REGIONAL CONVERGENCE: THEORY AND EMPIRICS

Stilianos ALEXIADIS *
Ministry of Rural Development & Foods, Department of Agricultural Policy & Documentation, Division of Agricultural Statistics, Room 519, 2 Acharnon Street, 104 32, Athens, Greece, Tel: ++30 210 2125925
salexiadis7@aim.com

Abstract
One of the most controversial issues in regional science is regional convergence. Do regions converge? Why the existing inequalities across regions persist overtime, despite some movements towards convergence. Such questions had bred an extensive literature. In this paper, a model of regional convergence focusing on technological factors is developed. This model is tested using data for the EU-27 regions. A possible explanation for these results is offered and suggests that might afford an interesting policy conclusion.
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1. Introduction

The debate on regional convergence has bred, and continues to do so, dozens of empirical studies. In this fast growing literature technological innovation has been acknowledged to be of critical importance in promoting regional convergence or sustaining existing inequalities across space. The relevant empirical studies have over-emphasised the role of capital accumulation at the *expense* of the diffusion of technology. It is the intention of this paper to develop a model that incorporates technology adoption. The rest of the paper is laid out as follows. The theoretical framework upon which the empirical analysis will be conducted is articulated in Section 2. Data related issues are overviewed in Section 3, and the models are submitted to the usual econometric tests yielding the main findings in Section 4. Section 5 concludes the paper.

2. Technological externalities

A major concern for regional economists is whether regional per-capita incomes tend to converge or diverge over the long-run. Differences in levels of technology concern both the creation of new technology and its adoption. Creation of technology promotes regional growth, since advances in technology are transformed into higher rates of productivity. However, not all regions are able to innovate and for those regions which lag behind, the alternative is the adoption of technological improvements. Thus, there is a possibility that these regions may converge or at least catch-up to some degree. If such regions are able to adopt technology, then they will exhibit a relatively faster rate of growth, ceteris paribus, and thereby experience a technological catch-up effect. Nevertheless a necessary condition for technological catch-up is that technologically lagging economies have an infrastructure and appropriate conditions that will allow the effective adoption of new technology (Abramovitz, 1986). Conditions related to the level of technology might be a satisfactory explanation for the observed fact that economic disparities across regions are persisting in the long-run.

Convergence can be seen as the tendency towards the reduction of income disparities, approximated in terms of GDP per-capita (or worker) or disposable income in a region. A useful starting point is the neoclassical theory, since the assumptions of this theory actually carry implications for the regional convergence/divergence debate. In the neoclassical model, a factor that promotes, and accelerates, regional convergence is the process of technology diffusion; a sort of 'entropic trend' towards spatial homogeneity (Camagni and Capello,

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2010). A central tenant of this model is that all regions are able to absorb technology to the same degree, so that the higher the technological-gap the higher the effect on growth, ceteris paribus. While the 'standard' model predicts absolute convergence, in the 'augmented' model, economies do not necessarily converge to the same 'steady-state' irrespective of their initial conditions. In this light, the 'augmented' neoclassical model introduces a new notion of convergence, conditional convergence. Sala-i-Martin (1996) claims that the concept of conditional convergence is encapsulated in the prediction of the neoclassical model that the growth rate of an economy will be positively related to the distance that separates it from its own steady-state. Generalising across a group of regional economies, the simple proposition that poor economies catch-up with rich economies no longer holds true. The latter prediction relies on the presence of common steady-state, so that initially poor economies which are further away from this steady-state will grow faster. It follows, therefore that, conditional convergence coincides with absolute convergence only if all the economies have the same steady-state.

Both forms of convergence, however, represent movements towards an equilibrium or 'steady-state' position. In order to examine the possibilities for non-convergence across regions, it is necessary to either assume certain conditions in the models do not hold, such as factors are not perfectly mobile, or to turn to alternative approaches to the analysis of regional growth, which do not rely on the concept of equilibrium. Alexiadis (2013) develops a model which implies a disequilibrium process. Whether regions converge towards a high or a low outcome depends on the degree to which infrastructure conditions are appropriate for the adoption of technological improvements.

The key feature in this model is that the rate of diffusion of technology (ε_i) is assumed to be a non-linear function of the technological gap (b_{lf}). Thus, $\varepsilon_i = \rho / b_{lf,i}^{\pi}$, with $\rho, \pi > 0$, implying that the rate of diffusion is not constant but varies across regions, according to the size of the gap. Thus, for a given value of ρ, a high technological gap implies a low capacity to absorb technology. The parameter ρ can be interpreted as a constant underlying rate of diffusion, which would apply to all economies if there were no infrastructure/ resource constraints upon technological adoption. However, the existence of such constraints causes the actual rate to diverge from ρ. In other words, the higher the technological gap, the slower the rate of technological diffusion (ε_i). Of critical importance is the parameter π, which determines the extent to which the existing gap, and implicitly therefore the existing infrastructure, impacts on the rate of diffusion. This parameter can be viewed as a measure of the appropriateness or suitability of regional infrastructure to adopt technology. As $b_{lf,i} \to \infty$, $\varepsilon_i \to 0$, i.e. for a region with a high b_{lf}, the rate of diffusion is low, severely limited by a lack of appropriate infrastructure conditions. Conversely, as $b_{lf,i} \to 0$ then $\varepsilon_i \to \infty$. The implications of modelling the rate of diffusion in this way can be seen by a simple expression for the rate of change in the technological gap: $\dot{b}_{lf} = \gamma\theta_{lf} - \rho b_{lf}^{(1-\pi)}$, where θ is the proportion of output to innovation. In equilibrium $\dot{b}_{lf} = 0$ so that $\gamma\theta_{lf} = \rho b_{lf}^{(1-\pi)}$, implying $b_{lf}^{*} = [(\gamma / \rho)\theta_{lf}]^{1/(1-\pi)}$. If $\pi = 0$, then $\varepsilon_i = \rho$ and the diffusion of technology occurs at a constant autonomous rate (ρ), while if $\pi = 1$ the size of b_{lf} changes in accordance with the rate is unrelated in the process of technological diffusion depends on the productivity of innovation and the constant rate of diffusion (if $\pi = 1$, then $\dot{b}_{lf} = \gamma\theta_{lf} - \rho$). Two distinct patterns of convergence arise when $\pi < 1$ and when $\pi > 1$. When $b_{lf} - b_{lf}^{*} < 0$, the dynamics of the system cause $b_{lf} \to b_{lf}^{*}$, since the rate of innovation outweighs the effect of technology diffusion and $\dot{b}_{lf_i} > 0 \; \forall i \in [0 \;\; b_{lf}^{*}]$. Conversely, when $b_{lf} - b_{lf}^{*} > 0$, there is movement towards equilibrium since $\dot{b}_{lf_i} < 0 \; \forall i \in [b_{lf}^{*} \;\; \infty]$. Convergence towards a single equilibrium is also possible if $\pi < 1$ but regions with unfavourable infrastructure conditions reflected in a large technological gap move towards equilibrium at a slower pace. However, if $\pi > 1$, then convergence towards a unique equilibrium, for all but the leading region, is no longer the case, and b_{lf}^{*} represents a threshold value. Consider an economy divided into three regions, one 'leader' and two followers. Convergence with the leading region at a terminal time (T) requires that $b_{lf,T} = 0$. However, a zero gap with the leader is not feasible by definition. Hence, a more realistic condition would be $b_{lf,T-0} \to 0$. For simplicity assume $\theta_1 - \theta_2 = 0$, so that $\theta_{lf,1} - \theta_{lf,2} = 0 \wedge \gamma_1 = \gamma_2$. It is also assumed that ρ is the same for both regions. If, however, the initial technological gaps differ between these regions ($b_{lf,1} < b_{lf}^* < b_{lf,2}$), then region 1 is able to close the technological gap with the leader at a faster rate than region 2. Despite a lower rate of innovation compared to the leader, this region is able to adopt technology from the leading region and it is this latter effect which dominates. However, region 2, with a high gap and hence poor infrastructure conditions exhibits too slow a rate of technology absorption and, as a result, the gap with the leader increases over time. Region 1 and the leading region constitute an *exclusive* convergence-club, which includes any region with a technological gap in the range $(0, b_{lf}^*]$ while regions in the range $[b_{lf}^*, \infty)$ diverge from the leader and the remaining regions. In this light, b_{lf}^* is not an 'equilibrium' level for the technology gap, but rather a 'threshold' level, which distinguishes between converging and non-converging regions and spatial inequalities may persist or even increase, so that income distribution becomes polarised. Nevertheless, the important point to grasp is that this model imposes a non-linear process of technological diffusion that depends on infrastructure conditions as embodied in the size of the gap at a point in time. If the adoption of technology is related in a particular way to the size of the initial technological gap and associated infrastructure conditions, then two groups of regions can emerge; one which is a convergence club while a second group that does not exhibit an 'equilibrium'. Whether a region belongs to the convergence-club depends on its capacity to adopt technology, and this capacity declines the higher the initial technology gap. A high technological gap might indicate that they lack the necessary conditions to allow for an effective adoption of technology. Investment in regions with high adaptive abilities will increase their growth rates and the growth of the economy as a whole. Regions with low adaptive ability, on the other hand, will experience a fall in their growth rates, widening the gap in regional incomes.

Convergence theory provides a framework that can be applied empirically in order to give specific answers to specific problems. Convergence regressions can be a valuable tool for policy-making. The fundamental issue behind the convergence debate is the extent to which there is increasing or decreasing inequality among economies. 'Inequality' is typically measured by reference to the distribution of per-capita income or output across countries or regions. In a very broad sense, therefore, one would expect changes in the distribution of income across economies to be a focus for attempts to measure convergence. Barro and Sala-i-Martin (1995) define convergence as a decline in income inequalities over time. This hypothesis can be examined by means of a regression equation. Thus,

$$g_i = a + by_{i,0} + \varepsilon_i \tag{1}$$

where $y_{i,0}$ is the natural logarithm of output per-worker at some initial time, a is the constant term, which represents the steady-state growth rate, b is the convergence coefficient and ε_i is the random error-term. The parameter b reflects the partial correlation between the growth rate and the initial level of output per-worker and its sign indicates whether economies, on average, are converging or not. The condition for convergence requires that $\partial g_i / \partial y_{i,0} \equiv f'_{g_i, y_{i,0}} = b < 0$. Following Barro and Sala-i-Martin (1992) $b = -(1 - e^{-\beta T})$, implying $\beta = -[\ln(b+1)]/T$, where T is the number of years included in the period of analysis. If $b < 0$ then $\beta > 0$, i.e. a higher β corresponds to more rapid convergence. Employing equation (1) using various data sets, Sala-i-Martin (1996) estimates a 'surprisingly' similar rate of convergence across both regional and national economies, and forms the 'mnemonic rule' that 'economies converge at a speed of about two percent per year.' (p. 1326). This means that on average, 2% of the gap in income per capita between two regions is eliminated so that it takes more than 30 years to eliminate one half of the initial gap in per capita incomes.

Another frequently used notion is that of 'conditional convergence' (Barro and Sala-i-Martin, 1992), which is based upon the argument that different regional characteristics will lead to different steady-states: $g_i = a + b_1 y_{i,0} + b_2 \mathbf{X_i} + \varepsilon_i$, where $\mathbf{X_i}$ represents a vector of variables to control for differences across regions[1].

Absolute (unconditional) convergence is signalised by $b_1 < 0 \wedge b_2 = 0$ while conditional convergence $b_1 < 0 \wedge b_2 \neq 0$. Having selected appropriate variables to represent the institutional, structural, preference and environmental variables that characterise the steady-state value of per-capita income it remains the case that convergence is said to be occurring when higher initial levels of per-capita income are associated with lower rates of growth, over a given time period.

As acknowledged by Abramovitz (1986), technological progress is driven not only by indigenous innovation but also by the process of absorption of new technologies. More specifically, the possibility of imitating, at low cost, technologies developed elsewhere should allow poor regions to grow faster than rich ones, ceteris paribus – the 'technological catch-up effect'. In the empirical application, the relative extent of technology adoption capacity is approximated by the share of a region's resources found in such sectors. In other words, this approach involves identifying technically dynamic sectors, which are perceived to be the most receptive to innovation and its utilisation. In this paper a region's level of adoption capacity is measured as the percentage of total employment in technologically dynamic sectors, which include manufacturing activities such as aerospace and services such as computer and related activities. More formally, $ADP_{i,t} = \sum_{\rho=1}^{k} \eta_{i,t}^{\rho} / \sum_{j=1}^{m} L_{i,t}^{j}$, where $\eta_{i,t}^{\rho}$ refers to personnel employed in high-tech manufacturing and knowledge-intensive high-technology services ($\rho = 1, \ldots, k$), while $L_{i,t}^{j}$ is total employment ($j = 1, \ldots, m$) in a region. The presence of technologically dynamic sectors in a regional economy, represents the level of technological development, but also, indicates a capacity for technology adoption, since these are taken to be the most technologically dynamic and advanced sectors. However, the potential for such technology diffusion increases as the technological gap increases, defined as the distance between a region's technological level and that of the most advanced technological region. Consequently, in this context a variable that approximates the technological gap for region i at time t can be defined as $TG_{i,t} = ADP_{L,t} - ADP_{i,t}$, where the subscript L refers to the leading-region, defined as the region with the highest percentage of employment in high-tech manufacturing and knowledge-intensive high-technology services during the initial year of the analysis. Embodied in this variable is the idea of both a gap and the capacity to adopt and implement technological innovations. A model of conditional convergence seems to be a suitable way to test for technological catch-up. Thus,

$$g_i = a + b_1 y_{i,0} + b_2 TG_{i,0} + \varepsilon_i \quad (2)$$

The presence of a technological-gap alone is not sufficient to promote significant technology diffusion. There has to be an appropriate level of capability to adopt technology. Thus, the bigger the gap the greater the potential for technology adoption, but the lower the capacity to actually achieve this.

In the case of the $TG_{i,0}$ variable, this variable reflects two distinct features, namely the level of 'technological distance' from the leading region and the degree to which existing (initial) conditions in a region allow adoption of technology. A high initial technological gap combined with a high rate of growth may indicate, ceteris paribus, that less advanced regions are able to adopt technology, which is transformed into high growth rates and, subsequently, convergence with the technologically regions. It may be argued, therefore, that the condition $b_3 > 0$ promotes convergence. On the other hand, a high initial value for $TG_{i,0}$ may indicate

1 Usually country dummies are included. The reason for this is country dummies capture country-specific determinants of spatial inequality (e.g. geographic factors such as fragmentations, mountains, coasts, deserts, etc.) which are determinants of spatial inequality, but difficult to consider in an econometric analysis which focuses on the variation in time. In contrast to the cross-section estimations, panel regressions concentrate on within-country variations, which are important because they consider the dynamics of structural changes. Panel data analysis allows considering country fixed effects, eliminating unobserved country heterogeneity (Lessmann, 2014).

that although there is significant potential for technology adoption, initial infrastructure conditions are not appropriate to technology adoption and, therefore, there are no significant impacts on growth. In other words, if $b_3 < 0$, then convergence between technologically lagging and technologically advanced regions is not feasible.

3. Some indicative empirics

Having outlined the empirical context in terms of the methodology and variables to be employed, the next step forward is to apply these to an investigation of the pattern of regional growth in Europe. The spatial units used in this paper are those delineated by EUROSTAT and refer to 270 NUTS-2 regions of 27 member countries in the EU. The EU uses NUTS-2[2] regions as 'targets' for convergence, defined as the 'geographical level at which the persistence or disappearance of unacceptable inequalities should be measured' (Boldrin and Canova, 2001, p. 212).

Despite considerable objections to the use of NUTS-2 regions as the appropriate spatial level for the assessment of convergence, they are nevertheless sufficiently small to be able to capture sub-national variations (Fischer and Stirböck, 2006). The growth of regional economies is measured using data on Gross Value-Added (GVA) per worker since this measure is a major component of differences in the economic performance of regions and is a direct outcome of the various factors that determine regional competitiveness (Martin, 2001).

The time period for the analysis extends from 1995 to 2014. This might be considered as rather short but Islam (1995), and Durlauf and Quah (1999), point out that convergence-regressions are valid for shorter time periods, since they are based on an approximation around the steady-state and are supposed to capture the dynamics toward the steady-state. The cross-section test for absolute is applied to the period 1995-2014. While these techniques have a number of statistical limitations, they are good at pin-pointing general trends and are relatively straightforward to interpret.

All results are presented in Table 1, and include the absolute convergence model and the technological-gap convergence.

Table 1. Regional Convergence, EU-27 NUTS-2 Regions, 1995-2014

	Equation (1)	Equation (2)
Depended Variable: g_i, n = 270 NUTS-2 Regions, Ordinary Least Squares		
a	1.95931**	2.20895**
b_1	−0.388593**	−0.418166**
b_2		−0.131488**
Implied β	2.4599	2.7078
Adjusted R^2	0.652107	0.705145
LIK	37.96280	60.79799
AIC	−71.92561	−115.5960
SBC	−64.72877	−104.8007
Diagnostic tests		
Ramsey RESET specification test[1]	8.0261 [0.0049]	2.55256 [0.11130]
White test for Heteroscedasticity[2]	20.9511 [0.0000]	39.0333 [0.00000]
Breusch-Pagan test for Heteroscedasticity[2]	36.4301 [0.0000]	39.0314 [0.00000]
Koenker test for Heteroscedasticity[2]	20.9455 [0.0000]	38.5747 [0.00000]
Test for Normality of the residuals[3]	18.5151 [0.0000]	10.9272 [0.00423]

Notes: 1. Null Hypothesis: Specification is adequate. 2. Null Hypothesis: Heteroscedasticity is not present. 3. Null hypothesis: Error is normally distributed. For each diagnostic test, the associated statistics together with the p-values are reported. ***, **, * significant at 1%, 5% and 10%, respectively.

[2] NUTS-2 regions differ considerably in terms of. On the one end, there is the Finnish island of Åland with a mere 25,000 inhabitants, and on the other, the Isle de France with a population of more than 10 million. In some cases, one and the same region pertains to NUTS-0, NUTS-1 and NUTS-2.

As can be seen from Table 1, there is a statistically significant inverse relationship between the rate of growth and the level of per-capita income at the start of the period. The estimated rate of convergence is about 2.5 per annum, close to the 'stylised fact' by Barro and Sala-i-martin (1992). While the explanatory variable has the expected sign and the estimated coefficient is highly significant, nevertheless, the various diagnostic tests indicate serious problems. To be more specific, the Ramsey test accepts the Ha hypothesis, i.e. that equation (1) is not adequate to explain the process of regional convergence in the EU. A model of absolute convergence might be of limited value, at least in the case of the NUTS-2 regions, since the heteroscedasticity tests accept the alternative hypothesis. Moreover, the errors are not normally distributed, given that that the test accepts the alternative hypothesis at the usual levels of significance. Based on that evidence, therefore, the property of absolute convergence does not characterise the European regions, irrespective of the primary evidence. This can be considered as evidence that the alternative hypothesis, namely conditional convergence, might explain regional inequalities in the EU in a more appropriate manner. Estimating equation (2) gives some support to this hypothesis. Indeed, both variables have the expected signs. It is important to note that although conditional convergence implies a lower rate of convergence, nevertheless, the introduction of the variable describing technology adoption increases the rate of convergence, although marginally. This is somehow expected given that the $TG_{i,0}$ variable encapsulates the impact of technological gap, which is an obstacle to convergence and the potential for technology adoption, a factor enhancing the process of regional convergence. The variable $TG_{i,0}$ is statistically significant and negative in sign. A high technological gap does not necessarily imply that technologically lagging regions will be able to adopt technology - a large gap may constitute an obstacle to convergence. This proposition is supported by the empirical analysis which suggests that, on average, regions with high technological gaps at the start of the period grow slower than regions with low gaps, ceteris paribus. Clearly, this is a factor that helps to sustain initial differences across regions, constraining any possibilities for sustainable growth. If technologically backward regions were successful in adopting technology, then the estimated coefficient b_2 would be positive. Since $\hat{b}_2 < 0$ this indicates that infrastructure conditions in regions with high technological gaps are inhibiting this process of technology adoption. Another important feature of the estimation procedure is that the superiority of the model described by equation (2) is supported by both the criteria for model selection applied here, namely the Akaike (AIC) and the Schwartz-Bayesian (SBC) information criteria. This provides support to the hypothesis the process of regional convergence in Europe is limited by substantial differences in the levels of technology adoption; a claim that is supported also by the Ramsey test, which accepts the Ho hypothesis that the specification given be equation (2) is adequate. The heteroscedasticiy and Normality tests, however, cast serious doubts on that hypothesis.

The conventional tests for convergence using cross section data is modified to take into account the relative *size* of each region. The population of each region can be used as the diagonal element in a weighting non-singular positive defined matrix $\mathbf{W}_{n\times n}$, with zero off-diagonal elements. Thus,

$$\mathbf{W}_{n\times n} = \begin{bmatrix} p_{11} & 0 & \dots & 0 \\ 0 & p_{22} & \dots & 0 \\ \vdots & \vdots & \dots & \vdots \\ 0 & 0 & \dots & p_{nn} \end{bmatrix}, \text{ where } p_t = p_t / \sum p_i$$

The Weighted Least Square (WLS) estimator defined as $b_{k\times 1}^{WLS} = \left(Y'_{k\times n}\mathbf{W}'_{n\times n}\mathbf{W}_{n\times n}Y_{n\times k}\right)^{-1} Y'_{k\times n}\mathbf{W}'_{n\times n}\mathbf{W}_{n\times n} g_{n\times 1}$, implies an estimated covariance matrix of the form $V(b^{WLS}) = s_{WLS}^2\left(Y'\mathbf{W}'\mathbf{W}Y\right)^{-1}$. Although WLS approach is unable to solve the problems of parameter heterogeneity, omitted variables, outliers and endogeneity, is a powerful test for convergence as regions are allowed to have an influence on regression results analogous to their size, captured by the weight matrix $\mathbf{W}_{n\times n}$. This adjustment is considered to be an important one because the regions vary widely in terms of population within EU countries. In order to account for bias in the estimated variances of the coefficients, heteroscedasticity corrected t-ratios (heteroscedasticity consistent covariance matrix estimator) are used whenever indicated by the tests results (White, 1980). Estimating equations (1) and (2) using WLS gives the results on Table 2.

Table 2. Regional Convergence, EU-27 NUTS-2 Regions, 1995-2014

	Equation (1)	Equation (2)
Depended Variable: g_i, n = 270 NUTS-2 Regions, Weighted Least Squares		
a	1.98642***	2.24374***
b_1	-0.395682***	-0.42633***
b_2		-0.14117***
Implied β	2.5182	2.77853

The rate of absolute convergence implied by the WLS estimator is slightly faster, compared to that obtained by the applying the OLS method, confirming the hypothesis that the NUTS-2 regions of EU are in a process of convergence. Estimating the conditional model implies a rate of convergence almost 3% per annum. Although the process of technology adoption is a source of convergence for the EU regions, nevertheless, the existing technological gaps constrain this process to a considerable extent.

4. Conclusions

Economic geographers and regional economists have long been concerned with regional inequalities and thence with the issue of how far and in what ways policy intervention can help to reduce such inequalities. Regional policies have been in operation for almost fifty years, yet the regional differentials still remain. The convergence-divergence debate is not longer simply an academic debate when viewed in light of policy issues related to growth of the economy as a whole and reducing interregional inequalities. If one accepts the absolute convergence hypothesis, then one can assume that lagging regions will tend to grow faster and inequalities will be resolved in the long-run simply by improving the functioning of the market. If, on the other hand, there are substantial market imperfections, then market inefficiencies will result in interregional inequalities. A strategy for improving the regional distribution of income, along with increasing the growth rate of the economy as a whole depends on the nature of the original source of divergence. In this paper a source of divergence is detected, i.e. technology adoption. Estimating a model of 'technological convergence'; using data for the NUTS-2 regions of the EU-27, yields an important conclusion. The EU regions exhibit a faster rate of convergence after conditioning for regional differences in the degree of technology adoption and overall infrastructure conditions. In case the results can withstand further scrutiny (e.g. when including data for other countries, which may become available in the future), there are certainly important policy lessons to be learned about the working of technology adoption and the role of regional policy.

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