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Technology Adoption and Club Convergence

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Abstract

Although the importance of technology adoption has been acknowledged, nevertheless, 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 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. In this model the possibility that high technological gaps might act as obstacles to convergence is taken explicitly into consideration. The model developed in this paper 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 a regional economy. The model 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 effect on regional growth patterns in Europe.

Key words: Convergence Clubs, Technological Gap, Technology Adoption

JEL: R11; O33

I. Introduction

Although 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. Bernard and Jones

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(1996) have succinctly put this argument as follows: ‘To the extent that the adoption and accumulation of technologies is important for convergence, the empirical convergence literature is misguided’ (p. 1037). 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 the existing literature 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. It is the purpose of this paper to develop a model capable to provide an appropriate framework to analyse some implications of technology adoption in the process of regional convergence.

This effort is organised as follows. Section II argues that if adoptive abilities differ across regions, then any possibilities for regional convergence are constraint. This will be the starting point for a more elaborate analysis in Section III. 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. 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). A process of technology diffusion, however, 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), 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 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

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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).

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

(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. 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 and approximate the ability of an economy to absorb technology in terms of levels of human capital and the endogenous rate of innovation.

De la Fuente (2000) develops a model in which 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. However, this model does not consider the possibility that high technological gaps might act as obstacles to convergence.

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 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 growth of technology in a region is the outcome of two sources. The first is a process of intentional creation of technology; a process that takes place exclusively within the 'borders' of a region. As regions are, by definition, open economies technology is also affected by technological improvements that take place in other regions. This constitutes the second source that induces the growth of technology. Alternatively, this refers to the part of technology that is generated from interaction between spatial units. Denoting by C_i the part of technological growth that is due to efforts within the region and 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:

$$G_{A_i} = f\left(C_i, E_i\right) \tag{1}$$

with the expectation of $f'_{G_{A_i},C_i} > 0$ and $f'_{G_{A_i},E_i} > 0$.

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

$$G_{A_i} = C_i \, E_i \tag{2}$$

It is assumed that both C_i and E_i are affected by the size of the 'technological gap'. This can be 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. $B_i = \frac{A_i}{X_i}$. Thus: $C_i = g(B_i)$ and $E_i = h(B_i)$. If $g'_{C_i,B_i} < 0$, then a high (low) technological gap is associated with a lower (high) level of technology creation. On the other hand, if $g'_{C_i,B_i} > 0$, then a high (low) technological gap implies a high (low) level of technology creation. In this case, a high technological gap acts as an incentive for technologically backward regions to increase their ability to create technology. A high (low) technological gap is linked to a low (high) ability to adopt technology if $h'_{C_i,B_i} < 0$. If a high (low) technological gap results to a high (low) ability to adopt technology, i.e. when $h'_{C_i,B_i} > 0$, then this a case of the 'advantages of backwardness'.

Once this knowledge is introduced, then each element of equation (2) can be written as follows:

$$C_i = \tilde{C}_i B_i^{\gamma} \tag{3}$$

$$E_i = \tilde{E}_i B_i^{\delta} \tag{4}$$

In equations (3) and (4) $\tilde{C}_i$ and $\tilde{E}_i$ denote the autonomous parts of the technological sources while the parameters γ and δ measure the rate at which the prevailing technological gap in a region induces the growth of internally generated technological change and diffusion, respectively. Convergence requires that $\gamma, \delta > 0$.

Equations (2), (3) and (4) can be written in linear form by taking logarithms as follows:

$$g_{A_i} = \dot{a}_i = c_i + \varepsilon_i \tag{5}$$

$$c_i = \tilde{c}_i + \gamma b_i \tag{6}$$

$$\varepsilon_i = \tilde{\varepsilon}_i + \delta b_i \tag{7}$$

Inserting equations (6) and (7) in (5) and rearranging yields:

$$\dot{a}_i = \tilde{\theta}_i + \xi b_i \tag{8}$$

where $\tilde{\theta}_i = (\gamma_i + \tilde{\varepsilon}_i)$ and $\xi = (\gamma + \delta)$

Of particular importance is the parameter ξ, which essentially, measures the degree or the ability of a region to create and implement technological innovations. In other words this parameter can be conceived as an adoptive parameter, reflecting the opportunities for technological catch-up.

If $\xi > 0$, then there is a case of the ‘advantages of backwardness’. It is possible to be $\xi > 0$ if $\gamma < 0$ and $\delta > 0$, which means that although a region is not able to create its own technology, technological growth is possible if $\delta > 0$, i.e. the higher (lower) the technological gap, the higher (lower) the adoption rate and, hence, the enhancement of technological growth. A value of $\delta < 0$, on the other hand, signifies inappropriate conditions for technology adoption.

Given that the technological distance can be written in logarithmic terms as $b_i = a_i - x_i$, then the technological distances between a leading and a follower region, are given by: $b_l = a_l - x$ and $b_f = a_f - x$, respectively. Using equation (8) we may write:

$$\dot{a}_l = \tilde{\theta}_l + \xi b_l \tag{9}$$

$$\dot{a}_f = \tilde{\theta}_f + \xi b_f \tag{10}$$

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

$$\dot{b}_{lf} = \dot{a}_l - \dot{a}_f = (\tilde{\theta}_l - \tilde{\theta}_f) + \xi (b_l - b_f) \tag{11}$$

Defining $b_{lf} = b_f - b_l$ and $\tilde{\theta}_{lf} = (\tilde{\theta}_l - \tilde{\theta}_f)$, equation (11) can be written as follows:

$$\dot{b}_{lf} = \tilde{\theta}_{lf} + \xi b_{lf} \tag{12}$$

Equation (12) can be written as a first-order differential equation:

$$\dot{b}_{lf} - \xi b_{lf} = \tilde{\theta}_{lf} \tag{13}$$

A general solution (*GS*) of a differential equation is given by a complementary function (*CF*) and a particular solution (*PS*), defined as follows:

$$b_{lf}^{CF} = \mathbf{A}e^{-\xi t} \tag{14}$$

where $\mathbf{A}$ is an arbitrary constant, estimated by initial conditions.

$$b_{lf}^{PS} = \frac{\tilde{\theta}_{lf}}{\xi} \tag{15}$$

Adding equation (14) and (15) gives the general solution of equation (13):

$$b_{lf,t} = \mathbf{A}e^{-\xi t} + \frac{\tilde{\theta}_{lf}}{\xi} \tag{16}$$

Setting $t = 0$ in equation (16) yields an expression for $\mathbf{A}$. Thus,

$$\mathbf{A} = b_{lf,0} - \frac{\tilde{\theta}_{lf}}{\xi} \tag{17}$$

Inserting equation (17) into (16) and rearranging terms yields a general solution of equation (13):

$$b_{lf,t} = \left(b_{lf,0} - \frac{\tilde{\theta}_{lf}}{\xi} \right) e^{-\xi t} + \frac{\tilde{\theta}_{lf}}{\xi} \tag{18}$$

Equation (18) can be written as follows:

$$b_{lf,t} = b_{lf,0}e^{-\xi t} + \left(- e^{-\xi} \right) \frac{\tilde{\theta}_{lf}}{\xi} \tag{19}$$

According to equation (19), the evolution of the technological gap depends upon the adoptive parameter ξ. If this parameter differs across regions, then any possibilities for regional convergence are constraint. This consideration can be shown using an example in which the economy is divided into three regions, one 'leader' (l), which is at the technological frontier $(b_l = a_l - x = 0)$, and two followers, i.e. $i = 1, 2$. 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. $\tilde{\theta}_{lf_1} - \tilde{\theta}_{lf_2} = 0$ and $b_{lf_1} - b_{lf_2} > 0$. Assume further that region 1 exhibits a higher ability in adopting technology, i.e. $\xi_1 - \xi_2 > 0$. If this difference is sustained through time, then a technological catch-up between region 1 and 2 is not feasible, as shown in Figure 1.

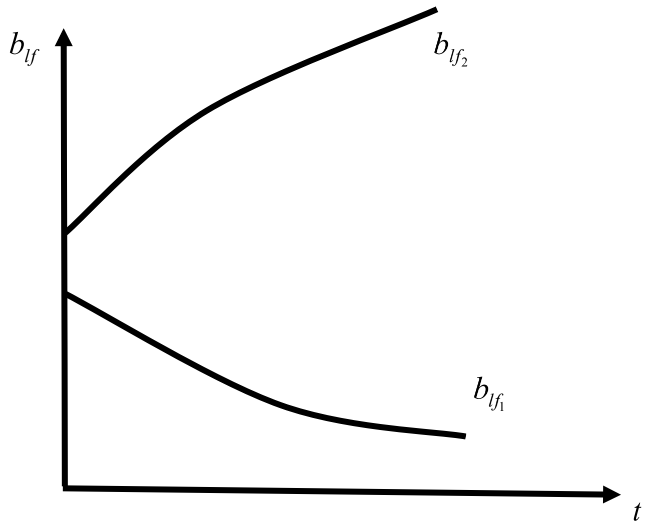

Figure 1: Technological Divergence

It seems thus legitimate to ask, if there is a way for region 2, the ‘technologically poor’ region to catch up with the ‘technologically rich’ region 1? A technological catch-up is feasible only if region 2 improves its adoptive ability, i.e. if the value of ξ_2 increases through time. Suppose that ξ_2 begins to increase after some time, let t_n. The technological gap amongst the regions shrinks through time, as shown in Figure 2.

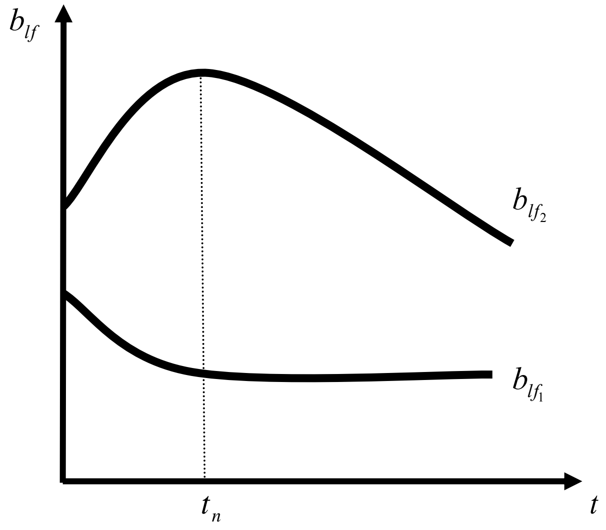

Figure 2: Technological Catch-up

There seems to be little doubt that differences in the adoptive abilities of regions affect the pattern of regional convergence. What is less clear, however, is what causes these abilities to differ across regions. It is quite possible that a significant technological gap is associated with unfavourable conditions for the adoption of new technology. This possibility is introduced in the next section.

III. Technology Adoption: Implications for Regional Convergence

Assume that the rate of technology adoption (ξ) is a non-linear function of the technological gap:

$$\xi_i = \rho b_{lf_i}^{-\pi} \text{ with } \rho, \pi > 0 \tag{20}$$

The intuition behind equation (20) is that the rate of adoption is not constant but varies across regions, according to the size of the gap. Thus, for a given value of ρ, a high technological gap implies a low capacity to absorb and create 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 adoption (ξ). 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 adoption. This parameter can be viewed as a measure of the appropriateness or suitability of regional infrastructure to adopt technology. Thus, the rate of technology adoption is endogenously determined[3].

To introduce these considerations equation (20) is substituted into equation (12):

$$\dot{b}_{lf} = \tilde{\theta}_{lf} - \rho b_{lf}^{(1-\pi)} \tag{21}$$

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

$$\tilde{\theta}_{lf} = \rho b_{lf}^{(1-\pi)} \tag{22}$$

which gives an equilibrium value for the technological gap:

$$b_{lf}^{*} = \left(\frac{\tilde{\theta}_{lf}}{\rho} \right)^{\frac{1}{1-\pi}} \tag{23}$$

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[3] This is in accordance with the literature on New Endogenous Growth Theory. For a more detailed review see Aghion *et al.* (1999), Alesina and Rodrik (1994), among others.

It is interesting to consider 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 (20) $\xi_i = \rho$ and the adoption 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 adoption. Two distinct patterns of convergence arise, however, when $\pi < 1$ and when $\pi > 1$. Figure 1 portrays the pattern of convergence implied by $\pi < 1$.

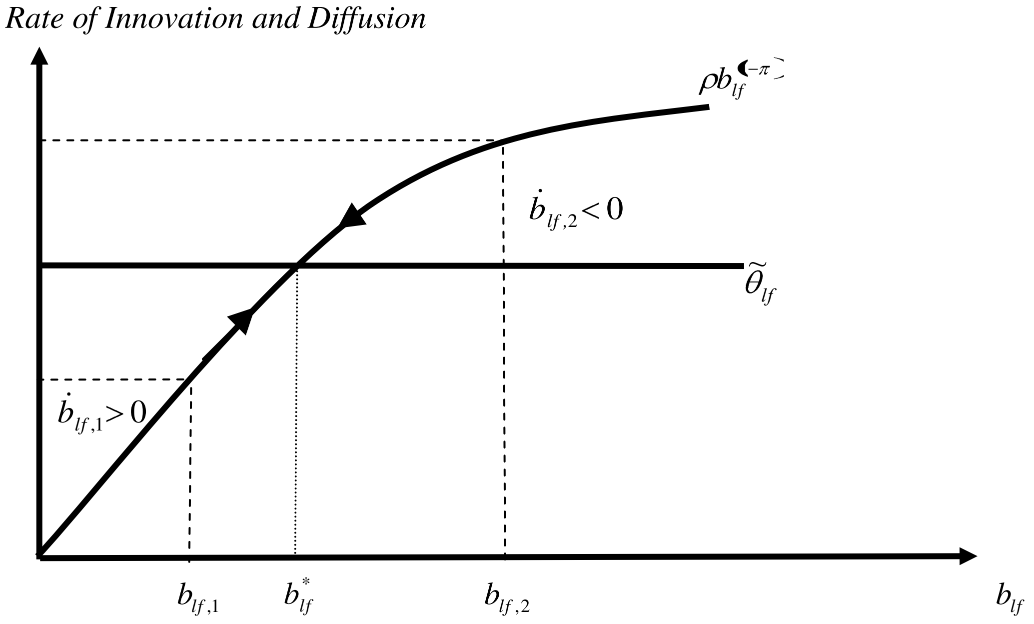

Figure 3: Convergence towards a single equilibrium when $\pi < 1$

As illustrated in Figure 3, 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 regions 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 the standard neoclassical model, 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 4.

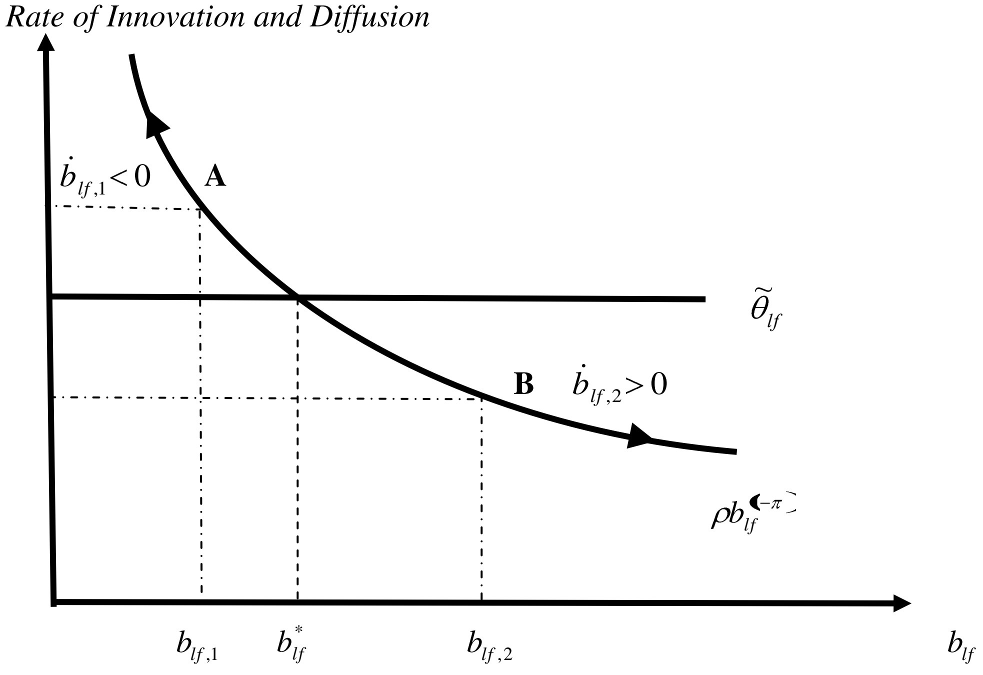

Figure 4: Convergence towards different equilibria when $\pi > 1$

As Figure 4 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. 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 4 indicates, a zero gap with the leader is not feasible, since by definition the curve $\rho b_{lf}^{(-\pi)}$ 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. $b_{lf,T-0} \to 0$.

For simplicity assume that $\widetilde{\theta}_{lf_1} = \widetilde{\theta}_{lf_2}$ and ρ is the same for both regions[4]. 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. Region 1 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 4, 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[5].

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

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[4] 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 $t \to \infty$.

[5] A similar situation emerges 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 the initial technological gap and associated infrastructure conditions, then two groups of regions can emerge; one which is a convergence club while a second group that does not exhibit an ‘equilibrium’. Whether a region belongs to the convergence club depends on its capacity to adopt technology, and this capacity declines the higher the initial technology gap.

In the preceding example it was assumed that $\tilde{\theta}_{lf_1} = \tilde{\theta}_{lf_2}$. A more complicated picture arises if this assumption is relaxed, i.e. when $\tilde{\theta}_{lf_1} \neq \tilde{\theta}_{lf_2}$[6].

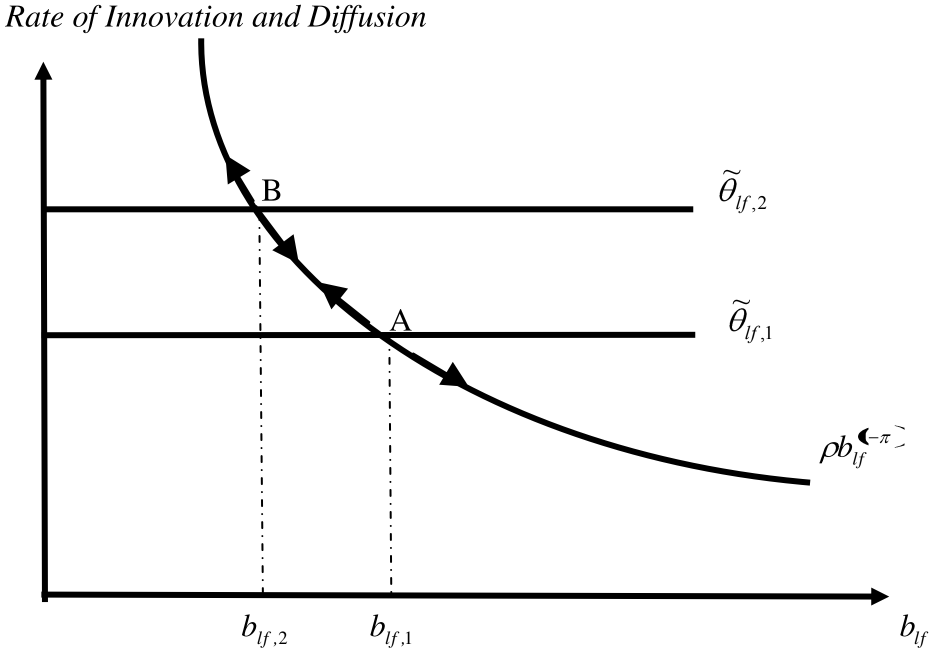

Figure 5: Club Convergence when $\pi > 1$ and $\tilde{\theta}_{lf_1} \neq \tilde{\theta}_{lf_2}$

Figure 5 shows a situation where $\tilde{\theta}_{lf_1} < \tilde{\theta}_{lf_2}$. Point B represents the critical threshold for region 2, showing that a large technological differential requires a high rate of technology absorption in order to prevent the region moving further away from the leading region in

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[6] Such a situation might also occur if region 1 develops a ‘technology-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: $b_{lf_i,t_n} \to 0$ and $\theta_{lf_i,t_n} \to 0$, as $n \to 0$.

terms of overall technology growth. On the other hand, point A is the threshold for region 1, which has a lower technology 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 $\widetilde{\theta}_{lf}$ and another to b_{lf_2}, with high $\widetilde{\theta}_{lf}$.

This model suggests that only regions with low technology gaps 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 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 $\widetilde{\theta}_{lf}$ is the same, or different, across regions. 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 apart from their initial position with regard to the size of the technological gap. From this perspective, convergence amongst regions is feasible only if they share similar structural characteristics, regarding the creation and adoption of technology.

This model argues that even in the case where technology creation is limited to one region, the remaining regions may converge towards the leader provided that they are able to adopt and assimilate technology. The higher the technological distance from the leader, the greater the incentive to adopt technology. However, this model has also shown that a high technological gap may indicate and reflect inappropriate conditions for the adoption of technology, which prevent or constrain convergence with the more technologically advanced regions. Hence, a technological catch-up is feasible only amongst those regions whose conditions are similar or close to those of the technologically advanced regions. In this way club convergence is a probable outcome. This outcome is in accordance with a fast growing literature on club-convergence (e.g. Galor, 1996, 1996a; Galor and Tsiddon, 1997)

According to the model developed in this paper, 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, 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 and, consequently, convergence towards leading regions is feasible only for regions with sufficient absorptive capacity.

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:

$$Q_{i,t} = k_{i,t}^{\alpha} \tag{24}$$

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[7]:

$$\frac{d \log Q_{i,t}}{dt} + \beta \log Q_i = \beta \log Q^{*}, \text{ where } \beta = (1 - \alpha)(\eta + g + \delta) \tag{25}$$

Equation (25) is a differential equation in $\log Q_i$ with the general solution:

$$\log Q_i = (1 - e^{-\beta t}) \log Q^{*} + e^{-\beta t} \log Q_{i,0} \tag{26}$$

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

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

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:

$$\log\left(\frac{Y_{i,t}}{L_{i,t}}\right) = \left(-e^{-\beta t}\right)\log Q^{*} + e^{-\beta t}\left(\log\left(\frac{Y_i}{L_i}\right)_0 - \log PI_{i,0} - \log TG_{i,0}\right) + \log PI_{i,t} + \log TG_{i,t} \quad (27)$$

Subtracting $\log\left(\frac{Y_i}{L_i}\right)_0$ from both sides of equation (27) yields:

$$g_{i,T} = c + b_1 \log\left(\frac{Y_i}{L_i}\right)_0 + b_2 \log PI_{i,0} + b_3 \log TG_{i,0} \quad (28)$$

where $g_{i,T} = \log\left(\frac{Y}{L}\right)_{i,t} - \log\left(\frac{Y}{L}\right)_{i,0}$, $T = t - 0$, $b_1 = -\left(-e^{-\beta t}\right)$, $c = \left(-e^{-\beta t}\right)\log Q^{*} + \left(\log PI_{i,t} + \log TG_{i,t}\right)$ and $b_2, b_3 = -e^{-\beta t}$.

In equation (28) 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 (29) and (30), respectively.

$$g_i = a + b_1 y_{i,0} + \varepsilon_i \tag{29}$$

$$g_i = a + b_1 y_{i,0} + b_{\mathbf{X_i}} \mathbf{X_i} + \varepsilon_i \tag{30}$$

where y_i represents per capita output of the ith 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[8].

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 $\beta = \ln\left(b_1 + 1\right)/-T$. [9,10] 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 (30), 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

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[8] 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.

[9] 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 $e^{-\beta t} = \frac{1}{2}$.

[10] 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).

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 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[11], 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[12]. 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.

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[11] 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).

[12] 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.'

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[13]. Data related to patents fall into the first category while R&D expenditures or labour employed in R&D 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.

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

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[14].

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,

$$ADP_{i,t} = \frac{\sum_{j=1}^{m} \eta_{i,t}^{j}}{L_{i,t}} \tag{31}$$

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.

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[14] 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.

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[15].

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

$$TG_{i,t} = \left(\frac{ADP_{L,t}}{ADP_{i,t}} \right) \tag{32}$$

Expressing equation (32) in logarithmic terms yields:

$$TG_{i,t} = \ln ADP_{L,t} - \ln ADP_{i,t} . \tag{33}$$

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:

$$g_i = a + b_1 y_{i,0} + b_2 PI_{i,0} + b_3 TG_{i,0} + \varepsilon_i \tag{33}$$

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.

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

Equation (33), 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 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 (33) 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 (29), 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:

$$\varepsilon_i = \zeta \mathbf{W}\varepsilon_i + u_i = (\mathbf{I} - \zeta \mathbf{W})^{-1} u_i \qquad (34)$$

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:

$$w_{ij} = \frac{1/d_{ij}}{\sum_j 1/d_{ij}} \qquad (35)$$

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:

$$g_i = a + b_1 y_{i,0} + (\mathbf{I} - \zeta \mathbf{W})^{-1} u_i \qquad (36)$$

Introducing a spatial error term in the test for 'conditional' convergence extends equation (33) as follows:

$$g_i = a + b_1 y_{i,0} + b_2 PI_{i,0} + b_3 TG_{i,0} + (\mathbf{I} - \zeta \mathbf{W})^{-1} u_i \qquad (37)$$

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):

$$E\left[\varepsilon_t\varepsilon_t'\right] = (\mathbf{I}-\zeta\mathbf{W})^{-1}\sigma^2\mathbf{I}(\mathbf{I}-\zeta\mathbf{W})^{-1'} \qquad (38)$$

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[16]. 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

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[16] 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).

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). The regional groupings used in this paper are those delineated by EUROSTAT and refer to 267 NUTS-2 regions. 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 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 2006, 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'.

Considering first the case of simple absolute convergence, this is typically associated with an inverse relationship between growth and some initial level of output per-worker. Thus, poor regions grow faster than rich regions. In the context of the EU regions between 1995 and 2006, the potential for absolute convergence is suggested by Figure 4, which shows a scatterplot of the average annual growth rate against the initial level of labour productivity. As shown in Table 1, there is a statistically significant inverse relationship between growth over the time period, and the level of GVA per-worker at the start of the period. Nevertheless, the rate of convergence of labour productivity is a slow one, estimated to be 0.65% per annum.

When spatial interaction is included the rate of convergence ranges from 0.64% to 0.71% per annum. In all cases, the spatial coefficient is statistically significant and positive and in two out of three cases the underlying rate of convergence is higher than in the non-spatial model, showing that spatial interaction plays a positive role in the convergence process. The superiority of the spatial models is supported by both the criteria for model selection applied here, namely the *Akaike* (AIC) and the *Schwartz-Bayesian* (SBC) information criteria.[17] Further support is also provided by the value of the Log-likelihood (LIK), which increases, as anticipated, with the introduction of spatial interaction. Overall, these results suggest a significant spatial dimension in the process of European regional convergence.

Turning to the role of technology in growth and convergence, the relevant results are of importance. The convergence coefficient is significantly negative and the rate of convergence is now estimated as 0.23% per annum. The coefficient on the propensity to innovate is negative, suggesting that regions with a high propensity to innovate, normally high productivity regions, grow slower than technologically lagging regions. This might act as source of convergence, provided that the poor regions are able to absorb technology. However, this does not seem to the case. A negative sign is also estimated for the variable representing technology adoption. The existence of a high technology gap and associated low capability for technology adoption is thus inhibiting growth and convergence.

The spatial versions of the model again show statistically significant spatial effects and confirm the impact of spatial interaction between regions upon regional growth patterns. Overall, the spatial equations would also appear to provide a better fit to the data. In particular, according to the both the AIC and SBC criteria and the LIK statistic, the spatial-error model is to be preferred.

Focusing on this spatial error model, Table 1 shows that the propensity to innovate variable is again negatively related to growth over the period. While this can be conceived as a convergence effect, nevertheless the impact of the technology adoption variable works in the opposite direction. On average, regions with high technological gaps at the start of the period grow slower than regions with low gaps, *ceteris paribus*. Thus, a 1% increase in the measure of capacity to adopt technology adoption leads to a 5% fall in growth over the period. The underlying rate of convergence is lower when the impact of technology factors is made explicit (0.71% compared to 0.33%).

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[17] As a rule of thumb, the best fitting model is the one that yields the minimum values for the AIC or the SBC criterion. The SBC test has superior properties and is asymptotically consistent, whereas the AIC is biased towards selecting an overparameterized model.

In summary, the evidence presented here clearly supports the arguments previously put forward, that technology adoption is a route by which lagging regions might be able to converge with leading regions, but that this is a process which is likely to be difficult, especially during the early stages of development when conditions in the lagging regions are least supportive. Thus, a high technology gap presents an obstacle to convergence because of the implied poor infrastructure and weak adoptive capacity. These factors work to sustain initial differences across regions, and suggest the possibility of *club convergence* towards different equilibria following the predictions of the model examined in Section 3.

In order to encapsulate this possbility, equation (37) is extended as follows:

$$\mathbf{g_i} = a + b_1 \mathbf{y_{i,0}} + b_2 y_{i,0}^2 + b_3 PI_{i,0} + b_4 TG_{i,0} + \left(- \zeta \mathbf{W} \right)^{-1} u_i \tag{38}$$

According to Baumol and Wolff (1988), a convergence-club is apparent when $b_1 > 0$ and $b_2 < 0$. Club-membership is determined by a threshold level of y_i, given by the unique maximum of equation (38): $y^* = \frac{-b_1}{2b_2}$. The essence of equation (38) can be summarised quite simply: only those economies with $y_{i,0} - y^* > 0$ belong to the convergence-club, in the sense that their growth rates are inversely related to initial labour productivity in

Essentially, equation (38) is a parametric method to detect convergence-clubs, and it might be argued that is inferior to other methods proposed in the literature.[18] Nevertheless, using such a method as a first step in a research project is more comprehensible, and it allows the inclusion of variables that might account for a pattern of club-convergence. It is thus possible to identify the appropriate areas for intervention if the aim of regional policy is to achieve overall convergence across regions.

The obtained econometric results in Table 2 confirm the pattern of club convergence. The convergence-club includes, almost exclusively, regions from EU-15 and only two regions from new member-states. The diverging regions are all located around the ‘edge’ of the EU, as shown in Figure 5.

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[18] For a more detailed review see Durlauf et al. (2005).

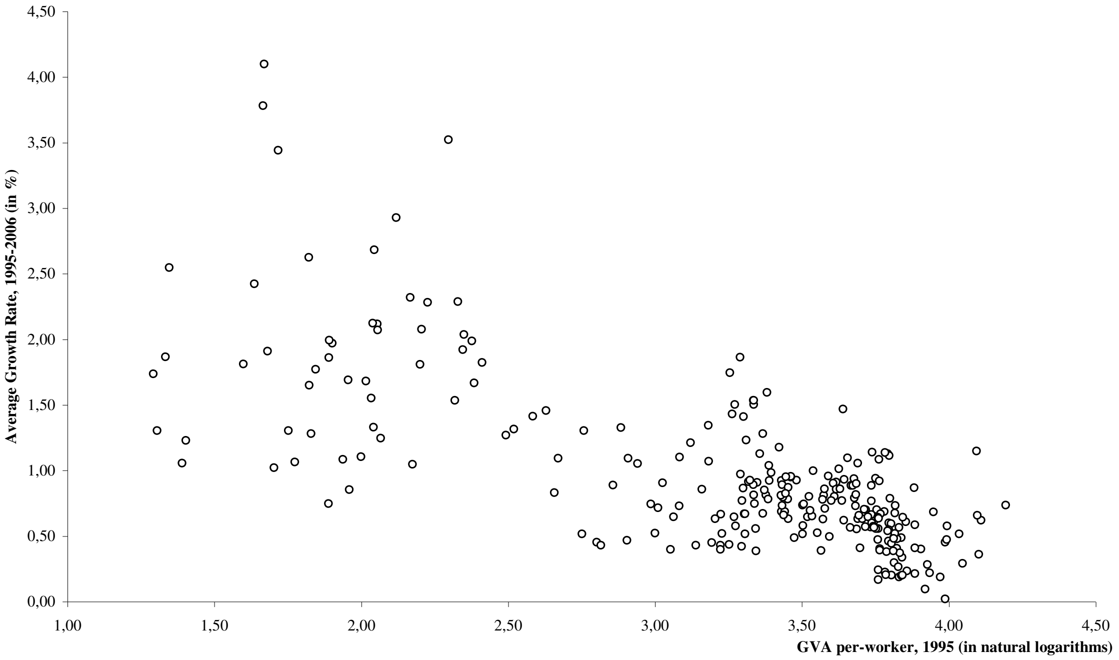

Figure 6: Absolute convergence, GVA per-worker, EU-27 NUTS-2 Regions, 1995-2006

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

Depended Variable: g_i, n = 267 NUTS-2 Regions								
a	0.5714**	0.6191**	0.5985**	0.5482**	0.5743**	0.6828*	0.5465**	0.6409**
b_1	-0.0747**	-0.0279*	-0.0819*	-0.0770	-0.0741**	-0.0361**	-0.0187	-0.0300**
b_2		-0.0401**				-0.0382**	-0.0428	-0.0399**
b_3		-0.0631**				-0.0504**	-0.0531*	-0.0714**
ζ			0.7506**			0.6667**		
ρ				0.1148			0.1490	
c					0.5979**			0.8671**
Implied β	0.0065**	0.0023**	0.0071**	0.0068	0.0064**	0.0033**	0.0015	0.0025**
LIK	147.552	163.971	270.2628	270.1091	164.9574	272.2321	271.3244	185.1642
AIC	-291.104	-319.943	-534.5256	-530.2182	-323.9148	-538.4643	-532.2182	-360.3280
SBC	-283.929	-305.594	-523.7639	-512.2820	-313.1531	-527.7026	-514.7127	-342.3918

Notes:

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

Table 2: Club Convergence Spatial error specification

Depended Variable: g_i , n = 267 NUTS-2 Regions	
a	0.1081**
b_1	0.3001**
b_2	-0.706**
b_3	-0.0353*
b_4	-0.0502**
ζ	0.3501*
Implied y^*	2.607

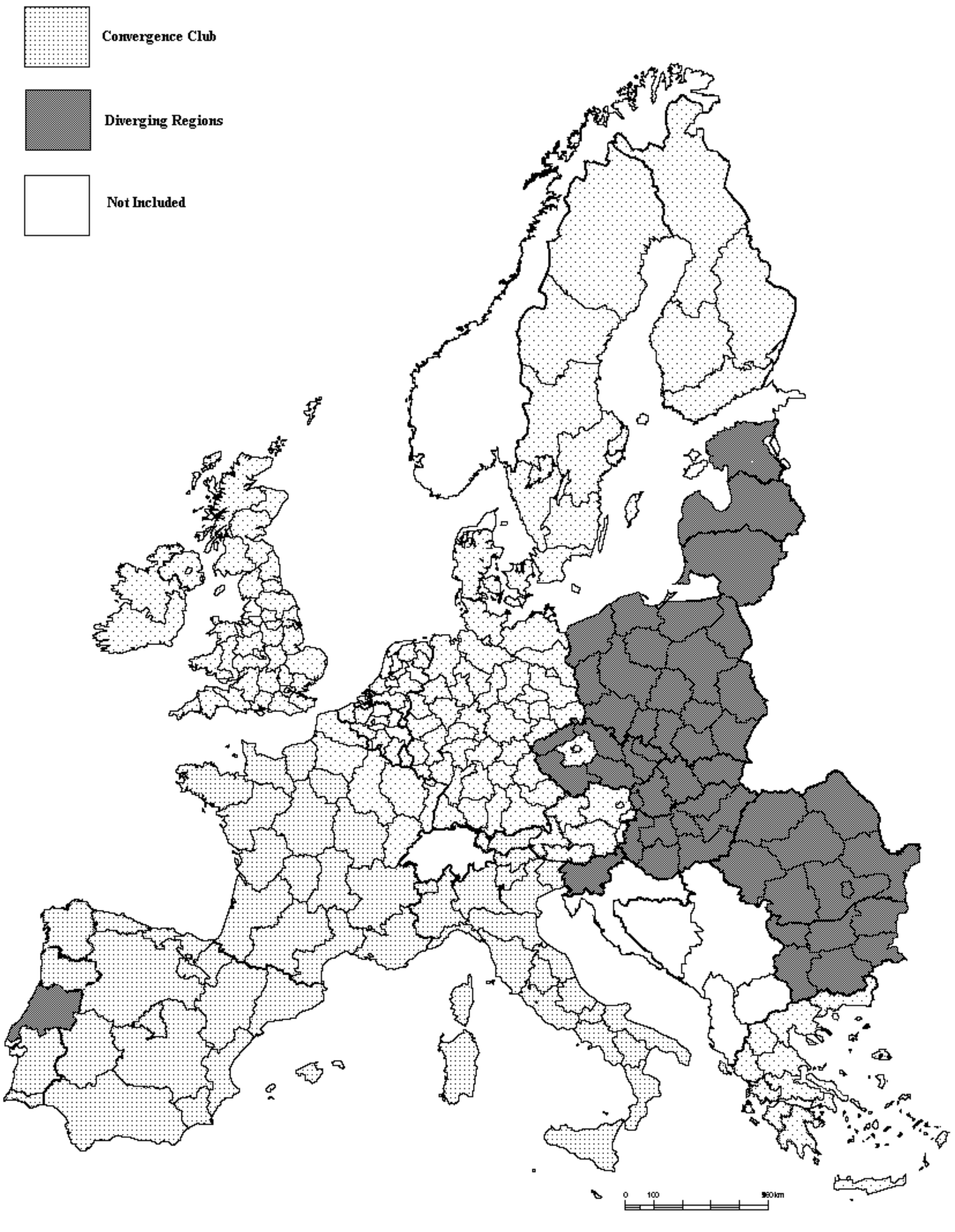

Figure 6: Convergence Club across the regions of Europe

V. Conclusions

Is it not time to abandon the simplistic idea of automatic technology adoption in favour of the more realistic assumption that technology adoption is strongly related to infrastructure conditions? According to the model developed in this paper, regions with high degrees of technology absorption, attributed to better infrastructure conditions, form a convergence club with the technologically leading regions, while regions with a low ability to absorb technology diverge. Convergence towards leading regions is feasible only for regions with sufficient absorptive capacity, which is assumed to be a function of infrastructure conditions in a region.

In empirical terms, 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 the question of whether regions with a high technology gap are able to take advantage of this potential for faster growth, using data for the 267 NUTS-2 regions of the EU-27 over the period 1995-2006. The results suggest that the NUTS-2 regions of EU-27 exhibit some underlying tendency towards convergence in terms of labour productivity, but an important conclusion which emerges is that the regions exhibit slower convergence 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 the EU are able to reap the 'benefits of backwardness'. This inability can be attributed, perhaps, 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 technology adoption and has stressed the impact of initial infrastructure conditions, there is no intention of implying that this approach represents the only route to understanding 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. Improving the model developed in this paper by adding more explanatory variables would open up an interesting avenue for future research.

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