Regional Income Convergence: Evidence from Panel Unit Root Tests

Jaewoon Koo and Seungjun Lee [1]

This paper investigates convergence of eleven regional incomes in Korea by employing a panel unit root test method proposed by Levin and Lin (1993). To test the robustness of the result, we rely on the method developed by Im, Pesaran, and Shin (1996) as well. Applying individual unit root test to income series of each region, we obtained mixed results such that only three out of eleven regional incomes converge. Panel unit root tests, however, reject the null hypothesis that all the Korean regional incomes do not converge. This empirical finding implies that, in a rapidly growing economy such as Korea, at least some regional incomes have tendency to converge to its own equilibrium level. This result is consistent with the prediction of neoclassical growth theory.

Keywords: Income convergence, Panel unit root test

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I. Introduction

A growing body of literature has empirically investigated convergence of incomes using various data sets since this debate plays a key role in economic growth theory. The neoclassical growth model predicts that incomes tend to converge at a steady-state level over time contrary to most endogenous growth models.

*Associate Professor, Department of Economics, Chonnam National University, 300 Yongbong-dong Bukgu Kwangju, 500-757, Korea, (TEL) +82-62-530-1551, (FAX) +82-62-530-1559, (E-mail) jwkoo@chonnam.ac.kr; Assistant Professor, Department of Economics, Chonnam National University, (TEL) +82-62-530-1554, (FAX) +82-62-530-1559, (E-mail) sjlee@chonnam.ac.kr, respectively. We are grateful for valuable comments from two anonymous referees.

Many cross-sectional studies including Barro and Sala-i-Martin (1995) find overwhelming evidence for convergence across countries and across regions. They test for the β-convergence defined as a negative relation between the average growth rate of incomes and the initial income level.

Some researchers employ time-series analysis technique to test for convergence of incomes by introducing stochastic convergence. The concept of stochastic convergence defined by Bernard and Durlauf (1995) is based on the idea that differences in incomes between economies are transitory. Using unit root tests, they find little evidence for convergence of incomes across 15 OECD countries. In contrast, Greasley and Oxley (1997) identify bi-variate convergence between some OECD countries. Carlino and Mills (1993) also define convergence as the stationarity of relative per-capita income shocks. They find that the U.S. regional incomes tend to converge only after allowing for a break in the rate in 1946. To our knowledge, most empirical studies employing time-series technique fail to support the convergence hypothesis claimed by the neoclassical growth theory.

It is quiet puzzling why cross-section analysis and time-series analysis yield such opposite result about the convergence hypothesis. Evans and Karras (1996a) shed light on the inconsistency between two approaches. They demonstrate that the concept of β-convergence is compatible with that of stochastic convergence under very restrictive conditions. Bernard and Durlauf (1996) also point out that cross-section tests are associated with a weaker notion of convergence than time series tests. Since the β-convergence is not sufficient for stochastic convergence, it is difficult to find strong support for the convergence from time-series techniques.

Furthermore, results from time series technique might be called into question since conventional unit root tests are criticized due to their lack of statistical power. To overcome these difficulties, researchers tend to rely on various methods of panel unit root test. Among them, Evans and Karras (1996a, b) find strong evidence for convergence of incomes across states in the U.S. by applying a panel unit root test.

The purpose of this paper is to test for convergence of Korean regional incomes using a panel unit root test. A few studies have examined whether regional incomes converge in Korea. Employing a variant of the Barro equation, Koo, Kim, and Kim (1998) show that the disparities of regional incomes has decreased over time. It is noteworthy that the estimated convergence rate is much higher than that found in the U.S. and European data.[1]

There has been, however, little research on convergence of Korean regional incomes using time-series methods. Panel unit root test has an advantage in analyzing convergence of Korean regional incomes, since most income series are very short. We employ the panel unit root test method proposed by Levin and Lin (1993) and Im, Pesaran, and Shin (1996).

The data covers income series of 11 regions from 1970 to 1998. Applying individual unit root tests to income series of each region, we obtained mixed results about convergence. Three regional incomes clearly converge while the remaining ones do not. Panel unit root tests, however, yield a definite rejection of the null hypothesis of non-convergence. We reject the null hypothesis that all regional incomes do not converge. This implies that, in a rapidly growing economy such as Korea, regional incomes have strong tendency to converge in spite of the growing concern about unbalanced growth across regions. This empirical finding that regional incomes have tendency to converge to its own equilibrium level is consistent with the prediction of neoclassical growth theory.

The rest of the paper is organized as follows. Section II formulates a model to describe a stochastic process of relative incomes and shows that a test for convergence is analogous to a unit root test. We describe the data and test for convergence by applying panel unit root test methods in Section III. Section IV includes concluding remarks.

II. The Model

We define y_{it} as relative income[2] of region i at time t. y_{it} is assumed to have the following process:

$$y_{it}=y^e_i+u_{it} \tag{1}$$

[1]The estimated convergence rate for Korea is over 4 percent while that for the U.S. and other countries is known to be around 2 percent per annum.

[2]This is defined as per-capita real income in each region relative to the national average.

where y_i^e is the equilibrium relative income level, and u_{it} represents deviations from the equilibrium. It is assumed that there is a time-invariant equilibrium level of relative income that each region is moving toward over time. Equilibrium relative income may differ across regions because of regional characteristics such as education and skill level of labor, and production technology.[3]

Let us assume that deviations u_{it} consists of a deterministic linear trend and a stochastic process,

$$u_{it}=v_{oi}+\beta_i t+v_{it} \tag{2}$$

where v_{oi} is the initial deviation from equilibrium and β_i is the deterministic rate of convergence. The β-convergence implies that, if a regional income is initially above its compensating differential, *i.e.*, $v_{oi}>0$, it should grow more slowly than the average of the nation, *i.e.*, $\beta_i<0$.

Substituting (2) into (1) yields

$$y_{it}=\alpha_i+\beta_i t+v_{it}, \tag{3}$$

where $\alpha_i=v_{oi}+y_i^e$. The stochastic convergence suggests that, for a specific region, deviations from relative trend growth, v_{it}, must be temporary.[4]

The v_{it} term is modeled as an $AR(q)$ process represented by

$$A_i(L)v_{it}=\varepsilon_{it} \tag{4}$$

where $A_i(L)=1-a_{1i}L-a_{2i}L^2-\cdots-a_{qi}L^q$. L is the lag operator, and ε_{it} is a serially uncorrelated shock to v_{it}.. If $A_i(L)$ does not have a unit root, shocks to relative regional incomes are transitory. That is, regional incomes converge to the steady-state level over time.

It is noted that examining the property of v_{it} is analogous to applying the unit root test devised by Dickey and Fuller. If v_{it} follows an $AR(1)$ process, the substitution of (4) into (3) yields the following Dickey-Fuller type equation:

[3]This concept is in the same spirit with the concept of conditional convergence in that each regional income may converge to a different equilibrium level.

[4]This definition is consistent with that in Bernard and Durlauf (1995, 1996).

$$\Delta y_{it} = \alpha_i(1-a_{1i}) + \beta_i a_{1i} + \beta_i(1-a_{1i})t - (1-a_{1i})y_{it-1} + \varepsilon_{it}. \quad (5)$$

In general, if the order of the *AR* term in v_{it} is q, greater than 2, we can get the Augmented Dickey-Fuller equation with (q-1) lagged difference of y_{it} terms.[5]

The coefficient in y_{it-1} does not have a standard distribution under the null hypothesis of a unit root. We will rely on the distribution developed by Dickey-Fuller to test the null hypothesis of $a_{1i}=1$. It thus implies that examining time-series properties of relative incomes is equivalent with conducting unit root tests.

III. Empirical Analysis

A. Data

The data set covers real income series of 11 regions from 1970 to 1998. We construct regional income series from two sources. One is the real per capita Gross Regional Product (GRP) from 1985 to 1998 published by the National Statistical Office. The other data of period 1970-86 is originally drawn from Kim, Chung, and Noh (1991). Since the two series are different in the base year, we adjust the latter series by multiplying the average ratio between the two series for the overlapping years, 1985 and 1986.

B. Unit Root Tests on Single Time Series

Equation (5) is simply reduced to:

$$\Delta y_{it} = a_{0i} + a_{1i}t + \delta_i y_{it-1} + \varepsilon_{it}., \ I=1, \cdots, N; \ t=1, \cdots, T. \quad (6)$$

Since v_{it} appears to follow an *AR*(1) process, the lagged difference in y_{it} is not included in the specification (6). Furthermore, we find that the optimal lag length is 0 except for one region, using the method offered by Campbell and Perron (1991).

We apply Dickey-Fuller tests to each regional income series by estimating equation (6) for each region. As presented in Table 1, the null hypothesis of a unit root (*i.e.*, $\delta_i=0$) is rejected for only

[5] If, for example, $q=2$, equation (5) reduces to the following Augmented Dickey-Fuller type equation:
$\Delta y_{it} = \alpha_i(1-a_{1i}-a_{2i}) + \beta_i(a_{1i}+2a_{2i}) + \beta_i(1-a_{1i}-a_{2i})t - (1-a_{1i}-a_{2i})y_{it-1} - a_{2i}\Delta y_{it-1} + \varepsilon_{it}.$

TABLE 1

THE DICKEY-FULLER TEST RESULTS FOR SINGLE TIME-SERIES

Region	DF statistics
City of Seoul	-3.1831
City of Pusan	-4.4138***
Kyunggi Province	-1.8075
Kwangwon Province	-2.4551
Chungbuk Province	-1.4197
Chungnam Province	-1.7713
Chonbuk Province	-2.5016
Chonnam Province	-1.8546
Kyungbuk Province	-3.8224**
Kyungnam Province	-2.9668
Cheju Province	-3.4093*

Note: The asterisks * (**, ***) indicate significance at 10 (5, 1) percent level respectively. The critical values are -3.2239, -3.5796, and -4.3226 respectively.

one region at the 1 percent significance level and for two regions at the 10 percent level. However, we can not reject the null hypothesis of a unit root for the remaining regions. Single unit root tests, at most, yield a mixed result about convergence in that a few regional incomes have tendency to converge, but most do not. We thus fail to obtain a decisive conclusion about convergence of regional incomes in Korea.

The results from a unit root test should be reconsidered since tests for a unit root are often criticized on the grounds to be lacking in power against alternatives close to one. It is widely known that unit root test results tend to be biased in favor of non-rejection of the null hypothesis of a unit root, especially for short time series. This implies that our results are likely to be biased toward non-convergence.

C. Panel Unit Root Tests

We apply various methods of panel unit root test instead of applying separate unit root tests to reinforce the tests power by increasing sample size. The null hypothesis is that each regional income contains a unit root, implying that each regional income diverges. Under the alternative hypothesis, all the regional incomes, taken as a group, are assumed to be stationary. The rejection of the null hypothesis thus suggests that all regional incomes tend to converge.

We evaluate the null hypothesis that $\delta_i=0$ and $a_{1i}=0$ against the alternative hypothesis that $\delta_i<0$ and $a_{1i}\neq 0$ for all i. According to the test procedures proposed by Levin and Lin (1993), we estimate the following auxiliary equations:

$$\begin{aligned} e_{it} &= \Delta y_{it} - a_{0i} - a_{1i}t \\ \xi_{it-1} &= y_{it-1} - a_{0i} - a_{1i}t. \end{aligned} \tag{7}$$

Now regress the orthogonalized innovations $\tilde{e}_{it}$ on the orthogonalized lagged innovations $\tilde{\xi}_{it}$:

$$\tilde{e}_{it} = \delta_i \tilde{\xi}_{it-1} + \varepsilon_{it} \tag{8}$$

where $\tilde{e}_{it}$ and $\tilde{\xi}_{it-1}$ are the normalized equivalents of regressed values of equation (7), $\hat{e}_{it}$ and $\hat{\xi}_{it-1}$.[6] Under the null hypothesis, Levin and Lin demonstrate that the adjusted value of the regression t statistic, t_δ^* has a standard normal distribution asymptotically.

The calculated t_δ^* is 2.5038, which rejects the null hypothesis at the 5% significance level. This implies that regional incomes are stationary around a constant and a time trend.

The major limitation of the Levin-Lin method is the assumption that δ_i is the same for all cross-sections. The null hypothesis makes sense, but the alternative is too strong under our framework. To test the convergence hypothesis, one can formulate the null hypothesis as implying that none of the regional incomes in Korea converges to its steady-state level, and thus $\delta_i=0$ for all regions. But it does not make any sense to assume that all the regions have the same process for transitory shocks.

Im, Pesaran, and Shin (1996) relax the assumption that δ_i is the same for all individuals under the alternative hypothesis. They propose the *LR*-bar test based on the average of log-likelihood ratio statistics, and the *t*-bar test based on the average of ADF

[6]We normalize $\hat{e}_{it}$ and $\hat{\xi}_{it}$ by the standard error from the regression, $\hat{e}_{it}=\delta_i \hat{\xi}_{it-1}+\varepsilon_{it}$.

t-statistics computed for each group in the panel. They demonstrate that for the small sample both tests are superior to the Levin-Lin test,[7] with the t-bar test performing marginally better than the LR-bar test.

The log-likelihood function of equation (6) is:

$$l_i(\alpha_{0i}, \alpha_{1i}, \delta_i, \sigma_i^2) = -\frac{T}{2}\log 2\pi\sigma_i^2 - \frac{1}{2\sigma_i^2}\sum_{t=1}^{T}(\Delta y_{it} - \alpha_{0i} - \alpha_{1i}t - \delta_i y_{it-1})^2. \qquad (9)$$

Let LR_i be the log-likelihood ratio statistic for testing the null hypothesis $\alpha_{1i}=0$ of and $\delta_i=0$ against the alternative hypothesis of $\delta_i<0$ for some i.[8] Then

$$LR_i = 2[l_i(\hat{\alpha}_{0i}, \hat{\alpha}_{1i}, \hat{\delta}_i, \hat{\sigma}_i^2) - l_i(\tilde{\alpha}_{0i}, 0, 0, \tilde{\sigma}_i^2)] = T\log\left(\frac{\tilde{\sigma}_i^2}{\hat{\sigma}_i^2}\right) \qquad (10)$$

where $\hat{\alpha}_{0i}, \hat{\alpha}_{1i}, \hat{\delta}_i$ are the unrestricted maximum likelihood estimators, and $\tilde{\alpha}_{0i}$ is the restricted maximum likelihood estimator. In equation (10),

$$\hat{\sigma}_i^2 = \frac{1}{T}\sum_{t=1}^{T}(\Delta y_{it} - \hat{\alpha}_{0i} - \hat{\alpha}_{1i}t - \hat{\delta}_i y_{it-1})^2 \text{ and } \tilde{\sigma}_i^2 = \frac{1}{T}\sum_{t=1}^{T}(\Delta y_{it} - \tilde{\alpha}_{0i})^2.$$

Therefore, we have the average of N individual log-likelihood ratio statistics such as $\overline{LR} = 1/N\sum_{i=1}^{T} LR_i$. The distribution of $\overline{LR}$ is presented in Im, Pesaran, and Shin (1996).

Table 2 presents the log-likelihood of the unrestricted and the restricted models of each individual series, $\overline{LR}$, and $\bar{t}$ statistics. The estimate of $\overline{LR}$ is 8.4263, which rejects the null hypothesis at the 1% significance level.

Alternatively, the $\bar{t}$ test is based on the average of DF unit root t statistics. The individual t statistic is:

[7] However, since the alternative is different, the power comparison between Levin-Lin and Im-Pesaran-Shin tests is not valid.

[8] Karlsson and Löthgren (2000) clarify that the alternative hypothesis of IPS test is that at least one of the individual series in the panel is stationary.

TABLE 2

$\overline{LR}$ AND $\overline{t}$ TEST RESULTS

Region	Log likelihood of restricted model	Log likelihood of unrestricted model
City of Seoul	38.0365	42.8966
City of Pusan	52.5504	61.4362
Kyunggi Province	58.4947	61.4239
Kwangwon Province	45.8142	48.8996
Chungbuk Province	43.6104	45.6698
Chungnam Province	53.7465	56.3443
Chonbuk Province	40.9337	44.1295
Chonnam Province	50.2319	52.3757
Kyungbuk Province	52.3981	59.0189
Kyungnam Province	43.0961	47.7128
Cheju Province	31.0206	36.3704
$\overline{LR}$ statistics=8.4263**	$\overline{t}$ statistics= −2.6914**	

Note: The asterisk ** indicates significance at 5 percent level. The critical value for $\overline{LR}$ is 7.0436 while that for $\overline{t}$ is-2.5892.

$$t_i=\frac{\hat{\delta}_i}{\sqrt{s_i^2(\sum_{t=1}^{T} y_{it-1}^2)^{-1}}},\quad I=1,\ \cdots\ ,N, \tag{11}$$

where $s_i^2=1/(T-3)\sum_{t=1}^{T}(\Delta y_{it}-\hat{\alpha}_{0i}-\hat{\alpha}_{1i}t-\hat{\delta}_i y_{it-1})^2$. We can define the average of the N individual DF t statistics by $\overline{t}=1/N\sum_{i=1}^{N} t_i$. The critical values of the $\overline{t}$ statistic are tabulated in Im, Pesaran, and Shin (1996). The calculated $\overline{t}$ in Table 2 is −2.6914, which rejects the null hypothesis at the 5 percent level.

Both $\overline{LR}$ and $\overline{t}$ test results thus indicate that the null hypothesis of non-convergence is rejected at the conventional significance level. We, therefore, conclude that some regional incomes have tendency toward convergence.

IV. Concluding Remarks

The ongoing debate on convergence important issue in economic growth theories. Numerous studies have investigated whether incomes converge across countries and across regions. This paper is test for convergence using the Korean regional income data.

We employ a panel unit-root test method to enhance the test power. The Levin-Lin test result suggests the rejection of the null hypothesis of non-convergence, implying that shocks to relative regional incomes are temporary. We conclude from this finding that, in a rapidly growing economy such as Korea, regional incomes have tendency to converge to their steady-state levels. Our evidence therefore supports one of basic implications of neoclassical growth models.

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