The Process of Convergence among the Japanese Prefectures: 1955 - 2012.

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Abstract

The paper analyzes the convergence process in Japan by time series analysis and the existence of clubs of convergence by finding if they are endogenously conformed.

We follow a two-stage approach. The first one consists of the analysis of stochastic convergence. Secondly, prove the existence of clubs of convergence among prefectures. We find two clubs of convergence conformed endogenously. The first club is integrated by 40 prefectures converging slowly toward a unique steady state. Five prefectures integrate the second club of convergence. Finally, Tokyo and Nara are not converging toward any steady-state like disconnected prefectures.

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1. Introduction

The process of convergence among different economies toward a unique steady-state has been theoretically and methodologically discussed since the nineties. Romer (2006) argues that on the neoclassical growth model, the inverse relationship between the rate of return of capital and the abundance of this factor, as same as the speed of technology's adoption, is the main reason for the convergence process.

Barro and Sala-i-Martin (1991, 1992) extended the neoclassical model to explain that economies could converge conditionally not only to a single steady-state, but they could be conditioned to their steady states. Theoretically, the differences between steady-states are related not only to the macroeconomic variables or economic policies but also depends on the ability to absorb and adapt technologies. See Sala-i-Martin (1996). Notwithstanding, it might be more likely that regions inside the same country converge in an absolute manner towards the same path of growth due to the possible greater homogeneity that exists amongst them and not just because they share the same government.

Carlino and Mills (1993) try to analyze the process of convergence amongst the American states by using an innovative methodology: time series analysis (unit root test) in contrast with the Panel Data and Cross Section models applied by other authors. They can analyze the presence of stochastic and β-convergence among the states [2]. They find evidence of stochastic convergence among the American states during 1929-1990.

A next plausible stage of analysis concerning the convergence process is to look into the possibility of having something between absolute and conditional convergence, which would mean probably not all regions inside a country converge toward a unique steady-state nor their own. On the contrary, some of them might converge to one steady-state, and others would tend towards another one. This fact brings us to the concept of clubs of convergence.

By following the objective of an analysis of the convergence process and clubs of convergence, this research examines the possibility of stochastic convergence using tests of unit root with and without structural breaks. As a second step, we identify clubs of

[2] Theoretically, the stochastic convergence implies temporary shocks on the main variable. On the other hand, β-convergence means that poor regions eventually might catch up rich regions by growing up faster than them. In this sense, β-convergence includes the possibility of absolute or relative convergence.

convergence among the Japanese Prefectures applying a methodology suggested by Phillips and Sul (2007).

In comparison with other researches, the main contribution of this paper is the application of new econometric methodology recently applied to analyze the presence of convergence and clubs of convergence among countries but not inside them. These results will allow us, in the case of finding clubs, to determine the number of clubs and the Japanese prefectures that are strongly connected and included in those clubs.

The results can be used as inputs for policies of economic deconcentration and decentralization looking for better regional policies. In that sense, the questions that guide this research are:

- Do subnational economies converge to a unique path of growth in the long-term (steady-state)? If convergence is not possible, could it be possible that a group of prefectures form clubs of convergence?
- Is there a break among the Real GDP per capita evolution for each prefecture? If there is, when did that break happen?
- If it is possible to prove the existence of clubs of convergence, how many clubs of convergence could be found? Which prefectures are forming them?

Therefore, this research's objectives are two-fold. First, the convergence process inside Japan can be analyzed by following two different concepts: the first one consists on the analysis of the existence of stochastic convergence, which allows us to analyze the presence of β-convergence and explore the possibility that prefectural economies with lower Real GDP per capita reach the highest ones. Secondly, it examines the existence of clubs of convergence for the Japanese Prefectures. This procedure is possible when the absence of absolute β-convergence is proved and allows us to search for clubs with different levels of steady states for each club.

This article is divided into the following sections: Section 2 shows the literature review, Section 3 corresponds to the methodology, Section 4 presents the stylized facts and results, and finally, in Section 5, the conclusions of this research are presented.

2. Literature Review

Concerning the classical approaches, we have the theories of Barro and Sala-i-Martin (1991, 2004) and Sala-i-Martin (1996) who found, in an analysis of the US, evidence of absolute convergence among its States for the period 1880 – 2000, a phenomenon which has been sustained for sub-periods of ten years. Sala-i-Martin (1996) finds evidence of β-convergence for the period between 1950-1990 for five countries (Germany, France, United Kingdom, Italy, and Spain) of the OECD (Organization for Economic Cooperation and Development) and also amongst those countries. Barro and Sala-i-Martin (2004) analyze all 47 Japanese Prefectures and find evidence of β-convergence between 1930 and 1990; however, due to the presence of outliers and relevant structural breaks, it was not possible to corroborate the robustness of the β-convergence in sub-periods[3].

Nagaraj et al. (1998) find evidence of conditional convergence inside the regions of India between 1960-94 by using Panel Data and Instrumental Variables models, as well as convergence among the States that share similar financial characteristics of infrastructure and education[4].

For the case of Latin America, Serra et al. (2006) following the model of Barro and Sala-i-Martin (2004) and a Panel Data estimation, they do not find relevant evidence of regional convergence in the last 30 years. Argentinian regions do not converge, while the regions of Brazil, Colombia, and Chile do converge in an absolute manner but with weakness in statistical terms. Cabrera-Castellano (2002) finds absolute β-convergence for the period between 1970-1995 in Mexico. For Peru, Delgado and Del Pozo (2008) do not find evidence of absolute convergence amongst provinces between 1970 – 2008. However, they show some evidence of relative convergence in sub-periods.

Fukao et al. (2015) analyze the presence of β-convergence for the case of Japan between 1955-2008. They find evidence that the Total Factor Productivity (TFP) is the leading cause of inequality among the prefectural average incomes. However, the β-convergence is held during this period, basically due to poorer prefectures have higher gross saving ratios, and they received private capital inflows and/or government capital transfers. Nevertheless, they are not able to find evidence of convergence or club of convergence even if they find

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[3] Other important references on the subject are: Barro (1991), Mankiw et al. (1992), Lichtenberg (1994), Bernard and Durlauf (1995), De la Fuente (2003), and Quah (1997).

[4] Other references on this matter are Siriopulus and Asterieu (1997), Mitchener and Mc. Lean (1999), Duncan and Fuentes (2005), and Elias (1995).

evidence of inequality among the Japanese Prefectures.

In contrast to the Cross Section and Panel Data models applied for many authors to analyze the convergence process, Carlino and Mills (1993) show the existence of β-convergence in the regional per capita incomes in the States of the US for the period between 1929-1990 using techniques of the time series approach. They obtain evidence of persistent shocks in per capita incomes since it was not possible for them to reject the null hypothesis of a unit root in the series. Nevertheless, when they incorporate the possibility of a structural breaking point in 1946, they get results that are consistent with the existence of stochastic β-convergence accompanied by transitory shocks in the per capita incomes. Loewy and Papell (1996) perform tests of unit root to the series of per capita income in eight regions of the United States, and they incorporate the possibility of an unknown structural breaking point. Finally, they find favorable evidence of the presence of stochastic convergence in seven out of eight regions in the US.

From the clubs of convergence perspective, Phillips and Sul (2009) show evidence of β-convergence and clubs of convergence for a set of countries and the US by applying econometric tools developed by them in 2007. The authors incorporate the possibility of heterogeneity in the patterns of growth as a consequence of technological disparities. They use three panels for their study: the first one uses 48 states of the US between 1929 and 1998; the second consists of 127 countries between 1950 and 2001, and the third includes 152 countries from 1970 to 2003 and 98 countries from 1960 to 2003. They do not find evidence of absolute convergence for the states of the US. For the case of the second and third panel, the authors find evidence of five clubs of convergence.

For the case of Japan, Shibamoto et al. (2016), by using a Panel Cointegration approach, find evidence of no convergence among the Japanese prefectures. However, by applying the cointegration methodology, there is evidence of heterogeneous long-run growth paths. Furthermore, they classified the prefectures in follower and leader ones, and they are assumed as clubs with the possibility of convergence among them. Finally, they highlight the effect of TFP, Labor productivity, and Real Capital on the convergence process.

3. Methodology

3.1. Concept of Convergence

The neoclassical models based on Solow (1956) propone a concept of convergence;

countries per capita income converge toward a single steady state. This concept is known as "absolute convergence". However, if the parameters estimated for this convergence process are not the same, the absolute convergence is not holding, on the contrary, each country converges toward their steady-state. This concept is known as "conditional convergence". Those concepts have been analyzed by using Cross Section and Panel Data models by authors as Barro and Sala-i-Martin (1991, 1992), Barro (1991), and so on.

Nevertheless, under the time series approach, two new concepts arise: stochastic and β-convergence. Carlino and Mills (1993) propose that the convergence is held only if the stochastic and β-convergence are proved. The idea of stochastic convergence refers to the shocks on the income gap among countries or regions that must be temporal. β-convergence, on the other hand, implies that countries with higher income levels must growth slower than poorer countries. In this way, the time series analysis results are convenient since they allow us to detect the presence of transitory shocks and analyze if higher income regions' growth is slower than poorer ones by applying unit root test over the income gaps among countries or regions.

3.2. Stochastic Convergence

We present different statistics necessary to verify the hypothesis of stochastic convergence among the Japanese prefectures between 1955–2012. Initially, we present statistics of unit root without a structural break such as the standard ADF (Said and Dickey, 1984), ADF-GLS and PT-GLS (Elliott et al., 1996), and the MPT-GLS (Ng and Perron, 2001). Next, tests of unit root with endogenous break suggested by Zivot and Andrews (1992) is used.

Following Carlino and Mills (1993), let y_t be the logarithm of the ratio of the GDP per capita for one prefecture for the average GDP per capita of the country (Japan). We assume the existence of an invariant compensation along the time of the difference for the series for their equilibrium levels in the long run for each prefecture to the national average. Under that assumption, y_t possesses two parts: the differential equilibrium in the long run, y^e; and the deviations in the series for the equilibrium in the long run, e_t (this occurs for each prefecture; however, we omit the sub-index *i* to simplify the notation):

$$y_t = y^e + e_t \,. \qquad (1)$$

The deviation of the product to its equilibrium level is consistent with a functional form with intercept and deterministic trend as follows:

$$e_t = v_0 + \beta t + u_t, \qquad (2)$$

where v_0 is the initial deviation from equilibrium, and β is the deterministic rate of convergence. By using equations (1) and (2), we obtain:

$$y_t = \mu + \beta t + u_t, \qquad (3)$$

where $\mu = y^e + v_0$. The stochastic convergence requires that if a prefecture is above the initial level of equilibrium (roughly the initial level of real GDP per capita) to its long term value, i.e., μ>0; then the prefecture should grow at a rate lower than the national average, i.e., β<0. Similarly, if μ<0, then β>0. In this way, the hypothesis of the presence of β-convergence can be corroborated.

The equation cannot be interpreted directly since u_t is a random process serially correlated and could be an integrated process of order one, that is, I(1)[5]. More precisely, when u_t is a process I(0) the inference of β can be obtained from the estimation of the slope. However, if u_t is a process I(1) we need to transform the equation (3) into a first differentiated equation where that coefficient of the slope would be zero and the inference should be found from the estimation of the intercept (i.e., β) in an autoregressive new representation of y_t. In this differentiated version of equation (3), we cannot keep discussing stochastic convergence as before; nevertheless, we can discuss the growth rate dynamics shown among prefectures.

In this way, the statistics of unit root help to identify the presence of stochastic convergence. If the stationary process is corroborated, then the prefectures converge to a unique stationary state (the concept of absolute convergence). On the contrary, under the presence of unit root, the series converges towards a different steady-state, which would corroborate the existence of conditional convergence. Nevertheless, it is necessary to consider the possibility of structural breaks as part of the temporal behavior of the series. Thus, it becomes essential to make tests of unit root under the context of series without and with a structural break.

3.3. Clubs of Convergence

Phillips and Sul (2007) allow for incorporating the possibility of cross-sectional heterogeneity of technical progress in the neoclassical growth model. They incorporate time-varying

[5] A process I(1) makes reference to a series that needs to be differentiated once to be transformed into a stationary series.

heterogeneity by including technological advancement in the function $A_{it} = A_{i0}e^{x_{it}t}$, where the growth rate of technological progress differs due to x_{it}, which varies throughout prefectures and time. Then, the individual transition path of the log of real per capita income, $logy_{it}$, depends on the parameter of technological progress, x_{it}, so we have:

$$logy_{it} = logy_i^* + [logy_{i0} - logy_i^*]e^{-\beta_{it}t} + x_{it}t, \quad , \qquad (4)^6$$

where log indicates natural logarithm, y_i^* denotes the steady-state level of real GDP per capita, y_{i0} is the initial level of the real GDP per capita, x_{it} is the growth rate of technical progress over time and β_{it} denotes the convergence speed, which is changing among the time. From equation (4):

$$logy_{it} = logy_i^* + logA_{i0} + [logy_{i0} - logy_i^*]e^{-\beta_{it}t} + x_{it}t = a_{it} + x_{it}t, \qquad (5)$$

where $a_{it} = logy_i^* + logA_{i0} + [logy_{i0} - logy_i^*]e^{-\beta_{it}t}$. Then, when $t \to \infty$, $a_{it} \to logy_i^* + logA_{i0}$.

Phillips and Sul (2007) thereby modified the equation in the following way:

$$logy_{it} = \left(\frac{a_{it} + x_{it}t}{\mu_t}\right)\mu_t = \delta_{it}\mu_t, \qquad (6)$$

where δ_{it} is the weight of the common trend (μ_t) experienced by the prefecture *i*. In general, the idiosyncratic component δ_{it} captures the individual transition path of a prefecture to the common steady-state determined by μ_t.

The estimation of δ_{it} is not feasible unless we incorporate some smoother or structural restrictions since the unknown variables are the same as observations. The alternative suggested by the authors for modeling the transition elements δ_{it} is:

$$h_{it} = \frac{logy_{it}}{N^{-1}\sum_{i=1}^{N} logy_{it}} = \frac{\delta_{it}}{N^{-1}\sum_{i=1}^{N} \delta_{it}}, \qquad (7)$$

where N is the number of prefectures. The variable h_{it} draws an individual trajectory for each prefecture "i" relative to the average, h_{it} is called “relative transition path”. In this way, any divergence cause of μ_t is reflected on the transition path h_{it}.

For the formulation of the null hypothesis of growth convergence, we use a semi-parametric model for the transition coefficients, which can incorporate technological heterogeneity over time among individuals. The model is determined as follows:

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6 See Phillip and Sul (2007).

$$\delta_{it} = \delta_i + \frac{\sigma_i \xi_{it}}{L(t)t^{\alpha}}, \qquad (8)$$

where δ_i is fixed, $\xi_{it} \sim i.i.d.(0,1)$ over "i", however, it might be weekly dependent on t, and $L(t)$ is a smoothly varying function (as $logt$) and $L(t) \to \infty$ when $t \to \infty$. The parameter α is the deceleration rate, i.e., the individual variation rate when the transition component converges toward zero through the time. This fact assures that δ_{it} converges to δ_i for all the values of $\alpha \geq 0$, which is the main null hypothesis. If the null hypothesis is not rejected and $\delta_i = \delta_j$, for any $i \neq j$, the model allows transition periods with $\delta_{it} \neq \delta_{jt}$, which means the model can incorporate the possibility of transitional heterogeneity or transitional divergence across i, i.e., the model can incorporate the chance of having temporal divergence and a following convergence process. Therefore, the null hypothesis would be considered:

$$H_0: \qquad \delta_i = \delta \;\&\; \alpha \geq 0,$$

which implies weak inequality of $\alpha \geq 0$, since:

$$\lim_{t\to\infty} \delta_{it} = \delta \;\; if\ and\ only\ if\ \delta_i = \delta \ and\ \alpha \geq 0,$$
$$\lim_{t\to\infty} \delta_{it} \neq \delta \;\; if\ and\ only\ if\ \delta_i \neq \delta \ and\ \alpha < 0.$$

The alternative hypothesis would be represented by:

H_a:{ $\delta_i = \delta \;\; \forall \;\; i$ with $\alpha < 0$} or {$\delta_i \neq \delta$ for some i, with $\alpha \geq 0$, or $\alpha < 0$}.

The main role of $L(t)$ is to assure that the convergence holds even when $\alpha = 0$, however, that convergence rate might be very slow. The alternative hypothesis includes divergence but also the possibility of having clubs of convergence.

Corresponding to the equation (8), Phillips and Sul (2007) shows that the transition distance H_t have the following limiting form $H_t \sim \frac{A}{L(t)^2 t^{2\alpha}}$ as $t \to \infty$ for some positive constant A. Then by equaling $L(t) = \log(1+t)$, the log t regression model takes the following form:

$$log\left(\frac{H_1}{H_t}\right) - 2logL(t) = a + blogt + u_t, \quad \text{for t=T}_0\text{,...,T}, \qquad (9)$$

where $H_t = N^{-1}\sum_{i=1}^{N}\left(\hat{h}_{it} - 1\right)^2$, $\hat{h}_{it} = \frac{logy_{it}}{N^{-1}\sum_{i=1}^{N} logy_{it}}$, $L(t) = \log(1+t)$, and the fitted coefficient of log *t* is $b = 2\alpha$. In the equation, log *t* regression is based on time-series data in which we discard the first 30% of the data as it is recommended by Phillip and Sul (2009). On the left side of the equation, the term -2logL(t) is the penalty function, and it will improve the statistic's performance under the null hypothesis[7].

Under the null hypothesis of convergence, the estimated parameter *b* convergence in probability to the speed of convergence parameter 2α. The corresponding t-statistic on the regression is calculated using heteroskedasticity and autocorrelation consistent error (HAC). The convergence test works as a one-tail t-test with $\alpha \geq 0$. Under the alternative hypothesis of growth divergence or clubs of convergence, at 1%, the null hypothesis is rejected if $t_{\hat{b}} < -2.345$.

To extract the long-run component required on the procedure, we employ the Hodrick-Prescott smoothing filter. As the authors mention, the filter is convenient for its flexibility and suitable when the time series are short.

As for the procedure itself, once we have the filtered times series of the GDP per capita to be used, we apply the log-t equation to obtain the coefficients that will help us to interpret the convergence process inside each club. When $\alpha \geq 0$, we observe a convergence process at a positive rate even if a temporal divergence is shown on the data; in this case, it is called a transition convergence process inside a club. Secondly, when $\alpha = 0$, the convergence can be held, but possibly at a prolonged rate, called slow convergence process. Finally, when $\alpha < 0$, we have a divergence process among the prefectures analyzed.

The algorithm of estimation can be summarized in the following four steps:

1. Sorting: Sort the members of the data under certain criteria, such as the average of the GDP per capita by prefecture from the highest to the lowest one.

2. Core Group Formation: Finding member subgroups estimating panel regression log *t* for *k* individuals with the highest levels of GDP per capita with $2 \leq k \leq N$, and calculate the t-statistic. The members of the subgroup are chosen based on the condition $\min\{t_k\} > -1.65$ at 5% of the significance level.

3. Filtration of individuals to form clubs: Add a new member to the *k* members chosen in step 2 and rerun the log t convergence test. Then compare the performance of the test log *t*. i.e., check if the b estimator is significant. If the estimator change to be insignificant, we stop adding more members to the conformed club. (see equation 9).

7 See Philipps and Sul (2009, p.1168).

4. Stop or detention Rule: To estimate a regression log *t* for the remaining members on the panel and check if the convergence criteria hold. That is, if a group with the remaining members hold the test log *t*, then those members are the second club of convergence. Otherwise, repeat steps 1 through 3, observing whether the remaining members can be subdivided into other convergence clubs. If any group can be formed in step 2, then those members have different behavior.

4. Data Sources, Stylized Facts, and Empirical Evidence

4.1 Data Sources

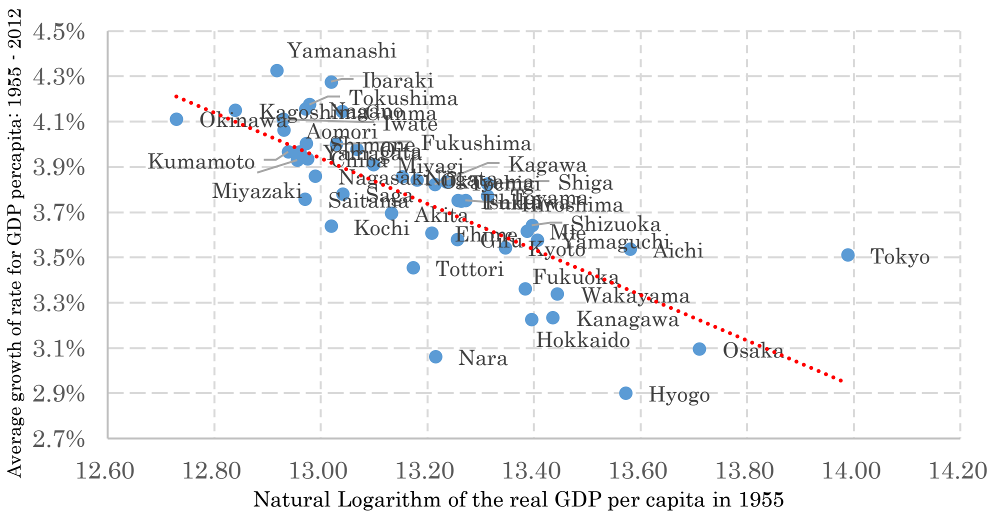
The data used in this research is the Gross Domestic Product by Prefecture from 1955 to 2012, extract from the database of the Statistic Bureau from the Minister of Internal Affairs and Communications of Japan. Additionally, to make the corresponding concatenation of the data and to transform it into real values, we use the Deflator of the GDP obtain from the same source and compare it with the information provided by the World Development Indicators (World Bank).

4.2 Stylized Facts

During its process of development between 1955 – 2012, Japan has shown many stages regarding growth's real GDP, which also impacted strongly in its prefectures' economic performance and their process of convergence. On its first stage until 1973, the average growth rate was 8.5% per year. After a big contraction in 1974, on its second stage, the growth rate dropped to 4.2% average per year between 1975-1991. Nevertheless, the average growth rate dropped again on its third stage toward 1.1%, 1992-2012. During this period, not only the ability of the country to increase its Real GDP was affected, but also the economic ability of its subnational economies (prefectures) were affected by the slowdown evolution of the national economy and the internal dynamics that exist among Prefectures.

To analyze the convergence phenomenon, Figure 1 displays the existing relationship of the natural logarithm of GDP per capita in 1955 against the mean rate of growth for 1955 to 2012 for each prefecture. A negative correlation is shown between both variables. This fact is evidence of a possible convergence among the Japanese prefectures. Under this hypothesis, there is a possibility that prefectural economies imply a pattern of convergence towards a unique path of national growth where the poorer prefectures reach the richer ones. Nonetheless, we observe that prefectures such as Nara, Hyogo, and Tokyo, lie far from the fitted line. This fact can indicate an economic performance disconnected from the rest of the country, which in turn weakens the evidence of convergence.

Figure 1: Convergence relationship



Source: Ministry of Internal Affairs and Communications

4.2 Empirical Evidence

In this section, we display the results of the econometric analysis for the hypothesis of stochastic convergence among the Japanese prefectures as well as the possibility to get clubs of convergence among prefectures. It is essential to mention the database was constructed using as sources the Ministry of Internal Affairs and Communications.

Table 1 presents the result of the statistics for Augmented Dickey-Fuller (ADF, 1979), Dickey-Fuller GLD detrending (DF-GLS, Said and Dickey, (1984)), Elliot, Rothenberg, and Stock (ERS, 1996), and Ng-Perron (2001). In most cases, the null hypothesis of the presence of unit root cannot be rejected in favor of the possibility of the presence of unit root for all the prefectural series from 1955 to 2012 except for Toyama, Ishikawa, and Aichi. This fact let us reject the idea of stochastic convergence among the Japanese prefectures among the time. In other words, each prefecture does not grow toward the same long-run level of GDP per capita or same steady-state (we are defining the steady-state or long-run level of GDP as the average national GDP per capita). Nonetheless, for the case of Aichi, Ishikawa and Toyama prefectures it is possible to reject the null hypothesis of unit root, it means that these prefectures have been converging to the long-run level of real GDP per capita under the most of the test used on the table.

Table 1: Unit Root Test by Prefecture: 1955-2012

Prefecture	ADF – stat Test Value	ADF – stat Lag	CR	ADF–GLS – stat Test Value	ADF–GLS – stat Lag	ERS – stat Test Value	ERS – stat Lag	Ng–Perron – stat Test Value	Ng–Perron – stat Lag
Hokkaido	−3.16	0		−1.979	0	22.649	0	15.49	0
Aomori	−3.046	0		−2.716	0	9.375	0	8.145	0
Iwate	−2.543	0		−2.52	0	8.782	0	8.813	0
Miyagi	−1.56	0		−1.594	0	18.469	0	19.114	0
Akita	−2.766	0		−2.151	0	15.302	0	12.005	0
Yamagata	−1.637	0		−1.702	0	15.882	0	16.415	0
Fukushima	−1.471	0		−1.417	0	23.088	0	22.158	0
Ibaraki	−1.726	2		−1.596	2	20.902	2	19.573	2
Tochigi	−1.127	2		−1.403	2	44.736	2	40.051	2
Gunma	−1.647	2		−2.03	3	66.595	2	13.451	3
Saitama	−3.061	2		−2.049	1	26.671	2	16.657	1
Chiba	−1.58	0		−1.314	0	30.346	0	27.387	0
Tokyo	−2.294	0		−1.609	0	28.386	0	22.857	0
Kanagawa	−3.372 [c]	0	C	−1.977	0	24.831	0	16.42	0
Niigata	−2.72	0		−2.734	0	7.605	0	7.733	0
Toyama	−3.463 [c]	0	C	−3.512 [b]	0	5.308 [b]	0	5.463 [b]	0
Ishikawa	−4.032 [b]	1	C	−4.130 [a]	1	3.579 [a]	1	3.680 [a]	1
Fukui	−2.151	4		−1.839	0	12.13	4	16.837	0
Yamanashi	−1.74	0		−1.779	0	14.852	0	14.901	0
Nagano	−1.292	0		−0.997	0	36.972	0	30.494	0
Gifu	−1.659	8		−1.145	8	27.836	8	58.182	8
Shizuoka	−1.638	1		−1.661	1	17.327	1	17.286	1
Aichi	−4.279 [a]	0	C	−3.921 [a]	0	5.372 [b]	0	4.847 [b]	0
Mie	−0.552	5		−0.921	4	63.422	5	34.567	4
Shiga	−2.017	0		−2.066	0	11.597	0	11.68	0
Kyoto	−1.257	3		−1.693	3	14.361	3	12.354	3
Osaka	−1.672	1		−1.741	0	17.508	1	16.525	0
Hyogo	−3.079	1		−1.739	1	23.416	1	15.969	1
Nara	−1.827	0		−1.441	0	26.819	0	22.875	0
Wakayama	−0.221	5		−1.115	0	42.591	5	23.097	0

Tottori	−1.518	0		−1.24	0	32.11	0	28.09	0
Shimane	−2.812	1		−2.249	1	11.295	1	9.487	1
Okayama	−1.672	0		−1.436	0	25.088	0	22.681	0
Hiroshima	−2.553	1		−1.876	0	36.144	1	17.998	0
Yamaguchi	−1.663	2		−1.931	2	24.271	2	19.708	2
Tokushima	−1.824	0		−1.881	0	13.419	0	13.44	0
Kagawa	−1.889	0		−1.826	0	15.373	0	15.075	0
Ehime	−1.311	4		−1.211	4	27.849	4	24.082	4
Kochi	−1.918	0		−1.962	0	12.731	0	13.173	0
Fukuoka	−1.83	0		−1.61	0	20.46	0	18.557	0
Saga	−2.741	0		−2.299	0	12.437	0	10.701	0
Nagasaki	−2.254	0		−2.336	4	20.512	0	4.938 [b]	4
Kumamoto	−1.761	5		−2.536	3	22.056	5	8.806	3
Oita	−3.264 [c]	0	C	−2.8	0	9.046	0	7.748	0
Miyazaki	−3.481 [c]	0	C	−2.548	0	13.061	0	9.478	0
Kagoshima	−2.469	0		−2.015	1	23.196	0	11.158	1
Okinawa	−1.909	4		−2.271	2	10.619	4	7.639	2
stat−1% level	−4.1273			−3.7434		4.2264		4.03	
stat−5% level	−3.4907			−3.1676		5.7072		5.48	
stat−10% level	−3.1739			−2.869		6.7732		6.67	

(*) supra-index "a", "b" and "c" indicates significance at 1%, 5%, and 10%, respectively. (**) In all cases, we choose the Lag Length using AIC indicator with a maximum lag length of 10. (***) In the case of ADF-stat, the column "CR" (Convergence Relationship) refers to the relationship between the intercept and trend estimated parameters. "C" = both of them have an inverse relationship in favor of convergence, and they are significant at least at 10%.
Source: Prepare by the Authors based on the data obtained from the Japanese Ministry of Internal Affairs and Communications

For the case of Zivot and Andrews test (1992), they make the breakpoint as an endogenous factor, building a null hypothesis of a unit-root process without any structural break, on the other hand, the relevant alternative is a trend-stationary process with structural changes at an unknown point. By applying the test, we show that for 26 prefectures, the null hypothesis is rejected (Table 2), i.e., for those prefectures, the series is stationary with a significant structural break. This fact implies the presence of stochastic convergence for most of the Japanese prefectures between 1955 – 2012 when we incorporate the possibility of break into them. On the other hand, for 21 prefectures, the null hypothesis cannot be rejected, i.e., they show a unit-root process without a structural break. This means that either prefectures do not converge to the same steady-state level, or they just diverge to the steady-state.

Table 2: Zivot and Andrews Test (1992): 1955-2012

Prefecture	Test value	Lags	Break	Model
Hokkaido	−4.135	2	1990	$z_t = \{1, 1(t \geq T_B)\}$
Aomori	−3.858	0	1974	$z_t = \{1, 1(t \geq T_B)\}$
Iwate	−4.043	3	1972	$z_t = \{1, 1(t \geq T_B)\}$
Miyagi	−4.494	3	1971	$z_t = \{1, 1(t \geq T_B)\}$
Akita	−4.955 [c]	3	1993	$z_t = \{1, 1(t \geq T_B), t, 1(t \geq T_B)(t - T_B)\}$
Yamagata	−4.598 [c]	0	1973	$z_t = \{1, 1(t \geq T_B)\}$
Fukushima	−4.895 [c]	0	1972	$z_t = \{1, 1(t \geq T_B)\}$
Ibaraki	−5.046 [c]	0	1974	$z_t = \{1, 1(t \geq T_B), t, 1(t \geq T_B)(t - T_B)\}$
Tochigi	−5.120 [b]	2	1978	$z_t = \{1, 1(t \geq T_B), t, 1(t \geq T_B)(t - T_B)\}$
Gunma	−3.750	3	1975	$z_t = \{1, 1(t \geq T_B)\}$
Saitama	−6.412 [a]	13	2001	$z_t = \{1, 1(t \geq T_B), t, 1(t \geq T_B)(t - T_B)\}$
Chiba	−5.985 [a]	10	1986	$z_t = \{1, 1(t \geq T_B), t, 1(t \geq T_B)(t - T_B)\}$
Tokyo	−4.378	3	1981	$z_t = \{1, 1(t \geq T_B)\}$
Kanagawa	−6.853 [a]	0	1971	$z_t = \{1, 1(t \geq T_B), t, 1(t \geq T_B)(t - T_B)\}$
Niigata	−5.174 [b]	4	1974	$z_t = \{1, 1(t \geq T_B), t, 1(t \geq T_B)(t - T_B)\}$
Toyama	−4.409	0	1973	$z_t = \{1, 1(t \geq T_B)\}$
Ishikawa	−4.413	0	1993	$z_t = \{1, 1(t \geq T_B)\}$
Fukui	−4.416	0	1974	$z_t = \{1, 1(t \geq T_B)\}$
Yamanashi	−5.074 [c]	0	1983	$z_t = \{1, 1(t \geq T_B), t, 1(t \geq T_B)(t - T_B)\}$
Nagano	−2.775	0	2001	$z_t = \{1, 1(t \geq T_B)\}$
Gifu	−3.953	8	1981	$z_t = \{1, 1(t \geq T_B)\}$
Shizuoka	−4.487 [b]	1	1973	$z_t = \{1, t, 1(t \geq T_B)(t - T_B)\}$
Aichi	−4.961 [a]	0	1966	$z_t = \{1, t, 1(t \geq T_B)(t - T_B)\}$
Mie	−5.580 [a]	4	1987	$z_t = \{1, 1(t \geq T_B), t, 1(t \geq T_B)(t - T_B)\}$
Shiga	−3.451	0	1969	$z_t = \{1, 1(t \geq T_B)\}$
Kyoto	−5.598 [a]	0	2001	$z_t = \{1, 1(t \geq T_B), t, 1(t \geq T_B)(t - T_B)\}$
Osaka	−4.064	0	1990	$z_t = \{1, 1(t \geq T_B)\}$
Hyogo	−4.364	0	1988	$z_t = \{1, 1(t \geq T_B)\}$
Nara	−4.314	0	1971	$z_t = \{1, 1(t \geq T_B)\}$
Wakayama	−3.617	0	1975	$z_t = \{1, 1(t \geq T_B)\}$
Tottori	−4.052	0	1971	$z_t = \{1, 1(t \geq T_B)\}$
Shimane	−4.283	0	1973	$z_t = \{1, 1(t \geq T_B)\}$
Okayama	−5.118 [b]	0	1972	$z_t = \{1, 1(t \geq T_B), t, 1(t \geq T_B)(t - T_B)\}$

Hiroshima	−4.892 [c]	9	1993	$z_t = \{1, 1(t \geq T_B)\}$
Yamaguchi	−4.801 [a]	2	1994	$z_t = \{1, t, 1(t \geq T_B)(t - T_B)\}$
Tokushima	−3.569	0	1984	$z_t = \{1, 1(t \geq T_B)\}$
Kagawa	−4.199 [c]	7	2004	$z_t = \{1, t, 1(t \geq T_B)(t - T_B)\}$
Ehime	−5.181 [b]	0	1985	$z_t = \{1, 1(t \geq T_B), t, 1(t \geq T_B)(t - T_B)\}$
Kochi	−3.152	1	1971	$z_t = \{1, 1(t \geq T_B)\}$
Fukuoka	−5.830 [a]	7	1983	$z_t = \{1, 1(t \geq T_B), t, 1(t \geq T_B)(t - T_B)\}$
Saga	−4.363 [b]	3	1979	$z_t = \{1, t, 1(t \geq T_B)(t - T_B)\}$
Nagasaki	−5.692 [a]	10	1986	$z_t = \{1, 1(t \geq T_B), t, 1(t \geq T_B)(t - T_B)\}$
Kumamoto	−5.852 [a]	3	1971	$z_t = \{1, 1(t \geq T_B), t, 1(t \geq T_B)(t - T_B)\}$
Oita	−4.061	0	1969	$z_t = \{1, 1(t \geq T_B), t, 1(t \geq T_B)(t - T_B)\}$
Miyazaki	−5.204 [b]	1	1983	$z_t = \{1, 1(t \geq T_B), t, 1(t \geq T_B)(t - T_B)\}$
Kagoshima	−4.716 [c]	9	1974	$z_t = \{1, 1(t \geq T_B)\}$
Okinawa	−7.249 [a]	1	1972	$z_t = \{1, 1(t \geq T_B), t, 1(t \geq T_B)(t - T_B)\}$
	model A	model B	model C	
stat−1% level	−5.34	−4.8	−5.57	
stat−5% level	−4.93	−4.42	−5.08	
stat−10% level	−4.58	−4.11	−4.82	

(*) supra-index “a”, “b” and “c” indicates significance at 1%, 5%, and 10%, respectively.
Source: Prepare by the Authors based on the data obtained from the Japanese Ministry of Internal Affairs and Communications

The main limitation when we use the Zivot and Andrew test is the lack of robustness under the possibility of having integrated error (I(1)). It means, if the residuals are autocorrelated, the results are not robust. Consequently, it is not possible to conclude if the prefectures convergence toward the steady-state in a robust way. However, the evidence of no convergence in an absolute manner does not mean the possibility of getting convergence among groups of prefectures, i.e., clubs of convergence.

To sum up, the analysis of stochastic convergence with and without structural breaks only let us know if the prefectures analyzed might converge or not in an absolute manner. However, we are not able to clarify if a group of those prefectures convergence among them. In this sense, the next natural step is to analyze the presence of clubs of convergence under a proper methodology, i.e., Phillip and Sul (2007) methodology.

Finally, when we apply the test developed by Phillip and Sul (2007), we find evidence of two clubs of convergence. Table 3 shows the results of Logt estimation after contrasting the null hypothesis of absolute convergence and clubs of convergence among the prefectures. The null hypothesis of absolute convergence is rejected at 1% with a t-statistic of -19.409, less than 1% critical value, which is -2.345. As a result, we proceed to contrast the possible clubs of convergence for the prefectural GDP per capita by using the Phillip and Sul (2007, 2009) algorithm.

The clubs of convergence test shows the presence of two clubs of convergence. Forty prefectures compose the first one. The second club is formed by Hyogo, Chiba, Kumamoto, Kochi, and Saitama. On the other hand, Tokyo and Nara are not able to conform to a club of convergence, which means their GDP per capita diverges, probably, toward their steady-states.

To support the previous results, Table 3 also shows the estimated values of $\hat{b}$ and their standard errors for the Logt regression. Those results are robust with the presence of heteroskedasticity and autocorrelation (HAC model). For the whole country, the estimated value is $\hat{b} = -0.188$, which is significantly less than zero, implying no convergence evidence among all the prefectures used in the sample. Then the null hypothesis $(H_0: \delta_{it} = \delta_i \ \& \ \alpha \geq 0)$ is rejected. On the other hand, for Club 1, the estimated value of $\hat{b} = 0.098$ is positive and statistically more than zero, implying a process of convergence within the club members. If the common stochastic trend component by prefecture is a random walk with drift or a stationary process in trend, then the speed of convergence is significantly less than 2, so the hypothesis of a club of convergence cannot be rejected even if the rate of convergence is close to zero. For Club 2, the estimated value is $\hat{b} = 0.343$, which means that we have the same consequences as Club 1, a parameter that is positive and statistically more than zero with a process of convergence with the prefectures inside the club. Finally, for the group composed by Tokyo and Nara, the estimated value is $\hat{b} = -0.904$, negative, and statistically significant, which means there is no convergence inside the group, and both prefectures economies go toward their steady-states.

Table 3: Test of Phillip and Sul (2007): 1955-2012

Absolute Convergence Test, t-value at 1% is -2.345 and at 5% is -1.64

	Log *t*	**t-statistic**	**Prefectures**
Entire Country	-0.188	-19.409	

Clubs of Convergence Test, t-value at 1% is -2.345 and at 5% is -1.64

	Log *t*	**t-statistic**	**Prefectures**

First Club	0.098	9.973	Aichi, Osaka, Shizuoka, Shiga, Toyama, Fukui, Yamaguchi, Mie, Tochigi, Ibaraki, Hiroshima, Ishikawa, Gunma, Kyoto, Kagawa, Okayama, Yamanashi, Niigata, Tokushima, Nagano, Wakayama, Fukuoka, Oita, Gifu, Ehime, Miyagi, Fukushima, Kanagawa, Shimane, Hokkaido, Aomori, Akita, Iwata, Kagoshima, Saga, Yamagata, Miyazaki, Nagasaki, Tottori, Okinawa
Second Club	0.343	30.479	Hyogo, Chiba, Kumamoto, Kochi, Saitama
Prefectures that do not form a club	-0.904	-20.042	Tokyo, Nara

Source: Prepare by the Authors based on the data obtained from the Japanese Ministry of Internal Affairs and Communications

Furthermore, the level of the parameter $\hat{b}$ represents the average speed of convergence of each club. In this way, the club of convergence 1 has a slower speed rate of convergence compared to Club 2. The main reason is that Club 1 is composed of a larger number of prefectures compared to Club 2, i.e., the connection needed to go toward the same steady-state is more challenging to get in a club with as many members as we observe in Club 1.

Graphically, to support the previous results and to take as a reference to the paper of Hamit-Haggar (2013), Figure 2 shows the transition curves inside Club 1. It is possible to observe a slow trend toward a steady-state. Also, we see three phases on the convergence process: Phase 1 or first impulse, the prefectures display the first impulse of convergence or divergences toward the steady-state; Phase 2 or transition period, prefectures might show a change on their trends toward the steady-state; and finally, Phase 3 of the catch-up phase, prefectures catch up to the steady-state.

Since Club 1 is composed of 40 prefectures, we divided the graphics into four Figures to clearly show the process of convergence inside the club. Figure 2-a displays, for example, how the Aichi prefecture starts with a GDP per capita higher than the steady-state; however, it shows a clear convergence process even when the rate of convergence is slow. The opposite can be said for the Aomori prefecture. In Figure 2-b, it is possible to observe the three phases of convergence for the Kanagawa prefecture. Before 1962, Kanagawa had been displaying a divergence process. After 1962 the prefecture economy changed to a catching-up phase with a high speed of convergence toward the steady-state. In Figure 2-c, Osaka Prefecture displayed a similar behavior as Kanagawa Prefecture in Figure 2-b with a less remarkable change process. In Figure 2-d, Yamaguchi and Tottori prefectures showed a convergence process.

Furthermore, after the late nineties, those convergence processes were reversed toward a divergence phase. Since during this period, both prefectures' economies showed a convergence process, they were included in Club 1. Figure 3 displays the convergence process for all the prefecture economies inside Club 2. In this figure, Hyogo prefecture started over the steady-state and showed a fast convergence toward the long-run GDP per capita.

5. Conclusions

One of the objectives of this research was to analyze the presence of permanent shocks on relative GDP per capita regarding the national average. First, we performed unit root tests to contrast the presence of stochastic convergence, as a result, in most of the cases the null hypothesis was not rejected, implying no presence of stochastic convergence among Japanese prefectures. Then, we consider the possibility of endogenous breaks inside the prefectural real GDP per capita, which might distort the unit root tests applied and bias our preliminary results. After using the Zivot and Andrews analysis of unit root with the presence of endogenous structural break, in several cases, the null hypothesis was rejected. In other words, for 26 of 47 prefectures, there is evidence of stochastic convergence once we incorporate the presence of endogenous structural break; however, for 21 prefectures, the evidence is not clear, and we cannot discuss the existence of convergence in any sense. In this sense, the next step is to analyze if a club of convergence analysis gives us better and robust results than these previous time series analysis.

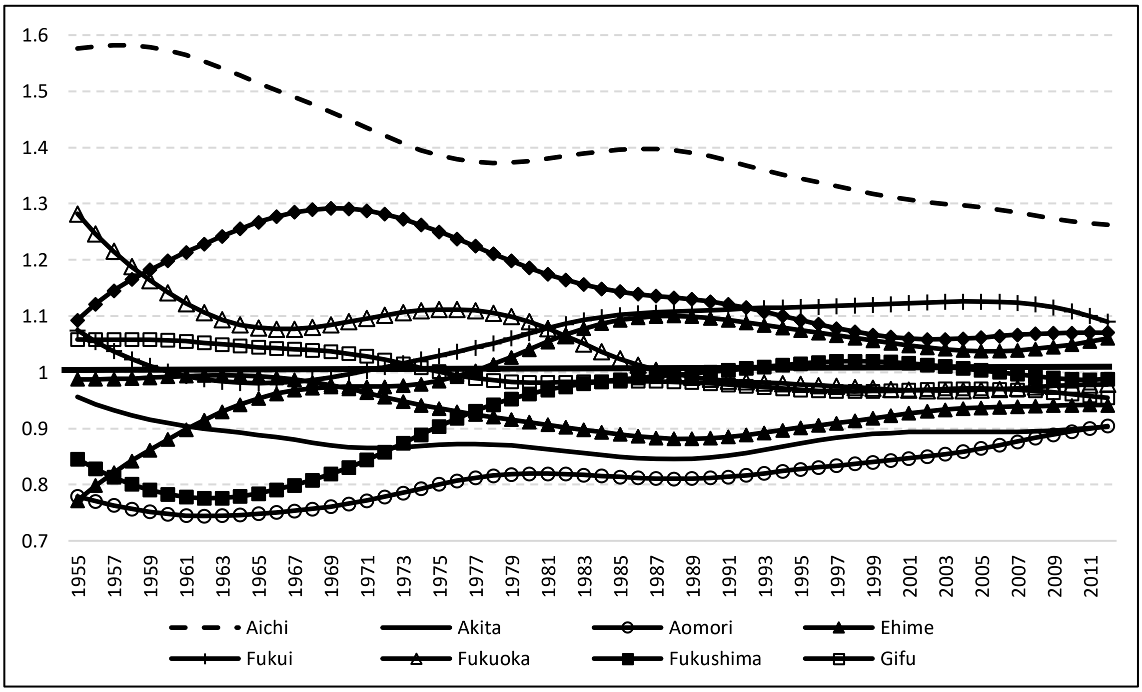
By using Phillip and Sul (2007, 2009), we left the assumption of homogeneity in technological adoption in favor of heterogeneity on it along with the prefectural economies. We were able to contrast the possibility of getting clubs of convergence among the prefectures. First, we rejected the null hypothesis of absolute convergence, supporting the previous results obtained with unit root tests. Then, we obtained the presence of two clubs of convergence. The first club of convergence composed of 40 prefectures, which showed a stable economic development with high levels of GDP per capita relative to other prefectures (except Tokyo prefecture which is not included in the first club of convergence), even when the speed of convergence was slow. The second club of convergence composed of 5 prefectures with middle GDP per capita levels and quite a high rate of convergence among them. Finally, we display the presence of a third group of prefectures, which do not converge toward a single steady state. Those prefectures were Tokyo and Nara; both of them do not present similar dynamics, which means they are not connected with the rest of the economy, implying particular internal dynamics.

The results showed in this paper contrast respect to Fukao et al. (2015) and Shibamoto et al. (2016) mainly since those papers do not reject the possibility to have clubs of convergence; even when they highlight the main variables that might affect the process of convergence among prefectures, they do not show any conformed club clearly. Nevertheless, our results make clear the presence of clubs of convergence after a time series analysis. These results are relevant, not only because of the new econometric methodology applied to the regional economic growth analysis but also because we look for important internal dynamics inside each club of convergence. As a first consequence of the presence of clubs of convergence, the assumption of heterogeneity on the technology adoption among the Japanese prefectures let us find clubs of convergence, so it seems to be a natural candidate of the primary driver of GPD per capita gaps among prefectures, i.e., there are essential singularities and disparities among them. As a second consequence, we can assume the presence of two levels of steady-state. The first one is a higher one inside Club 1 of convergence, where 40 prefectural economies converge. The second one is a middle steady-state level on the Club 2 of convergence, where five prefectural economies converge.

Finally, the analysis of convergence and the results obtained in this research are important as the first step for studies of convergence at a subnational level, and it might be useful for developing countries where the gaps among regions are critical. Regardless of the number of clubs, the output obtained is also a powerful policy tool to reduce disparities and promote development policies among regions.

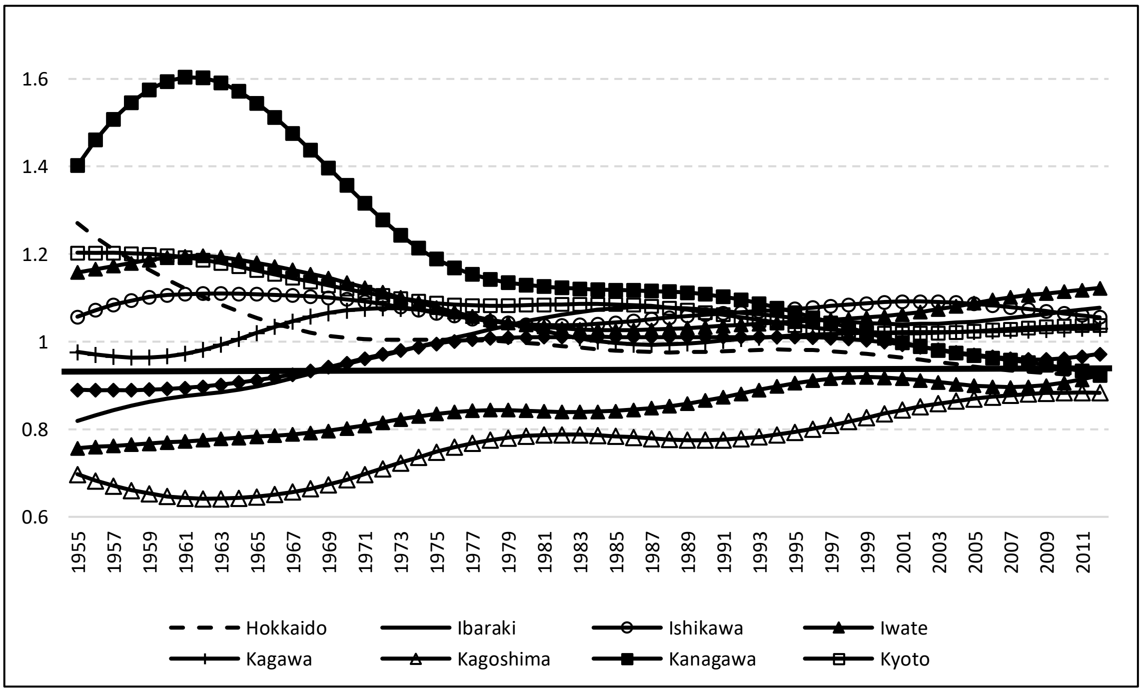
Appendix A

Figure 2a: Club 1 of convergence 1955 – 2012



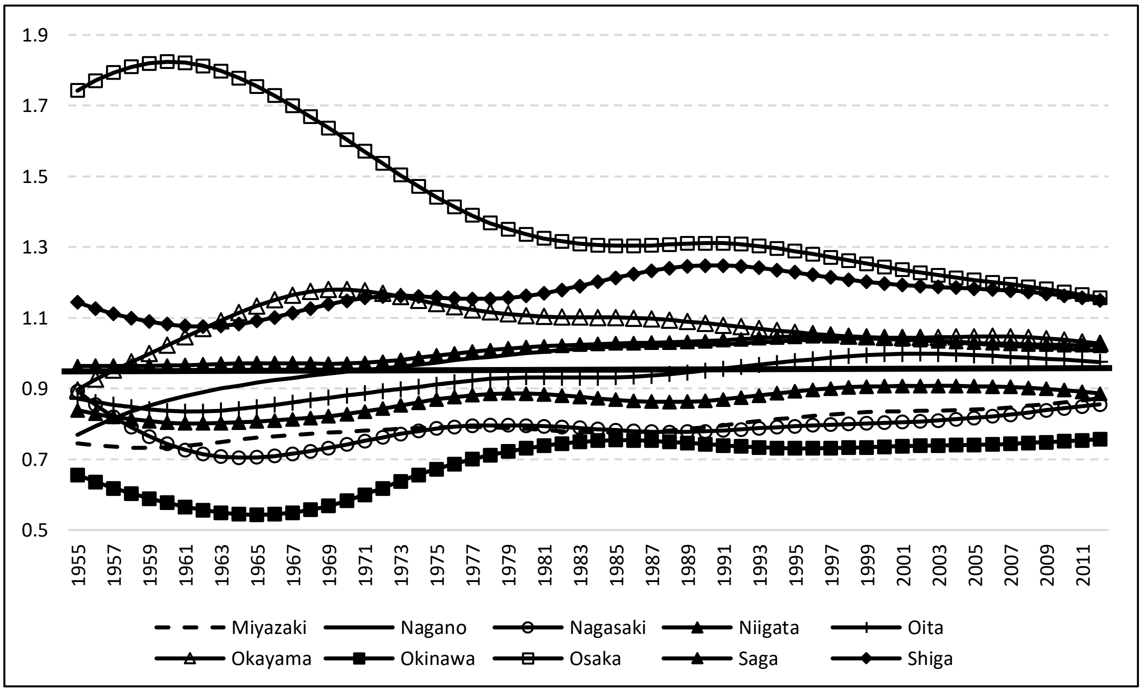
Source: Prepare by the Authors based on the data obtained from the Japanese Ministry of Internal Affairs and Communications

Figure 2b: Club 1 of convergence 1955 – 2012



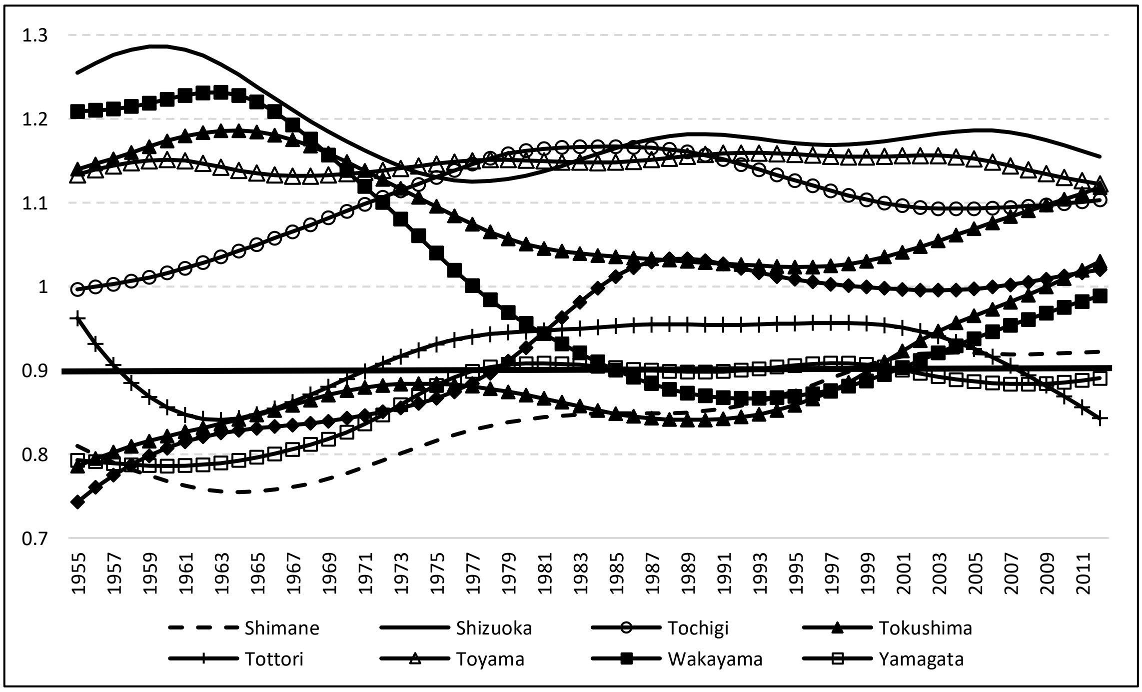
Source: Prepare by the Authors based on the data obtained from the Japanese Ministry of Internal Affairs and Communications

Figure 2c: Club 1 of convergence 1955 – 2012



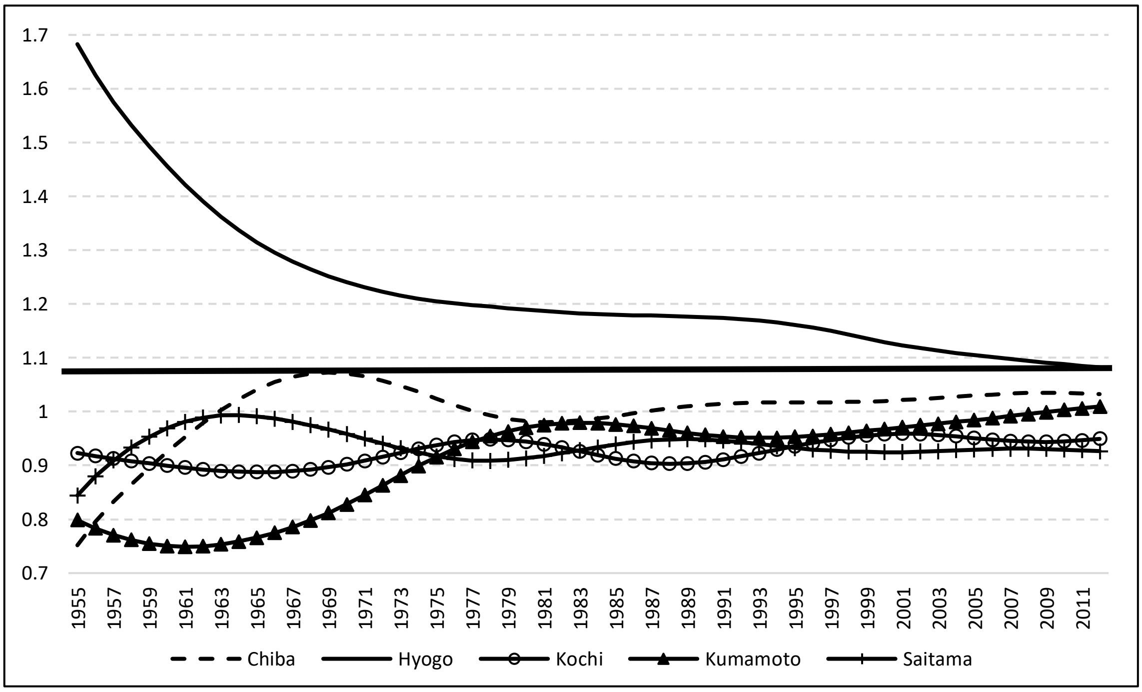
Source: Prepare by the Authors based on the data obtained from the Japanese Ministry of Internal Affairs and Communications

Figure 2d: Club 1 of convergence 1955 – 2012



Source: Prepare by the Authors based on the data obtained from the Japanese Ministry of Internal Affairs and Communications

Figure 3: Club 2 of convergence 1955 – 2012



Source: Prepare by the Authors based on the data obtained from the Japanese Ministry of Internal Affairs and Communications

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