Table1
Fixed-effect panel with spatial error

Variable	Parameters	Standard Error	t-Statistics
$y_{it-1} - \overline{y}_{t-1}$	-0.0216	0.0053*	-4.0829
$\Delta(y_{it-1} - \overline{y}_{t-1})$	0.2210	0.0301*	7.3400
$\Delta(y_{it-2} - \overline{y}_{t-2})$	-0.0221	0.0285	-0.8076
λ	-0.0682	0.0399**	-1.7099
Log likelihood: 1360. σ : 0.025			

*** significant at 5% and 10% percent level.

Table 2
Pooled panel model with spatial error
(restricted fixed-effect panel with spatial dependence)

Variable	Parameters	Standard Error	t-Statistics
$y_{it-1} - \overline{y}_{t-1}$	-0.0097	0.0019*	-5.2413
$\Delta(y_{it-1} - \overline{y}_{t-1})$	0.2657	0.0302*	8.8027
$\Delta(y_{it-2} - \overline{y}_{t-2})$	0.0153	0.0322	0.4742
λ	-0.0309	0.0404	-0.9670
Log likelihood: 8920. σ : 0.026			

*** significant at 5% and 10% percent level.

Table 3
Fixed-effect panel without spatial dependence
(Estimated using LSDV method)

Variable	Parameters	Standard Error	t-Statistics
$y_{it-1} - \overline{y}_{t-1}$	-0.0368	0.0057*	-6.4221
$\Delta(y_{it-1} - \overline{y}_{t-1})$	0.2178	0.03*	7.2476
$\Delta(y_{it-2} - \overline{y}_{t-2})$	-0.0099	0.0293	-0.3386
Log likelihood: 1800. σ : 1.012			

* ** significant at 5% and 10% percent level.

The spatial error model implies this lower speed of convergence. A change in the factors affecting economic growth has two effects: global effect that is affecting the global common convergence speed, and local effect that is carried out by the spatial correlation. For example, we can consider the knowledge spillover effect among countries. Knowledge spillover effect (and also migration, trade, homogeneity of culture, political setup) generally becomes weaker with distance going up. Firms located within the same continent are more likely to benefit each other, which is referred as local knowledge spillover. As countries located within the same continent become more homogenous in knowledge level, the inter-continent differences are growing. Therefore, the local effect may contribute to inter-continental divergence. On the other hand, knowledge accumulation in one region improves the productivity of all firms wherever they are located. Thus, a global geographic spill-over effect may contribute to inter-continental convergence. The final effect of knowledge spillover should be the combination of the global effect and local effect. Therefore, study without spatial effect consideration tends to overestimate the common convergence speed because the local effect that induces inter-continental differences is ignored. This problem becomes even worse due to the biased OLS estimator under the dynamic panel model structure.

5. Concluding remarks

This study tests the convergence hypothesis by taking advantage of a new panel unit root test. The study investigates output convergence of log GDP per capita among 24 OECD countries over 48 years. A fixed-effect panel model is estimated. In particular, considering the cross-sectional dependence that might produce invalid statistical inference in standard panel unit root tests, we revise the 4-step procedure proposed by Evans and Karras to accommodate a spatial autoregressive error structure.

Our empirical results show that output is converging among OECD countries, but the convergence is characterized as a conditional one. The results also report a relatively lower convergent speed compared to normal panel studies. Given the cross-section correlation and interactions, which in particular is common among countries, this study provides more robust evidence of conditional convergence among OECD countries.

References

Abreu, M., Groot., H., and Florax, R., 2005, Space and growth: a survey of empirical evidence and methods, *Region et Development*, 21, 13-44.

Armstrong, H.W., 1995, Convergence among regions of the European Union, 1950-1990, *Papers in Regional Science*, 74,143-152.

Anselin, L., 1988, *Spatial econometrics: methods and models,* Kluwer Dordrecht.

Anselin, L. and Hudak, S., 1992, Spatial econometrics in practice: a review of software options, *Regional Science and Urban Economics*, 22, 509-536.

Barro, R.J., 1991, Economic growth in a cross section of countries, *Quarterly Journal of Economics,* 106, 407-443.

Barro, R.J. and X. Sala-i-Martin, 1995, *Economic Growth*, New York: McGraw-Hill.

Baumol, W.J., 1986, Productivity growth, convergence, and welfare: What the long-run data show, *American Economic Review* 76, 1072-1085.

Baltagi, B.H., Bresson, G., and Pirotte, A., 2005, Panel unit root tests and spatial dependence, *Texas A&M University Working Paper in Economics*.

Bernard, A.B., and S.N, Durlauf, 1995, Convergence of international output, *Journal of Applied Econometrics*, 10, 97-108.

Breusch, T. S., and Pagan, A.R., 1980, The Lagrange multiplier test and its application to model specifications in econometrics, *Review of Economic Studies,* 47, 239-253.

Coe, D.T. and Helpman, E., 1995, International R&D Spillovers, *European Economic Review*, 39, 134-149.

Durlauf, S.N. and Johnson, P. A., 1995, Multiple Regimes and Cross-Country Growth Behavior, *Journal of Applied Econometrics*, 10, 365-384.

Elhorst, P.,J., S., 2003, Specification and estimation of spatial panel data models, *International Regional Science Review*, 26, 244-268.

Evans, P., and Karras.,G, 1996, Convergence revised, *Journal of Monetary Economics*, 37, 249-265.

Gaulier,G., Hurlin, C., and Jean-Pierre., P. ,1999, Testing convergence: A panel data approach, *Annales D'economie Et De Statisticque*, 55, 412-427.

Im, K., Pesaran, H., and Y. Shin, 2003, Testing for Unit Roots in heterogeneous panels, *Journal of Econometrics* 115, 53-74.

Keller, W., 2002, Geographic localization of international technology diffusion, *American Economic Review,* 92, 120-142.

Kosfeld, R., and Lauridsen, J., 2004. Dynamic spatial modelling of regional convergence processes, *Empirical Economics*, 29, 705-722.

Lall, S., and Yilmaz, S., 2001, Regional economic convergence: do policy instruments make a difference?, *Annals of Regional Science*, 35, 153-166.

Levin, A., C.F. Lin and J. Chu, 2002, Unit root test in panel data: asymptotic and finite sample properties, *Journal of Econometrics*, 108,

Lucas, R.E. Jr., 1988, On the mechanics of economic development, *Journal of Monetary Economics*, 22, 2-42.

Pesanran, H., 2004, General diagnostic tests for cross section dependence in panels, *Cambridge Working Papers in Economics*.

Pesanran, H., 2005, A simple panel unit root test in the presence of cross section dependence, *Cambridge Working Papers in Economics*.

Quah, D., 1997, Empirics for growth and distribution: stratification, polarization, and convergence clubs, *CEPR Discussion Papers 1586*.

Rebelo, S., 1991, Long-run policy analysis and long-run growth, *Journal of Political Economy,* 99, 500-521.

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

Romer, P.M., 1990, Endogenous technological change, *Journal of Polictical Economy,* 98, 71-102.

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