EUROPEAN SPATIAL RESEARCH AND POLICY
10.2478/s10105-010-0012-6
Volume 17 2010 Number 2

Stilianos ALEXIADIS*, George M. KORRES**

ADOPTION OF TECHNOLOGY AND REGIONAL CONVERGENCE IN EUROPE[1]

Abstract: This paper examines the pattern of convergence in labour productivity across regions due to their ability to adopt technology. Whether regions exhibit a pattern of convergence depends on the degree to which infrastructure conditions are appropriate for the adoption of technological improvements. The ability of a region to adopt or create technology is reflected in the percentage of its labour force employed in technologically dynamic sectors or, more generally, in the resources devoted to science and technology. A high percentage of labour employed in technologically advanced sectors leads a region to a pattern of convergence. This hypothesis is tested using data for the NUTS-2 regions of the EU-27 during the time period 1995–2006. The results suggest that adoption of technology has a significant and positive effect on regional convergence in Europe. The analysis is also shown to have important implications for the direction of regional policy in Europe. To be more specific, regional policies, in order to enhance regional growth and convergence, should encourage employment in advanced technological sectors.
Key words: technological catch-up, regional convergence, European regions.

1. INTRODUCTION

The debate on regional convergence has bred, and continues to do so, dozens of empirical studies. The majority of them examine regional convergence in Europe (e.g. Button and Pentecost, 1995; Neven and Gouyette, 1995; Ezcurra *et al.*,

* Stilianos ALEXIADIS, Department of Economics, University of Piraeus, Greece, e-mail: salexiadis7@aim.com
** George M. KORRES, Department of Geography, University of the Aegean, University Hill, Mitilene, Greece, e-mail: gkorres@geo.aegean.gr
[1] An earlier draft of this paper was presented for the 49th European Congress of the Regional Science Association International, 25–29th August 2009, Łódź, Poland.

2005, to name but a few), expressed in terms of a negative relation between growth rate and the initial level of *per capita* income or labour productivity. Although in this fast growing literature technological progress has been acknowledged to be of paramount importance in promoting convergence across regions, nevertheless, the impact of the *adoption* of technology has received less attention. Indeed, Bernard and Jones (1996) claim that empirical studies on convergence have over-emphasised the role of capital accumulation in generating convergence at the expense of the diffusion of technology. In particular, Bernard and Jones (1996, p. 1037) have succinctly put the argument as follows:

> To the extent that the *adoption* and accumulation of technologies is important for convergence, the empirical convergence literature is *misguided* [emphasis added].

Technological progress is driven not only by indigenous innovation but also by the process of technology absorption, and thus the ability of a region to 'catch-up' might substantially depend on its capacity to imitate and adopt innovations developed in more technologically advanced regions. Abramovitz (1986, p. 225) offers a lucid explanation of this phenomenon:

> Countries that are technologically backward have a potentiality for generating growth more rapid than that of more advanced countries, provided their social capabilities are sufficiently developed to permit successful exploitation of technologies already employed by the technological leaders.

In this paper a model is developed in an attempt to elucidate the impact of technology adoption in an extensive regional context, that of the NUTS 2 regions of the EU. Divided into five sections, the theoretical model is analysed in section 2. In section 3 the methods employed and the data used in the process of econometric estimations are discussed, followed by the presentation and a detailed account of the econometric results in section 4. In section 5 a possible explanation for the results obtained is offered, which might afford an interesting policy conclusion.

2. A MODEL OF TECHNOLOGICAL ADOPTION

Following the standard neoclassical model, a factor that accelerates regional convergence is technological progress and diffusion. A process of technology diffusion, however, is not a simple and automatic process. Instead, it requires that lagging economies should have the appropriate infrastructure or conditions to *adopt* or *absorb* the technological innovations. If 'social capabilities' or *infrastructure conditions* are not 'sufficiently developed' then it cannot be presumed that there is an 'advantage of backwardness' associated with a high technological gap.

However, several criticisms have been raised against the conclusions which such models have yielded, because of various simplifying assumptions underlying the results. At a more general level, a critical question arises: how do the overall infrastructure conditions affect the absorptive ability of a regional economy? This question can be stated alternatively as: what are the implications of a 'poor' or a 'superior' infrastructure for regional convergence? Therefore, it might prove more instructive to develop a model of regional convergence that encapsulates the impact of infrastructure in the absorptive ability of a regional economy.

This model is built upon the premise that regions are, by definition, open economies and technology evolves as a result of *interaction* between agents in each region.[2] Stated in alternative terms, technological growth in a given region is affected by improvements and innovation that take place in other regions. Denoting by E_i the growth of technology due to implementation of technologies developed in other regions, it is possible to express the growth of technology in a region i in terms of the following general function:

$$G_{A_i} = f(E_i) \text{ with } f'_{G_{A_i},E_i} > 0 \tag{1}$$

An essential assumption for the purpose of this paper is that technological growth is affected by the size of the *technological gap*. This can be defined as the difference between an exogenously determined best-practice frontier (X_i), and the prevailing level of technology in a region (A_i): $B_i = \frac{A_i}{X_i}$, or in logarithmic terms $b_i = a_i - x_i$. Thus

$$E_i = \tilde{E}_i B_i^{\sigma} \tag{2}$$

where $\tilde{E}_i$ denotes the autonomous part of technological growth while σ is a parameter.

Equations (1) and (2) can be written in linear form by taking logarithms as follows:

$$g_{A_i} = \dot{a}_i = \varepsilon_i \tag{3}$$

$$\varepsilon_i = \tilde{\varepsilon}_i + \sigma b_i \tag{4}$$

[2] For a more detailed presentation of this model see Alexiadis (2009), Alexiadis and Korres (2009).

Inserting equation (4) in (3) yields:

$$\dot{a}_i = \tilde{\varepsilon}_i + \sigma\varepsilon_i \tag{5}$$

The degree or the ability of a region to create and implement technological innovations is represented by σ, which can be conceived as a parameter, reflecting the opportunities for technological catch-up. Given that $b_i = a_i - x_i$, then the technological distances between a leading (l) and a follower region (f), are given by: $b_l = a_l - x$ and $b_f = a_f - x$, respectively. Using equation (5) we may write: $\dot{a}_i = \tilde{\varepsilon}_l + \sigma\varepsilon_l$ and $\dot{a}_f = \tilde{\varepsilon}_f + \sigma\varepsilon_f$. The growth rate of the technology gap between the two regions ($\dot{b}_{lf}$) evolves as follows:

$$\dot{b}_{lf} = \dot{a}_l - \dot{a}_f = \left(\tilde{\varepsilon}_l - \tilde{\varepsilon}_f\right) + \sigma\left(b_l - b_f\right) \tag{6}$$

Equation (6) can be written in terms of the gaps between the leader and the follower. Thus, $\dot{b}_{lf} - \sigma b_{lf} = \tilde{\varepsilon}_{lf}$ (7)

where $b_{lf} = b_f - b_l$ and $\tilde{\varepsilon}_{lf} = \left(\tilde{\varepsilon}_l - \tilde{\varepsilon}_f\right)$.

Equation (7) is a first-order differential equation with the following solution:

$$b_{lf,t} = b_{lf,0}e^{-\sigma t} + \left(1 - e^{-\sigma}\right)\frac{\tilde{\varepsilon}_{lf}}{\sigma} \tag{8}$$

According to equation (8), the evolution of the technological gap depends upon the ratio of the autonomous technological growth and the rate of technology adoption. It is quite clear that the adoptive parameter σ determines the pattern of convergence. If this parameter differs across regions, then any possibilities for regional convergence are constrained. This consideration can be shown by introducing in the above example three regions; one 'leading-region' (l), at the technological frontier ($b_l = a_l - x = 0$), and two region-followers ($i = 1, 2$). Assume that the autonomous parts of technology creation and diffusion and the initial technological gaps with the leader are the same for the two region-followers, i.e. $\tilde{\varepsilon}_{lf_1} - \tilde{\varepsilon}_{lf_2} = 0$. Assume further that during an initial time ($t = 0$) the technological gap between region 1 and 2 differs, with $b_{lf_1,0} - b_{lf_2,0} > 0$, and region 1 exhibits a higher ability in adopting technology, i.e. $\sigma_1 - \sigma_2 > 0$. If this difference is sustained through time, then a technological catch-up between region 1 and 2 is not feasible. If $\left(\Delta\sigma_{1,2}\right)_t \to \infty$, then $\left(\Delta b_{lf_{1,2}}\right)_t \to \infty$, as $t \to \infty$. A catch-up is feasible only if region 2 improves its adoptive ability. In terms of the example above, catch-up requires that the value of σ_2 increases through time. If $\left(\Delta\sigma_{1,2}\right)_t \to 0$, then it follows that $\left(\Delta b_{lf_{1,2}}\right)_t \to 0$.

Moving away from these abstract considerations, so as to get closer to the complications of real situation, account has to be taken, first, of the empirical approaches to convergence. Thus, the general framework discussed in this section will be tested empirically in the context of the European NUTS 2 regions. Prior to this, however, section 3 briefly reviews the most commonly used ways to approach the issue of convergence empirically together with an extended discussion of the appropriate measurement of the key variables of the model.

3. BUILDING THE EMPIRICAL FRAMEWORK

The empirical literature on regional convergence makes extensive use of two alternative tests for convergence, namely absolute and conditional convergence, described by equations (9) and (10), respectively.

$$g_i = a + b_1 y_{i,0} + \varepsilon_i \tag{9}$$

$$g_i = a + b_1 y_{i,0} + b_{\mathbf{X_i}} \mathbf{X_i} + \varepsilon_i \tag{10}$$

where y_i represents *per capita* output of the i[th] economy (in logarithm form), $g_i = (y_{i,T} - y_{i,0})$ is the growth rate over the time interval $(0,T)$, and ε_i is the error term, which follows a normal distribution.

Absolute convergence occurs if $b_1 < 0$ while the speed at which regions move towards the same steady-state level of *per capita* output is calculated as $\beta = \ln(b_1 + 1)/-T$. Conditional convergence requires that $b_1 < 0$ and $b_{\mathbf{X_i}} \neq 0$. If different economies have different technological parameters, captured by the vector ($\mathbf{X_i}$) in equation (10), then convergence is conditional on these parameters, giving rise to different steady states.[3] It follows, therefore, that a test for conditional convergence is more suitable to accommodate an empirical application of the model developed in section 2, and it becomes of critical importance to choose the appropriate variables that will be included in the vector $\mathbf{X_i}$.

For the purpose of this paper, a region's technological capacity ($\mathrm{T}_{i,t}$) is measured as the percentage of total employment in technologically dynamic sectors. More formally,

$$\mathrm{T}_{i,t} = \frac{\sum_{j=1}^{m} \eta_{i,t}^{j}}{L_{i,t}} \tag{11}$$

[3] For a review of these notions see Alexiadis (2010).

where $\eta_{i,t}^{j}$ refers to personnel employed in high-tech manufacturing and knowledge-intensive high-technology services ($j = 1 \ldots m$) and $L_{i,t}$ is the total employment in region i.

Equation (11) represents the level of technological development, but also indicates a capacity for technology adoption, since these are taken to apply high technology. 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 with the highest percentage of employment in high-tech manufacturing and knowledge-intensive high-technology services.[4] Consequently, in this context a variable that approximates the technological gap for region *i* at time *t* can be defined as follows:

$$TG_{i,t} = \ln T_{L,t} - \ln T_{i,t} . \tag{13}$$

Embodied in this variable is the idea of both a gap and the capacity to adopt technological innovations. The further away a region's technology is from that of the most advanced region, the faster will be its rate of technological progress. The logic behind this hypothesis is that technology transfer will be relatively cheap for lagging regions, when compared to regions which are already employing the most modern technologies and which cannot therefore simply imitate existing production techniques in order to promote further growth. Low technology regions can therefore experience faster growth provided, of course, that they possess the necessary infrastructure to facilitate the adoption of technology from the more technically advanced regions. According to this model, the potential for technology adoption is positively related to the technological gap, i.e. the higher the technological gap, the higher the potential for technology adoption and faster the rate of convergence. 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. Therefore, it is possible to express a model of 'technologically-conditioned' convergence as follows:

$$g_i = a + b_1 y_{i,0} + b_2 TG_{i,0} + \varepsilon_i \tag{14}$$

In equation (14) the variable TG_i is expressed in the initial time. There are two primary reasons for such an approach. The first is related to the fact that adoption of innovations, normally, has long-run effects on regional growth. In other words, future growth is affected by current efforts to enhance technology. Therefore, including the TG_i variable at the initial time captures these long-run effects of technology on regional growth over a specific time period. A second

[4] This is the region of 'Berkshire, Bucks and Oxfordshire' in the UK.

reason for using initial values is that it tests the hypothesis that initial conditions 'lock' regions into a high or low position, for example, how high or low levels of technology affect the pattern of regional growth and convergence. In addition, including the TG_i variable in initial time reflects the argument that a low (high) initial technological gap can be conceived as favourable (unfavourable) infrastructure conditions. In this sense infrastructure conditions critically affect the process of regional convergence, with regions having the appropriate (inappropriate) infrastructure to adopt technology from technologically advanced regions converging towards a high (low) equilibrium. From an econometric point of view, inclusion of the technological variable measured at the initial time helps to avoid the problem of endogeneity.

Equation (14), thus, incorporates the potential impact of both internally generated technological change and technology adoption upon a region's growth. The TG_i 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 advanced regions. It may be argued, therefore, that the condition $b_2 > 0$ promotes convergence. On the other hand, a high initial value for TG_i may indicate 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 the latter effect dominates then $b_2 < 0$, and convergence between technologically lagging and technologically advanced regions is severely constrained.

Having outlined the empirical context, the next step forward is to begin to investigate more systematically the pattern of regional convergence in Europe. As argued in section 2, if infrastructure conditions are not favourable to adopting technology (approximated by a high technological gap), then convergence is not feasible. The next section, therefore, attempts to test this hypothesis empirically.

4. EMPIRICAL APPLICATION

In this section some points about the data used in the process of econometric estimations are discussed, followed by the presentation and an account of the obtained econometric results.

In this paper data on Gross Value Added (hereafter GVA) per worker are exploited since this measure is a major component of differences in the economic performance of regions and a direct outcome of the various factors that determine regional ‘competitiveness’ (Martin, 2001). The regional groupings used in this article are those delineated by Eurostat and refer to 272 NUTS 2 regions. This data set allows one to examine the relative movements in GDP *per capita* across the European regions in some detail. The EU uses NUTS 2 regions as ‘targets’ for convergence and are 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 level at which convergence should be measured, the NUTS 2 regions are sufficiently small to capture sub-national variations (Fischer and Stirböck, 2006). The time period for the analysis extends from 1995 to 2006, which might be considered as rather short. However, 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’.

Convergence is identified with an inverse relationship between growth and initial level of per capita output. Such a notion of convergence embodies the essence of the neoclassical argument that poor regions grow faster than rich regions, and produces estimates of the rate at which poor regions are catching up with rich regions. The potential for absolute convergence is indicated by a cross-section test, based on estimation of equation (9) for the 272 NUTS 2 regions of the EU, over the period 1995–2006 using data for GVA per worker. Furthermore, the conventional test of regional absolute convergence is modified to include the hypothesis of ‘technologically-conditioned’ convergence. The results are set out in table 1.

Table 1. Regional Convergence, GVA per worker, EU regions: 1995–2006

Depended variable: g_i , n = 272 NUTS 2 regions		
	equation (9)	equation (14)
a	0.5746**	0.6161**
b_1	–0.0753**	–0.0812**
b_2		–0.0187*
Implied ß	0.0065**	0.0070**

** Indicates statistical significance at 95% level of confidence; * 90% level.

Considering first the results of testing for absolute convergence it might be argued that there is a slow tendency for absolute convergence across the regions of Europe. The rate of convergence of labour productivity is, on average, about 0.65% *per annum*. Of particular importance to this paper, however, are the results obtained for the conditional convergence model. Conditioning for the technological variable tends to increase the estimated rate of convergence (0.7%). The variable describing technology adoption and infrastructure conditions ($TG_{i,0}$) is also 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 more slowly than regions with low gaps, ceteris paribus. But what can this possibly mean? Clearly, a high initial technological gap is a factor that helps to sustain initial differences across regions, constraining any possibilities for overall convergence and, in turn, suggesting the possibility of convergence towards different equilibria following the predictions of the model, examined in section 2. If technologically backward regions of the EU were successful in adopting technology, then the estimated coefficient b_3 would be positive. Since $b_2 < 0$ this indicates that infrastructure conditions in regions with high technological gaps are inhibiting this process of technology adoption.

It follows, therefore, that adoption of technology, although it might be the best 'vehicle' for lagging regions to converge with leading regions. Nevertheless, this is a process which might be difficult for lagging regions, especially during the early stages of development when conditions are least supportive. In order, therefore, for the adoption of technology to set the lagging regions of the EU in a process of convergence with the leading regions an improvement in infrastructure conditions is necessary. The message, therefore, from the empirical application of the model developed in this paper is clear. The adoption of technology to set the lagging regions of the EU in a process of convergence with the leading regions requires an improvement in infrastructure conditions.

5. CONCLUSIONS AND POLICY IMPLICATIONS

It is beyond argument that, although an increasing number of empirical studies have paid attention to issues of economic convergence in the EU, the impact of technology adoption on regional convergence has so far received more limited attention. This paper has attempted to address this question, using data for the 272 NUTS 2 regions of the EU 27 over the period 1995–2006. The recent accession of several new countries has caused important changes in the geography of development in Europe, leading to what Ertur and Koch (2005) have aptly called a shifting from the historical North/South dualism to the North-

West/East income disparities. The results reported in this paper suggest that the NUTS 2 regions of EU 27 exhibit a slow rate of convergence in terms of labour productivity. An important conclusion to emerge from the empirical application is that the EU 27 regions exhibit some tendency to converge faster, although not substantially, *after* conditioning for technological differences across regions. While the 'technological gap' approach predicts in principle that the higher the technological distance from the leader, the greater the incentive to adopt technology, the results in this paper imply that not all the lagging regions of Europe are able to reap the 'benefits of backwardness'. This inability can be attributed, possibly, to inappropriate infrastructure conditions prevailing in lagging regions, which prevent or constrain convergence with the more technologically advanced regions. Convergence, where possible, is not towards a single equilibrium but towards different equilibria. Catch-up to the leading regions is feasible only amongst those regions whose technological conditions are similar or close to those of the technologically advanced regions.

Therefore, a primary aim of regional economic policy in the context of an enlarged Europe should be the promotion of high-technology activities, and R&D, including universities and scientific and research institutions. Moreover, in order to enhance regional growth and convergence, policy should seek to reorient these activities. High-technological and knowledge-creating activities should be directed, if possible, at regions with unfavorable infrastructure conditions, the purpose being to stimulate the production structures of those regions to shift to activities that implement high technology.

Although this paper has been concerned with regional convergence, focusing on the role of labour employed in advanced technological sectors, this is by no means to imply that this approach is the only route to understanding regional growth and convergence. While the empirical results are significant for the case of the EU 27 regions in their own right, they should nevertheless be placed in perspective. Indeed, it is not claimed that the foregoing analysis has provided an exhaustive account of all the factors that affect the process of regional convergence. Hence, improving the model developed in this paper by adding more explanatory variables would open up an interesting avenue for future research. However, the model developed in this paper is sufficiently flexible to be applied to other regional contexts, such as the US states. Empirical studies in those contexts using alternative variables might reveal different and more interesting features in regard to regional growth and convergence. Nevertheless, the present work suggests possible avenues for future research in different contexts and examining different factors shaping the pattern of regional convergence.

REFERENCES

ALEXIADIS, S. (2009), 'A Model of Regional Convergence with Technology Adoption', [in:] PAPADOURAKIS, G. and LAZARIDIS, I. (eds), *New Horizons in Industry, Business and Education*, Santorini, pp. 492–498.

ALEXIADIS, S. (2010), 'Regional Convergence Clubs and Dynamic Externalities', *Italian Journal of Regional Science*, 9 (1), pp. 41–64.

ALEXIADIS, S. and KORRES, G. (2009), 'Technology Adoption and Spatial Interaction: Evidence from the European Regions', [in:] MARKOWSKI, T., TURAŁA, M. and ŻUBER, P. (eds), *Innovation and Space – European and National Approach*, Warsaw: Polish Academy of Sciences, pp. 24–42.

ABRAMOVITZ, M. (1986), 'Catching up, Forging Ahead and Falling Behind', *Journal of Economic History*, 46 (2), pp. 385–406.

BERNARD, A. and JONES, C. (1996), 'Technology and Convergence', *Economic Journal*, 106 (437), pp. 1037–1044.

BOLDRIN, M. and CANOVA, F. (2001), 'Inequality and Convergence in Europe's Regions: Reconsidering European Regional Policies', *Economic Policy*, 16 (32), pp. 207–253.

BUTTON, K. and PENTECOST, E. (1995), 'Testing for Convergence of the EU Regional Economies', *Economic Inquiry*, 33 (4), pp. 664–671.

DURLAUF, S. and QUAH, D. (1999), 'The New Empirics of Economic Growth', [in:] TAYLOR, J. and WOODFORD, M. (eds), *Handbook of Macroeconomics*, 1, Amsterdam Elsevier, pp. 235–308.

ERTUR, C. and KOCH, W. (2005), 'Une analyse exploratoire des disparités régionales dans l'Europe élargie', *Région et Développement*, 21, pp. 65–92.

EZCURRA, R., GIL, C. and PASCUAL, P. (2005), 'Regional Welfare Disparities: The Case of the European Regions', *Applied Economics*, 37 (12), pp. 1423–1437.

FISCHER, M. and STIRBÖCK, C. (2006), 'Pan-European Regional Income Growth and Club Convergence', *Annals of Regional Science*, 40, pp. 693–721.

FUNKE, M. and STRULIK, H. (1999), 'Regional Growth in West Germany: Convergence or Divergence', *Economic Modelling*, 16 (4), pp. 489–502.

MARTIN, R. (2001), 'EMU versus the Regions? Regional Convergence and Divergence in Euroland', *Journal of Economic Geography*, 1 (1), pp. 51–80.

NEVEN, D. and GOUYETTE, C. (1995), 'Regional Convergence in the European Community', *Journal of Common Market Studies*, 33 (1), pp. 47–65.