OPTIMAL ALLOCATION OF INVESTMENT AND REGIONAL DISPARITIES

Alexiadis Stilianos[1] and Ladias Christos[2]
[1] Ministry of Rural Development and Foods, Department of Agricultural Policy & Documentation, Division of Agricultural Statistics[*], e-mail: salexiadis7@aim.com
[2] Department of Regional Economic Development, University of Central Greece

Abstract
A model of optimal allocation of investment across regions is developed. It is shown that the optimality conditions may lead to increasing inequalities at the spatial level. Introducing an element of endogenous innovation dualistic situation emerges. An empirical analysis, using data for the NUTS-2 regions of the European Union seems to confirm this argument.

Keywords: Regional Allocation of Investment, Regional Inequalities, Regional Policy
JEL: C21; O18; R11

1. Introduction

The enlargement of the EU to 25 Member States, and later to 27, and the intensification of cooperation between the EU and Norway and Switzerland, presents an unprecedented challenge for the competitiveness and internal regional cohesion of the European Union. 'Economic and social cohesion', is mentioned in the Preamble of the Treaty of Rome and has become one of the major goals of the EU (as formulated in the Single European Act, title XIV, currently title XVII, Articles 2 and 4). According to Article 158 of the Rome Treaty 'reducing disparities between the levels of development of the various regions and the backwardness of the least favoured regions or islands, including rural areas' is one of the primary objectives of EU development policies, given that 'imbalances do not just imply a poorer quality of life for the most disadvantaged regions and the lack of life-chances open to their citizens, but indicate an under-utilisation of human potential and the failure to take advantage of economic opportunities which benefit the Union as a whole' (European Commission, 1996, p. 13). The strongest argument for regional policies lies in the persistence and even widening of regional disparities over the long-run. Indeed, market forces and social trends are increasing the geographical concentration of activities. Furthermore, externalities and market failures are needed to justify policy intervention from an economic efficiency point of view (Hurst et al., 2000). Differences in output, labour productivity and income across the regions of the EU are far more extreme than in similar economies such as the US or Japan. The richest regions on the EU are eight times richer than the poorest regions (European Commission, 2004). The primary dimension of income disparities remains East-West, with a weaker North-South dynamic and core-periphery at both EU and national levels. As a result, the EU has implemented a range of development policies and projects (and continues to do so) to achieve regional cohesion, such as the Mediterranean Integrated Programs the direction of funds towards less-advanced areas of Europe from sources, such as the European Regional Development Fund (ERDF), the European Social Fund (ESF) – the two 'Structural Funds', supplemented by the 'Cohesion Fund'[1]. The structural funds are now the most important

[*] 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.

[1] The Cohesion Fund was established by the Maastricht Treaty (Article 130d) for countries with: per capita GDP less than 90% of the community average, an agreed programme to 'avoid excessive government deficits' (i.e. in accordance with Article 104c of the Treaty) and to be used for environmental and Trans-European transport networks.

financial instruments for supporting the renewed Lisbon strategy and in some countries were able to increase their GDP by almost 4% (European Commission, 2004). The concentration of the Structural Funds and the Cohesion Funds in the less privileged areas of the Community has meant that European development support throughout the 1990s has hovered between 3-3.5% of GDP in Portugal, between 2.5-3% in Greece and Ireland, between 2-3% in many Italian and Spanish Objective-1 regions (Cuadrado-Roura, 2001).Cohesion policy aims to promote a more balanced territorial development and is broader than the ‘conventional’ regional policy, with the latter specifically linked to the ERDF. The Structural Funds cover a wide range of areas – technological Research and Development (R&D), the information society, support for business, infrastructure development (transport, telecoms, healthcare and education), energy, risk prevention, the environment, employment, tourism, culture, etc. There are many potential recipients, such as business, especially Small and Medium Enterprises (SMEs), associations, public bodies and individuals. It is up to each individual country to divide the funds between the EU’s ‘Convergence Objective’ and regions covered by the ‘Competitive and Employment Objective’. Countries then use the funds to finance thematic programmes covering the whole country (for instance on environment, transport, etc) or programmes channelling funds to particular regions. Regional policy in the EU has to tackle with an ‘inconsistent triangle’ (Mancha-Novarro and Garrido-Yserte, 2008): budget restrictions, the aspirations of the new member-states as the main beneficiaries of the European regional policy and the vindication of the cohesion countries (Ireland, Spain, Portugal and Greece) of maintaining their financial resources. Thus, the regional-geographical dimension is increasingly important for a rational allocation of the existing resources.

Recently, the Lisbon strategy, and its successor ‘Europe 2020’, aims to make Europe the most competitive and dynamic knowledge-based economy in the world capable of sustainable growth (promoting a more resource efficient, greener and more competitive economy) with more and better jobs and greater social and territorial cohesion (inclusive growth). The transformation to a knowledge and service economy is profound as the earlier changeover from agriculture to industry. This strategy is monitored by a set of indicators, covering the domain of employment, innovation, research, economic reforms, social cohesion, overall economic and environmental background. In 2004, the European Commission suggested a ‘short list’ of 14 structural indicators, allowing for a “concise presentation and a better assessment of achievement over time vis-à-vis the Lisbon agenda”. These indicators include for example, gross domestic product per-capita and per-worker, employment rate, gross domestic expenditure on R&D, long-run unemployment rate, etc. Of these indicators only the ‘dispersion of employment rates’ has, by definition, an explicit spatial dimension, suggesting that ‘Europe 2020’ is in sharp contrast to aim of regional cohesion. There is a need, therefore, for an *optimal allocation* of resources/funds in order to achieve the aims of competitiveness and cohesion.

This paper attempts to approach this issue empirically using a model that attributes the process of regional growth to the degree that the regions of the EU are able to *absorb* technology. To complete this introduction, mention must be made to the structure of this paper. The issue of optimal allocation of investment across regions is developed in the next section. The analysis is extended further by introducing the notion of technology adoption and it is argued that differences in the adoptive abilities of regions might lead to dualism. These considerations are introduced in the ambit of a single model. The model is submitted to the usual econometric tests yielding the main findings in section 3. Section 4 concludes the paper.

2. Optimal allocation of investment

The issue of the optimal allocation of investment across regions was introduced initially by Rahman (1963). Nevertheless, Intriligator (1964) demonstrated that the conclusions by Rahman (1963) can be derived using the framework of Optimal Control Theory. Consider an economy divided into two regions, denoted by $i = 1, 2$. Total output (Y_N), i.e. at the national level, is the sum of regional outputs: $Y_N = Y_1 + Y_2$. In each region output is a function of capital stock (K_i), available in each region. More specifically, $Y_i = v_i K_i$, where

$v_i = Y_i / K_i$ denotes the constant output-capital ratio. National investment (I_N) is conceived as additions to the capital stock of the economy as a whole (K_N), i.e. the sum of the changes in the capital stock of each region. Thus, $I_N = \dot{K}_1 + \dot{K}_2$. Investment is financed through the available savings in the economy: $I_N \equiv S_N$. In other words it is assumed that all savings are automatically invested[2] Assuming that investment is a constant proportion of output, i.e. $S_i = s_i Y_i$, then $S_N = s_1 Y_1 + s_2 Y_2$. Given that $Y_1 = v_1 K_1$ and $Y_2 = v_2 K_2$, then $S_N = s_1 v_1 K_1 + s_2 v_2 K_2$. The identity $I_N \equiv S_N$ is known as 'Say's Law'. Despite its simplicity, its implications are quite deep. On the assumption that markets, i.e. for goods and services, and for the factors of production, respond instantaneously to market signals, and that income is spent immediately, Say's Law must hold. By the same assumptions, though, it must be the case that an increase in demand will create its own supply. In both cases, the limiting situation would be given by the condition of full employment, when all the labour resources are utilised to the full (Chisholm, 1990). In the present context Say's Law implies that $I_N = s_1 v_1 K_1 + s_2 v_2 K_2$ and $\dot{K}_1 + \dot{K}_2 = s_1 v_1 K_1 + s_2 v_2 K_2$, or $\dot{K}_1 + \dot{K}_2 = \gamma_1 K_1 + \gamma_2 K_2$, where $\gamma_i = s_i v_i$ denotes the constant growth rate of each region.

The problem, therefore, is how to allocate savings in order to achieve a certain objective, given the constraints outlined above. Intriligator (1964) assumes constant returns and that once capital is placed in one region, it cannot be shifted into the other region. The 'allocation parameter', δ, is defined as the proportion of investment allocated to a specific region. Therefore, in a two-region economy:

$$\dot{K}_1 + = \delta(\gamma_1 K_1 + \gamma_2 K_2) \tag{1.1}$$

$$\dot{K}_2 = (1-\delta)(\gamma_1 K_1 + \gamma_2 K_2) \tag{1.2}$$

$$0 \le \delta \le 1 \tag{1.3}$$

Given the assumption of constant returns the optimal time path of the allocation parameter, $\delta^*(t)$, at any point in time is either $\delta^*(t) = 0$ or $\delta^*(t) = 1$, namely savings are allocated in only one region. Intriligator (1964) considers the problem of maximising national output at some terminal time (*T*): $Y_N(T) = v_1 K_1(T) + v_2 K_2(T)$ by choice of $\delta(t)$, subject to the constraints, given by equations (1.1), (1.2) and (1.3). Since $\delta^*(t) = 0$ or $\delta^*(t) = 1$, this is a typical 'bang-bang' solution and the problem is solved by the $\delta(t)$ that maximises the Hamiltonian function[3]:

$$H = p_1 \delta(\gamma_1 K_1 + \gamma_2 K_2) + p_2(1-\delta)(\gamma_1 K_1 + \gamma_2 K_2) \tag{2}$$

where p_1 and p_2 are the auxiliary variables, interpreted as the shadow price of capital.

Equation (2) can be written equivalently as follows:

$$H = [p_1 \delta + p_2(1-\delta)](\gamma_1 K_1 + \gamma_2 K_2) \Rightarrow H = (p_1 \delta + p_2 - p_2 \delta)(\gamma_1 K_1 + \gamma_2 K_2) \tag{2.1}$$

implying that

$$H = [\delta(p_1 - p_2) + p_2](\gamma_1 K_1 + \gamma_2 K_2) \tag{2.2}$$

The optimal path of δ depends on the sign of the difference $(p_1 - p_2)$. In particular, if $(p_1 - p_2) > 0$, then $\delta^* = 1$ while if $(p_1 - p_2) < 0$, then $\delta^* = 0$. This condition simply states that the funds should be invested in the region where the implicit (shadow) price of capital is

---

[2] For a more detailed analysis of savings behaviour see Cesaratto (1999).

[3] The reader interest in these issues can refer to the contribution Pontryagin et al (1962).

higher. According to the Maximum Principal the auxiliary variables must satisfy the following terminal conditions: $p_1(T) = \frac{\partial Y_N(T)}{\partial K_1(T)}$ and $p_2(T) = \frac{\partial Y_N(T)}{\partial K_2(T)}$, implying that $p_1(T) = v_1$ and $p_2(T) = v_2$. Additionally, the Hamiltonian system must satisfy the conditions: $\dot{p}_1 = -\frac{\partial H}{\partial K_1}$ and $\dot{p}_2 = -\frac{\partial H}{\partial K_2}$. Thus, $\dot{p}_1 = [\delta(p_1 - p_2) + p_2]\gamma_1$ and $\dot{p}_2 = [\delta(p_1 - p_2) + p_2]\gamma_2$, implying that $\dot{p}_1 / \dot{p}_2 = \gamma_1 / \gamma_2$. Setting $\frac{\partial H}{\partial \delta} = 0$ yields:

$$(p_1 - p_2)(\gamma_1 K_1 + \gamma_2 K_2) = 0 \tag{2.3}$$

Adding a time dimension in equation (2.3) yields

$$[p_1(t) - p_2(t)][\gamma_1 K_1(t) + \gamma_2 K_2(t)] = 0 \tag{2.4}$$

Differentiating equation (2.4) with respect to time yields:

$$(\dot{p}_1 - \dot{p}_2)(\gamma_1 K_1 + \gamma_2 K_2) + (p_1 - p_2)(\gamma_1 \dot{K}_1 + \gamma_2 \dot{K}_2) = 0 \tag{2.5}$$

In the steady-state $\dot{K}_t = 0$, so $(\dot{p}_1 - \dot{p}_2)(\gamma_1 K_1 + \gamma_2 K_2) = 0$ and given that $\frac{\partial H}{\partial \delta} = 0$, then $\dot{p}_1 - \dot{p}_2 = p_1 - p_2$, implying that $(p_1 - p_2) = p_2\left(\frac{\gamma_1 - \gamma_2}{\gamma_2}\right)$ for $0 \le t < T$. Given that $\frac{p_1(T)}{p_2(T)} = \frac{v_1}{v_2}$, then $(p_1(T) - p_2(T)) = p_2(T)\left(\frac{v_1 - v_2}{v_2}\right)$ for $t = T$. For a given planning period (*T*), the optimal time path can be described as follows. Before at the end of the planning period ($0 \le t < T$) invest only in the region with the higher rate of growth, i.e. $\delta^*(t) = 1$ if $\gamma_1 > \gamma_2$ or $\delta^*(t) = 0$ if $\gamma_1 < \gamma_2$. At the end of the planning period ($t = T$) invest only in the region with the highest output/capital ratio, namely $\delta^*(t) = 1$ if $v_1 > v_2$ or $\delta^*(t) = 0$ if $v_1 < v_2$.

In a critical appraisal Rahman (1966) argues that the theory of optimal control is applicable only if the switch was to occur always at $t = T$ only. Thus $(p_1 - p_2)_T = v_1 - v_2$, implying that if $v_1 > v_2$, then $\delta^*(t) = 1$. Therefore, equation (2.2) can be written as $H = p_1(\gamma_1 K_1 + \gamma_2 K_2)$. Combining the conditions $\dot{p}_1 = -\frac{\partial H}{\partial K_1} = -p_1\gamma_1$ and $\dot{p}_2 = -\frac{\partial H}{\partial K_2} = -p_1\gamma_2$ yields the differential equation $\dot{p}_1 = -p_1\gamma_1$. Given the initial condition $(p_1)_T = v_1$ the following solution is obtained:

$$(p_1)_t = v_1 e^{\gamma_1 t_1}, \text{ with } t_1 = T - t \tag{2.6}$$

Given the initial condition $(p_2)_T = v_2$, then the differential equation $\dot{p}_2 = -p_1\gamma_2$ implies the following solution:

$$(p_2)_t = \frac{\gamma_2}{\gamma_1} v_1 e^{\gamma_1 t_1} + v_2 - \frac{v_1\gamma_2}{\gamma_1} \tag{2.7}$$

Subtracting $(p_1)_t$ from both sides of equation (2.7) yields

$$(p_1 - p_2)_t = \frac{(p_1)_t(\gamma_1 - \gamma_2) + v_1\gamma_2 - v_2\gamma_1}{\gamma_1} \tag{2.8}$$

Differentiating equation (2.8) with respect t_1 the following expression is obtained:

$$\frac{d(p_i - p_2)_t}{dt_1} = (p_1)_t(\gamma_1 - \gamma_2) = -\frac{d(p_1 - p_2)_t}{dt} \quad (2.9)$$

Rahman (1966) points out that the condition $\gamma_2 > \gamma_1$ does not imply that $(p_i - p_2)_t < 0$ and $\delta^*(t) = 0$, for any $t < T$, as Intriligator (1964) argues. As $t' = T - t$ increases, then $(p_i - p_2)_t < 0$ is possible and a 'switch' in δ takes place. Nevertheless, at this point, it is worth mentioning that the conditions $\dot{p}_1 = -p_1\gamma_1$ and $\dot{p}_2 = -p_1\gamma_2$ imply $\dot{p}_1 / \dot{p}_2 = \gamma_1 / \gamma_2$. It is clear, therefore, that the solution is equivalent to that suggested by Intriligator (1964).

While the analysis by Intriligator (1964) suggests a 'switch' in the allocation parameter, nevertheless, the particular conditions under which this 'switch' takes place are not specified, at least in an explicit way. These issues constitute the departure point for a more extensive analysis by Takayama (1967) who attempts to show whether, and under which particular conditions, a 'switch' will (or will not) occur. Takayama (1967) concludes that a 'switch' takes place if $\nu_1 < \nu_2$. Rahman (1966), however, claims that the analysis by Intriligator (1964) does not include an explicit 'political constraint on regional income disparity' (p. 159). Indeed, the objective function considered by Intriligator (1964) and Takayama (1967) is to increase output at the national level or maximising aggregate growth. The possibility that the allocation of investment, which is optimal at the aggregate level, might increase regional disparities is not considered. Stated in alternative terms, the analysis by Intriligator (1964) ensures maximising aggregate output or increasing competitiveness, nevertheless, regional incomes will deviate. Regional incomes can be equalised if the allocation parameter switches according to the initial conditions of regions. Introducing the question of regional income inequalities modifies the optimal program as follows. At the beginning of the planning period invest in the region with the highest output while at the end of the planning period invest in the region with the lowest output. In this case there will be an improvement in the distribution of income at the regional level but the competitiveness of the economy as a whole will be reduced. Which specific measure will be applied depends on the available resources, budget constraints, the time length or the 'tolerable' level of regional inequalities and the weight that policy-makers attach to the issue of regional inequalities. According to Intriligator (1964), the allocation decision is based on the parameters γ and ν. But which factors determine the 'autonomous' growth rate of a region and the productivity of capital?

According to the 'conventional' neoclassical model arbitrage possibilities arising from competition and factor mobility were expected to induce a more than average growth performance in lagging regions (Hurst et al., 2000, p.9) where convergence was not swift enough, most likely this could be accelerated by increasing public infrastructure. An implicit assumption of this model is that all regions are able to absorb technology to the same degree, so that the higher the technological gap the higher the effect on growth, ceteris paribus. However, it may be argued that large gaps do not necessarily promote growth in this way. It is quite possible that a significant technological gap is associated with unfavourable conditions for the adoption of new technological innovations[4]. Assume that the ability of a region to implement technological innovations (ξ) is *endogenously* determined, as a decreasing function of the 'technological proximity', expressed in terms of the *initial* technological gap: $\xi_i = f(b_{lf_{i,0}})$, with $f' < 0$, or in a non-linear specification: $\xi_i = \rho b_{lf_{i,0}}^{-\pi}$ with $\rho, \pi > 0$. Thus, the rate of adoption is not constant but varies across regions, according to the size of the gap[5].

[4] Innovation is an iterative process, building upon the results of R&D activities and in turn inform, and being informed by, new research and innovations in product and processes.

[5] A more detailed elaboration of this model can be found in Alexiadis (2010).

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, depending on the value of π, which determines the extent to which the existing gap impacts on the rate of diffusion. Alternatively, the higher the technological gap, the slower the rate of technological adoption (ξ_i). Assuming that the growth rate of output per-worker (y_i) is an increasing function of ξ_i: $g_{y_i} = h(\xi_i)$ with $h' > 0$, then $g_{y_i} = h(f(b_{lf_{i,0}}))$, with $h' \cdot f' < 0$. Consider a two-region's economy $(i = 1,\ 2)$ with $b_{lf_{1,0}} - b_{lf_{2,0}} > 0$ and $\xi_1 - \xi_2 < 0$, implying that $g_{y_1} - g_{y_2} < 0$. If $(\Delta\xi_{1,2})_t \to 0$, then $(\Delta b_{lf_{1,2}})_t \to 0$ and $(\Delta g_{y_i})_t \to 0$, which implies that region 2 converges with region 1. If, on the other hand, $(\Delta\xi_{1,2})_t \to \infty$, then $(\Delta b_{lf_{1,2}})_t \to \infty$ and $(\Delta g_{y_i})_t \to \infty$, as $t \to \infty$. From this perspective, this model implies a dualistic economy. There are several approaches to dualism ranging from the one-sector neoclassical transitional dynamics to models based on the existence of increasing returns (economies of agglomeration, for instance) and on technology diffusion[6]. According to this approach migration towards the modern sector may leave unaffected the level of output in the traditional one. Paci and Pigliaru (1999) depart from this approach and develop a model of dualism, based on the neoclassical two-sector model of the dual economy, as proposed by Dixit (1970) and Mas-Colell and Razin (1973). According to this approach, the value of marginal productivity in agriculture along the transitional path to the steady-state is neither zero nor constant, and it stays continuously below that of the other (non-agricultural) sector. Contrary to what happens in non-dualistic models, therefore, equalisation of marginal productivity values across sectors takes time, with workers shifting from the low- to the high-wage sector, where the capital-good is produced. On the assumption that the rate at which workers migrate from agriculture is a decreasing function of the wage differential, poorer dualistic economies are generally characterised by faster expansion of their high-productivity sector, and by higher growth rates of per-capita output. Assume, further, that output in each region is produced by two sectors; a technologically advanced and a 'traditional' sector: $Y_i = Y_A + Y_T$. The technological gap can be approximated in terms of a decreasing function of the labour employed in the technologically advanced sector: $b_i = f(l_{A,i})$ with $f' < 0$. Assume further that productivity and wages are higher in the advanced sector relative to the 'traditional' sector: $w_A - w_T > 0$. This framework implies that $l_{A,i} = h(r_i)$, where $r_i = w_{A,i1} / w_{T,i2}$ with $h' > 0$ and $b_i = f \cdot h(r_i)$, with $f' \cdot h' < 0$. The condition $w_A - w_T > 0$ induces labour to move from the 'traditional' to the advanced sector. If $r_1 - r_2 > 0$, then the advanced sector in region 1 attracts labour from the 'traditional' sector in that region and labour from both sectors in region 2, leading to $b_1 - b_2 < 0$.

Essentially, this condition implies that the property of convergence is restricted to a *selected* group of regions. The argument runs as follows. Consider a given distribution of output per worker across a system of *n* regions: $y_i, \forall i = 1, \ldots n$. The average growth rate of each region over a given time period, $T = t - t_0$, is $g_{i,T}, \forall i = 1, \ldots n$. The relation between initial output per worker and average growth rate is shown in Figure 1:

[6] See for example Lewis (1954), Fei and Ranis (1961), Sen (1966) inter alia.

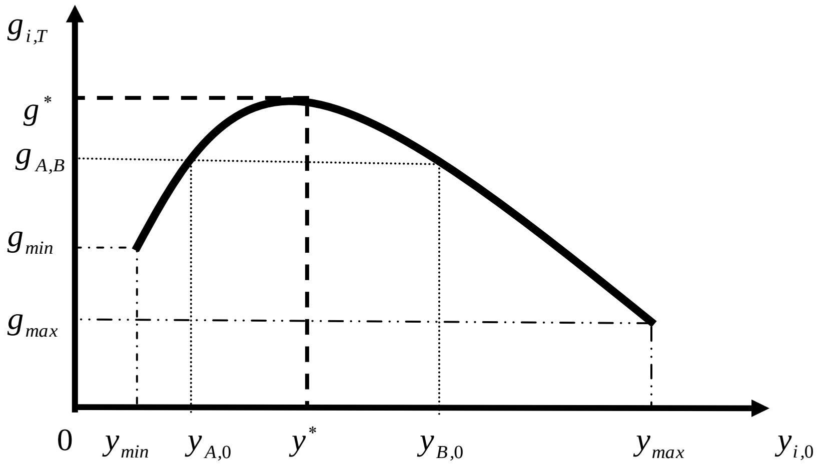

Figure 1. Club convergence

A negative relation between the initial level of output per worker and the growth rate, $\partial g_{i,T} / \partial y_{i,0} < 0$, is apparent only for the regions in the range $[y^* \quad y_{\max}]$ while for regions in the range $[y_{\min} \quad y^*]$ $\partial g_{i,T} / \partial y_{i,0} > 0$. This relation is also evident amongst the 'poorest' and the 'richest' region, given that $y_{\min} < y_{\max}$ and $g_{\min} > g_{\max}$. If, however, this growth differential remains the same, the 'poor' region is not to able to close the gap $y_{\min} - y_{\max}$. This is feasible if $(g_{\min} - g_{\max})_t > 0$ and $(g_{\max})_t \to 0$ as $t \to \infty$. Consider two regions, A and B, for which $y_{A,0} < y_{B,0}$ and $g_{A,T} = g_{B,T}$. Although both regions exhibit similar rates of growth, ($g_{A,T} = g_{B,T} > g_{\max,T}$) nevertheless region B is able to close the gap faster given that $(g_{A,T} - g_{B,T})_t = 0$, as $t \to \infty$. Indeed, the gap between region B and the richest region is smaller compared to that of region A, i.e. $(y_{\max,0} - y_{A,0}) > (y_{\max,0} - y_{B,0})$. Region A will be able to catch-up with region B, if $(g_{A,T} - g_{B,T})_t > 0$, as $t \to \infty$. In short, there are two groups; one includes regions with $\partial g_{i,T} / \partial y_{i,0} < 0, \forall i \in [y^* \quad y_{\max}]$ and another including regions for which $\partial g_{i,T} / \partial y_{i,0} > 0, \forall i \in [y_{\min} \quad y^*]$.

Nevertheless, this issue is, to a certain extent, an empirical one. The general framework, discussed in this section will be tested empirically in an extensive regional context, viz. the NUTS-2 regions of Europe[7].

The empirical literature on regional convergence makes extensive use of two alternative tests for convergence, namely absolute and conditional convergence:

$$g_i = a + b_1 y_{i,0} + \varepsilon_i \quad (4)$$

$$g_i = a + b_1 y_{i,0} + b_{\mathbf{X_i}} \mathbf{X_i} + \varepsilon_i \quad (5)$$

where $g_i = (y_{i,T} - y_{i,0})$ is the growth rate and ε_i is the error-term. The rate of convergence is calculated as $\beta = -[\ln(b_1 + 1)]/T$, where T is the number of years in the period. Absolute convergence is signalised by $b_1 < 0$. Conditional convergence is based upon the argument that different regional characteristics will lead to different steady-states. A test for conditional convergence, with variables representing technology, is more suitable to accommodate the empirical analysis.

---

[7] Nomenclature des Unités Territorial les Statistiques.

Technical change originates either from within the region, namely indigenous innovation (IC_i), or technological spillovers from adopting innovations created elsewhere (ADP_i). In the former case, technical change may be approximated in terms of the 'Human Resources in Science and Technology' (HRST), i.e. persons who have completed a tertiary education in a field of science or technology and/or are employed in science and technology. The second source of technical growth is approximated as the percentage of total employment in technologically dynamic sectors (ADP_i), which indicates a capacity for technology adoption, since these are taken to apply high technology; two variables in accordance with the notion of 'smart growth', i.e. attempts to strengthen knowledge and innovation, which conceived as drivers of future growth. Therefore, a model of 'technologically-conditioned' convergence can be structured as follows:

$$g_i = a + b_1 y_{i,0} + b_2 IC_{i,0} + b_3 ADP_{i,0} + \varepsilon_i \qquad (6)$$

The time dimension of variables describing technology refers to the initial time. From an econometric point of view, this 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 technological variables ought to be included in initial values. Broadly speaking, it is anticipated that $b_2 > 0$, since high levels of innovation are normally associated with high levels of growth and vice versa. However, it is not automatically the case that this condition promotes convergence. If poor regions have a low level of $IC_{i,0}$, then no significant impacts on growth are anticipated and, hence, it may be difficult to converge with advanced regions. The latter case is the more likely.

The $ADP_{i,0}$ variable reflects two distinct features, namely the initial level of 'technological adoption' and the degree to which existing conditions in a region allow further adoption of technology. A low level of $ADP_{i,0}$ 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 to converge with the advanced regions. Conversely, a low value for $ADP_{i,0}$ may indicate that although there is significant potential for technology adoption, infrastructure conditions are not appropriate to technology adoption and, therefore, there are no significant impacts on growth. If the latter effect dominates then convergence between technologically lagging and advanced regions is severely constrained.

Equation (6) treats regions as 'closed' economies. It is possible to overcome this, clearly unrealistic, assumption by introducing in equation (6) the effects of spatial interaction. Indeed, in the light of recent literature (e.g. Fingleton, 2001) it may be argued that any empirical test for regional convergence is misspecified if the spatial dimension is ignored 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. Assume that any effects from spatial interaction are captured in the error term. Thus,

$$\varepsilon_t = \zeta \mathbf{W} \varepsilon_t + u_t = (\mathbf{I} - \zeta \mathbf{W})^{1} u_t \qquad (6.1)$$

Equation (6), then, can be written as follows:

$$g_i = a + b_1 y_{i,0} + b_2 PI_{i,0} + b_3 ADP_{i,0} + (\mathbf{I} - \zeta \mathbf{W})^{1} u_i \qquad (7)$$

In equation (7) ζ is a scalar spatial-error coefficient to be estimated, $\mathbf{W}$ is the $n \times n$ spatial weights matrix and u_t is the new error term. The spatial links between regions are constructed as to produce declining weights as distance between regions increases:

$$w_{ij} = \frac{1/d_{ij}}{\sum_j 1/d_{ij}} \qquad (8)$$

Here, d_{ij} denotes the distance between two regions i and j. The denominator is the sum of the (inverse) distances from all regions surrounding region *i*, within a selected boundary. Equation (8) implies that interaction effects decay as the distance from one area to another increases (weights decline as distance increases). From econometric point of view, estimation of equation (7) is carried out by the maximum likelihood (ML) method, as Ordinary Least squares (OLS) estimator may result in problems of bias.

3. Empirical Application

In this paper we exploit data on Gross Value Added (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). EUROSTAT is the main source for data used in this paper.

The regional groupings used in this paper are those delineated by EUROSTAT and refer to 267 NUTS-2 regions[8]. Estimation of equation (4) suggests that the regions of the EU converge at a low rate (0.65% per-annum).

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

Depended Variable: g_i n = 267 NUTS-2 Regions	Equation (4) (OLS)	Equation (6) (OLS)	Equation (7) (ML)
a	0.5714**	0.6144**	0.6902**
b_1	-0.0747**	-0.0825**	-0.1087**
b_2		0.0014	0.0021*
b_3		0.0203*	0.0349**
ζ			0.1451**
Implied β	0.0065**	0.0071**	0.0086**
LIK	137.552	148.832	152.670
AIC	-271.104	-289.663	-295.340
SBC	-263.922	-275.314	-277.385

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.

A positive coefficient is estimated for the variable describing technology creation, which does not necessarily promote convergence as such, since regions with relatively high initial level of innovation exhibit relatively higher rates of growth. A positive value for the $ADP_{i,0}$ variable is also estimated. This suggests that, on average, regions with low values of $ADP_{i,0}$ at the start of the period grow slower than regions with high values, ceteris paribus. If technologically backward regions were successful in adopting technology, which subsequently is transformed into faster growth, then the estimated coefficient b_3 would be negative. Since $b_3 > 0$, this indicates that infrastructure conditions in lagging regions are inhibiting this process of technology adoption. Technology adoption, although it might be the best 'vehicle' for lagging regions, nevertheless, this is a process which might be difficult, especially during the early stages of development when conditions are least supportive. Normally, conditional convergence implies a slower rate of convergence. Nevertheless introducing the technological variable increases the estimated rate of convergence. To be more precise, the non-spatial version of the technologically conditional model implies that the regions of the EU-27 converge at an average rate 0.71% per annum. An even faster rate of convergence (0.86%) is implied by the spatial version of the technologically conditional model, encapsulated by equation (7). Moreover, the estimated coefficient of the $ADP_{i,0}$ variable is highly significant.

The superiority of the model described by equation (7) is supported by both the criteria for model selection applied here, namely the Akaike (AIC) and the Schwartz-Bayesian (SBC)

[8] The NUTS regions are not the same with the so-called 'Euro-regions', which are associations without a precise legal status, dating back to the period after World War II when local politicians in border regions tried to promote common interests on both sides of the borders.

information criteria[9] and the value of the Log-likelihood (LIK), which increases with the introduction of the technological variables.

The empirical analysis is extended further by estimating a model that incorporates the possibility of 'club-convergence', which implies that the property of convergence is restricted to a selected group of regions. Although, there are several approaches for identifying convergence-clubs[10] nevertheless, the empirical analysis is based upon application of Baumol and Wolff's (1988) specification: $g_i = a + b_1 y_{i,0} + b_2 y_{i,0}^2 + \varepsilon_i$. A pattern of club-convergence is established if $b_1 > 0$ and $b_2 < 0$. Members of a convergence-club are identified as those regions which exhibit an inverse relation between the growth rate and initial level of GVA per-worker and exceed a threshold value of initial GVA per-worker, calculated as: $y^* = -b_1 / 2b_2$.

Introducing the two technological variables in a club-convergence context yields the following regression equation:

$$g_i = a + b_1 y_{i,0} + b_2 y_{i,0}^2 + b_3 \ln IC_{i,0} + b_4 \ln ADP_{i,0} + \varepsilon_i \qquad (9)$$

The hypothesis of club convergence due to differences in technology in an explicit spatial context can be expressed in terms of a spatial version of equation (9). Thus,

$$g_i = a + b_1 y_{i,0} + b_2 y_{i,0}^2 + b_3 \ln IC_{i,0} + b_4 \ln ADP_{i,0} + (\mathbf{I} - \zeta \mathbf{W})^{-1} u_i \qquad (10)$$

Estimating equation (9) and (10) yields the results in Table 2.

Table 2. Club-Convergence

Depended Variable: g_i n = 267 NUTS-2 Regions	Equation (9) (OLS)	Equation (10) (ML)
a	-0.1226	-0.0854
b_1	0.4486**	0.5896**
b_2	-0.0922**	-0.1203**
b_3	-0.0124	-0.0839*
b_4	0.0439**	0.0674**
ζ		0.8651**
Implied y^*	2.43**	2.45**
LIK	167.098	172.134
AIC	-324.196	-332.268
SBC	-306.241	-310.722

Note: ** indicates statistical significance at 95% level of confidence, * 90% level.

The coefficients b_1 and b_2 have the appropriate signs suggesting the existence of two groups across the EU-27 regions; one which includes regions with $y_{i,0} - y^* > 0$ and another including regions with $y_{i,0} - y^* < 0$. The former group corresponds to the convergence-club while the latter constitutes a diverging-club. Turning to the impact of the other explanatory variables, only the $ADP_{i,0}$ variable yields a statistically significant coefficient at the 95% level. The $IC_{i,0}$ variable indicates a negative relationship with growth for the overall period, which can be interpreted as a source of convergence. The condition $b_4 > 0$, however, suggests a substantial barrier to the diffusion of technology across the regions of the EU-27. In the lagging, and remote geographically regions of the EU, the adoption process is not

[9] As a rule of thumb, the best fitting model is the one that yields the minimum values for the AIC or the SBC criterion.

[10] The reader interest in this issue can, for instance, refer to Alexiadis et al (2010).

immediate and these regions generally access innovations at a later stage. If this time-lag remains then regional disparities in the EU, and the centre-periphery pattern, will take a persisting character. As previously, the spatial version of the model is to be preferred, based on the AIC and the SBC criteria.

Figure 5 shows the spatial distribution of the convergence-club member regions. The convergence club includes, almost exclusively, regions from the ‘advanced’ members-states of the European Union (EU-15). The club includes regions with large agglomerations, London, Paris, Milan, Munich and Hamburg, the so-called ‘central pentagon’ (Figure 6), together with peripheral regions of the EU-15 (e.g. Dublin, Central Scotland, Lisbon, Madrid, Athens, Rome, Naples and Stockholm). Such an outcome is in accordance with the view put forward by Dunford and Smith (2000), which highlight a significant ‘development divide’ between the EU-15 and the East Central Europe.

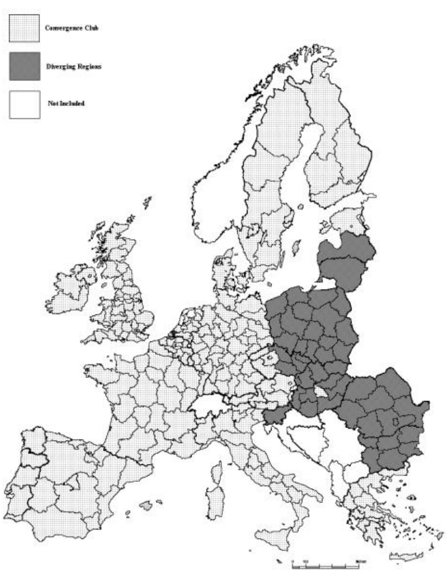

Figure 5. Converging and Diverging clubs

Figure 6. The ‘Central Pentagon’

Table 3. Regional Convergence and Technology, Diverging group

Depended Variable: g_i n = 49 NUTS-2 Regions	Equation (3) (OLS)	Equation (4) (ML)
a	-0.1583	-0.1628
b_1	0.2863**	0.2061**
b_2	-0.0062*	-0.0091*
b_3	0.0486**	0.0643**
ζ		0.3478*
Implied β	-0.0210**	-0.0156**
LIK	140.907	142.866
AIC	-273.814	-275.732
SBC	-266.246	-266.272

Note: ** indicates statistical significance at 95% level of confidence, * 90% level.

Conditioning upon levels of technology confirms the diverging tendencies of the regions excluded from the convergence-club (2.1% per-annum). Nevertheless, the rate of divergence is reduced when spatial interaction is explicitly introduced. The results in Table 3 imply that regions with a low $ADP_{i,0}$ grow at a relatively lower rate. The condition $b_2 < 0$ is not enough to cancel-out this diverging effect. There may also be increased mobility for the highly-skilled, but a continued lack of mobility for the lower-skilled workforce. Together with inflexible labour markets this situation could reinforce a very unequal distribution of unemployment. Given that the scope for innovation is subject to sectoral variations, it is possible that there could be the polarisation of Europe into more advanced regions and poorer lagging regions in the long-run.

In this light, regional policy should first identify which regions in a diverging-club are characterised by relative high adoptive levels. These regions have more possibilities to innovate if they are connected to central regions[11]. Improving conditions and the adoptive ability of these regions by investing the existing funds will, therefore, increase their growth rates, enabling them, in a subsequent period, to join the initial convergence-club. In terms of the model presented in section 2, the sequence of investment should be as follows. Before the end of the planning period invest in the regions of the convergence club. At the end of the planning period invest in the regions of the diverging club with the highest initial conditions. This will cause positive effects to the degree of competitiveness of the EU-27, as a whole, improving also the long-run process of regional convergence[12]. In this context, a critical question arises: which particular conditions should be the target of regional policy? Accordingly, it may be adequate, but with much caution, to associate the prevailing conditions in the diverging group with a series of structural elements that characterize the regions in this group. Although it is beyond the scope of this paper to go into detail, nevertheless it is worth mentioning that the list of these elements includes the usual suspects such as science, technology, which constitute the focus of the econometric specification, R&D and conditions related to the structure of the regional economy. In 2005 the R&D intensity, measured in terms of R&D expenditure as a percentage of GDP[13] in the diverging group was less than 0.5%. Only in two regions the R&D intensity is about 1% (Mazowieckie in Poland and Bucuresti-Ilfov, the capital-region of Romania). Over the periods 1998-2000 and 2005-2007, GDP per-capita in these regions was above 75% of the EU average; a threshold, which is a key criterion for being eligible to support from the Structural Funds. In the remaining regions, GDP per-capita is still below this threshold. The patent applications to the European Patent Office (EPO) in this group, is less than 5 patents per million inhabitants. In 2006, the HRST indicator was less than 35%. An exemption is Bucuresti-Ilfov with a percentage above 40%[14]. An average share of high-tech sectors in total employment was less than 4% in the diverging group, contrary to the central regions (above 5%). A similar share can be found in regions Közép-Dunántúl, Közép-Magyarország Nyugat-Dunántúl (in Hungary) and in Bratislavský-Kraj (in Slovakia). The three Hungarian regions are located in close geographical proximity while the regions Bratislavský Kraj and Nyugat-Dunántúl are close to Austria. Agriculture is of importance to the diverging regions and contributes about 3-6% in their GDP and in several cases over 6% (mainly in Romania and Bulgaria). The percentage of rural population in these regions is in the range between 20% and over 50%.

---

[11] A view put forward by Rodríguez-Pose and Crescenzi (2008).

[12] It should be noted, however, that there is no clear model available which shows the maturity period required in order to obtain results on the long-run growth of these regions

[13] A target set is the EU as whole to reach R&D intensity above 3%, responding to the new world-wide division of labour and globalisation The EU should reach a level of R&D intensity, by 2010, above 3%. This target is set by the Barcelona Council in 2002 and maintained in the EUROPE 2020 strategy. R&D spending in Europe, however, is below 2%, compared to 2.6% in the US and 3.4% in Japan, mainly due to low levels of private investment. It would take more than 50 years for Europe to reach the US level of innovation performance. Only 10% of the EU regions were able to reach this target. In 2007, only 19 out of 287 NUTS-2 regions, corresponding to only (6.6%) were able to meet the target of 3% . These include regions Pohjois-Suomi, Länsi-Suomi and Etelä-Suomi in Finland, Stockholm, Östra Mellansverige, Västsverige and Sydsverige in southern Sweden, seven regions in Germany (Dresden, Oberbayern, Darmstadt, Karlsruhe, Unterfranken, Stuttgart and Berlin), two in France (Île-de-France and Midi-Pyrénées) and Austria (Wien and Steiermark) and one in the Netherlands (Noord-Brabant). In some of these regions, capital-cities are located (e.g. Paris, Vienna, Berlin, Stockholm and Helsinki). Overall, there is a tendency for R&D expenditure to be higher in urban parts of Europe.

[14] The best educated labour force is located in the urbanised regions of Northern Europe. There is a tendency for HRST to concentrate in or around capital cities, particularly in countries with a low overall proportion of HRST.

Furthermore, the diverging group exhibits a low degree of business concentration (an exception is Bucuresti-Ilfov) due to demographic decline[15] and to the rural nature of those regions[16]. These regions are characterized by high unemployment[17], a large proportion of the labour force employed in declining industrial sectors and a relatively small proportion of young people, reflecting migration to other areas[18] as well as by low fertility rates. Low population density[19] and a low growth potential (due to a shrinking labour force) intensify income disparities in the diverging group. A ratio between 60 and 120 is estimated for the diverging group[20]. This puts them in a difficult position to finance essential public goods and services (e.g. health care, housing, transportation, ICT infrastructure) in a sustainable manner in order to avoid increasing social polarisation and poverty and, as a result, the operation of favourable externalities, which will put them in a path of fast growth, is constrained.

'Spatial development is increasingly understood as a complex, multi-dimensional phenomenon and the illusion about the existence of simple, short-cut strategies is progressively abandoned' (Camagni & Capello, 2010, p. 12). While economic and social fluctuations in the short (or medium) run are frequent, the features of the territory are largely shaped by factors that change extremely slowly. These features include the settlement pattern, the infrastructure endowments, the basic environmental characteristics and even the cultural peculiarities of the population. Overall, focusing on challenges such as energy security, transportation, climate change and resource efficiency, health and ageing, environmentally-friendly production methods and land management is essential.

Nevertheless, an important point to grasp, from a policy perspective, is the impact of technology adoption in the process of regional growth and convergence. Technology adoption, however, is not a simple and automatic process. Instead, it requires that lagging regions should have the appropriate infrastructure to adopt the technological innovations[21]. High-technological and knowledge-creating activities should be directed, if possible, at regions with unfavorable infrastructure conditions, as to stimulate the production structure in those regions towards activities that implement high technology. Regional policies should promote high-technology activities, and R&D, including universities, scientific and research institutions, support clusters, modernize the framework of copyright and trademarks, improve access of SMEs to Intellectual Property Protection, speed up setting of interoperable standards, and improve access to capital by reducing transaction costs of doing business.

Policy makers should also identify bottlenecks and develop a strong knowledge base with encouragement of 'knowledge partnerships' and links between business, research, innovation and education. Improvements in education will help employability and increase the rate of employment. A greater capacity for R&D as well as innovation across all sectors, combined with increased efficiency will foster job creation and improve competitiveness. A reform of regional R&D and innovation systems, will reinforce cooperation between universities,

---

[15] Only few EU-27 NUTS-2 regions (e.g. Ireland, Malta and Cyprus) appear to be in a relatively favourable position. An inspection, however, at the NUTS-3 level might reveal a different picture.

[16] Nevertheless, a rural character is not always a disadvantage. Several rural regions, for example, attract retirees, which provide a source of income and future growth.

[17] In 2008, regions with the highest unemployment rates (above 10%) are mainly located in Southern Spain, Southern Italy, Greece, Eastern part of Germany, Poland, Hungary and Slovakia. The lowest levels can be found in the United Kingdom, Belgium, and Netherlands and in capital city-regions of Eastern Europe.

[18] Population in several Central-Eastern European regions, which joined the EU in 2004 or 2007, has decreased due to migration.

[19] Population density is defined as the ratio of the population of a territory to its size (inhabitants per km^2).

[20] The capital city-regions of the EU-27 are among the most densely populated, located in central areas of Europe especially around Brussels. 'It has often been noted that night-time satellite photos of Europe reveal little of political boundaries but clearly suggest a *centre-periphery pattern* whose hub is somewhere in or near Belgium' (Krugman, 1991, p. 484., emphasis added).

[21] An argument commonly attributed to Abramovitz (1986).

research and business, and will enable to implement joint programming, which will enhance cross-border cooperation. Adjustments of school curricula, based on creativity, innovation and entrepreneurship is also an effective policy tool.

Regional policies should oriented towards supporting internationalisation of SMEs, technologies and production methods that reduce natural resource use and increase investment in the EU's existing natural assets. Of particular importance is the transition of manufacturing sectors to greater energy and resource efficiency. Research in cleaner, low carbon technologies will not only help the environment by contributing to fighting climate change, but also will create new business and employment opportunities.

Finally, an important feature that policy-makers should take into consideration refers to the appropriate *timing* for policy intervention, given that their effects differ from region to region. Clearly this factor increases the need for policy coordination. Nevertheless, developing answers to policy issues requires a good deal of further work specific regional case studies, which will evaluate the efficiency of regional policies and programs and the contexts in which they are likely to succeed.

5. Conclusion

Regional growth is a complex phenomenon, based upon a number of factors, which shape, to a considerable extent, the regional policies. There is a need to rethink regional policy along the lines of the implementation of more innovative and region-specific development strategies. Hence, new analytical tools are needed. The relatively fragmented nature of the spatial patterns of mobility and persistence suggests that broad administrative regions are a poor basis for the implementation of policy. Consequently, policy may need to be targeted towards specific localities rather than broad areas such as those, for example, covered by the current regional grouping of the EU. A classification of areas based on the notions of persistence, divergence and the conditions identified in this paper may provide a useful framework for policy development at the regional level.

References

1. Abramovitz, M. (1986) 'Catching Up, Forging Ahead and Falling Behind', *Journal of Economic History*, Vol. 46, pp. 385-406.
2. Alexiadis, S. (2010) 'Interregional Differences in Adoptive Abilities: An Alternative Framework', *Regional Science Inquiry*, Vol. 1 (2), pp. 41-52.
3. Alexiadis, S. Ladias, C. and Polo, A. (2010) Converging and Diverging Regions in the EU: Implications for Regional Policy, *Regional Science Inquire*, Vol. 2 (2), pp. 55-70.
4. Baumol, W. and Wolff E. (1988) 'Productivity growth, convergence and welfare: A reply', *American Economic Review*, 78 (5), pp. 1155-1159.
5. Camagni, R. And Capello, R. (2010) 'Macroeconomic and territorial policies for regional competitiveness: An EU perspective', *Regional Science Policy and Practise*, Vol. 2 (1), pp. 1-19.
6. Cesaratto, S. (1999) 'Savings and Economic Growth in Neo-classical theory', *Cambridge Journal of Economics*, Vol. 23 (6), pp. 771-793
7. Chisholm, M. (1991) *Regions in Recession and Resurgence*, London: Allen and Unwin
8. Cuadrado-Roura, J. (2001) 'Regional Convergence in the European Union: From Hypothesis to Actual Trends', *Annals or Regional Science*, Vol. 35 (3), pp. 365-384.
9. Dixit (1970) 'Growth Patterns in a Dual Economy' *Oxford Economic Papers*, Vol. 22, pp. 229-234.
10. Dunford, M. and Smith, A. (2000) 'Catching-up or falling behind? Economic performance and regional trajectories in the New Europe', *Economic Geography*, 76 (2), pp. 169-195.
11. European Commission (1996) *First Report on Economic and social Cohesion*, Office for Official Publications of the European Communities, Luxemburg.

12. European Commission (2004) *Third Report on Social Cohesion*, Official Publication Office, Luxembourg.
13. Fei, J. and Ranis, G. (1961) 'A Theory of Economic Development', *American Economic Review*, Vol. 51, pp. 533-556.
14. Fingelton, B. (2001) 'Theoretical Economic Geography and Spatial Econometrics: Dynamic Perspectives', *Journal of Economic Geography*, Vol. 1 (2), pp. 201-225.
15. Intriligator, M. (1964) 'Regional Allocation of Investment: Comment', *Quarterly Journal of Economics*, 78 (4), pp. 659-662.
16. Hurst, C., Thisse, J. and Vanhoudt, P. (2000) 'What diagnosis for Europe's ailing regions?', *European Investment Bank Papers*, Vol. 5 (1), pp. 9-29.
17. Krugman, P. (1991) 'Increasing returns and economic geography', *Journal of Political Economy*, Vol. 99, pp. 483-499.
18. Lewis, A. (1954) 'Development with Unlimited Supplies of Labour', *Manchester School of Economic and Social Studies*, Vol. 20, pp. 139-192.
19. Mancha-Novarro, T. and Garrido-Yserte, R. (2008) 'Regional policy in the European Union: The cohesion-competitiveness dilemma', *Regional Science Policy and Practice*, Vol. 1 (1), pp. 47-66.
20. Martin, R. (2001) 'EMU versus the Regions? Regional Convergence and Divergence in Euroland', *Journal of Economic Geography* 1 (1), pp. 51-80.
21. Mas-Colell, A. and Razin, A. (1973) 'A Model of Inter-sectoral Migration and Growth' *Oxford Economic Papers*, Vol. 25, pp. 72-79.
22. Paci, R. and Pigliaru, F. (1999) 'Is Dualism a Source of Convergence in Europe?', *Applied Economics*, Vol. 31 (11), pp. 1423-1436.
23. Pigliaru, F. (2003) Detecting Technological Catch-up in Economic Convergence. *Metroeconomica*, Vol. 54, pp. 161-178.
24. Pontryagin, L., Boltyanski, V., Gamkrelidze, R. and Mishchenko, E. (1962) *The Mathematical Theory of Optimal Processes*, New York, Interscience Publications, (Translated by Trirogoff, K.)
25. Rahman, A. (1963) "Regional Allocation of Investment", *Quarterly Journal of Economics*, 77 (1), pp. 26-39
26. Rahman, A. (1966) "Regional Allocation of Investment: The Continuous Version", *Quarterly Journal of Economics*, 80 (1), 159-60.
27. Rodríguez-Pose, A. and Crescenzi, R. (2008) 'Research and Development, Spillovers, Innovation Systems and the Genesis of Regional Growth in Europe', *Regional Studies* 42, pp. 51-67.
28. Sen, A. (1966) 'Peasants and Dualism with and without Labour Surplus', *Journal of Political Economy*, Vol. 74, pp. 425-450.
29. Takayama, A. (1967) 'Regional Allocation of Investment: A Further Analysis', *Quarterly Journal of Economics*, 81 (1), pp. 330-333.