Assessing Regional Convergence under Conditions of Technology Creation and Adoption: Evidence from an Enlarged Europe

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Abstract

This paper investigates the extent of convergence amongst the European regions. Set within this context, the purposes of this paper are twofold. The first is to discover whether there is a pattern of absolute or club convergence amongst the NUTS-2 regions of Europe. Regional convergence is a complex phenomenon and is based upon a number of factors. Predominant among these are factors related to technology. This brings us to the second aim of the paper, namely to shed some further light on the impact of regional capacities to create and adopt technology in shaping the pattern of convergence in Europe. Given that the existing empirical studies on regional convergence have emphasised the role of capital accumulation in generating convergence at the expense of the absorption and adoption of technology, this paper develops a formal model in which the pattern of convergence is attributed to the rate of technological adoption across regional economies. If the rates of technological adoption, or absorptive abilities, vary across regions, convergence is constrained amongst a certain group (or even groups) of regional economies that share common structural characteristics; an outcome that in the relevant literature is known as club convergence. Absorption and adoption of technology is not a simple and automatic process. Instead, it requires that lagging regions should have the appropriate infrastructure or conditions to adopt or absorb the technological innovations. Whether regions exhibit a pattern of absolute or club convergence depends on the degree to which infrastructure conditions are appropriate for the adoption of the latest technological improvements. Stated in alternative terms, this model shows the conditions that lead some regional economies to converge towards a leading region. Particular attention is paid to differences in the ability of lagging regions to adopt technology and hence to catch-up with advanced regions. The model is tested using data for the NUTS-2 regions of the EU-25 during the time period 1995-2004. Using appropriate proxies for technology creation and adoption, regional convergence is examined in terms of per capita income and labour productivity. The results suggest that adoption of technology has a significant and positive effect in regional convergence in Europe. The analysis is also shown to have important implications for the direction of regional policy in Europe.

Key words: Convergence clubs, Technological Gap, European Regions.
JEL: C21; O18; R11; R12

I. Introduction

The publication of the ground breaking work of Baumol (1986) was the spark that ignited an enormous interest in the issue of convergence across national economies. The debate on convergence has since become one of the most foremost topics in economic research. This topic can also be tackled with respect to different areas within a country, that is to say, *regions*. In the context of *regional convergence*, the term 'region' refers either to areas determined according to similarities in geographical characteristics or areas corresponding to administrative divisions, which may be arbitrary.

The debate on regional convergence has bred, and continues to do so, dozens of empirical studies (e.g. Button and Pentecost, 1995; Neven and Gouyette, 1995; Sala-i-Martin, 1996; Alexiadis *et al*., 2008; Álvarez-Garcia *et al*., 2004; Ezcurra *et al*., 2005). 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 this context, some remarks by Bernard and Jones (1996) are highly pertinent:

[***] The findings, interpretations and conclusions are those entirely of the authors and do not necessarily represent the official position, policies or views of the Ministry of Rural Development and Foods and/or the Greek Government.

> ‘To the extent that the *adoption* and accumulation of technologies is important for convergence, the empirical convergence literature is misguided’. (Bernard and Jones, 1996, p. 1037) [Emphasis added]

As acknowledged by Abramovitz (1986), technological progress is driven not only by indigenous innovation but also by the process of technology absorption, and thus the ability of a regional economy to ‘catch-up’ may substantially depend on its capacity to imitate and adopt innovations developed in more technologically advanced regions. Although some attempts have been made to capture the impact of technology adoption (e.g. de la Fuente, 2000; Rogers 2004) nevertheless this issue remains a fruitful area of research, especially, for regional economists. Given that the adoption of technology is manifested more clearly across regions and is accelerated by geographical proximity, its impacts on enhancing regional convergence is an ‘area’ where more work is needed by regional economists.

It is the intention of this paper to confront theory with facts. In doing so, we develop and apply empirically a model that explicitly takes into account technology adoption in an extensive regional context, that of the NUTS-2 regions of the EU, widening thus the range of empirical studies on European regions. We should emphasise at the outset that the approach used in this paper is mainly quantitative. However, it is hoped that this paper will be able to isolate some interesting views on the issue of regional convergence across Europe due to technology diffusion and adoption.

This effort is organised as follows. Section II reviews some approaches that have been put forward to explain the impact of technological diffusion and adoption in the process of economic growth. The existing literature, however, is limited to the extent that it only highlights specific aspects of technology adoption without offering a general model that captures its impacts on regional convergence. Section II, subsequently, develops such a model. In Section III 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 IV. Section V provides a brief conclusion.

II. A Model of Regional Convergence with Technology Creation and Adoption

In the standard neoclassical model, a factor that promotes, and accelerates, regional convergence is technological progress and diffusion. If the labour force and technology grow at constant rates, and if there is instantaneous diffusion of technology in conjunction with a movement of factors of production, then convergence in levels of labour productivity (or in per capita output) is an inevitable outcome of the neoclassical model.

Under the assumption of perfect competition it may be argued that technology has such characteristics and is, as Borts and Stein (1964) argue, ‘available to all’ (p. 8). However, several criticisms have been raised against this argument and many economists are searching for an alternative way forward. A process of technology diffusion is not a simple and automatic process. Instead, it requires that lagging economies (countries or regions) should have the appropriate infrastructure or conditions to *adopt* or *absorb* the technological innovations. As Kristensen (1974) points out, technological spillovers are not likely to be effective if the capability of the receiving economy is too low:

> ‘The most rapid economic growth should be expected to take place in countries that have reached a stage at which they can begin to apply a great deal more of the existing knowledge’ (p. 24)

On similar lines, Abramovitz (1986) recognises this possibility by arguing as follows:

> ‘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’ (p. 225) [Emphasis Added]

In other words, 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[1]. The absorptive ability of an economy is therefore of paramount importance to the convergence process and has already been examined seriously by, for example, Baland and Francois (1996), Keller (1996), Parente and Prescott (1994, 1999), all of which consider the implications of technology absorption for economic growth in national economies, and express the absorptive ability in terms of human capital. Other authors approximate the absorptive abilities of an economy in terms of the level of innovation in an economy (e.g. Griffith *et al.*, 2003). In particular, Griffith *et al.* (2003), building upon the arguments of Schumpeter (1934), put forward the idea that Research and Development (hereafter R&D) activities affect not

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[1] Although Gerschenkron (1962) is acknowledged as the initiator of this view, nevertheless, the basis of the argument is based on Veblen (1925). See also Fagerberg (1994) and Inkster (2002).

only the degree of innovation but also the absorptive ability of an economy. Four regional studies emphasise the absorptive ability of regions in promoting economic growth, with each highlighting different factors. Acs *et al*. (1994) put emphasis on the average size or age of local firms, Dosi (1988) considers the dominant production structure and the existence of networks, Henderson (2003) uses available human capital in a location while in Drifflied (2006) the spillover effects from foreign direct investment are the focus[2]. However, these models do not consider the implications for convergence, at least in an explicit way.

A link between the absorption of technology and economic convergence is also considered explicitly in a further five models. In particular, Barro and Sala-i-Martin (1997), Detragiache (1998), Rogers (2004), Duczynski (2003), and Howitt and Mayer-Foulkes (2005) examine this relationship for national economies. Duczynski (2003) proposes a model that combines technology diffusion, perfect capital mobility and adjustment cost for capital investment. This model predicts variation in the rates of convergence, with undercapitalised countries exhibiting relatively fast initial rates of convergence[3]. Rogers (2004) implements a form of human capital measure in that approximation to the absorptive ability of an economy is expressed in terms of number of students studying abroad. Howitt and Mayer-Foulkes (2005) develop a model on Schumpeterian lines[4] and approximate the ability of an economy to absorb technology in terms of levels of human capital and the endogenous rate of innovation.

From this brief review of the existing literature, it is clear that although the importance of technology adoption has been acknowledged, nevertheless, only specific aspects of the *infrastructure conditions* are examined. 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? It is possible to provide

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[2] Bode (2004) develops a model that distinguishes between spillovers from abroad and local spillovers.

[3] A related issue pertains to the model by Daniels (1999) who examines the hypothesis of technology transfer through international trade.

[4] This model is also based extensively on Nelson and Phelps (1966), Phelps (1966) and Nelson (1956, 1960, 1962 and 1981).

some answers to these questions by constructing a model of regional convergence that encapsulates the impact of infrastructure in the absorptive ability of a regional economy.

The approach adopted in this paper takes a model developed by de la Fuente (1995, 1997 and 2000) as a point of departure. This model provides an appropriate framework to analyse the implications of technology creation and adoption in regional convergence. The model is based on the usual assumption that technological progress depends on the extent of technology diffusion from the most advanced economy but income disparities are also attributed to differences in the levels of investment in physical capital and technology, i.e. there is indigenous innovation possible in any economy[5]. According to this model the potential for technology adoption is positively related to the technological gap[6], i.e. the higher the technological gap, the higher the potential for technology adoption and faster the rate of convergence. However, this model does consider the possibility that high technological gaps might act as obstacles to convergence.

In this paper the model by de la Fuente (2000) is extended further as to take into account the impact of existing infrastructure in the adoptive ability of economies. Under the assumption that the adoptive ability of a regional economy is linked to infrastructure conditions, our model yields two possibilities of convergence; convergence towards a 'high' and a 'low' equilibrium. Whether regional economies converge towards a high or a low equilibrium depends on the degree to which infrastructure conditions are appropriate for the adoption of the latest technological improvements.

Following de la Fuente (2000), the growth of technology is assumed to be an increasing function firstly of the proportion of output invested in R&D to produce 'technological capital' (Θ)[7] and secondly the opportunities for 'technological catch up', as measured by the gap between the existing level of technology in a region and that of a 'technological

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[5] Pigliaru (1999, 2003) develops a similar model in which technology accumulation in a region depends not only on technology diffusion from the leading region but also on the proportion of regional output devoted to innovation.

[6] The 'technological gap' is defined as the distance between the best-practice frontier and the level of technology prevailing in a region.

[7] De la Fuente (1997, p. 25) defines technological capital as 'the accumulated stock of useful technical knowledge' and argues that it is subject to the same constraint as physical capital, namely exhibiting diminishing returns. This variable represents indigenous innovation in an economy.

best-practice frontier', (B). Thus, it is possible to express the growth of technology in a region i in terms of the following general function:

$$G_{A_i} = f(\Theta_i, B_i) \tag{1}$$

with the expectation of $f'_{G_{A_i},\Theta_i} > 0$ and $f'_{G_{A_i},B_i} > 0$.

More specifically, it is anticipated that the ability of a region to produce technological capital, i.e. the 'intentional creation of technology', as reflected in R&D activities, will have positive effects on the growth of technology in the region. Regarding the second source of technological growth, a high technological gap in a region implies opportunities for adopting technological improvements in the technologically advanced regions. In such circumstances, the further away a region's technology is from that of the most advanced region, the faster will be its rate of technological progress (Fagerberg, 1987; Gomulka, 1971, 1986, 1990).

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. Specific resources must be allocated to innovation activities, and hence innovation is a much higher cost activity for leading regions. 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.

The functional form given by equation (1) can be specified in a multiplicative form. Thus,

$$G_{A_i} = \Theta_i^{\gamma} B_i^{\varepsilon} \tag{2}$$

Equation (2), in turn, can be written in linear form by taking logarithms as follows:

$$g_{A_i} = \gamma\theta_i + \varepsilon b_i \text{ with } \gamma, \varepsilon \geq 0 \tag{3}$$

Given that θ_i approximates 'technological capital' or the level of innovation in a region, measured as the proportion of its output to R&D, then the parameter γ measures the productivity of innovation in augmenting technology while ε represents the rate of diffusion of technology across economies and, hence, reflects the opportunities for technological catch-up[8]. The technological distance (b_i) is defined as the difference between a best-practice frontier (x), which is determined exogenously, and the prevailing level of technology in a region, represented by some index a_i, i.e. $b_i = a_i - x$. Assuming that the economy is divided into two regions, a leading and a follower-region ($i = l, f$), then the technological distances are given by: $b_l = a_l - x$ and $b_f = a_f - x$, respectively.

Assuming further that each region devotes a different proportion of its output to R&D, equation (3) is used to show the growth of technology in the leading and following region:

$$\dot{a}_l = \gamma\theta_l + \varepsilon b_l \tag{4}$$

$$\dot{a}_f = \gamma\theta_f + \varepsilon b_f \tag{5}$$

The growth rate for the technology gap between the two regions ($\dot{b}_{lf}$) is therefore:

$$\dot{b}_{lf} = \dot{a}_l - \dot{a}_f = \gamma(\theta_l - \theta_f) + \varepsilon(b_l - b_f) \tag{6}$$

Defining $b_{lf} = b_f - b_l$ and $\theta_{lf} = (\theta_l - \theta_f)$, equation (6) can be written as follows:

$$\dot{b}_{lf} = \gamma\theta_{lf} - \varepsilon b_{lf} \tag{7}$$

An implicit assumption of this model is that all economies are able to absorb technology to the same degree, so that the higher the technological gap the higher the effect on growth, ceteris paribus. However, it may be argued that large gaps do not necessarily promote convergence in this way. It is quite possible that a significant technological gap is associated with unfavourable conditions for the adoption of new technology. This consideration can be introduced in a regional convergence framework by assuming that the rate of diffusion of technology (ε) is a non-linear function of the technological gap. More specifically,

$$\varepsilon_i = \frac{\rho}{b_{lf_i}^{\pi}} \tag{8}$$

where $\rho, \pi > 0$ are parameters.

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[8] Verspagen (1991) develops a model on similar lines.

The intuition behind equation (8) is that the rate of diffusion is not constant but varies across regions, according to the size of the gap[9]. 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 regions 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). 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. Thus, the rate of technology diffusion is endogenously determined.

The implications of modelling the rate of diffusion in this way can be seen by substituting equation (8), into de la Fuente's framework (equation 7) to yield an expression for the rate of change in the technological gap as follows:

$$\dot{b}_{lf} = \gamma\theta_{lf} - \rho b_{lf}^{(1-\pi)} \tag{9}$$

In equilibrium $\dot{b}_{lf} = 0$ so that:

$$\gamma\theta_{lf} = \rho b_{lf}^{(1-\pi)} \tag{10}$$

which gives an equilibrium value for the technological gap:

$$b_{lf}^{*} = \left(\frac{\gamma}{\rho}\theta_{lf}\right)^{\frac{1}{1-\pi}} \tag{11}$$

It is interesting to consider, however, the implications for a regional economy when its gap with the leading economy is not at this equilibrium level. The outcome turns upon the value of the parameter π. If $\pi = 0$, then according to equation (8) $\varepsilon_i = \rho$ and the diffusion of technology occurs at a constant autonomous rate equal to ρ implying a linear process of convergence, while if $\pi = 1$ the size of the gap becomes irrelevant in the process of technological diffusion (using equation 9). Two distinct patterns of convergence arise, however, when $\pi < 1$ and when $\pi > 1$.

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[9] For a more detailed analysis see Alexiadis (2006).

Figure 1 portrays the pattern of convergence implied by $\pi < 1$.

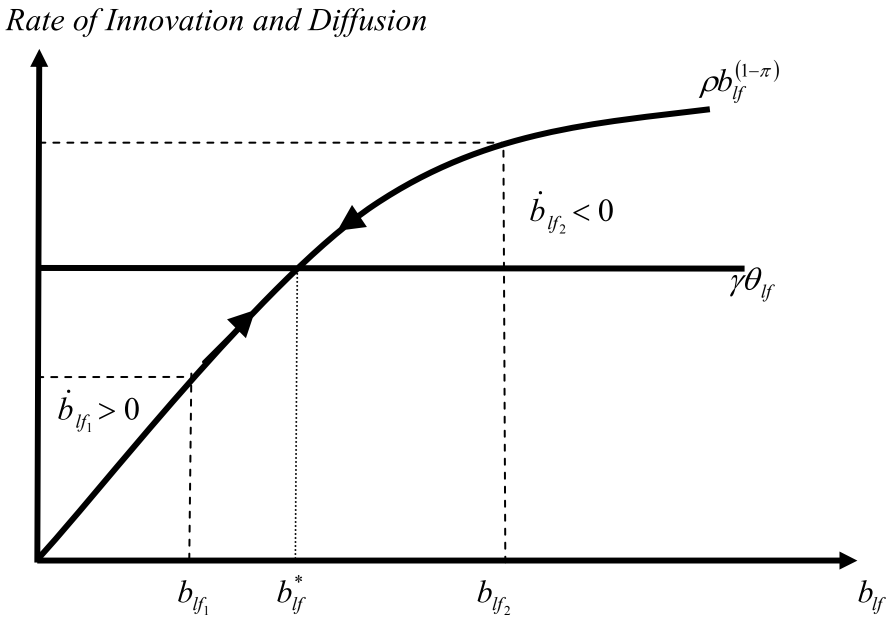

Figure 1: Convergence towards a single equilibrium when $\pi < 1$

As illustrated in Figure 1, the process of convergence is a non-linear one. When the gap between leader and follower is below b_{lf}^{*}, the dynamics of the system cause the gap to grow towards its steady-state value, since the rate of innovation investment outweighs the effect of technology diffusion and, hence, $\dot{b}_{lf_i} > 0 \; \forall i \in [0 \;\; b_{lf}^{*}]$. Conversely, when the gap is greater than b_{lf}^{*}, there is movement towards equilibrium since $\dot{b}_{lf}$ is negative, i.e. $\dot{b}_{lf_i} < 0 \; \forall i \in [b_{lf}^{*} \;\; \infty]$. Assuming, further, that the leading region maintains its leading position over a given time period, then economies with a large technology gap, i.e. above b_{lf}^{*}, converge towards equilibrium but at slower rates compared to those regions where the gap is below b_{lf}^{*}. Thus, when $\pi < 1$ convergence towards a single equilibrium is possible but regions with unfavourable infrastructure conditions reflected in a large technological gap move towards equilibrium at a slower pace.

Up to this point the pattern of convergence is similar to that implied by de la Fuente (2000), although is specified in non-linear terms. Convergence towards a unique equilibrium is still the case, although this non-linearity implies that regions with low (high) initial technological gaps converge at a higher (slower) rate. 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 now. In this case technology diffusion is represented by a convex function implying that regions converge towards different equilibria, as shown in Figure 2.

Rate of Innovation and Diffusion

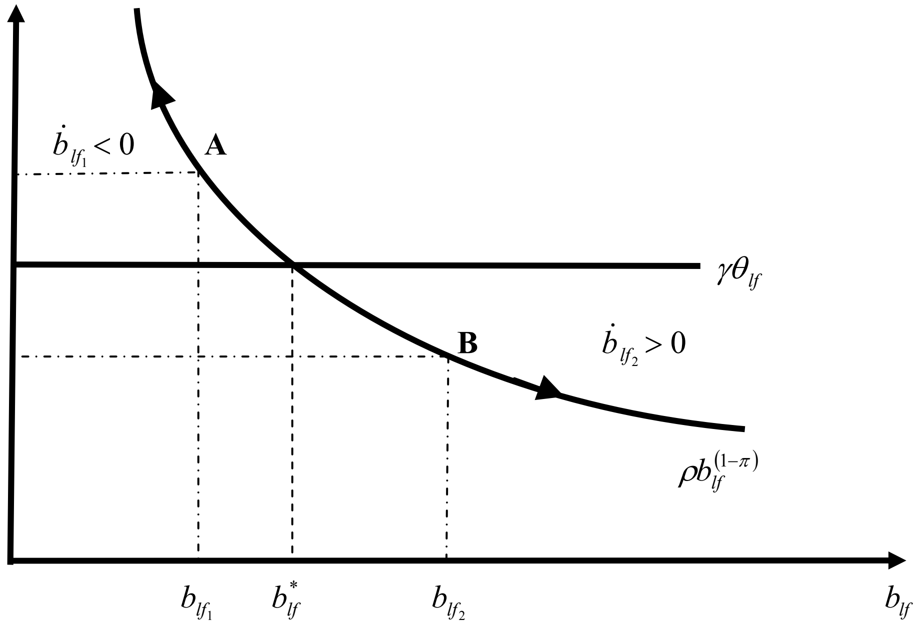

Figure 2: Convergence towards different equilibria when $\pi > 1$

As Figure 2 shows, economies on either side of the threshold b_{lf}^{*} move in different directions. This pattern of convergence and divergence can be illustrated using a simple example. Consider an economy divided into three regions, one 'leader' (l) and two followers, i.e. $(i = 1,\ 2)$. Assuming that the leading region is at the technological frontier $(b_l = a_l - x = 0)$ so that steady-state equilibrium is, therefore, approximated by the leading region, then convergence with the leading region requires that the gap at a terminal time (T) should be zero, i.e. $b_{lf,T} = 0$. However, as Figure 2 indicates, a zero gap with the leader is not feasible, since by definition the curve $\rho b_{lf}^{(1-\pi)}$ is asymptotic to the axis of the graph. Hence, a more realistic condition would be that the technological gap tends towards zero over a given time period, i.e. $b_{lf,T-0} \rightarrow 0$.

Assume that the leading region devotes a proportion of its output to R&D that is higher compared to regions 1 and 2, namely that $\theta_l > \theta_f$. For simplicity assume that regions 1 and 2 devote the same proportion of output to R&D, i.e. $\theta_1 = \theta_2$, so that $\theta_{lf_1} = \theta_{lf_2}$ and that $\gamma_1 = \gamma_2$. It is also assumed that ρ is the same for both regions[10]. A crucial assumption for the purposes of this paper is that the initial technological gaps differ between the two region-followers $(b_{lf_1} \neq b_{lf_2})$, with $b_{lf_1} < b_{lf_2}$. If 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, and the gap approaches zero asymptotically. 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. Convergence, therefore, is a property apparent only for region 1 and the leading region. These regions can be conceived as an *exclusive convergence club*. In terms of Figure 2, this club includes any region with a technological gap in the range $(0, b_{lf}^*]$, for which $\dot{b}_{lf_i} < 0$, while regions with gaps in the range $[b_{lf}^*, \infty)$, which $\dot{b}_{lf_i} > 0$, diverge from the leader and the remaining regions. In other words, the technological advantages of particular regions would accumulate and militate against convergence for all. 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[11]. These assumptions impose a non-linear process of technological diffusion (i.e. $\pi > 1$) that depends on infrastructure conditions as embodied in the size of the gap at a point in time.

To be more precise, 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

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[10] Relaxing this assumption leads to similar conclusions. To be more precise, redefining ρ in terms of differences in infrastructure conditions in a region and a leading region, i.e. $\rho_{lf} = \rho_f - \rho_l$, then convergence requires that $\rho_{lf} \to 0$, as $t \to \infty$ while divergence occurs when $\rho_{lf} \to \infty$, as $t \to \infty$.

[11] A similar situation emerges if a time dimension is introduced to the model or if the parameter π varies through time. Assume that some regions are able to adopt technological innovations, developed in time t, in time $t+1$, and others, due to poor infrastructure conditions or large technology gaps, in time $t+n$ with $n > 1$. The former group will exhibit relatively higher rates of technology growth and, hence, to converge with the leader while the latter group will probably diverge or exhibit a slow rate of convergence, depending on the length of the lag in the adoption of technology.

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.

The assumption in the preceding example with two following, or lagging, regions is that both exhibit the same characteristics, such as the propensity to innovate. A more complicated picture arises if this assumption is relaxed, allowing the creation of technology to differ between the lagging regions, for example, i.e. when $\theta_{lf_1} \neq \theta_{lf_2}$[12].

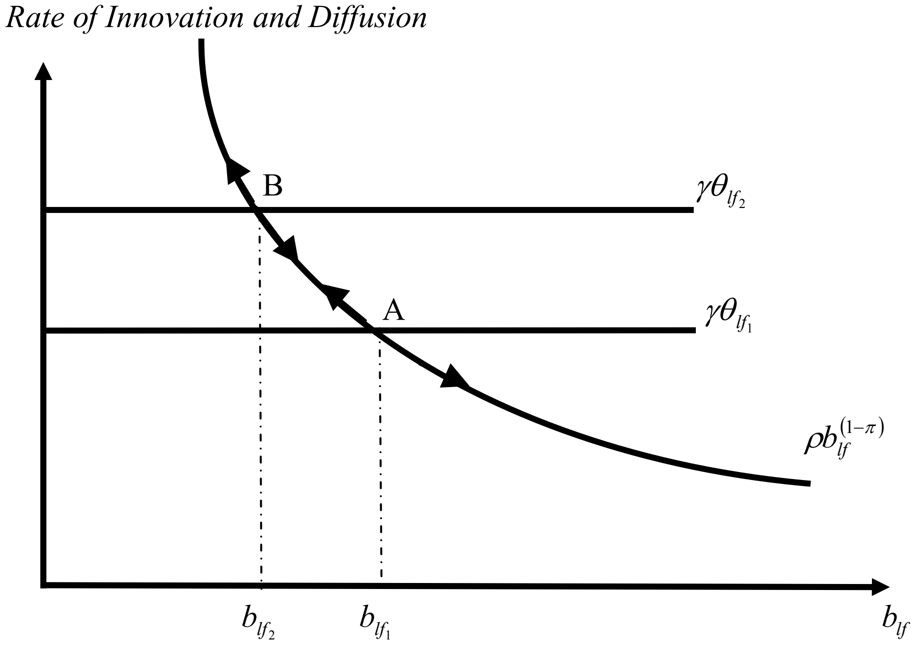

Figure 3: Club Convergence when $\pi > 1$ and $\theta_{lf_1} \neq \theta_{lf_2}$

Figure 3 shows a situation where region 1 has a higher rate of technology creation, compared to region 2, which is reflected in a lower differential in technology creation

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[12] Such a situation might also occur if region 1 develops a ‘knowledge-producing’ sector in a subsequent time period (t_1) due to the combined effect of a relatively low initial technological gap and high absorptive ability. In particular, assume that $b_{lf_1,t_0} > b_{lf_1,t_1}$, which signifies that conditions in region 1 are favourable as to allow adoption of technology, that leads to $\theta_{lf_1,t_0} > \theta_{lf_1,t_1}$. If this sequence continues, providing of course that the adoptive ability of this region remains, at least, the same in future periods, then convergence towards the leader is feasible. Thus, we may express this process as: $b_{lf_1,t_n} \to 0$ and $\theta_{lf_1,t_n} \to 0$, as $n \to 0$.

with the leader, i.e. $\theta_{lf_1} < \theta_{lf_2}$. Point B represents the critical threshold for region 2, showing that a large difference in innovation rates requires a high rate of technology absorption in order to prevent the region moving further away from the leading region in terms of overall technology growth. On the other hand, point A is the threshold for region 1, which has a lower innovation differential compared to the leader. As a result, the rate of technology absorption that is required to prevent region 1 from following a divergent path, is lower compared to that of region 2. A diverging path for region 1 corresponds to movements to the right of point A. Hence, by imposing different abilities to create and absorb technology, two thresholds exist, one that corresponds to b_{lf_1}, with low θ_{lf} and another to b_{lf_2}, with high θ_{lf}.

Broadly speaking, this model suggests that only regions with low technology gaps, relative to leading regions, are likely to converge towards a steady-state equilibrium growth path, as represented by the growth rate of the leading region. Regions with relatively large technology gaps may fall progressively behind. Depending on the value of the absorptive parameter π, two distinct cases can be identified. If $\pi < 1$, then this model predicts a constant equilibrium gap, with different equilibrium positions possible depending upon whether θ_{lf} is the same, or different, across regions or, more generally, whether regions share the same characteristics or not. The pattern of convergence implied by $\pi > 1$ is the most interesting. In this case, two equilibria emerge, even when all regions share the same characteristics, or parameters, apart from their initial position with regard to the size of the technological gap; a case for club-convergence[13]. It is the size of this initial gap that distinguishes whether a region follows a convergent or divergent path. Further, if regions also differ with respect to their structural characteristics (i.e. in terms of θ_{lf} or the values of parameters ρ and γ), then the membership of the convergence club is more 'complex' to establish but fundamentally there is still one convergence club. This club is most likely to include regions with structural characteristics similar to the leader. The model, discussed in this section, clearly indicates that convergence towards leading regions is feasible only for regions with sufficient absorptive capacity, which is assumed to be a function of infrastructure conditions in an economy.

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[13] See also Alexiadis and Tomkins (2004, 2006).

To understand the forces at work it is useful to consider a way to incorporate the above framework into a formal model of regional convergence. Assume that the production functions are identical across regions and take the form of a standard Cobb-Douglas production function, expressed in intensive terms as follows:

$$Q_{i,t} = k_{i,t}^{\alpha} \tag{12}$$

where $Q_{i,t} = Y_{i,t} / (AL)_{i,t}$, $k_{i,t} = K_{i,t} / (AL)_{i,t}$, $Y_{i,t}, K_{i,t}$ and $L_{i,t}$ are output, the stock of physical capital and the labour force, respectively, $A_{i,t}$ is a measure of technological progress and $0 < \alpha < 1$ is the share of capital.

Given a constant and spatially invariant rate of depreciation ($\delta > 0$), and assuming that labour force and technology grow at constant and exogenously determined rates, η and g respectively ($L_i = L_0 e^{\eta t}$ with $\eta \geq 0$ and $A_i = A_0 e^{gt}$), then, $Q_{i,t}$ converges towards its steady-state value $Q_{i,t}^{*}$ in accordance with the following relation[14]:

$$\frac{d \log Q_{i,t}}{dt} + \beta \log Q_i = \beta \log Q^{*}, \text{ where } \beta = (1-\alpha)(\eta + g + \delta) \tag{13}$$

Equation (13) is a differential equation in $\log Q_i$ with the general solution:

$$\log Q_i = \left(1 - e^{-\beta t}\right) \log Q^{*} + e^{-\beta t} \log Q_{i,0} \tag{14}$$

According to equation (2), technological progress derives from two sources, namely technology produced within a region, i.e. the resources that a region devotes to innovation or a 'propensity to innovate' ($PI_{i,t}$) and technological progress that results from adoption of innovations developed in other regions ($TG_{i,t}$). This element is expressed in terms of the technological gap in order to capture both the process of technology adoption and the degree of appropriateness in infrastructure conditions, as this is reflected captured by a high or low technological gap. Hence, technology can be expressed as $A_{i,t} = PI_{i,t} TG_{i,t}$, which implies that output per effective units can be written $\log Q_i = \log\left(\frac{Y_i}{L_i}\right) - \log PI_i - \log TG_i$. Thus, equation (14) can be written as follows:

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[14] For a more detailed elaboration see Barro and Sala-i-Martin (1995).

$$\log\left(\frac{Y_{i,t}}{L_{i,t}}\right)=\left(1-e^{-\beta t}\right)\log Q^{*}+e^{-\beta t}\left(\log\left(\frac{Y_i}{L_i}\right)_0-\log PI_{i,0}-\log TG_{i,0}\right)+\log PI_{i,t}+\log TG_{i,t} \quad (15)$$

Subtracting $\log\left(\frac{Y_i}{L_i}\right)_0$ from both sides of equation (15) yields:

$$g_{i,T}=c+b_1\log\left(\frac{Y_i}{L_i}\right)_0+b_2\log PI_{i,0}+b_3\log TG_{i,0} \quad (16)$$

where $g_{i,T}=\log\left(\frac{Y}{L}\right)_{i,t}-\log\left(\frac{Y}{L}\right)_{i,0}$, $T=t-0$, $b_1=-\left(1-e^{-\beta t}\right)$, $c=\left(1-e^{-\beta t}\right)\log Q^{*}+\left(\log PI_{i,t}+\log TG_{i,t}\right)$

and $b_2, b_3=-e^{-\beta t}$.

In equation (16) the variables related to technology are expressed in initial values. There are two primary reasons for such an approach. The first is related to the fact that R&D effort and adoption of innovations, normally, have future or long-run effects on regional growth. Funke and Niebuhr (2005, p. 149) have succinctly put this argument as follows: '[…] current R&D should affect future GDP.' In other words, future growth is affected by current efforts to enhance technology. Therefore, including the two technological elements at the initial time captures these long-run effects of technology on regional growth over a specific time period. A second 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 advance regions converging towards a high (low) equilibrium.

The general framework, discussed in this section, will be tested empirically in the context of the European NUTS-2 regions in a subsequent section. Prior to this, however, section III briefly reviews the most commonly used ways to approach the issue of convergence empirically and an econometric technique that is of particular importance to the aims of this paper. In particular, a model that is able to provide an empirical approximation of the effects of *spatial interaction* is discussed. This section also includes a discussion of the appropriate measurement of the key variables of the model.

III. The Empirical Context

The empirical literature on regional convergence makes extensive use of two alternative tests for convergence, namely absolute and conditional convergence, described by equations (17) and (18), respectively.

$$g_i = a + b_1 y_{i,0} + \varepsilon_i \tag{17}$$

$$g_i = a + b_1 y_{i,0} + b_{\mathbf{X_i}} \mathbf{X_i} + \varepsilon_i \tag{18}$$

where y_i represents per capita output of the i^th^ economy (in logarithm form), $g_i = \left(y_{i,T} - y_{i,0}\right)$ is the growth rate over the time interval $\left(0, T\right)$, and ε_i is the error term, which follows a normal distribution[15].

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 $\beta = \ln\left(b_1 + 1\right)/-T$. [16,17] Conditional convergence requires that $b_1 < 0$ and $b_{\mathbf{X_i}} \neq 0$. If different economies have different technological and behavioural parameters, captured by the vector ($\mathbf{X_i}$) in equation (18), then convergence is conditional on these parameters, giving rise to different steady states. It follows, therefore, that a test for conditional convergence is more suitable to accommodate an empirical application of the model developed in section II, and it becomes of critical importance to choose the appropriate variables that will be included in the vector $\mathbf{X_i}$.

A key feature of the model discussed in Section II is that technical change, leading to regional productivity growth, originates either from within the region or from other

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[15] The error term is assumed have zero mean and variance, and to be independent and identically distributed over time ($E\left[\varepsilon_t \varepsilon_t^{'}\right] = \sigma_t^2 \mathbf{I}$) and across the observational units and uncorrelated with the initial level of output per worker.

[16] The time at which output per worker ($y_{i,t}$) is halfway between the value during the initial year and the 'steady-state' (y^*) satisfies the condition $e^{-\beta t} = \frac{1}{2}$.

[17] However, several criticisms have been put forward regarding this model – see, for example, Friedman, 1992, Quah, 1993). For a more detailed review see Capolupo (1998).

regions (technological spillovers). In the former case, such internally generated technical change would be the outcome of R&D activities, patent applications and subsequent investment expenditures; features that form the underpinnings of Endogenous Growth Theory (hereafter EGT). According to the relevant models[18], the relationship between R&D and economic growth is not a simple linear process, due to strong threshold effects and external economies associated with investment in R&D[19]. More recent models attribute the returns from investment in R&D to a number of specific factors such as human capital in a region (Cheshire and Carbonaro, 1995; 1996), or the spatial concentration of R&D centres (Audretsch and Feldman, 1994; 1996; 1996a; Verspagen, 1992; 1999). Nevertheless, all these various formulations acknowledge the importance of R&D. The practical problem, however, is effective measurement of R&D.

In empirical studies (e.g. Fagerberg *et al.*, 1996; 1999; Fagerberg, 1987; Jaffe *et al.*, 1993; Piergiovanni and Santarelli, 2001), patent applications and patent citations are often used to approximate innovative activity, although an alternative approach outlined by Pigliaru (1999, 2003) provides a more appropriate measure in the context of the observed slow rate of convergence across regions. According to this approach, technological growth is related to the 'propensity to innovate', as defined by Pigliaru (2003). Thus, the resources devoted to innovation in a region as a share of total regional resources represents the propensity to innovate.

Problems arise, however, in choosing appropriate ways to measure the resources utilised in the knowledge producing sector. In the relevant empirical studies (e.g. Paci and Pigliaru, 1999; 1999a; 2001; Paci and Usai, 1998; 2000; 2000a), R&D expenditures or patent applications and citations are used. Soete (1981), however, makes a distinction between technology output measures and technology input measures[20]. Data related to patents fall into the first category while R&D expenditures or labour employed in R&D

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[18] Examples of EGT models can be found in the work of Romer (1986, 1990), Rebelo (1991), Grossman and Helpman (1994), Dosi (1988), Dosi *et al.* (1988, 1990), among others. For a recent and more detailed review see Fine (2000), Moulaer and Seria (2003).

[19] It should be noted, however, that the contribution of the R&D sector, and its spatial distribution, to regional growth has long been recognised in regional economics. Richardson (1973, p. 56) notes: 'Innovations and technical progress do not spread evenly and rapidly over space but frequently cluster in a prosperous region; for instance, technical progress may be a function of the levels of R and D expenditures which are higher in high-income regions.'

[20] Marjit and Beladi (1998) make a distinction between product and process patents.

activities belong in the second category. It is argued by both Soete (1981) and Fagerberg (1988, 1994, 1996) that the former category is a better measure of the impact of innovative effort since the latter often reflects efforts related to both innovation and diffusion. Ideally, therefore, an output measure of innovation would be preferable for the present study, given the objective of distinguishing between innovation and the diffusion of innovation.

In this paper the 'propensity to innovate' ($PI_{i,t}$) is expressed in terms of patents per million inhabitants as those are reported by the Patent applications to the European Patent Office (EPO) by priority year at the regional level, obtained by EUROSTAT. Patents per capita have been used extensively in the empirical literature of European regional convergence as a proxy for activities related to technology creation and a measure of the degree of regional innovation.

Turning to the ability of regions to adopt technology and innovations, this is even more difficult to measure. Peri and Urban (2006), for example, approximate technology adoption in terms of spillovers from foreign direct investment. While such approaches are interesting, it is difficult to apply them directly in the present context due to data limitations. However, other approaches put emphasis on the role of dynamic, advanced technological sectors in driving the technology diffusion process. Here, the relative extent of technology adoption capacity is therefore 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.

At this point it is worth mentioning that one of the first attempts to include industrial structure that recognizes high technology in a model of conditional regional convergence is by Gripaios *et al*. (2000). These authors select four high technology industries, as defined by the OECD, namely aerospace, pharmaceutical, TV-radio and communication equipment and computer and office equipment . Gripaios *et al*. (2000) use the proportion of employment in high technology industries as an explanatory variable in a test for regional convergence across the UK counties. This variable is used, in conjunction with a series of employment variables (traditional manufacturing, utilities and financial/business services) to approximate industrial structure, to test for the differential impacts of various sectors in shaping patterns of regional growth. According to Gripaios *et al.* (2000):

> '[…] different sectors will have different growth patterns arising from long-term changes in technology and demand' (p. 1165)

Similarly, Plummer and Taylor (2001, 2001a) also select five such industrial sectors: pharmaceutical and veterinary, aircraft manufacturing, photographic, professional and scientific equipment, data-processing services and, finally, research and scientific institutions[21].

For the purpose of this paper, a region's level of technological development and adoption capacity is thus measured as the percentage of total employment in sectors where labour is used to approximate total resources. The approach adopted here is based on the contention that this measure encapsulates the sectors highlighted by the studies mentioned previously, and provides a more comprehensive measurement of the adoptive ability of a regional economy. More formally,

$$ADP_{i,t} = \frac{\sum_{j=1}^{m} \eta_{i,t}^{j}}{L_{i,t}} \tag{19}$$

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, obtained by EUROSTAT.

Equation (19), 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[22].

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[21] Andonelli (1990), Alderman (2004) and Alderman and Fisher (1992) use a similar approach in identifying sectors that are able to adopt technological innovations, although in a context other than of regional convergence.

[22] This is the region of 'Berkshire, Bucks and Oxfordshire'.

Consequently, in this context a variable that approximates the technological gap for region *i* at time *t* can be defined as follows:

$$TG_{i,t} = \left(\frac{ADP_{L,t}}{ADP_{i,t}} \right) \tag{20}$$

Expressing equation (20) in logarithmic terms yields:

$$TG_{i,t} = \ln ADP_{L,t} - \ln ADP_{i,t} . \tag{21}$$

Embodied in this variable is the idea of both a gap and the capacity to adopt technological innovations. As shown by the model in Section II, 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:

$$g_i = a + b_1 y_{i,0} + b_2 PI_{i,0} + b_3 TG_{i,0} + \varepsilon_i \tag{22}$$

As shown in Section II, the time dimension of variables describing technology should refer to the initial point in time for the period of study. From an econometric point of view, inclusion of technological variables measured at the initial time helps to avoid the problem of endogeneity. Moreover, Pigliaru (2003) claims that models which include measures of technology require data on total factor productivity. In the absence of such data, econometric estimation requires that the variables related to technology ought to be included in initial values.

Equation (22), thus, incorporates the potential impact of both internally generated technological change and technology adoption upon a region’s growth. Broadly speaking, it is anticipated that $b_2 > 0$, since regions with high initial levels of patents per capita are normally associated with high levels of growth and vice versa. However, it is not automatically the case that this condition promotes convergence. In other words, this view accepts the argument that if low productivity regions have a high initial level of intentional technology creation, then this will have positive impacts on convergence, by

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enhancing their growth rates. On the other hand, if such regions have a low propensity to innovate, then no significant impacts on growth are anticipated and, hence, it may be difficult to converge with technologically advanced regions. The latter case is the more likely.

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. The approach adopted here is based on the contention that 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 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 $b_3 < 0$, and convergence between technologically lagging and technologically advanced regions is severely constrained.

Despite its simplicity, this model aims to highlight the importance of initial conditions regarding spatial technology in the process of regional growth and convergence. As it stands, this approach neglects spatial factors. Equation (22) treats regions as 'closed' economies, apart from the recognition of a technological gap with the leading region. It is possible to overcome this, clearly unrealistic, assumption by introducing in equation (22) the effects of spatial interaction. Indeed, in the light of recent literature it may be argued that any empirical test for regional convergence is misspecified if the spatial dimension is ignored (Rey and Montouri, 1999; Rey and Janikas, 2005; Lall and Yilmaz, 2001), the presumption being that the extent of regional interactions, such as technology spillovers, are significantly dependent upon the location of regions relative to each other.

According to Rey and Montouri (1999) the potential for spatial interaction can be incorporated within convergence analysis by means of the spatial-error model. In this model, the key feature is that spatial interaction occurs through the error term of equation (22), and hence the usual assumption of independent error terms is not sustainable.

Following Rey and Montouri (1999), the error term incorporating spatial dependence is shown as follows:

$$\varepsilon_i = \zeta \mathbf{W} \varepsilon_i + u_i = (\mathbf{I} - \zeta \mathbf{W})^{-1} u_i \tag{23}$$

where ζ is the spatial error coefficient and u_i is a $n \times 1$ vector for the new independent error-term with $u \sim N(0, \sigma^2 \mathbf{I})$. Inter-regional spatial dependence is generated by means of the $n \times n$ spatial-weights matrix ($\mathbf{W}$) the elements of which (w) may be devised in various ways. For example, a common practice is to allow these weights to take the value of 1 if a region is contiguous to another and 0 otherwise (a first order continuity matrix). Alternatively, the spatial weights may be continuous variables (Cliff and Ord, 1981), constructed so as to produce declining weights as distance between regions increases. Thus:

$$w_{ij} = \frac{1/d_{ij}}{\sum_j 1/d_{ij}} \tag{24}$$

where d_{ij} denotes the distance between two regions i and j, as measured by the distance between the major urban centres where the majority of economic activities are located. The denominator is the sum of the (inverse) distances from all regions surrounding region i. This approach is used in the empirical analysis in section IV.

Taking into account the effects of spatial interaction, the test for absolute convergence in equation (17) is transformed as follows:

$$g_i = a + b_1 y_{i,0} + (\mathbf{I} - \zeta \mathbf{W})^{-1} u_i \tag{25}$$

Introducing a spatial error term in the test for ‘conditional’ convergence extends equation (22) as follows:

$$g_i = a + b_1 y_{i,0} + b_2 PI_{i,0} + b_3 TG_{i,0} + (\mathbf{I} - \zeta \mathbf{W})^{-1} u_i \tag{26}$$

It should be noted that contemporary empirical literature on regional convergence is based on models that combine conditional variables with spatial terms (that is to say ‘spatial conditional convergence’ models) focused mainly on the EU regions (e.g. Maurseth, 2001; Lopez-Bazo *et al.*, 2004) with fewer studies referring to individual countries (e.g. Funke and Niebuhr, 2005). Equation (26) is consistent with this literature and can be applied to the regional context of any individual country, provided that the required data are available.

At this stage, however, it is important to comment on the estimation methods for these spatial econometric models. Estimation of the spatial error model is carried out by the maximum likelihood method, as OLS may result in problems of bias. To be more specific, the presence of spatial interaction in the error term leads to the following non-spherical covariance matrix (Rey and Montouri, 1999, p. 149):

$$E[\varepsilon_t \varepsilon_t'] = (\mathbf{I} - \zeta\mathbf{W})^{-1} \sigma^2 \mathbf{I} (\mathbf{I} - \zeta\mathbf{W})^{-1'} \tag{27}$$

The presence of non-spherical errors results in unbiased OLS estimators but biased estimations of a parameter's variance. Bernat (1996) notes that the presence of spatial autocorrelation invalidates the standard tests in OLS regressions in a way similar to heteroscedasticity[23]. Thus, all inferences based on that model are invalid. Hence, the recommended estimation method is through maximum likelihood (Anselin, 1988; Anselin *et al*., 1996; Pace, 1997; Anselin and Florax, 1995a).

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 II, if infrastructure conditions are not favourable to adopt technology (approximated by a high technological gap), then convergence is not feasible. The next section, therefore, attempts to test this hypothesis empirically.

IV. Empirical Application

In this paper we exploit data on Gross Value Added (hereafter GVA) per worker 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). Nevertheless, apart from testing convergence in terms of labour productivity, which is what essentially GVA per worker measures, the empirical analysis is extended further by testing for regional convergence in terms of disposable or per capita income, as this is approximated by Gross Domestic Product (hereafter GDP) per capita in a region. The regional groupings used in this paper are those delineated by EUROSTAT and refer to 258 NUTS-2 regions. The EU uses NUTS-2 regions as 'targets'

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[23] Heteroscedasticity occurs when the disturbance variance is not constant and arises due to measurement problems, inadequate specification or omitted variables. See also Stewart and Gil (1998) and Gujarati (1995).

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 for the use of NUTS-2 regions as the appropriate level at which convergence should be measured, the NUTS-2 regions are sufficient small to capture sub-national variations (Fischer and Stirböck, 2006).

The time period for the analysis extends from 1995 to 2004, which might be considered as rather short. However, Islam (1995) and Durlauf and Quah (1999) point out that convergence-regressions, such as equation (17), 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’.

As explained in Section III, convergence is identified with an inverse relationship between growth and initial level of per capita income/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, should convergence be detected. The potential for absolute convergence is indicated in Figure 4, which shows a scatterplot of the average annual growth rate against the initial level of labour productivity, while Figure 5 portrays the same basic relationship in terms of GDP per capita.

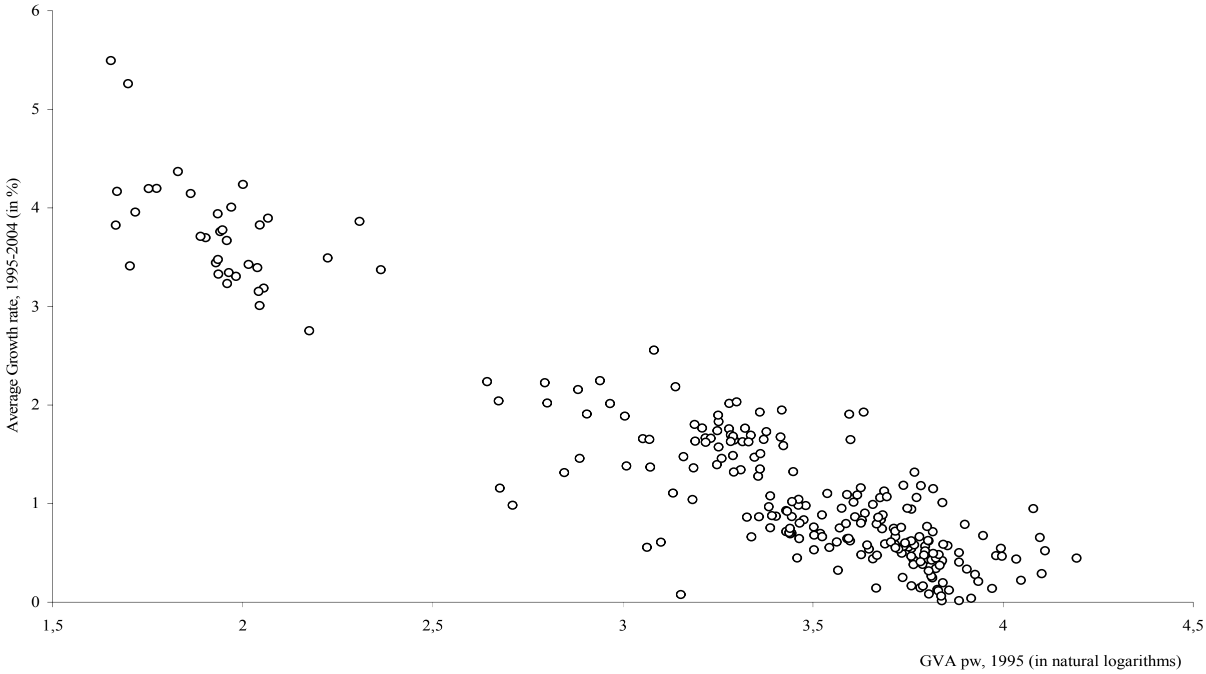

Figure 4: β-convergence, GVA per worker

Figure 4 clearly indicates a case for absolute convergence in terms of GVA per worker, and to a lesser extent in terms of GDP per worker (Figure 5).

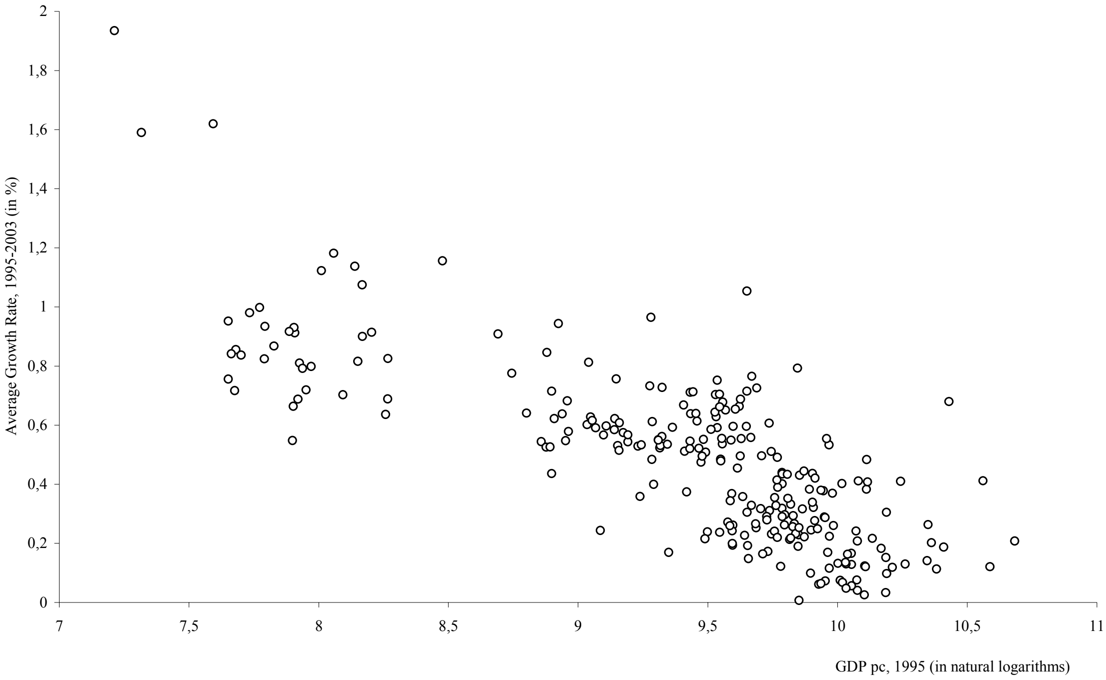

Figure 5: β-convergence, GDP per capita

The presence of absolute or β-convergence, however, cannot be confirmed by visual inspection alone. Therefore, the cross-section test, based on estimation of equation (17) for the 258 NUTS-2 regions of the EU, is applied to the period 1995-2004 using data for GVA per worker and GDP per capita.

Furthermore, the conventional test of regional absolute convergence is modified to include an explicit spatial dimension, as in equation (25). Finally, the hypothesis of 'technologically-conditioned' convergence is also estimated for both the non-spatial and spatial specifications, namely equations (22) and (25), respectively[24]. The results are set out in Tables (1) and (2) where Table (1) shows the outcomes when GVA per worker is used, and Table (2) when GDP per capita is employed.

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[24] In estimating eequations (17) and (22) OLS is applied while equations (25) and (26) are estimated by the Maximum-Likelihood method.

Table 1: Convergence in terms of GVA per worker, EU regions, 1995-2004

	Equation (17)	Equation (22)	Equation (25)	Equation (26)
Depended Variable: g_i				
a	1.2278**	1.4417**	1.2433**	1.4380**
b_1	- 0.2576**	- 0.3239**	- 0.2619**	- 0.3120**
b_2		0.0147*		0.0069
b_3		- 0.0339*		- 0.0370**
ζ			0.8505**	0.8227**
Implied β	0.0309**	0.03915**	0.0337**	0.0374**
LIK	145.9317	159.5092	231.2425	236.9179
AIC	- 287.8634	- 311.0184	- 452.4851	- 467.8358
SBC	- 280.7574	- 296.8065	- 434.7202	- 457.1769

Notes: ** indicates statistical significance at 95% level of confidence, * 90% level. AIC, SBC and LIK denote the *Akaike*, the *Schwartz-Bayesian* information criteria and Log-Likelihood, respectively.

Table 2: Convergence in terms of GDP per capita, EU regions, 1995-2004

	Equation (17)	Equation (22)	Equation (25)	Equation (26)
Depended Variable: g_i				
a	2.3195**	2.4358**	2.2573**	2.3391**
b_1	- 0.2046**	- 0.2121**	- 0.1976**	- 0.1994**
b_2		- 0.0011		- 0.0039
b_3		- 0.0387**		- 0.0423**
ζ			0.8755**	0.8457**
Implied β	0.0254**	0.0264**	0.0244**	0.0247**
LIK	119.6348	120.5214	204.5173	218.8897
AIC	- 235.2696	- 233.0428	- 399.0346	- 431.7794
SBC	- 228.1636	- 218.8304	- 381.2698	- 421.1205

Notes: ** indicates statistical significance at 95% level of confidence, * 90% level. AIC, SBC and LIK denote the *Akaike*, the *Schwartz-Bayesian* information criteria and Log-Likelihood, respectively.

Considering first the results of testing for absolute convergence, i.e. equation (17), it might be argued that there is some tendency for absolute convergence across the regions of an enlarged Europe, both in terms of labour productivity, measured by GVA per worker and in per capita GDP. The rate of convergence of labour productivity is, on average, about 3% per annum while for GDP per capita it is estimated to be slower, at 2.5% - quite close to the 'stylized fact' of 2%, proposed by Barro and Sala-i-Martin (1991, 1992).

The rate of absolute convergence changes slightly when spatial interaction is included (equation (25)), ranging from 3.4% per annum for the labour productivity measure to 2.4% for per capita GDP. The spatial coefficient is also statistically significant and can be taken as an indication that there is a significant spatial dimension in the process of European regional convergence. This view is further supported by the fact that both the criteria for model selection that are applied here, namely the *Akaike* (AIC) and the *Schwartz-Bayesian* (SBC) information criteria,[25] clearly indicate the superiority of the spatial specifications. Further support is also provided by the value of the LIK, which increases, as anticipated, with the introduction of the $(\mathbf{I}-\zeta\mathbf{W})^{-1}$ term.

Of particular importance to this paper, however, are the results obtained for the conditional convergence model (equations 22 and 26). Conditioning for the two technological variables tends to increase the estimated convergence rates, which extend from 3.9% in the non-spatial specification (Table 1) to 2.5% in the spatial model (Table 2). Both the AIC and SBC criteria support the spatial version of the 'technologically-conditioned' specification.

Turning to the impact of innovation, in three out of four cases the propensity to innovate variable ($PI_{i,0}$) is statistically insignificant. A significant positive relationship between intentional knowledge/ technology creation and growth is detected only in the non-spatial model for GVA per worker, shown in Table 1. The estimated value of b_2 here suggests

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[25] As a rule of thumb, the best fitting model is the one that yields the minimum values for the AIC or the SBC criterion, calculated as $AIC=-2L+2K$ and $SBC=-2L+K\ln(T)$, where L is the value of the log likelihood function, T is the number of observations and K stands for the number of parameters estimated. The SBC test has superior properties and is asymptotically consistent, whereas the AIC is biased towards selecting an overparameterized model (Anselin, 1995, Enders, 1995).

that a 1% increase in patents per capita induces an increase in a region's growth of labour productivity about 1.5%, on average, ceteris paribus. However, as argued in Section II, a positive value of b_2 does not necessarily promote convergence as such, since regions with relatively high initial level of innovation exhibit relatively higher rates of growth.

On the other hand, the variable describing technology adoption and infrastructure conditions ($TG_{i,0}$) is always highly statistically significant and negative in sign. As argued in Section II, 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 overall convergence and, in turn, suggesting the possibility of convergence towards different equilibria (a pattern of club convergence) following the predictions of the model, examined in Section II. If technologically backward regions of the EU were successful in adopting technology, then the estimated coefficient b_3 would be positive[26]. Since $b_3 < 0$ this indicates that infrastructure conditions in regions with high technological gaps are inhibiting this process of technology adoption.

In quantitative terms, the impact of the technology gap variable is such that a 1% change is associated with an impact on a region's growth in the range 4.2% to 3.4% per annum. This effect is considerably higher than that implied for technology creation. This relatively greater impact also suggests that adoption of technology, although it might be the best 'vehicle' for lagging regions to converge with leading regions, is nevertheless a process which might be difficult for lagging regions, especially during the early stages of development when conditions are least supportive. The message, therefore, from the empirical application of the model developed in this paper is clear. The adoption of

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[26] It should be noted, however, that Gripaios *et al*. (2000) using *actual* percentages of employment in high technology sectors for the UK counties, estimate a negative coefficient, which can be interpreted as a source of convergence, if employment in these sectors is located mainly in rich regions. In this case, a high percentage of employment in such sectors is associated with low rates of growth, thus, promoting convergence between rich and poor regions. However, the technological variable is chosen because of its ability to embody two concepts, namely the extent of the potential for technology adoption and the appropriateness of infrastructure conditions to take advantage of this potential.

technology to set the lagging regions of the EU in a process of convergence with the leading regions requires an improvement in infrastructure conditions.

VI. Conclusions

Although an increasing number of empirical studies have paid attention to issues of economic convergence in the EU, the impact of technology adoption in regional convergence has so far received more limited attention. We have attempted in this paper to address this question, using data for the 258 NUTS-2 regions of the EU-26 over the period 1995-2004. The results suggest that the NUTS-2 regions of EU-26 exhibit a tendency towards convergence in terms of labour productivity and per capita output. Convergence appears to be faster in terms of labour productivity compared to GDP per capita, with the latter at a rate around the 'stylised fact' of 2% per annum, proposed by Barro and Sala-i-Martin (1992). However, absolute convergence does not seem to be the case in the EU regions. An important conclusion to emerge from the empirical application is that the EU-26 regions exhibit faster tendencies to converge *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 the lagging regions of Europe are not able to reap the 'benefits of backwardness'. This inability can 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, creating thus a pattern of club convergence. Catch-up to the leading regions is feasible only amongst those regions whose conditions are similar or close to those of the technologically advanced regions.

While this paper has been concerned with the role of adoption technology and has stressed the impact of initial infrastructure conditions, there is no intention of implying that this approach represents the only route to understanding the contribution of these factors in regional growth and convergence. It must be recognised that the foregoing analysis does not provide an exhaustive account of all the factors that affect the process of regional convergence. What then is the purpose of this paper? Perhaps the main purpose of this paper should be to provoke interest in further work on the appropriate conditions for, and impact of, technology adoption in regional convergence.

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