The Role of Human Capital in the Iberian Countries' Growth and Convergence

Catarina M. Cardoso

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ABSTRACT

This thesis examines the role of human capital in the growth and convergence of the Iberian countries. Using a newly computed series for human capital at the NUTS III level for the Portuguese regions, the comparison between Portugal and Spain suggests a positive role for human capital proxied by the average years of schooling in both Iberian countries regional growth, which supports the hypothesis that higher levels of education improved the regions' ability to adopt new technology; although the levels of education indicate that secondary schooling is important for technology adoption in Portugal, but not in Spain, and its effect is higher than that of tertiary education. Using Exploratory Spatial Data Analysis (ESDA), two convergence clubs are identified within the Iberia Peninsula (Core and Periphery), but convergence occurs mainly in the Periphery group and education plays a positive and significant role only in the Core club.

Keywords: Human capital, economic growth, regional growth, convergence, spatial effects, European Union

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Chapter 1
Introduction

Portugal and Spain are neighbouring countries which share some similar historical, social and economic background such as non-democratic regimes until the 1970s, joint adhesion to the European Economic Community in 1986 and low income per capita and education levels in comparison with the most developed European countries. Since the beginning of the democratic regimes in the Iberian countries there has been a significant improvement in the education levels of the two countries, along with some catching-up towards the older members of the European Union (EU15) in terms of income per capita, more significant in Spain than in Portugal. Despite the progress at the national level, significant disparities among the regions persist. The main objective of this thesis is to study the effect of human capital on the Iberian countries' economic growth, more in particular, analyse if Portugal and Spain show any signs of catching-up within the EU15; compare the effect of human capital on the two countries' regional growth; assess the role of human capital and the production structure on the reduction of regional disparities in Portugal and Spain; identify convergence clubs within the Iberia Peninsula and study if the effects of human capital differ according to the club.

The importance of human capital for economic growth has been strongly emphasised since the influential work of Schultz (1961) who considers all the skills and knowledge embodied in the individuals as human capital and distinguishes five categories: health, on-the-job training, formal education, study programs for adults and migration. Nevertheless, it was only around the 1990s that growth models started to incorporate human capital; either as an input in the production function, like the Mankiw *et al.* (1992) extended neoclassical model and Lucas's (1988) endogenous growth model, or alternatively, as a determinant of technological progress in line with the seminal work of Nelson and Phelps (1966) and subsequent endogenous growth models which focus on the role of human capital in the adoption of new technologies [Benhabib and Spiegel (1994)] and innovation [Romer (1990)]. In empirical work these two approaches imply testing different hypotheses about what affects the output growth: changes *versus* levels of human capital stock. Though human capital includes all the skills and knowledge of the individuals, at an empirical level it is often reduced to formal education due to data constraints. In contrast with micro-studies, which usually find a positive impact of schooling on the individual returns, at the macro level the effect of human capital on economic growth is ambiguous and not always in accordance with the theoretical predictions. Most studies apply the well-known β-convergence model and work with cross-country data, however it has been recognized that regional datasets have some advantages and should be used instead: "due to the difficulties of unreliable cross-country data on education attainment, it might be more promising to examine growth across regions of countries with reliable data" [Krueger and Lindahl (2001), p. 1131]. Within the same country, data is collected consistently across regions, which reduces measurement error problems, and there are also less parameter heterogeneity biases since the regions have the same national background and share similar institutions. The main aim of this thesis is to take advantage of the Iberian countries regional data in order to study the effects of human on economic growth.

There are a few studies on Portugal but they are all at the national level. For instance, Pereira and St. Aubyn (2009) disaggregated human capital stock according to the level of education and found a positive impact on growth, over the period 1960-2001, of both primary and secondary education but not of higher education. At the regional level studies on the role of human capital on growth are absent for Portugal due to lack of data.

This thesis makes several contributions to the literature. It computes a series for the human capital stock for the Portuguese NUTS III regions for the period 1991-2006 (Chapter 4). Raw data on qualifications and wages was collected from the *Quadros de Pessoal* (Personnel Records) of the Portuguese Ministry of Labour and Social Solidarity, which is a firm level dataset that has been mainly applied in labour economics empirical studies. By converting qualifications into years of schooling, alternative human capital proxies are computed for each region: the average years of schooling and its disaggregation into different levels, primary, secondary and tertiary. The Mulligan and Sala-i-Martin (1997) labour income measure, which uses an efficient parameter based on the workers' wages to adjust the education structure of the working population, is also calculated. This allows, for the first time, the introduction of human capital proxies in a study of growth and convergence in the Portuguese regions.

Using the new measures of the Portuguese regional human capital, the second contribution is the comparison of the effects of human capital on regional growth between Portugal and Spain at the NUTS III level of regional disaggregation (Chapter 5). The role of human capital in the Spanish regions convergence has been studied by several authors [de la Fuente (2002), Galindo-Martín and Álvarez-Herranz (2004), Di Liberto (2007)] but most work with the NUTS II levels. Therefore, this chapter adds to the current literature by working with the NUTS III level, instead of II of regional disaggregation, and by comparing the effects of human capital and the production structure on the reduction of regional disparities in the two Iberian countries.

Third, growth and convergence clubs in the Iberian NUTS III regions is studied by taking into account human capital and applying spatial econometrics in Chapter 6. In contrast with Spain, for which there are a couple of papers for the Spanish NUTS III units that take into account the spatial effects [Villaverde (2006) and Maza and Villaverde (2009)], for Portugal there is no work published which controls for spatial effects. There are several empirical studies on the EU NUTS II regions [López-Bazo *et al.* (2004), Ertur *et al.* (2006), Dall'Erba and Le Gallo (2008), Ramajo *et al.* (2008)] but they exclude human capital due to data limitations. As the sub-sample of the Iberian regions has never been considered before, this chapter adds to the current literature by applying an Exploratory Spatial Data Analysis to identify convergence clubs within the Iberia Peninsula, studying the effects of human capital on growth in different clubs and analysing regional spillovers among the Iberian regions.

The thesis is structured as follows. Chapter 2 provides a review of the role of human capital in growth and convergence models, methods applied and some of the empirical studies' findings. In Chapter 3 income per capita convergence between each Iberian country and the other EU15 members is evaluated for the period 1960-2006 using a time series approach.

From Chapter 4 onwards the focus shifts from national to regional growth over the period 1991-2006. The level of regional disaggregation considered is the EU

Commission's NUTS III. Human capital effects on regional growth are studied by applying a conditional β-convergence model and panel data methods, and human capital performance is compared with the production structure as an alternative conditional variable. Chapter 4 focuses on Portugal and estimates the human capital stock for each region using both an education and labour-income approach, Chapter 5 follows the same procedures to study growth in the Spanish regions and compares the results of the two Iberian countries. Finally, Chapter 6 builds on the previous chapters on regional growth by combining the two countries' regions and takes into account possible spatial effects, both spatial dependence and spatial heterogeneity, and tests for the presence of convergence clubs among the Iberian regions using the Exploratory Spatial Data Analysis.

Chapter 7 presents the main conclusions which are: the lack of income per capita convergence of the Iberian countries within the EU15; a positive effect of human capital on both Iberian countries regional growth, but the effects differ according to the level of education considered; reduction of regional disparities is driven by different sectors in the two Iberian countries; identification of two convergence clubs within the Iberia Peninsula; convergence occurs only in the periphery and human capital proxied by the average years of total and higher education plays a positive and significant role only in the core club. This implies that investments on human capital reinforce regional economic growth only after a certain threshold of economic development. At the policy level, the European Regional Policy seems to have been ineffective on the reduction of the regional disparities in the Iberia Peninsula.

Chapter 2
Literature Review

The literature on economic growth and convergence is extensive both at the theoretical and empirical level and excellent reviews have been published [Temple (1999a), Islam (2003), Durlauf *et al.* (2005, 2009)]. The purpose of this chapter is therefore to examine the role of human capital in models of economic growth which will be the focus of the empirical work developed across the thesis. This will lead to the specification of the testable hypotheses explored in subsequent chapters. Though there is currently a large literature on the determinants of the Total Factor Productivity (TFP) growth through a micro-level analysis, this review focuses on the neoclassical growth model and its extensions since the thesis follows this approach.

The Chapter is organized as follows: Section 2.1 provides a brief review of the growth theory and discusses the role of human capital in the growth models. In Section 2.2 the link between the neoclassical growth model and convergence is explored. Section 2.3 provides a short description of the different methodologies applied by growth empirics. Section 2.4 summarizes empirical studies on the effect of human capital on economic growth and section 2.5 concludes.

2.1. Human capital in growth models

Economic growth models are usually clustered into neoclassical or endogenous growth models.[1] The Solow (1956) neoclassical growth model is based on the aggregate production function and excludes human capital. It assumes diminishing returns to physical capital and therefore if economies have the same technology, saving rate and population growth rate, those with lower initial levels of output per capita will exhibit higher output per capita growth rates. In the long run the poorer economies tend to catch up to the richest ones. Divergence is a temporary situation and all economies converge to the same steady-state in which income per capita

[1] The Keynesian approach of Harrod and Domar has been ignored in recent years and this precedence has been maintained in this thesis.

growth depends only on the technological progress which remains unexplained by the model. Despite the importance of human capital for economic growth which had been recognized since the seminal work of Schultz (1961), it was only in the 1990s that human capital was added to the neoclassical growth model by Mankiw *et al.* (1992). The boom in endogenous growth theory also happened in the 1990s and in many of these models human capital plays an important role. The next subsections review the most important models within each theory.

2.1.1. The augmented neoclassical growth model

In the augmented Solow (1956) growth model proposed by Mankiw *et al.* (1992) human capital is included in the same way as physical capital. The model begins with constant returns to scale aggregate production function:

$$Y_t = K_t^{\alpha} H_t^{\beta} (A_t L_t)^{1-\alpha-\beta} \tag{2.1}$$

where Y is real output, K and L are the amount of capital and labour, H is the human capital stock, A is the labour-augmenting technical progress and t stands for the time subscript. α, β and $(1-\alpha-\beta)$ are, respectively, the output elasticity with respect to physical capital, human capital and labour. Under the assumption of perfect competition, each input is remunerated by its marginal product and therefore each elasticity is equal to the share of income paid to the respective production factor. $\alpha + \beta < 1$, which means that all capital (both physical and human) exhibits decreasing returns. Labour and technology growth rates, n and g respectively, are assumed to be exogenous:

$$L_t = L_0 e^{nt} \tag{2.2}$$

$$A_t = A_0 e^{gt} \tag{2.3}$$

The physical and human capital per effective unit of labour, are respectively k and h:

$$k = K / AL \tag{2.4}$$

$$h = H / AL \tag{2.5}$$

and the output per effective unit of labour is:

$$y = Y / AL = k^{\alpha} h^{\beta} \tag{2.6}$$

The crucial dynamics in the augmented Solow model are the behaviour of physical and human capital stocks:

$$\Delta k = s_k y - (n + g + \delta)k \tag{2.7}$$

$$\Delta h = s_h y - (n + g + \delta)h \tag{2.8}$$

where s_k and s_h are the fraction of income invested in physical and human capital, respectively, and δ is the capital depreciation rate which is the same for both physical and human capital. All these rates are considered exogenous. These equations show that the evolution of k and h depends on the total investment in physical and human capital, respectively, and the investment needed to keep constant the stock per effective unit of labour. Economies tend to converge to their steady-state levels, where $\Delta k = 0$ and $\Delta h = 0$. Solving the former system, the steady-state levels of physical and human capital per effective worker are obtained:

$$k^* = \left(\frac{s_k^{(1-\beta)} s_h^{\beta}}{n + g + \delta} \right)^{1/(1-\alpha-\beta)} \tag{2.9}$$

$$h^* = \left(\frac{s_k^{\alpha} s_h^{(1-\alpha)}}{n + g + \delta} \right)^{1/(1-\alpha-\beta)} \tag{2.10}$$

The income per worker equation is obtained by substituting k^* and h^* in the production function per worker:

$$\left(\frac{Y}{L}\right)_t = A_t k^{\alpha} h^{\beta} = A\left(\frac{s_k^{(1-\beta)} s_h^{\beta}}{n+g+\delta}\right)^{\alpha/(1-\alpha-\beta)} \left(\frac{s_k^{\alpha} s_h^{(1-\alpha)}}{n+g+\delta}\right)^{\beta/(1-\alpha-\beta)}$$
$$= A_t\left(\frac{\left(s_k^{\alpha} s_h^{\beta}\right)^{1/(1-\alpha-\beta)}}{(n+g+\delta)^{(\alpha+\beta)/(1-\alpha-\beta)}}\right) \quad (2.11)$$

By taking logarithms in the above equation, the steady-state income per worker becomes:

$$\ln\left(\frac{Y}{L}\right)_t^* = \ln A_0 + gt + \frac{\alpha}{1-\alpha-\beta}\ln(s_k) + \frac{\beta}{1-\alpha-\beta}\ln(s_h) - \frac{\alpha+\beta}{1-\alpha-\beta}\ln(n+g+\delta) \quad (2.12)$$

which depends positively on the accumulation rate of both physical (s_k) and human capital (s_h) and negatively on the population growth rate (n). According to Mankiw *et al.* (1992), A_0 represents not only the initial level of technology but also factors such as resource endowments, climate and institutions which may differ across countries. Working with the output per effective unit of labour (Equation 2.6), the respective steady-state level is:

$$\ln y^* = \frac{\alpha}{1-\alpha-\beta}\ln(s_k) + \frac{\beta}{1-\alpha-\beta}\ln(s_h) - \frac{\alpha+\beta}{1-\alpha-\beta}\ln(n+g+\delta) \quad (2.13)$$

By applying logarithms to equation (2.10) and rearranging, the human capital accumulation rate $\ln(s_h)$ is obtained as a function of the other variables:

$$\ln(s_h) = \frac{(1-\alpha-\beta)\ln h^* - \alpha \ln s_k + \ln(n+g+\delta)}{1-\alpha} \quad (2.14)$$

Thus by substituting $\ln(s_h)$ in equation (2.12), the level of income per worker can be written as function of the steady-state level of human capital (h^*) instead of the respective accumulation rate (s_h):

$$\ln\left(\frac{Y}{L}\right)_t^* = \ln A_0 + gt + \frac{\alpha}{1-\alpha}\ln(s_k) + \frac{\beta}{1-\alpha}\ln(h^*) - \frac{\alpha}{1-\alpha}\ln(n+g+\delta) \qquad (2.15)$$

and per effective unit of labour:

$$\ln y^* = \frac{\alpha}{1-\alpha}\ln(s_k) + \frac{\beta}{1-\alpha}\ln(h^*) - \frac{\alpha}{1-\alpha}\ln(n+g+\delta) \qquad (2.16)$$

and:

$$\ln\left(\frac{Y}{L}\right)_t^* = \ln y^* + \ln A_0 + gt \qquad (2.17)$$

A higher level of human capital increases the steady-state level of both income per worker and per effective unit of labour. Since the latter is not observed, at the empirical level studies work with equation (2.15).

The augmented Solow growth model shows that human capital accumulation generates growth towards the steady-state. Once there, human capital affects the level of income per worker but not the respective growth rate which is only determined by the exogenous rate of technological progress. As in the previous neoclassical growth models, the technological progress remains unexplained and economies will converge to the same income per capita levels if they share the same steady-state determinants.

2.1.2. The endogenous growth models

In the neoclassical growth model, with or without human capital, long-run growth depends on the technological progress which is exogenous. This inability of the neoclassical theory to generate growth within the models is, together with the lack of empirical evidence of convergence among large samples of countries, the main motivation for the advent of endogenous growth theory [Islam (2003)]. This theory includes a heterogeneous group of models which have in common the ability to generate long-run growth endogenously by abandoning the diminishing returns hypothesis. Many models focus on the role of human capital, either as input in the production function, as in the neoclassical model case, or as a determinant of the technological progress. These are referred to, respectively, as the Lucas or Nelson-Phelps approach [Aghion and Howitt (1998, Chapter 10)].

One of the first important contributions is the Lucas model [Lucas (1988)] in which human capital is included as another input in the production function, but in contrast with the neoclassical hypothesis, it exhibits no diminishing returns. The main sources of human capital accumulation considered are education and learning-by-doing. In what concerns the former, individuals allocate their time between current production and schooling and the production function of the representative agent is:

$$y = k^{\beta}(uh)^{1-\beta}(h_a)^{\gamma} \tag{2.18}$$

in which h is his current human capital stock, u is the fraction of time allocated to the current production and h_a is the average level of human capital in the economy. The latter is incorporated to reflect human capital externalities: an individual productivity depends not only on his own skills but also on the average level of skills. These externalities are positive if $\gamma > 0$. Human capital production does not need physical capital and the accumulation process is described by the following equation:

$$\Delta h = \delta h(1-u) \tag{2.19}$$

where $(1-u)$ is the fraction of time allocated to human capital formation and δ is the maximum human capital growth rate which is achieved if no time is allocated to current production. Due to constant returns to scale in the production of human capital, in the steady-state its growth rate is:

$$\frac{d \ln h}{dt} = \delta(1-u^{*}) \tag{2.20}$$

in which u^* is the optimal allocation of time between production and education that results from the maximization of the representative agent's inter-temporal utility function. The long-run income per capita growth is driven by the human capital accumulation. Convergence either in levels or growth rates is not predicted in this model since countries (or regions) that invest more in human capital will grow faster.

Other endogenous growth models follow the Nelson and Phelps approach and include human capital as a determinant of the technological progress. Nelson and Phelps (1966) seminal work suggested that human capital enhances a country's ability to adopt and implement new technologies, speeding up technological diffusion, and since then many have been inspired by the idea that technological progress, in the double sense of both production and absorption of technology, needs human capital (*H*). In their model, the growth of the technological index *A* is given by:

$$\frac{d \ln A}{dt} = c(H)\left[\frac{T_t - A_t}{A_t}\right] \tag{2.21}$$

which shows how the growth rate of A depends on the gap between the country's level of technology (A), the "theoretical knowledge" (T) and the speed at which this gap is eliminated which is a function of the human capital level [$c(H)$]. As in the Solow model T is assumed to grow at an exogenous rate. This model implies convergence since a country that is further from (T) will grow faster due to the technology transfer which is facilitated by a higher level of human capital.

Instead of technology adoption, Romer (1990) focuses on the mechanisms that generate innovation. In his model the perfect competition assumption is abandoned and three economic sectors are considered: final goods, intermediate goods and research. The latter is the most human capital intensive and produces ideas that will generate better intermediate goods. The technology level (*A*) is a function of the human capital allocated to the R&D activities and the aggregate production function exhibits increasing returns to scale due to the knowledge spillovers. An increase in human capital allocated to R&D activities will increase the production of capital and, consequently, will lead to faster growth. The long-run growth rate depends on the human capital stock in the R&D sector and no convergence mechanism is predicted since a country with a higher allocation of human capital to research will grow faster than the others.

Benhabib and Spiegel's (1994) take inspiration in both Nelson and Phelps (1966) and Romer (1990), combining innovation and technology adoption in the same model. The total factor productivity growth is determined by the human capital stock through these two channels and for each country i is given by:

$$\left(\frac{d \ln A}{dt}\right)_i = c + gH_i + mH_i\left[(Y_{max} - Y_i)/Y_i\right] \tag{2.22}$$

in which c stands for the exogenous technological progress, gH represents the endogenous technological progress related to innovation, Y_{max} stands for the output of the leader country and $mH_i\left[(Y_{max} - Y_i)/Y_i\right]$ represents the technological catch-up. As in Nelson and Phelps (1966), convergence is expected. More recently Benhabib and Spiegel (2005) introduce an important extension to the Nelson-Phelps hypothesis: without a critical value of human capital the technological catch-up mechanism does not work and there will be divergence in the total factor productivity growth rates. Therefore, both convergence and divergence are possible outcomes.

There is currently a trend in the endogenous growth literature that focuses on the determinants of the total factor productivity from a micro perspective; such as the models of firm entry and exit, according to which the innovation behind the overall total factor productivity growth is facilitated by the entry of new firms in the market [Aghion *et al.* (2009)]; or the capital misallocation models which focus on the effects of the reallocation of resources among firms on the aggregate total factor productivity [Restuccia and Rogerson (2008) and Hsieh and Klenow (2009)]. These models are connected with the extensive empirical work on the links between the micro and the aggregate total factor productivity growth which has been facilitated by the increasingly available firm level datasets.

The new theories of endogenous growth leave behind the assumption of diminishing returns and therefore convergence of the economies is not predicted anymore. In some models per capita income differences among countries can persist and indeed grow over time [Lucas (1988), Romer (1990)]. Other models that consider technology transfer imply convergence but even though only under certain conditions [Benhabib and Spiegel (2005)].

2.2. The links between convergence and the growth models

As noticed before, convergence is a general prediction of the neoclassical growth theory but not of the endogenous growth models which may predict either divergence or convergence. Though the first well known empirical convergence studies from the 1980s do not have a clear connection with growth models [Baumol (1986) and Abramowitz (1986)], since the 1990s literature on growth and convergence has been growing and many cross-section and panel data empirical studies are based on the seminal work of Mankiw *et al.* (1992) who derived the speed of convergence directly from the augmented neoclassical growth model presented in subsection 2.1.1. The chapters on regional growth of this thesis apply this model and so full derivation of the convergence equation follows.

Taking into consideration equation (2.6) in subsection 2.1.1, the output per effective unit of labour (y) growth rate can be written as:

$$\frac{d\ln y_t}{dt} = \alpha \frac{d\ln k}{dt} + \beta \frac{d\ln h}{dt} \tag{2.23}$$

and from the equations (2.7) and (2.8) the growth rates of k and h can be easily obtained:

$$\frac{d\ln k}{dt} = \frac{\Delta k}{k} = s_k \frac{y}{k} - (n + g + \delta) \tag{2.24}$$

$$\frac{d\ln h}{dt} = \frac{\Delta h}{h} = s_h \frac{y}{h} - (n + g + \delta) \tag{2.25}$$

Using the production function per effective unit of labour (2.6), these growth rates become:

$$\frac{d\ln k}{dt} = s_k k^{\alpha-1} h^{\beta} - (n + g + \delta) \tag{2.26}$$

$$\frac{d\ln h}{dt} = s_h k^{\alpha} h^{\beta-1} - (n + g + \delta) \tag{2.27}$$

By applying the logarithms properties, these can be written as:

$$\frac{d\ln k}{dt} = s_k e^{(\alpha-1)\ln k + \beta \ln h} - (n + g + \delta) \tag{2.28}$$

$$\frac{d\ln h}{dt} = s_h e^{\alpha \ln k + (\beta-1)\ln h} - (n + g + \delta) \tag{2.29}$$

The approximation of these growth rates to the steady-state can be obtained by applying the first-order Taylor expansion which leads to:

$$\frac{d\ln k}{dt} \approx s_k e^{(\alpha-1)\ln k^* + \beta \ln h^*} \left[(\alpha-1)(\ln k - \ln k^*) + \beta(\ln h - \ln h^*)\right] \tag{2.30}$$

$$\frac{d\ln h}{dt} \approx s_h e^{\alpha \ln k^* + (\beta-1)\ln h^*} \left[\alpha(\ln k - \ln k^*) + (\beta-1)(\ln h - \ln h^*)\right] \tag{2.31}$$

which by using the logarithms properties and the production function (2.6) becomes:

$$\frac{d\ln k}{dt} \approx s_k \frac{y^*}{k^*} \left[(\alpha-1)(\ln k - \ln k^*) + \beta(\ln h - \ln h^*)\right] \tag{2.32}$$

$$\frac{d\ln h}{dt} \approx s_h \frac{y^*}{h^*}\left[\alpha(\ln k - \ln k^*) + (\beta - 1)(\ln h - \ln h^*)\right] \tag{2.33}$$

In the steady-state the growth rate of both k and h is zero so from equations (2.24) and (2.25) result that:

$$s_k \frac{y^*}{k^*} = s_h \frac{y^*}{h^*} = (n + g + \delta) \tag{2.34}$$

The growth rates of k and h around the steady-state are therefore:

$$\frac{d\ln k}{dt} = (n + g + \delta)\left[(\alpha - 1)(\ln k - \ln k^*) + \beta(\ln h - \ln h^*)\right] \tag{2.35}$$

$$\frac{d\ln h}{dt} = (n + g + \delta)\left[\alpha(\ln k - \ln k^*) + (\beta - 1)(\ln h - \ln h^*)\right] \tag{2.36}$$

Inserting both growth rates into equation (2.23), the output per effective unit of labour growth rate close to the steady-state is obtained:

$$\begin{aligned}\frac{d\ln y}{dt} = (n + g + \delta)[\alpha(\alpha - 1)(\ln k - \ln k^*) + \alpha\beta(\ln h - \ln h^*) + \\ + \alpha\beta((\ln k - \ln k^*) + \beta(\beta - 1)(\ln h - \ln h^*)]\end{aligned} \tag{2.37}$$

By reorganizing the terms it becomes:

$$\begin{aligned}\frac{d\ln y}{dt} = (n + g + \delta)[\alpha(\ln k^\alpha + \ln h^\beta) - \alpha(\ln k^{*\alpha} + \ln h^{*\beta}) + \beta(\ln k^\alpha + \ln h^\beta) + \\ - \beta(\ln k^{*\alpha} + \ln h^{*\beta}) - (\ln k^\alpha + \ln h^\beta) + (\ln k^{*\alpha} + \ln h^{*\beta})]\end{aligned} \tag{2.38}$$

By using the production function (2.6), the above equation can be written as:

$$\frac{d\ln y}{dt} = (n+g+\delta)\left[\alpha(\ln y - \ln y^*) + \beta(\ln y - \ln y^*) - (\ln y - \ln y^*)\right]$$
$$= (n+g+\delta)(1-\alpha-\beta)(\ln y^* - \ln y) \tag{2.39}$$

So close to the steady-state, which is unique and stable, the output per effective worker growth rate is:

$$\frac{d\ln y_t}{dt} = \lambda(\ln y^* - \ln y_t) \tag{2.40}$$

and the speed of convergence λ is given by:

$$\lambda = (n+g+\delta)(1-\alpha-\beta) \tag{2.41}$$

Equation (2.40) is a first-order linear differential equation in $\ln y_t$. Following the procedures to solve this kind of equations [Barro and Sala-i-Martin (1995), pp. 468-469], the terms should be reorganized:

$$\frac{d\ln y_t}{dt} + \lambda\ln y_t = \lambda\ln y^* \tag{2.42}$$

and then both sides are multiplied by $e^{\lambda t}$, in which e is the Napier number, and integrated with respect to time:

$$\int e^{\lambda t}\left(\frac{d\ln y_t}{dt} + \lambda\ln y_t\right)dt = \int e^{\lambda t}\lambda\ln y^* dt \tag{2.43}$$

On the left-hand side, the term inside the integral can be transformed into:

$$e^{\lambda t}\frac{d\ln y_t}{dt} + e^{\lambda t}\lambda\ln y_t = \frac{d}{dt}\left(e^{\lambda t}\ln y_t + C_o\right) \tag{2.44}$$

in which C_0 is a constant. As a result, equation (2.43) becomes:

$$\int \frac{d}{dt}\left(e^{\lambda t}\ln y_t + C_0\right)dt = \int e^{\lambda t}\lambda \ln y^* dt \tag{2.45}$$

and it can be easily solved in order to obtain $\ln y_t$:

$$e^{\lambda t}\ln y_t + C_0 = e^{\lambda t}\ln y^* + C_1 \tag{2.46}$$

in which C_1 is also a constant. By reorganizing the terms, $\ln y_t$ is obtained:

$$\ln y_t = \ln y^* + e^{-\lambda t}(C_1 - C_0) \tag{2.47}$$

At $t = 0$, $\ln_t = \ln y_0$ and by substituting into (2.47)

$$\ln y_0 = \ln y^* + (C_1 - C_0)$$

$$(C_1 - C_0) = \ln y_0 - \ln y^* \tag{2.48}$$

Then, by plugging the constant $(C_1 - C_0)$ into equation (2.47), it becomes:

$$\ln y_t = (1 - e^{-\lambda t})\ln y^* + e^{-\lambda t}\ln y_0 \tag{2.49}$$

By subtracting $\ln y_0$ in both sides the convergence equation becomes:

$$\ln y_t - \ln y_0 = (1 - e^{-\lambda t})\ln y^* - (1 - e^{-\lambda t})\ln y_0 \tag{2.50}$$

Taking into consideration the steady-state level (2.13) the convergence towards to the steady-state is represented by:

$$(\ln y_t - \ln y_0) = (1-e^{-\lambda t})\frac{\alpha}{1-\alpha-\beta}\ln s_k + (1-e^{-\lambda t})\frac{\beta}{1-\alpha-\beta}\ln s_h$$
$$-(1-e^{-\lambda t})\frac{\alpha+\beta}{1-\alpha-\beta}\ln(n+g+\delta) - (1-e^{-\lambda t})\ln y_0 \qquad (2.51)$$

This equation (2.51) shows that the growth rate of y depends on the initial level of y (y_0) and on the determinants of the steady-state. Both physical and human capital accumulation have a positive effect on the growth rate, in contrast with the negative effect of the population growth rate and the initial level of income per effective worker. Alternatively, working with equation (2.16), the growth rate of y becomes:

$$(\ln y_t - \ln y_0) = (1-e^{-\lambda t})\frac{\alpha}{1-\alpha}\ln s_k + (1-e^{-\lambda t})\frac{\beta}{1-\alpha}\ln h^*$$
$$-(1-e^{-\lambda t})\frac{\alpha}{1-\alpha}\ln(n+g+\delta) - (1-e^{-\lambda t})\ln y_0 \qquad (2.52)$$

which shows a positive effect of the human capital level on the growth rate. Since Mankiw *et al.* (1992), these equations have been largely used in empirical studies.[2] Since the income per effective unit of labour is not observed, the equation used at the empirical level is expressed in terms of income per worker:

$$\ln\left(\frac{Y}{L}\right)_t - \ln\left(\frac{Y}{L}\right)_0 = (1-e^{-\lambda t})\frac{\alpha}{1-\alpha}\ln s_k + (1-e^{-\lambda t})\frac{\beta}{1-\alpha}\ln h^*$$
$$-(1-e^{-\lambda t})\frac{\alpha}{1-\alpha}\ln(n+g+\delta) - (1-e^{-\lambda t})\ln\left(\frac{Y}{L}\right)_0 \qquad (2.53)$$
$$+(1-e^{-\lambda t})\ln A_0 + gt$$

As in the first empirical studies of Baumol (1986) and Abramowitz (1986), it is a regression of the growth of income per worker on the initial level, but in contrast with them it is derived directly from the growth model and allows estimation of the speed of convergence. If economies have the same technology, physical and human capital accumulation rates and population growth rate, those with lower initial levels of

[2] A similar convergence equation was derived from the Cass-Koopmans (1965) growth model with exogenous technical progress by Barro and Sala-i-Martin (1992). The convergence coefficient is more complicated and human capital is not included in the production function but added ad hoc as a determinant of the steady-state.

output per worker will exhibit higher output per worker growth rates because they are further from the steady-state. At the end they will converge to the same steady-state output per worker level. Both physical and human capital accumulation generate growth during the adjustment of the economy towards its steady-state. Once the economy gets to the steady-state, the output per worker growth depends only on the rate of technological progress which is exogenous.

The interpretation of the speed of convergence, λ, in cross-country studies is problematic. According to Islam (2003), it should be considered as the speed at which the poorer countries are reducing their income gap with the richer, only if they share the same steady-state. If not, there is a conceptual problem concerning the interpretation of λ since it is derived from the neoclassical model as the speed of convergence towards the steady-state. The assumption that economies share identical steady-states is more likely to hold in regional studies than in cross-country ones.

2.3. Growth and convergence empirics

Empirical literature is extensive and the results differ significantly across studies. In terms of methodology, four different approaches are usually considered: Cross-section, panel data, time-series and distribution approach. The concept of convergence is often linked with the methodology. A brief review follows.[3]

2.3.1. Cross-section approach

The cross-sectional approach seems to have predominated among the convergence empirical literature and apart from Mankiw *et al.* (1992) the most well-known researchers are Barro and Sala-i-Martin. In cross-sectional studies two different concepts of convergence have been used: σ-convergence and β-convergence. The inverse relationship between the initial level of income per capita or productivity and the respective average growth rate is called β-convergence. On the other hand, the decline over time of the cross-section income per capita or productivity dispersion

[3] Extended recent reviews are provided by Durlauf *et al.* (2005) and Durlauf *et al.* (2009).

across countries (or regions) evidences σ-convergence. The dispersion is usually measured by the standard deviation or the coefficient of variation[4]. Sala-i-Martin (1990) introduced this terminology in his PhD thesis but the concepts themselves had been used before by the pioneers of empirical convergence literature which are Baumol (1986) and Abramovitz (1986). These two well known seminal empirical convergence studies do not have a clear connection with the growth models but propose ideas that are developed later.

Baumol (1986) worked with the long period data available by Maddison (1870-1973) of GDP per work hour for the sixteen industrialized countries and by Summers-Heston (1950-1980) of GDP per capita for seventy two countries to test long-run convergence. The regression of the growth rate on the initial level of GDP per work hour shows a high inverse correlation among the sixteen industrialized countries which is explained by investment and innovation spillover effects that enhanced faster productivity growth in the laggard countries. Among the seventy two countries of Summers and Heston' dataset there is evidence of three convergence clubs (the free market industrialized countries, centrally planned countries and the intermediate countries) but no convergence among all the countries. The poorest less developed countries are left out of these convergence clubs because their production structure do not allow them to benefit from the leader innovations and their low education levels prevent shifts of resources to other production sectors. Abramowitz (1986) also used the Maddison's dataset and found evidence of convergence among the industrialized countries measured by the decline of the GDP per hour coefficient of variation and the inverse relation between its initial level and the respective growth rate from 1870 to 1979. An exception was the World War II period during which the set of countries exhibited no convergence. According to Abramowitz (1986) convergence tends to occur if countries have similar economic and social structures. There is a potential for rapid productivity growth when a country is "technologically backward but socially advanced". This was the case of Europe in the post-war period. The technological gap between Europe and USA was an opportunity for European countries catching-up. A country needs to develop its "social capability" in order to benefit from the technological gap opportunity and consequently to grow faster. Only with "social capability" it is possible to exploit the leader's technology. This catching-up process

[4] The standard deviation divided by mean.

is self-limited, the followers potential for higher growth declines as they converge to the leader productivity levels.

Though conceptually different, σ and β convergence are related. β-convergence is a necessary but not a sufficient condition for σ-convergence [Sala-i-Martin (1996)]. In the regressions of growth rates on the income per capita initial levels it is also important to distinguish absolute (or unconditional) from conditional convergence. Following Barro and Sala-i-Martin (1995), without the assumption that economies have the same parameters they do not converge to the same steady-state. Each economy has its own steady-state and its growth rate is higher the further it is from the respective steady-state. There is absolute convergence when "poor economies tend to grow faster than richer ones without conditioning on any other variables". On the other hand, there is conditional β-convergence among a set of economies when the cross-sectional regression of the growth rate on the initial income level, holding constant a number of additional variables, exhibits a negative coefficient. Absolute convergence means that countries or regions are converging to the same steady-state level. Conditional convergence means that they are converging towards different steady-state levels. They found evidence of absolute β-convergence among sets of homogenous economies like OECD members or USA states but not among all the 118 countries analysed. Barro and Sala-i-Martin (1992) worked with a set of 98 countries and found evidence of convergence conditional on the initial school enrolment rates and ratio of government consumption to GDP.

According to Mankiw *et al.* (1992), the Solow model predicts conditional convergence because convergence only occurs under the control of the steady-state parameters. If economies do not share the same steady-state parameters, they will converge to different income per worker levels. In their paper absolute and conditional convergence for OECD countries over the period 1960-85 are tested and, as seen, human capital is among the conditional variables, together with the physical capital accumulation rate and the population growth rate. Human capital can be introduced either through its accumulation rate or level, depending on the specification (Equations 2.51 and 2.52, respectively). Evidence of β-convergence was found in both senses, but stronger when the conditional variables were included and even stronger when human capital proxied by the secondary school enrolment rate was added. In contrast with most empirical work done before, the Mankiw *et al.* (1992) growth regression is directly derived from a theoretical model and this explains its subsequent influence.

The results of many convergence studies summarized by Sala-i-Martin (1996) show evidence of both σ and β convergence across regions of the United States of America, Japan, Europe, Spain and Canada. The speed of β convergence found was about 2% per year in all cases over different periods. This rate of convergence is considered slow because it implies that "one fourth of the original income differences are predicted to remain after a long period of 70 years" [Sala-i-Martin (1996), p. 1349].

de la Fuente (1997) reviews cross-section empirical literature on convergence and concludes that most results are consistent with theoretical predictions. Higher investment in physical and human capital leads to higher growth. Most empirical studies evidence conditional convergence, a positive effect of political stability, openness to trade and financial development on growth rate and a negative effect of monetary shocks, variability of inflation and weight of public consumption, but usually the estimated rate of convergence is much lower than the one predicted by the neoclassical growth model. This implies that the coefficient of capital is much higher than its share in national income, which is around 1/3.

A large number of additional variables have been used across the cross-section empirical literature. Durlauf and Quah' (1999) survey identified over than ninety but to these authors most of the studies fail to explain if the regressions fit within an economic model and it is not clear what the inclusion of a particular variable means. The additional variables considered are quite often correlated with one another and are chosen arbitrarily from a set of possibilities. These regressions, which are not clearly derived from a theoretical model, are usually called *ad hoc* growth regressions.[5]

Many criticisms to the robustness of cross-sectional studies have arisen. Levine and Renelt (1992) evaluated the degree of confidence of cross-country growth regressions and concluded that most of them were fragile. The results are very sensitive to the

[5] Sometimes the term "Barro regressions" is also used [Sianesi and Van Reenen (2003)].

conditioning information set and it is very difficult to find any strong empirical relationship between long-run growth and a specific macroeconomic indicator. Many conditioning variables loose significance or their coefficients change sign when other variables are added to the right-hand-side of the convergence equation. They were only able to find a positive and robust correlation between growth and the share of investment in GDP and between this share and the ratio of international trade to GDP. No robust correlation was found between growth and fiscal and monetary policy indicators, political stability indexes and international trade indicators. Their study evidences income per capita convergence when the initial level of human capital investment is included in the regression, but only over the whole period considered 1960-89, not in the sub-period 1974-89. Quah (1993) argued that the cross-section regressions of growth rates on the initial level of the variables are regressions towards the mean, the so called Galton's Fallacy.

2.3.2. Panel data approach

As the cross-section approach this methodology has been mainly used to study conditional β-convergence and one of the main advantages is the introduction of country-specific effects in the regressions. Again the starting point is usually the neoclassical model and the respective aggregate production function. Islam (1995) took inspiration in Mankiw *et al.* (1992) and found evidence of higher rates of conditional convergence (between 4.3% and 9.3%) comparing to cross-section regressions. His fixed-effects approach solves the problem of the omitted variable bias but the endogeneity problems remain since the country-specific unobserved effects include the initial level of technology (A_0) which is correlated with the other right-hand-side variables, in particular the initial level of output per capita. In order to correct endogeneity instrumental variables methods have been applied, especially the Generalized Method of Moments (GMM) has been proposed by Caselli *et al.* (1996) and Bond *et al.* (2001).

Lee *et al.* (1997) also applied a panel data approach but to a stochastic version of Solow model. The main difference compared to the deterministic version is the inclusion of an *ad hoc* stochastic specification in the model. Both technology (A) and employment (L) are determined by stochastic processes but the respective shocks effects on the output are quite different. Contrasting with Islam (1995), who only considered heterogeneity in the productivity shift parameter, Lee *et al.* (1997) allowed heterogeneity in all the parameters and countries can differ not only in terms of steady-state levels but also in steady-state growth rate (g). According to this stochastic version it is possible that countries converge to different steady-state income per capita levels at a different convergence speed. Relaxing the assumption that countries share the same technology growth rates, the convergence speed found is much higher (around 30%) than the 2% found in most cross-section studies but its interpretation is quite difficult within the stochastic version. Their results are evidence of increasing income dispersion and therefore divergence. Mutual criticism arose between these authors and Islam. Lee *et al.* (1998) pointed out that Islam's (1995) fixed effects (FE) estimator was inconsistent and his work failed to allow time trends heterogeneity across countries. Islam's (1998) response was that these authors were working with a useless concept of convergence because when g is also allowed to vary across countries the notion of convergence looses its economic meaning. According to Islam (1998) the parametric heterogeneity is an inevitable result of the underlying tension between convergence *within* and *across* economies.

Endogenous and exogenous growth theories were compared by Evans (1998) by applying a panel data approach. According to his findings the exogenous growth models seem more consistent with the empirical evidence when countries have a well-educated population and the opposite happens with the endogenous growth models, suggesting that countries with low levels of per capita human capital have no access to technological knowledge.

A meta-analysis of a sample of cross-section and panel data studies to evaluate how the methodology and the study design influence the rate of β-convergence was applied by Dobson *et al.* (2006). Their findings indicate a higher average convergence rate in intra-national studies than in cross-national ones. Cross-national studies show higher estimates for β conditional convergence than for unconditional, biased rate of convergence estimators if the spatial dependence is not controlled (for example, OLS estimator does not capture the cross-border spill-over effects) and smaller rate of convergence the longer the time period. It was also found that the rate of convergence depends significantly on the inclusion of human capital and investment rate, but seems to be unrelated to variables such as the number of regions included in the study, developing countries included or not, the average year considered and the share of agriculture and industry in GDP. The estimation technique is also important to the estimated rate of convergence. When panel data approach is applied, the control of time invariant unobserved effects is important for the cross-national results but not for the intra-national ones. Comparing the different methods, the GMM is the one that leads to higher convergence rates both in cross-national and intra-national studies. Investment rate is an important conditional variable in both kind of studies but human capital is only significant in the cross-national ones.

Table 2.1. summarizes these and other empirical work on convergence applying panel data approaches. The estimated speed of convergence varies much more across panel studies than the 2% found by most cross-section ones. Important disadvantages of the panel approach have also been pointed out, especially concerning the interpretation of the speed of convergence. As Durlauf and Quah (1999) explain one of the main merits of the panel data approach is to allow the heterogeneity between countries but when the researcher allows the heterogeneity across countries of the initial level of technology (A_0) they cannot study if the poor countries are catching-up with rich ones anymore. Another relevant criticism is the low power of the tests for β-convergence, which use cross-section or panel data, against the alternative hypothesis of multiple steady-states [Durlauf *et al.* (2009)]. In contrast with the Solow model, in the multiple steady-states models the cross-country behaviour is nonlinear and only countries that share the same steady-state follow a common linear path.

Azariadis and Drazen (1990) use models in which multiple, locally stable stationary-states emerge due to increasing returns to scale in human capital accumulation. They consider two ways in which this factor accumulation may result in multiple balanced growth paths: either a critical level of human capital facilitates obtain more knowledge or it generates a sharp increase in the production possibilities. In the presence of multiple steady-states, the estimated β-convergence equation (2.53) is misspecified and a negative β coefficient maybe consistent with economic non-convergence. The alternative of multiple regimes in cross-country growth was clearly favoured by Durlauf and Johnson (1995) whose findings using the same dataset as Mankiw *et al.* (1992) show that there are significant differences between the aggregate production functions of countries which belong to different groups according to the respective initial conditions. When the economic system is characterized by multiple locally stable steady-state equilibria the club convergence hypothesis emerges and the introduction of variables such as human capital reinforces its viability as a competing hypothesis with conditional convergence [Galor (1996)]. Club convergence means that economies converge to the same steady-state within the group they belong according to the respective initial conditions.

Temple (1998) tested the robustness of the cross-section and panel data estimations of Mankiw *et al.*'s (1992) augmented Solow model and demonstrated that both the convergence rates and technology parameters are very sensitive to the measurement error in the initial income and conditional variables. Therefore, the 2% found in many cross-country studies is not reliable. The main advantages of panel data techniques to empirical growth studies are the control of omitted variables bias and the use of the regressor's lags as instruments to reduce measurement error and endogeneity biases which are the main problems of cross-section studies [Temple (1999a)].

Table 2.1 – Panel Data Approach Summary

Reference	Period/ Time observations (T)	Dataset/ No. countries (N)	Procedures	Main conclusions
Islam (1995)	1950-85 T=9 (quinquenium)	OECD N=22	Heterogeneity in the intercept term, FE	Annual convergence rate between 3.8-9.1%
Caselli *et al.* (1996)	1960-85 T=5 (quinquenium)	Penn World Tables (1991) Barro and Lee (1994) N=97	GMM	Annual convergence rate around 10% Rejection of Solow model
Evans and Karras (1996)	1970-86 T=17	USA States N=48	Panel-Unit Roots Output per worker decomposition: technology level, share of output paid to capital owners, rental rate paid to capital	Convergence across states but not absolute
Lee *et al.* (1997)	1960-89 T=30	Penn World Tables (1991) N=102	Stochastic Solow model Heterogeneity in all the parameters	Divergence
Lee *et al.* (1998)	1950-90 T=41 vs. T=9 (quinquenium)	OECD N = 22	OLS, FE Instrumental variables (IV) GMM	Annual convergence rate around 2-4% (towards steady-state)
Fleissig and Strauss (2001)	1900-87	OECD N=15	Panel-Unit Roots	Convergence only for the period 1948-87 at 4-8%

2.3.3. Time series approach

This approach is based on the cointegration properties of the time-series and leads to the definition of *stochastic convergence*. The main advantage is to provide a precise statistical definition of the convergence hypotheses, but has the drawback of no link with a growth theory [Durlauf *et al.* (2009)]. The first empirical work using this approach was the study of USA regions per capita income convergence for the period 1929-90 developed by Carlino and Mills (1993) which found some inconsistency between cross-section and time-series evidence, conditional convergence in all the regions and no *stochastic convergence* respectively. By applying the time-series approach they were only able to detect signs of convergence in three out of eight regions after allowing for a time-break in 1946. This concept of convergence was developed by Bernard and Durlauf (1995, 1996) who reported several problems in the traditional cross-sectional approach: two countries might exhibit the inverse relationship between the average growth rate and the initial level of income per capita without convergence; intermediate possibilities are not admitted, only convergence or divergence, and biased β-coefficient estimators due to multicollinearity and endogeneity of the conditional variables. Alternatively a time-series approach based on the stationarity and cointegration analysis is proposed which distinguishes strong from weak convergence. There is strong convergence between two countries, *i* and *j*, if in the long-run their predicted income per capita is the same, this is:

$$\lim_{k \to \infty} E\left(y_{i,t+k} - y_{j,t+k} \mid I_t\right) = 0 \qquad (2.54)$$

where E is the expected value operator, y_i and y_j are the income per capita logarithms, k is the period of time and I is the information available at the moment t. This means that y_i and y_j are cointegrated with the cointegration vector [1,-1]. It is also possible that there is a common trend in the evolution of two countries income per capita which means that their predicted values are not the same but proportional and this is the concept of weak convergence, this is:

$$\lim_{k \to \infty} E\left(y_{i,t+k} - \alpha\, y_{j,t+k} \mid I_t\right) = 0 \qquad (2.55)$$

where α represents this proportionality. This means that y_i and y_j are cointegrated with the cointegration vector [1,-α]. Their results evidence weak convergence between fifteen OECD countries[6] during the period 1900-87.

In contrast with the cross-sectional approach which considers that the economies are in transition to the steady-state, this time-series approach assumes that economies have already transited to an invariant output process [Durlauf *et al.* (2009)]. Since the seminal work of Bernard and Durlauf (1995, 1996), it has been applied by many authors which Table 2.2 summarises.

Most studies focus on OECD countries GDP per capita convergence using annual data. The influence of time-series structural breaks on unit-roots tests has led to the development of techniques that allow trend-breaks. Although studies have applied different techniques, most of them found a break around the World War II and concluded that there is more evidence of convergence when the trend breaks are allowed, exogenously or endogenously, but the meaning of convergence becomes more unclear [Durlauf *et al.* (2009)].

Greasley and Oxley (1997), for example, applied Bernard and Durlauf (1996) approach to many OECD countries for the period 1900-87 and found bivariate convergence between Belgium and The Netherlands; France and Italy; Australia and United Kingdom. Evidence of convergence between Sweden and Denmark was only found after a time break in 1939 was considered, reflecting the Danish occupation and the neutrality of Sweden during the World War II.

Fractional integration has also started to be applied to test for convergence, like Cunado *et al.* (2006) study. According to this methodology, series might have roots between 0 and 1. If the root is smaller than one the series is mean reverting, this is, after a shock the variable exhibits a tendency to return to the average and consequently there is evidence of convergence.

[6] Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Norway, Sweden, UK , USA.

A stochastic version of the Solow model was developed by Pesaran (2007b) who proposed a pair-wise approach to testing output convergence across N economies based on a probabilistic definition of output convergence. Countries *i* and *j* converge, in this sense, "if for some finite positive constant C, and a tolerance probability measure $\pi \geq 0, \Pr\{|y_{i,t+s} - y_{j,t+s}| \langle C|\tau\rangle\} \pi$, at all horizons $s = 1,2,...,\infty$." In practical terms convergence test can be done by testing if the output gaps are stationary with a constant mean. This mean will be zero only if the economies are identical, namely in terms of population growth rate, saving rate and initial endowments. Within a multi-country setup, there will be multi-country convergence if there is pair-wise convergence across all country combinations. The results show no output but growth convergence, suggesting that besides the technological diffusion there are important country-specific factors that lead to the persistence of output gaps, and also some evidence of convergence clubs but one shall not forget that "club membership change over time".

Unit root tests with covariates were applied by Christopoulos and León-Ledesma (2008) to test output convergence of 14 OECD countries towards the USA during the last century (1900-2000). The results show that conditioning on the time varying covariates of the population growth rate increases the power of the unit root tests and evidence of convergence was found for 12 countries.

Table 2.2 – Time-series Approach Summary

Reference	Variable	Period	Dataset	Tests	Main conclusions
Carlino and Mills (1993)	Income pc	1929-90	USA regions	ADF Structural break in 1946 (exogenous)	Convergence towards USA average of 3 out of 8 regions when a trend break is allowed
Bernard and Durlauf (1995)	GDP pc	1900-87	15 OECD	ADF Philips-Ouliaris Johansen	Weak convergence
Greasley and Oxley (1997)	GDP pc	1900-87	OECD	ADF Structural break in 1939 (exogenous)	Bivariate convergence between Belgium-The Netherlands, France-Italy, Australia-UK, Sweden-Denmark
Loewy and Papell (1999)	Income pc		USA regions	Structural break (endogenous, additive *vs.* innovative outlier)	Convergence towards USA average of 7 out of 8 regions when a trend break is allowed
St. Aubyn (1999)	GDP pc	1890-89	16 industrialized countries	Kalman filter, ADF Structural break following World War II (exogenous)	Convergence towards USA when the trend break is allowed
Li and Papell (1999)	GDP pc	1900-89	16 industrialized countries	ADF Structural break (endogenous)	Deterministic convergence among 10 countries and stochastic convergence among 14
Tsionas (2000)	Total factor productivity	1960-97	EU15	Phillips-Perron, KPSS, Bayesian	Convergence towards the average depends on the test
Data (2003)	GDP pc	1950-98	15 OECD	Kalman filter Johansen Haldane and Hall (1991) time-varying approach	Convergence towards USA

Reference	Variable	Period	Dataset	Tests	Main conclusions
Beliu and Higgins (2004)	Industrial production	1957-2000 quarterly	EU15	Fractional cointegration	No convergence
Strazicich *et al.* (2004)	GDP pc	1870-1994	15 OECD	2 structural breaks in level and trend (endogenous) Minimum Lagrange multiplier (LM) unit root test	Convergence towards the average, stronger between the World Wars 1 or 2 breaks for each country, mostly around World Wars
Le Pen (2005)	GDP pc	1870-1994	France, Germany, Japan, UK, USA	Park and Hahn (1999) time-varying approach	Japan, France and Germany convergence towards USA
Carvalho and Harvey (2005)	GDP pc	1950-1997	Euro-zone except Luxembourg	Multivariate unobserved components model	Low power of ADF test with constant Convergence within the two possible convergence clubs
Cunado and Gracia (2006)	GDP pc	1950-2003	Some CEECs *vs.* USA and Germany	ADF and LM Structural breaks in early 70's and late 80's (endogenous)	Convergence during 1990-03: Poland, Czech Republic and Hungary towards Germany, Poland towards USA
Cunado *et al.* (2006)	GDP pc	1870-2001	14 OECD	Fractional cointegration Structural break at World War II (exogenous)	Convergence towards USA when a trend break is allowed
Yau and Hueng (2007)	GDP pc	1900-1987	15 OECD	Stochastic Unit Root	Convergence between USA-UK, USA-Sweden
Pesaran (2007b)	GDP pc	1950-2000	Penn World Tables 6.1	ADF, ADF-GLS, ADF-WS, KPSS	No output but growth convergence
Christopoulos and León-Ledesma (2008)	GDP pc	1900-2000	14 OECD countries	Unit root tests with covariates	Rejection of no convergence towards USA for 12 countries

2.3.4. Panel cointegration

This concept of *stochastic convergence* has been recently applied by panel data studies. Cointegration techniques and unit-root tests were applied within a panel framework by Evans and Karras (1996) and Fleissig and Strauss (2001) among others. The first tested for output per worker convergence among the 48 states of the USA. They analysed the three series that determined output per worker which are the level of technology level, share of output paid to capital owners and rental rate paid to capital. It was found that the level of technology was stationary around a common trend. The second used the same data as Bernard and Durlauf (1995) and applied three different panel-unit root tests: Abuaf and Jorion (1990), Im, Pesaran and Schin (1997) and also Madala and Wu (1998) tests. In all of them the null hypothesis is that countries do not converge stochastically to the panel average. In general, they show convergence among the fifteen OECD countries and within the European subsample not over the whole period but for the sub-period 1948-87. This means that, after 1948, country-specific economic shocks affect countries relative per capita income only temporarily. The rates of conditional convergence found are sensitive to the test applied but across all the methods the rates of convergence for European countries (5.8%-9.0%) are higher than for OECD (4.0%-8.1%). Convergence was interpreted as "country-specific economic shocks affect only temporarily countries relative per capita income". Costantini and Lupi (2005) also applied several panel unit root tests to check GDP per capita convergence in EU15 over the period 1950-2003 and found little evidence of convergence, only for the sub-period 1950-1976. Convergence is seen by these authors simple as "countries share a balanced growth path".

2.3.5. Distributional approach

Quah (1996a, 1996b) criticized the traditional convergence studies based on the cross-section approach and introduced a new approach whose focus is not how an economy performs towards its own steady-state, but how the whole cross-country income per capita distribution evolves. The concern is not with the speed of convergence but with the dynamics of the income distribution, which are studied by applying kernel density methods. The use of this alternative methodology is evidence that the world cross-section income distribution evolution tends to exhibit twin-peaks. Two twin-peaks is the polarization case, when the rich countries become richer, the poor ones become poorer and the middle-income countries tend to disappear. Quah (1997) focuses on the emerging twin-peaks and their properties and adds two new-stylized facts about cross-country growth regularities: "persistence" and "bi-modality" which are consistent with the convergence clubs hypothesis.

2.4. Human capital in growth empirics

At the empirical level, the Lucas and the Nelson-Phelps approaches of introducing human capital in the theoretical models imply testing two different hypotheses about what affects the output growth rate: changes *versus* levels of human capital, respectively. In contrast with micro-studies that usually find a positive impact of schooling on individual returns, the empirical results on the effect of human capital at the macroeconomic level are not consistent across the studies and are sensitive to the proxies, the specifications and the estimation methods.

2.4.1. Human capital proxies

Human capital concept is complex and only partially observable so finding a good proxy is a difficult mission. Schultz (1961) considered five categories of human capital (health, on-the-job training, formal education, study programs for adults and migration). Though it has been argued by many, most recently by Rogers (2008), that schooling is a necessary but not a sufficient condition to increase the level of human capital, formal education has been the main source of proxies for human capital due to data availability. A brief review of the most common proxies used in empirical literature[7] follows.

Education

Cross-country empirical studies have relied heavily on Barro and Lee (1993, 1996, 2001) datasets that contain several proxies based on education apart from the

[7] For an extended review of the human capital proxies see Wößmann (2003).

schooling enrolments, such as schooling attainment ratios and the average years of schooling. These datasets provide data on a five year basis for a large number of countries and have been updated and largely applied. They are based on survey/ census data reported by UNESCO and the missing observations are derived using the data on the enrolment rates. This methodology has been criticized on the basis that it leads to significant measurement errors and alternative datasets appeared. de la Fuente and Doménech (2006) improved the Barro and Lee dataset for 21 OECD countries, for the period 1960-1995, by taking other sources of data (OECD and national sources) and by eliminating sharp breaks. Cohen and Soto (2007) also developed their own proxy of schooling years for a large set of countries over the period 1960-2000 but, in contrast with the previous studies, data is provided at 10-years intervals. The quality of these series is improved by using surveys based on a uniform classification of the education systems and deep information on the age structure of the population. This new dataset suggests a correlation between the data quality and the sign and significance of the human capital in the growth regressions. Recently Barro and Lee (2010) updated their dataset for the period 1950-2010 and increased its accuracy by estimating both survival/ mortality rates by age and education group and completion ratios by age group.

Apart from the data quality, other criticisms of the education proxies have been developed and include the following arguments: a year of schooling has the same weight regardless the education level and field of study, the quality of schooling is not taken into consideration and education is not the only contribution to human capital levels, other issues, like training and health, should also be considered [Wößmann (2003)]. Therefore alternative human capital proxies have been proposed by the literature.

Education Quality

Hanushek and Kimko (2000) were the first to propose measures for labour-force quality based on international cognitive tests on mathematics and science achievement and concluded that it has a strong effect on growth. Other proxies for quality of schooling applied by empirical literature include educational inputs such as the students-teacher ratio and the education expenditure as a percentage of GDP.

Income

Mulligan and Sala-i-Martin (1997) proposed a labour-income human capital proxy in which the schooling levels of the population are adjusted by an efficiency parameter that depends on the wages relative to the zero-schooling worker. Pritchett (2001) took inspiration from microeconomic specification of earnings and created a measure of educational capital as “the discounted value of the wage premium due to education”. His results show an insignificant negative relationship between GDP per worker growth and educational capital growth. According to Pritchett (2001) “school enrolment rates are a terrible proxy for growth in years of schooling” (p. 380) because what matters to growth is not the current enrolment rate, but the difference between the enrolment rate of the labour force who is leaving and the rate of the labour force that is coming in.

Health

Fogel (1994) recognized the great importance of health improvements to long-run economic growth, in his words there are “thermodynamic and physiological factors in economic growth” that have been neglected but should be include in the growth models in the human capital context and taking into consideration the long time lags (sometimes a century) between the investment and the respective benefits. Health capital was added to the Mankiw *et al.* (1992) model by Knowles and Owen (1995) who chose life expectancy as the proxy. Their findings show that the cross-country relationship between income per capita and health capital is stronger and more robust in comparison with that between income per capita and educational capital. Bhargava and Tamison (2001) proxied health by both life expectancy and adult survival rates and found as well a positive impact of health on output growth in low-income countries.

Unproductive Education

Rogers (2008) argued that little empirical support of the impact of schooling on growth derives from the fact that the regressions do not include the productive use of schooling. Using data on corruption, black market premium on foreign exchange and brain drain as proxies for the inability of a country to use school productively, the author found that the impact of schooling is much higher in the sub-sample of countries with higher ability.

2.4.2. Main findings

Most part of the empirical literature on the effects of human capital on growth is constituted by either cross-section or panel data studies that include large samples of countries and proxy human capital by education. The specifications vary from an *ad hoc* growth regression, in which the inclusion of human capital is guided by informal theoretical considerations, to a structural convergence equation or an aggregate production function [de la Fuente and Ciccone (2003)].

Cross-section

Among the cross-section empirical studies, Barro (1991) was one of the first to demonstrate the importance of human capital to economic growth in a study involving 98 countries for the period 1960-86. Human capital was proxied by the school enrolment rates and his results show that growth rates depend highly on the initial amount of human capital when the fertility and investment rates are not controlled for. By adding these two variables, human capital looses significance which suggests that part of its effect on growth is indirect through a reduction in the fertility rate and an increase in investment. These results are confirmed by the two extra regressions that show the effect of human capital on the fertility (negative) and investment rate (positive). Barro subsequent studies, such as Barro and Sala-i-Martin (1995), use the average years of education of the working age population as a proxy for human capital and distinguish between male and female schooling. The results suggest that only male education have a positive effect on growth. In contrast with these *ad hoc* growth regressions, Mankiw *et al.* (1992) test their structural convergence equation and find a positive effect of human capital proxied by the percentage of working age population enrolled in secondary schooling on the GDP per worker growth rate.

Benhabib and Spiegel (1994) used the Cobb-Douglas aggregate production function specification and tested both the Lucas's and the Nelson-Phelps's hypotheses. Their results show that changes in human capital, proxied by the number of years of schooling from different studies [Kyriacou (1991) and Barro and Lee (1993)] and for different samples of countries, are not significant to explain income per capita growth. In contrast, there is a positive effect of the levels of human capital on the total factor productivity growth suggesting that "the role of human capital is indeed one of facilitating adoption of technology from abroad and creation of appropriate domestic technologies rather than entering on its own as a factor of production." [Benhabib and Spiegel (1994), pp. 160]. Benhabib and Spiegel (1994) results were contradicted by Temple (1999b), who used the least trimmed squares (LTS) estimator to replicate their results and found a positive correlation between increases in the average years of schooling and output growth, and Krueger and Lindahl (2001) who found a positive relationship between the change in education and economic growth when the measurement error in education is controlled for.

Pritchett (2001) also estimated the production function using his educational capital proxy and found no effect of human capital changes on the output per worker growth. Three possible reasons for the disappointing results concerning the effects of human capital at the macroeconomic level are pointed out: educational capital might have gone to unproductive activities; returns of education could have declined as a result of a supply excess of educated labour force and education quality could have been so bad that created no skills and human capital at all. This work was revisited by Temple (2001). Though alternative human capital specifications and estimators are applied, the results remain unclear: "the aggregate evidence on education and growth, for large sample of countries, continues to be clouded with uncertainty" [Temple (2001), pp. 916].

The direction of the causality in the relation between growth and human capital is also uncertain. Human capital affects growth but growth also interferes with the individual choices about schooling and consequently has an effect on human capital. Bils and Klenow (2000) modelled both channels and argued that the causality is stronger from growth to schooling than the other way round (which is weak); and also that an important part of the positive relation found by many empirical studies between schooling and growth might reflect omitted factors.

Benhabib and Spiegel (2005) also tested their model of technology diffusion for the period 1960-95 using a sample of 84 countries and the Barro and Lee (1993) average years of education. The results indicate a positive effect of the level of human capital on total factor productivity growth, which confirms its importance for innovation and technology diffusion, though the estimated critical level of human capital for the beginning of the period suggests the exclusion of 27 countries from the catching-up mechanism. Due to significant improvements in education levels across countries, in 1995 only four countries remained below the critical level.

Panel data

In contrast with the results obtained for cross-section by Mankiw *et al.* (1992), the panel estimations of their convergence equation led to some disappointing results. Islam (1995) used the fixed-effects estimator and found no significant effect on growth of human capital proxied by the average years of education [Barro and Lee (1993) dataset]. The GMM results of Caselli *et al.* (1996) for the convergence equation even suggest a negative effect of human capital proxied by the secondary school enrolment rate [also from Barro and Lee (1993)]. Quite the opposite, by applying the Pooled Mean Group estimator and annual data (1970-1998) Bassanini and Scarpetta (2001) found a positive effect of the average years of education on growth for the OECD countries.

The production function specification was used by de la Fuente and Doménech (2006) to test the performance of their average years of schooling data on growth regressions for a sample of 21 OECD countries. Their results suggest a positively significant effect of human capital growth on GDP per worker growth, in contrast with the insignificant coefficient obtained when the average years of education is taken from other datasets [Kyriacou (1991), Barro and Lee (1993, 1996, 2001)]. Cohen and Soto (2007) also estimated the production function for a large sample of countries and found a positive effect of their human capital proxy on the output per worker level.

2.5. Conclusion

Traditionally there have been two ways of including human capital in growth models. It can be considered an input in the production function, as Mankiw *et al.* (1992) augmented Solow model or the Lucas (1988) endogenous growth model. Alternatively human capital is introduced as a determinant of technological progress in line with the seminal work of Nelson and Phelps (1966) and subsequent endogenous growth models that focus on the role of human capital in the adoption of new technologies and/ or innovation [Benhabib and Spiegel (1994, 2005), Romer (1990)]. In empirical work these two approaches imply testing different hypotheses about what affects the output growth: changes *versus* levels of human capital stock. In contrast with micro-studies, at the macro level the impact of human capital on growth is ambiguous and not always in accordance with the theoretical predictions.

Empirical studies on growth have applied different methods which are usually linked with different definitions of convergence. Cross-section studies usually distinguish σ-convergence, when the dispersion of income per capita (or productivity) exhibits a decline, from β-convergence, when there is an inverse relationship between the initial level of income per capita (or productivity) and the respective growth rate. β-convergence might be absolute, when the economies converge to the same steady-state levels, or conditional, when the economies exhibit different steady-state parameters. Consequently in order to find an inverse relationship between the initial income per capita and its growth rate, it is necessary to add a number of additional variables to the regression. The Mankiw *et al.* (1992) conditional convergence equation was derived directly from the augmented Solow growth model and allows studying the effect of human capital on growth.

This chapter provided a summary of the main methods. Apart from the distribution approach all the others are applied across the thesis. It starts with a time series approach to assess the persistence of the income per capita differences between each Iberian country and the other EU15 members. When the focus shifts from the national to the regional level, the panel methods are applied to estimate the Mankiw *et al.* (1992) conditional β-convergence model and study the effect of human capital on income per capita growth.

Chapter 3
Convergence within the EU15:
A preliminary examination of aggregate data

3.1. Introduction

This chapter's main purpose is to assess if European integration is associated with a higher level of convergence in output per capita between each Iberian country and the other EU15 countries. The objective is to check if the income per capita differences are narrowing over time or not, that is, if Portugal and Spain show any signs of catching-up. The Iberian countries have benefited to a large extent from the EU regional policy (also called cohesion policy) whose main objective is the reduction of income disparities between countries and regions. Not only have Portugal and Spain been receiving (together with Greece and Ireland) the Cohesion Fund, which was created by the Maastricht Treaty in 1992 to help the poorer country members (GDP per capita below 90% of the EU average) to adjust towards the budget discipline required to adopt the common currency; but also their regions have been receiving the majority of the Structural Funds under the Objective 1 of the European Regional Policy (helping the regions whose GDP per capita remains below the 75% of the Union average).

Though the weight of the Structural Funds in the EU's budget has increased significantly over time, according to Bähr (2008) there was an increase from 6% in 1975 to 36% in 2007, its effect on growth and convergence is ambiguous. Some studies, like Beugelsdijk and Eijffinger (2005) and Kutan and Yigit (2007), concluded it was positive, others like Boldrin and Canova (2001) are pessimistic and conclude the funds have been ineffective. The effectiveness of the European Cohesion Policy depends on the countries' institutional quality and the effect of the funds on growth is positive if and only if, the countries have the "right" institutions [Ederveen *et al.* (2006)].

This chapter applies a time-series approach to analyse pair-wise convergence between each Iberian country and the other members of EU15 and some cases of group convergence such as among the "Cohesion" countries. The structure is the following: Section 3.2. introduces the formal definitions of convergence and Section 3.3. describes the data. In Section 3.4. is presented the methodology and Section 3.5. concludes.

3.2. Definitions of convergence

As discussed in Chapter 2, the time-series approach is quite flexible and allows us to test different kinds and degrees of convergence. In Bernard and Durlauf (1996) seminal work the following definitions of convergence are proposed:

(1) Catching-up (tendency of output per capita differences to narrow over time) *versus* equality of the long-run forecasts, in formal terms equation (3.1) and (3.2) respectively:

$$E(y_{i,t+T} - y_{j,t+T} \mid I_t) < y_{i,t} - y_{j,t} \tag{3.1}$$

$$\lim_{k \to \infty} E\left(y_{i,t+k} - y_{j,t+k} \mid I_t\right) = 0 \tag{3.2}$$

where y_i and y_j are the income per capita logarithms of country *i* and *j* respectively, *k* is the period of time and I_t is the information available at the moment *t*. Definition 2 implies definition 1, but not the reverse.

(2) Strong *versus* weak convergence: definition 3.2 is also classified as strong convergence and it implies that y_i and y_j are cointegrated with the cointegrating vector [1,-1]. It is also possible that the two countries income per capita predicted values are not the same but there is a common trend between them and this is the concept of weak convergence:

$$\lim_{k \to \infty} E\left(y_{i,t+k} - \alpha\, y_{j,t+k} \mid I_t\right) = 0 \tag{3.3}$$

where α represents the proportionality between the income per capita predicted values and it means that y_i and y_j are cointegrated with the cointegrating vector [1,-α].

(3) Convergence between pairs of economies *versus* group convergence

The above definitions were extended to a multi-country setup. There is strong convergence among countries p=1,…,n if in the long-run their predicted income per capita is equal. In formal terms this means:

$$\lim_{k \to \infty} E\left(y_{1,t+k} - y_{j,t+k} \mid I_t\right) = 0, \forall p \neq 1 \qquad (3.4)$$

All the pairs of countries' GDP per capita convergence implies convergence within the group. Weak convergence means that countries p=1,…n contain a single common trend and this happens if their long-term predicted output levels are proportional at a fixed time t:

$$\lim_{k \to \infty} E\left(y_{1,t+k} - \alpha'_p \, \bar{y}_{j,t+k} \mid I_t\right) = 0 \qquad (3.5)$$

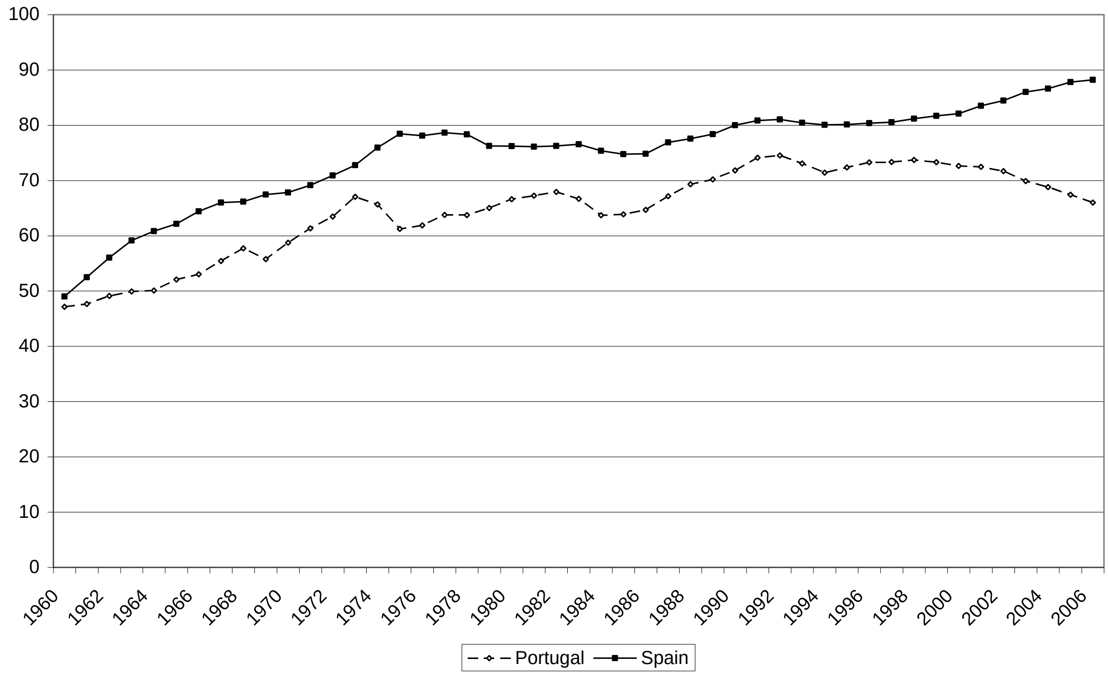
where $\bar{y}_t = \left\lfloor y_{2,t} y_{3,t} \ldots y_{p,t} \right\rfloor$.

3.3. Data

The data for the EU15 countries GDP per capita was taken from the Groningen Growth and Development Centre and the Conference Board (GGDC), Total Economy Database, January 2007, http://www.ggdc.net. The period considered is 1960-2006. German GDP per capita data includes West and East Germany together. The total number of observations is 47 years. The series are GDP per capita in 1990 USD, converted at Geary Khamis Purchasing Power Parity (PPP)[8]. Figure 3.1 plots the Iberian countries GDP per capita as a percentage of the EU15 average.

[8] The Geary-Khamis method applied to compute the PPPs involves estimating simultaneously the international prices for each commodity *c* and the PPP for each country *j* from a system of inter-dependent linear equations which are, respectively:

Figure 3.1 – GDP per capita as percentage of the EU15 average



As seen above, the living standards of both Portugal and Spain were around half the European average in the beginning of the period and though a substantial improvement their backward position still remains. Spain started the period with a slightly higher income per capita than Portugal but the gap between the two countries has increased over time, especially since the late 1990s when Portugal started diverging from the EU average. During the first decade of the new century Spain has continued the catching-up process with the EU average while in Portugal the reverse has happened. The reasons for the Portuguese economic stagnation since the late 1990s are related to the decline in the productivity growth, which is due to a relatively low rate of human capital accumulation and possible diminishing returns in physical capital accumulation, and the difficult adjustment to the Euro [Pereira and Lains (2010)]. The fact that the wages growth rate was above the productivity growth contributed to decrease the exports competitiveness in the international markets and therefore to increase the current account deficit. Though in Spain there was also a

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$P_c = \frac{\sum_j (p_{cj} q_{cj}) / PPP_j}{\sum_j q_{cj}}$ and $PPP_j = \frac{\sum_c p_{cj} q_{cj}}{\sum_c P_c q_{cj}}$, in which p stands for price and q for quantity. For more details see the International Comparison Programme of the United Nations Statistics Division: http://unstats.un.org/unsd/methods/icp/ipco_htm.htm.

stagnation of productivity in the beginning of the new century, the competitiveness losses were less striking due to the moderate wage growth. The superior Spanish economic performance in this more recent period is also explained by a significant increase of the participation and employment rates which compensated the decline in the productivity growth [Martinez-Mongay (2008)].

3.4. Methodology and Results

3.4.1. Pair-wise convergence

According to the definition (3.2) convergence between the countries *i* and *j* is accepted if $(y_i - y_j)$ is stationary with a zero mean. In practical terms convergence can be tested by checking the presence of a unit root in the series $(y_i - y_j)$, performing the test with no constant and no trend. Failure to reject the null of a unit root means no convergence. Since this zero mean convergence is a very strict definition, other possibilities have been proposed by the literature. In the absence of convergence according to definition (3.2), there might be either deterministic or stochastic convergence [Li and Papell (1999)]. Deterministic convergence is accepted when $(y_i - y_j)$ is stationary but around a constant different from zero. In this case there is growth convergence. On the other hand, stochastic convergence is accepted when $(y_i - y_j)$ is trend stationary, which allows permanent per capita income differences, and therefore there is no time series convergence. The tests for deterministic convergence include a constant, while the tests for stochastic convergence include both a constant and a time trend. As long as the growth rate differentials are stationary, both deterministic and stochastic convergence processes are consistent with β-convergence [Christopoulos and León-Ledesma (forthcoming)]. Though the criticisms that stochastic convergence is a very weak version of convergence, the concept is useful in the sense that indicates catching-up [Oxley and Greasley (1995)].

In order to have a general idea of the situation of the Iberian countries relative to the others, this approach was applied to all pairs of countries within EU15 GDP per capita gap. When the number of countries is n there are $n(n-1)/2$ possible pairs which means 105 pairs of EU15 countries. Each country output gap towards the EU15 average was also analyzed. Stationarity was tested according to the most common unit root tests, Augmented Dickey-Fuller (1981), Phillips-Perron (1988), and also the Kwiatkowski-Phillips-Schmidt-Shin (1992) test for which the null hypothesis is that the series is stationary. From now on the notation will be ADF, PP and KPSS respectively. For the first two tests, the rejection of the null means GDP per capita convergence between the two countries. In reverse, when the KPSS test is applied the non-rejection of the null indicates convergence.

One of the main problems when unit root tests are applied to detect convergence is the possibility of structural breaks in the time series. In order to solve this problem unit root tests with structural breaks have been widely applied by the literature [Carlino and Mills (1993, 1996), Oxley and Greasley (1995), Greasley and Oxley (1997, 1998), Loewy and Papell (1999), Strazicich and Day (2004)]. The Zivot and Andrews (1992) test (ZA) which endogenously determines the time break is also applied to all pairs of countries. It tests the null of a unit root against the alternative that the series is stationary with one break.

All the tests were run with both a constant and trend[9] which is associated with the weakest notion of convergence. Rejecting the presence of a unit root in this case indicates catching-up instead of long-run convergence [Oxley and Greasley (1995)]. For the ADF test, the number of lags used was chosen according to the Schwarz criteria (SIC). The SIC was followed instead of the Akaike information criteria (AIC) because the later tends to include a higher number of lags which reduces the power of the test to reject the null of a unit root. Both PP and KPSS were performed using the Bartlett kernel estimation method and the Newey-West bandwidth. All the tests were performed using EViews 6.0. The ZA test was performed using Stata 9.0 and both a break in the intercept and in the trend was allowed. The number of lags was chosen as well according to SIC. All the tests results are reported in Appendix at the end of the chapter. Table 3.1 summarizes the cases when some evidence of stochastic

[9] The inclusion of the trend reduces the power of the test but, as Cheung and Pascual (2004) pointed out, if it is not included and the series is stationary around a time trend the test will not be consistent.

convergence was found. The first row shows the results of each country's output gap relative to the benchmark, the EU15 average, but in all the other rows pair-wise results are reported. In the case of ZA test the time-break appears in brackets.

The results vary according to the test applied. The test that considers stationarity as the null hypothesis, KPSS, found a significantly higher number of pair-wise convergence, 39 out of 105. In contrast, the ADF and PP only rejected the null of a unit root in 6 and 9 cases respectively, providing very little evidence of convergence. When a structural break was allowed in the unit root test (ZA), the null was rejected more often, 13 out of 105. Finland was the country for which the results change more according to the type of unit root test applied. When the test with a structural break was performed most Finland's pairs evidenced convergence and this country also converged towards the EU average. In this country's case the ZA test identified 1991 as the time-break which is associated with the Gulf War and the German reunification. Towards the EU15 average there were signs of convergence in the case of Denmark, Finland, Netherlands, Spain and Sweden. In contrast with the others, Finland's evidence of convergence is given by both a unit root (ZA) and a stationary test (KPSS).

A limitation of this analysis is that apparently there is no transitivity of the results. There is evidence that country A (Italy) is catching-up with country B (Finland) which is catching-up with country C (Denmark), however there is no evidence that country A (Italy) is catching-up with country C (Denmark). This might be due to the limitations of this approach. It is known in the literature that the unit root tests have several problems, such as low power in finite small samples, tendency to reject convergence in the presence of structural breaks [Durlauf *et al.* (2005)], low power against the alternative of a root close to one [Cunado *et al.* (2006)] and also in the presence of a non-linear process [Christopoulos and Tsionas (2007)]. Even the Zivot-Andrews test, which controls for structural breaks, has been criticized since it tends to select the break when the size distortions are larger in the presence of a unit root [Strazicich *et al.* (2004)].

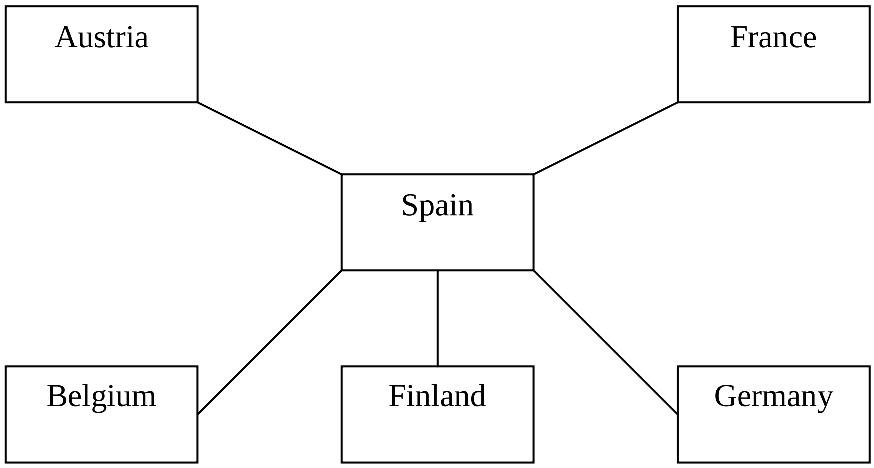
Focus on the results obtained for the Iberian countries, there is more evidence of catching-up for Spain than for Portugal. The PP test suggests that Spain is catching-up with the EU15 average in contrast with Portugal for which all the tests reject this hypothesis. In what concerns pair-wise evidence, the findings suggest that Spain is catching-up with other 11 countries (Austria, Belgium, Finland, France, Germany, Greece, Italy, Luxembourg, Netherlands, Portugal and UK), though the bivariate test confirmed by the rejection of the null of a unit root by at least one test and the failure to reject the null of stationarity by the KPSS test only occurs for the pairs Spain-Austria, Spain-Belgium, Spain-Finland, Spain-France and Spain-Germany. The ZA test identifies a break for the pair Spain-Austria in 1979 which corresponds to the second oil crisis. For Portugal the KPSS gives some evidence of catching-up with Austria, Belgium, Finland, France, Germany, Greece and Italy, though this not confirmed by any unit root test.

Table 3.1 – Pair-wise stochastic convergence

	AT	BE	DK	FI	FR	DE	GR	IE	IT	LU	NL	PT	ES	SE	UK
EU15			KPSS	KPSS ZA (1991)							KPSS		PP	KPSS	
AT	-	PP KPSS ZA (1983)		KPSS ZA (1991)	KPSS	KPSS	KPSS		KPSS			KPSS	ADF PP KPSS ZA (1979)		
BE		-		KPSS ZA (1991)	KPSS	KPSS			KPSS			KPSS	ADF PP KPSS		
DK			-	KPSS ZA (1991)							KPSS ZA (1982)			KPSS	
FI				-	KPSS ZA (1991)	KPSS ZA (1991)			KPSS ZA (1991)		KPSS ZA (1991)	KPSS	ADF KPSS	ZA (1991)	
FR					-	KPSS			KPSS			KPSS	PP KPSS		
DE						-			ADF PP	ZA (1975)		KPSS	PP KPSS	KPSS	
GR							-		ADF KPSS			KPSS	KPSS		
IE								-		KPSS					
IT									-			KPSS	KPSS		
LU										-			ADF PP		
NL											-			KPSS	
PT												-	KPSS		
ES													-		PP
SE														-	
UK															-

Figure 3.2 summarizes the cases for which evidence of the Iberian countries pair-wise stochastic convergence is suggested by at least one of the unit root tests and the stationarity test simultaneously, suggesting catching-up. Portugal is not included because the convergence hypothesis is rejected by all the unit root tests (ADF, PP and ZA).

Figure 3.2 – Bivariate convergence of Spain



The strong or weak notions of convergence imply the two series to be cointegrated with a (1,-1) or (1,-α) cointegrating vector respectively. Cointegration can be tested through the Johansen tests [Johansen (1988, 1991)] which permits the identification of the cointegrating vector. In general terms, n countries converge if there are $(n-1)$ cointegrating vectors which means the countries share a common long-run trend. The basic model to apply Johansen cointegration tests is the vector autoregression model (VAR) of the output per capita of all the countries (Y_t):

$$Y_t = \beta_1 Y_{t-1} + \beta_2 Y_{t-2} + ... + \beta_k Y_{t-k} + u_t \qquad (3.6)$$

where Y_t is an ($n \times 1$) vector and β_i is an $(n \times n)$ parametric matrix. It can be written as a vector error correction model (VECM):

$$\Delta Y_t = \Gamma_1 \Delta Y_{t-1} + ... + \Gamma_{k-1} \Delta Y_{t-(k-1)} + \Pi Y_{t-1} + u_t \tag{3.7}$$

where $\Gamma_i = -(I - \beta_1 - ... - \beta_i)$, $i = 1,2,...k-1$, and $\Pi = -(I - \beta_1 - \beta_2 - ... - \beta_k)$. Γ_i and Π are the short and long-run coefficients matrixes respectively. The number of cointegrating vectors (r) is the rank of Π and two tests were developed by Johansen (1988, 1991) to test it:

1) The trace statistic, which tests the null that the rank of Π is $r \leq r_0$ against the alternative that is $r \geq r_0 + 1$.
2) The maximum eigenvalue, which tests the same null against the alternative $r = r_0 + 1$.

The number of common trends is ($n - r$). If the rank of Π is zero it means that the long-run output per capita across the n countries are driven by n stochastic trends and consequently they are not related at all.

Table 3.2 shows the results of the Johansen cointegration tests in order to confirm convergence of Spain towards the countries identified in Figure 3.2 and also the EU15 average. The number of lags included in the VAR was chosen according to Schwarz Criterion. The test was performed using Eviews 6.0 for the unrestricted intercept and no linear trend case.[10]

Table 3.2 – Johansen cointegration test for Spanish bivariate convergence

Trace test								
Cointegrating	Test statistics						Critical Values (5%)	
Vectors	EU15	Austria	Belgium	Finland	France	Germany	EViews 6.0	MHS
0	8.18	19.51*	12.30	13.72	13.24	10.47	15.41	18.11
At most 1	3.15	1.96	1.59	1.73	1.31	2.31	3.76	8.19
Maximum eigenvalue test								
Cointegrating	Test statistics						Critical Values (5%)	
Vectors	EU15	Austria	Belgium	Finland	France	Germany	EViews 6.0	MHS
0	5.04	17.55*	10.72	11.99	11.93	8.16	14.07	15.02
At most 1	3.14	1.96	1.59	1.73	1.31	2.31	3.76	8.19

* indicates significant at 5% level, MHM are estimates of 5% critical value taken from MacKinnon, Haug and Michelis (1999) for the Pesaran, Shin and Smith (2000) Case III.

[10] The unrestricted intercept and no linear trend case in EViews is equivalent to the Pesaran, Shin and Smith (2000) Case III [Turner (2009)].

The critical values applied in EViews might be inappropriate and lead too often to the rejection of the null of no cointegration due to an incorrect specification of the deterministic terms included in the VECM [Turner (2009)]. Following Turner's (2009) recommendation, the MacKinnon *et al.* (1999) estimates (MHM) of the Pesaran, Shin and Smith (2000) classification critical values are also used to check if the significance of the test statistics is sensitive to the critical values applied. As seen, regardless which critical value is used, both the trace and the maximum eigenvalue tests indicate no cointegration at 5% level of significance for all the cases except Austria.

For the pair Spain-Austria there is evidence of one cointegrating vector which is (1,-0.75). The estimated $\alpha = -0.75$ has the expected sign and is significant at 1% level. Since it is different from 1 suggests only weak convergence. Spain shares a common trend with Austria but there is no prediction of GDP per capita equalization in the long-run. Convergence of Spain towards the EU15 average is not confirmed since both the trace and the maximum eigenvalue tests show no cointegration. This suggests that like Portugal, Spain is not strictly converging to the core EU economies and the Austrian result is likely to be spurious.

3.4.2. Multivariate convergence

The results of the previous subsection show very little evidence of catching-up of the Iberian countries with the other EU15 members. This section applies the Johansen cointegration tests to groups of countries within the EU15. If the n countries that integrate the group converge, there will be $(n-1)$ cointegrating vectors, and the countries share a common long-run trend. The Johansen tests are one of the most common procedures to detect the existence of cointegrating vectors among the output per capita series in a multi-country setup. The sub-samples of EU 15 countries considered here are following:

1) The original members of the EU, EU6, these are Belgium, France, Germany, Italy, Luxembourg and Netherlands.

2) The oldest members of EU, EU9, these are the EU6 countries plus Denmark, Ireland and UK.
3) The members of Euro zone since its creation: Austria, Belgium, Finland, France, Germany, Ireland, Italy, Luxembourg, Netherlands, Portugal and Spain.[11] All of these countries were able to meet the nominal convergence criteria in order to become members of the European Monetary Union (EMU) in 1999.
4) The Cohesion group: Portugal, Spain, Greece and Ireland.

Portugal and Spain integrate both the European Monetary Union and the Cohesion group but it is interesting to compare the group results.

1) EU6 convergence

Table 3.3 reports the results concerning the countries that have been members of the EU since the beginning, this is 1956. Since they constitute a very homogeneous group, a higher degree of convergence was expected within this subsample of countries but the results obtained do not confirm it.

Table 3.3 – Johansen cointegration test for the EU6 convergence

	Trace test			Maximum eigenvalue test		
Cointegrating		Critical Values (5%)			Critical Values (5%)	
Vectors	Statistics	EViews 6.0	MHS	Statistics	EViews 6.0	MHM
0	139.17*	94.15	97.26	76.67*	39.37	40.19
At most 1	62.50	68.52	71.44	28.00	33.46	34.03
At most 2	34.50	47.21	49.64	15.55	27.07	27.80
At most 3	18.95	29.68	31.88	10.59	20.97	21.49
At most 4	8.36	15.41	18.11	8.34	14.07	15.02
At most 5	0.02	3.76	8.19	0.02	3.76	8.19

* indicate significant at 5% level, No. of lags in the underlying VAR (k) = 1, MHM are estimates of 5% critical value taken from MacKinnon, Haug and Michelis (1999) for the Pesaran, Shin and Smith (2000) Case III.

As seen, only one cointegrating relationship was found according to the trace and maximum eigenvalue tests and the results are not sensitive to the critical value

[11] These are the countries that joined the EMU in 1999, Greece joined only three years later (2002).

chosen. This suggests that the long-run output per capita of these countries is very little related with a very high number of trends driving the respective series.

2) EU9 convergence

Table 3.4 reports the Johansen test results obtained for the EU9. Again a relatively small number of cointegrating vectors is identified, only three according to both the trace and the maximum eigenvalue tests and regardless which critical value is used. The high number of trends driving the output per capita series of this group of countries indicates very little evidence of convergence.

Table 3.4 – Johansen cointegration test for the EU9 convergence

	Trace test			Maximum eigenvalue test		
Cointegrating		Critical Values (5%)			Critical Values (5%)	
Vectors	Statistics	EViews 6.0	MHS	Statistics	EViews 6.0	MHM
0	306.85*	192.89	198.72	100.39*	57.12	58.51
At most 1	206.46*	156.00	160.87	68.72*	51.42	52.41
At most 2	137.74*	124.24	127.05	47.83*	45.28	46.31
At most 3	89.91	94.15	97.26	32.81	39.37	40.19
At most 4	57.11	68.52	71.44	20.79	33.46	34.03
At most 5	36.32	47.21	49.64	13.96	27.07	27.80
At most 6	22.36	29.68	31.88	12.31	20.97	21.49
At most 7	10.04	15.41	18.11	9.87	14.07	15.02
At most 8	0.18	3.76	8.19	0.18	3.76	8.19

* indicate significant at 5% level, No. of lags in the underlying VAR (k) = 2, MHM are estimates of 5% critical value taken from MacKinnon, Haug and Michelis (1999) for the Pesaran, Shin and Smith (2000) Case III.

3) EMU

As seen in Table 3.5 among the Euro zone members it was possible to find a higher number of cointegration vectors, seven and four according to the trace and maximum eigenvalue tests and for both critical values used, which might reveal a higher degree of convergence within the monetary union group. These results are consistent with the pair-wise convergence cases which are mostly between countries that integrate EMU. These countries were able to achieve the nominal convergence criteria in order to adopt the common currency and this might be a factor of economic convergence in the long-run.

Table 3.5 – Johansen cointegration test for the EMU convergence

	Trace test			Maximum eigenvalue test		
Cointegrating		Critical Values (5%)			Critical Values (5%)	
Vectors	Statistics	EViews 6.0	MHS	Statistics	EViews 6.0	MHM
0	514.45*	277.71	286.39	131.48*	68.83	70.59
At most 1	382.97*	233.13	240.58	89.90*	62.81	64.56
At most 2	293.07*	192.89	198.72	81.94*	57.12	58.51
At most 3	211.13*	156.00	160.87	52.32*	51.42	52.41
At most 4	158.81*	124.24	127.05	42.91	45.28	46.31
At most 5	115.89*	94.15	97.26	39.07	39.37	40.19
At most 6	76.82*	68.52	71.44	31.17	33.46	34.03
At most 7	45.66	47.21	49.64	21.47	27.07	27.80
At most 8	24.18	29.68	31.88	14.74	20.97	21.49
At most 9	9.44	15.41	18.11	8.90	14.07	15.02
At most 10	0.54	3.76	8.19	0.54	3.76	8.19

* indicate significant at 5% level, No. of lags in the underlying VAR (k) = 2, MHM are estimates of 5% critical value taken from MacKinnon, Haug and Michelis (1999) for the Pesaran, Shin and Smith (2000) Case III.

4) Cohesion countries

Among the four EU15 cohesion countries, three cointegration vectors were found as seen in Table 3.6 This indicates a common trend among Portugal, Spain, Greece and Ireland which in a way is expected since they share common features, specially the fact that all of them have been receiving structural help from EU in order to catch-up with the richest members.

Table 3.6 – Johansen cointegration test for the Cohesion countries convergence

	Trace test			Maximum eigenvalue test		
Cointegrating		Critical Values (5%)			Critical Values (5%)	
Vectors	Statistics	EViews 6.0	MHS	Statistics	EViews 6.0	MHM
0	109.17*	47.86	49.64	68.11*	27.58	27.80
At most 1	41.05*	29.80	31.88	22.08*	21.13	21.49
At most 2	18.97*	15.50	18.11	17.44*	14.26	15.02
At most 3	1.53	3.84	8.19	1.53	3.84	8.19

* indicate significant at 5% level, No. of lags in the underlying VAR (k) = 2, MHM are estimates of 5% critical value taken from MacKinnon, Haug and Michelis (1999) for the Pesaran, Shin and Smith (2000) Case III.

In general, this methodology gives little support to the group convergence hypothesis. Some common trends were identified but this does not seem enough to be very optimistic about the positive effects of economic integration on the convergence process. The group of countries that exhibit a higher number of cointegrating relations is the EMU. As it was mentioned before these time-series methods are not appropriate when countries are still converging and have not yet achieved the steady-state. If convergence is still a going on process other methodologies should be applied instead, like the time-varying parameter (TVP) model which is considered in the next subsection.

3.4.3. Time-varying convergence

The time-varying parameter (TVP) model is the best approach to apply when convergence is still an on-going process [Hall *et al.* (1992)] and it has been largely applied to study cross-country convergence of variables such as exchange rates and interest rates, but not income per capita. Following Hall *et al.* (1992), in a set of three countries, *i*, *j* and *k* (Germany, United Kingdom and US in their example), there will be convergence between countries *i* and *j* if the differential between the series X_i and X_j is not affected by the differential between X_i and X_k. The following equation translates the definition:

$$\lfloor X_i - X_j \rfloor(t) = a(t) + b(t)[X_i - X_k](t) + e(t) \tag{3.8}$$

where *a* and *b* are the time-varying parameters and e_t is the independently and identically distributed (i.i.d) error term with zero mean and constant variance (σ_e^2). X_i will converge to X_j if *b* is expected to be zero. Alternatively there will be convergence between X_i and X_k if *b* is expected to be one. According to this approach the requirements for convergence are that the time-varying coefficients *a* and *b* tend, respectively, to a constant and zero. As the convergence process approaches the completion the time-varying parameter *b* tends to zero. Babetskii *et al.* (2004) consider convergence as weak when *a* tends to a constant not close to zero and *b* tends to zero, divergence when *a* tends to a constant and *b* tends to 1 and the process unclear when there is an erratic pattern for either *a* or *b*.

The time-varying parameter model (TVM) is a particular case within the state-space models group and it is characterized by two kinds of equations: the measurement or signal equation and the state or transition equation. Equation (3.8) is the measurement equation and defines the convergence process between country *i*, *j* and *k*. The transition equations describe the dynamics of the time-varying parameters over time and might be a first-order autoregressive model like the following:

$$a_t = a_{t-1} + \eta_t \tag{3.9}$$

$$b_t = b_{t-1} + v_t \tag{3.10}$$

where η_t and v_t are the random error terms with zero mean and variance σ_η^2 and σ_v^2, respectively. The time-varying parameters are estimated using the Kalman filter technique which is a recursive method. It is an iterative process of prediction and updating: for each moment *t*, the estimation of the parameter takes into account all the information up to time *t*.

In contrast with the previous methods, which may reject the convergence hypothesis due to transitional dynamics [Bernard and Durlauf (1996)], this TVM approach allows a check for convergence when it is still an on-going process and also allows identify the periods of catching-up or not.

The TVM was applied to check for convergence between each Iberian country and the EU15 average. The USA was chosen as country *k*, so for each Iberian country *i*, the signal equation is the following:

$$[GDPpc_i - GDPpc_{EU}](t) = a(t) + b(t)[GDPpc_i - GDPpc_{US}](t) + e(t) \tag{3.11}$$

When Portugal or Spain is converging towards the EU average the respective GDP per capita evolution is explained by the European Union behaviour and *b* tends to zero. When it is diverging from EU, the rest of world, namely the USA, becomes more important to explain that country dynamics and *b* tends to one. The results obtained are reported in the next figures.

Figure 3.3 – Estimated coefficients a(t)

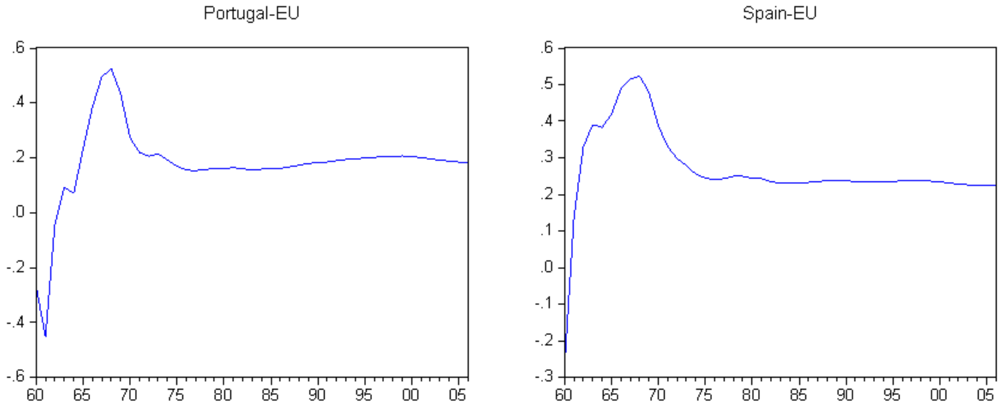
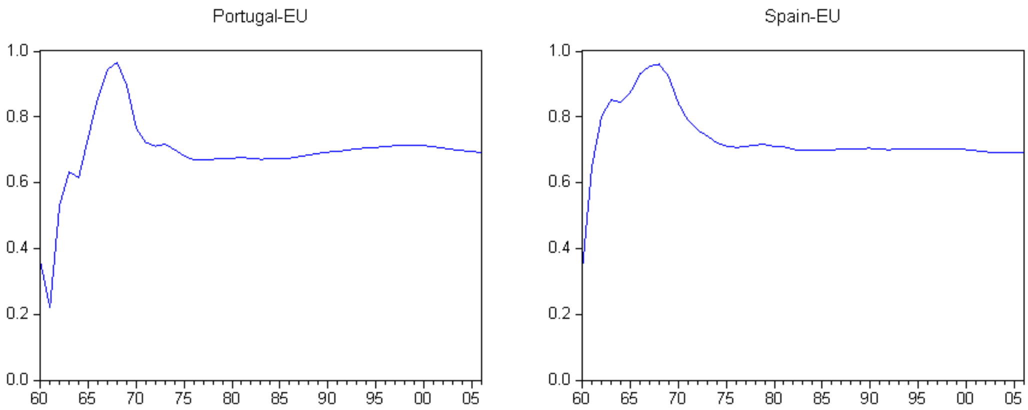


Figure 3.4 – Estimated coefficients b(t)



In both Iberian countries *a(t)* seems to tend to a constant different from zero and the performed ADF test confirms its stationarity. If *b(t)* tends to zero, these countries are converging towards the EU average. In reverse, if it tends to 1 they are diverging from the EU and converging towards the US. None of the countries shows a tendency to converge towards the EU average since *b(t)* does not become closer to zero over time. Both in Portugal and Spain there was a decline until the middle of the 1970 which shows some convergence in the beginning of the period but since then the evolution has been very modest.

3.4.4. Panel unit root tests

This approach is appropriate when the number of economies is large and it improves the power of unit root tests. Following the convergence definition of Evan and Karras (1996), *n* economies will converge if, and if only, their GDP per capita approaches the mean:

$$\lim_{T\to\infty} E_t(y_{i,t+T} - \bar{y}_{t+T} \mid I_t) = \mu_i \quad i = 1,2,...n \tag{3.12}$$

This is, if, and if only, every $y_{i,t}$ is non-stationary and $(y_{i,t} - \bar{y}_t)$ is stationary. In reverse, the economies diverge if, and only if, every $(y_{i,t} - \bar{y}_t)$ is non-stationary for all *i*. According to their definition convergence might be absolute or conditional, depending on $\mu_i = 0$ for all *i* or $\mu_i \neq 0$ for some *i*. They applied the earlier version of Levin and Lin panel unit root test and found conditional convergence among 48 US states and 54 countries.

In order to check for global convergence among the EU15 countries and the subsamples considered in subsection 3.4.2., some of the panel unit root tests were applied. The Levin, Lin and Chu (2002), Im-Pesaran-Shin (2003) and Maddala and Wu (1999) tests assume that the individual series are cross-sectional independent. Since the probability of cross-sectional dependence among this set of countries is high, the Pesaran's CADF (2007) test which assumes cross-sectional dependence is also applied. A brief explanation of them follows.

1) Levin, Lin and Chu (LLC)

This test is an extension of the ADF:

$$\Delta(y_{i,t} - \bar{y}_t) = \delta_i + \rho(y_{i,t-1} - \bar{y}_{t-1}) + \sum_{k=1}^{p} \varphi_{i,k} \Delta(y_{i,t-k} - \bar{y}_{t-k}) + u_{it} \tag{3.13}$$

where δ_i and $\varphi_{i,k}$ are parameters. It tests the null of ρ =0 against the alternative ρ <0, which means that all the series have a unit root against the alternative that all are stationary. Economies converge under the alternative hypothesis. The main drawback of this test is the assumption of ρ to be homogeneous across all the members of the panel. It was demonstrated that the normal distribution is a very good approximation to the test statistic distribution in a sample of at least T=25 and N=10, which is the case for EU15 and EMU.

2) Im-Pesaran-Shin (IPS)

This test improves the previous one by allowing individual unit root processes, this is ρ varies across countries.

$$\Delta(y_{i,t} - \bar{y}_t) = \delta_i + \rho_i(y_{i,t-1} - \bar{y}_{t-1}) + \sum_{k=1}^{p} \varphi_{i,k} \Delta(y_{i,t-k} - \bar{y}_{t-k}) + u_{it} \tag{3.14}$$

It tests $\rho_i = 0$ for all *i* against the alternative $\rho_i < 0$ for at least one *i*, which means it takes a unit root in all cross units as the null hypothesis against the alternative that at least one of the series is stationary. The IPS test statistic is the average of the individual ADF t-statistics for testing $\rho_i = 0$ and it also follows a standard normal distribution in large samples.

3) Maddala and Wu (Fisher ADF and Fisher PP)

As IPS test, it also allows ρ heterogeneity across units and takes the unit root in all cross units as the null hypothesis against the alternative that at least one of the series does not have a unit root. The main difference is the fact that it uses the *p*-values from the individual ADF (or PP) tests to compute the test statistic instead of ADF (or PP) statistics themselves. It is considered to perform better than IPS when there is a mix of both stationary and non-stationary series.

4) Pesaran's CADF

This test considers the mean of individual ADF statistics for each member of the panel. It takes the unit root of all the series as the null hypothesis, against the alternative that some cross-section series are stationary. In order to eliminate the cross-dependence, the cross section averages of lagged levels and first-differences of the individual series are included in the ADF regression. Since T is fixed (37 observations), the test is applied to the deviations of the variable from the initial cross-section mean in order to guarantee that the CADF statistics do not depend on the nuisance parameters [Pesaran (2007a)].

The Hadri test, which is the panel version of KPSS, was also applied. It assumes cross-section independence and takes the absence of a unit root in any of the series as the null hypothesis.

Table 3.7 reports the results for the tests that assume cross-section independence. An individual constant and trend terms were included and the number of lags was chosen according to Schwarz criteria (SIC). As shown, all the unit root tests fail to reject the null at the conventional levels and simultaneously the Hadri test rejects the stationarity hypothesis. This result implies no stochastic convergence towards the EU average for all the 15 countries and it is consistent with the previous results.

Table 3.7 – Panel unit root tests: cross-sectional independence

	LLC	IPS	Fisher ADF		Fisher PP		Hadri
			Chi-square	Choi-Z	Chi-square	Choi-Z	
Statistic	-0.64	1.89	20.52	1.93	24.78	2.26	11.92
p-value	0.26	0.97	0.90	0.97	0.74	0.99	0.00

Table 3.8 displays the results for the CADF test, which is the only one that assumes cross-section dependence, and confirms the non convergence hypothesis towards the EU15 average at the conventional levels of significance.

Table 3.8 – CADF test

	Number of lags		
	k=1	k=2	k=3
Statistic – Z[t-bar]	0.11	0.62	0.09
p-value	0.54	0.73	0.54

The same tests were applied to the subsamples of countries that were considered before in subsection 3.4.2., these are the EU6, EU9, EMU and the Cohesion group.

1) EU6 convergence

Table 3.9 and 3.10 confirm the lack of convergence among the EU6 evidenced before by the Johansen test which found a small number of cointegration vectors in this group. All the panel unit root tests fail to find any evidence of convergence.

Table 3.9 – Panel unit root tests: cross-sectional independence

	LLC	IPS	Fisher ADF		Fisher PP		Hadri
			Chi-square	Choi-Z	Chi-square	Choi-Z	
Statistic	-1.25	1.30	4.93	1.35	7.67	0.70	8.30
p-value	0.11	0.90	0.96	0.91	0.81	0.76	0.00

Table 3.10 – CADF test

	Number of lags		
	k=1	k=2	k=3
Statistic – Z[t-bar]	0.91	1.25	2.24
p-value	0.82	0.89	0.99

2) EU9 convergence

As shown in Tables 3.11 and 3.12 again all the tests fail to find any signs of convergence. The panel unit root tests do not reject the null and simultaneously the stationarity hypothesis is rejected by the Hadri test. Decades of EU membership does not seem to have narrowed the income per capita differences among countries, which suggest the EU regional policy have been ineffective.

Table 3.11 – Panel unit root tests: cross-sectional independence

	LLC	IPS	Fisher ADF		Fisher PP		Hadri
			Chi-square	Choi-Z	Chi-square	Choi-Z	
Statistic	-1.02	1.84	11.89	1.79	8.76	2.14	10.18
p-value	0.15	0.97	0.85	0.96	0.97	0.98	0.00

Table 3.12 – CADF test

	Number of lags		
	k=1	k=2	k=3
Statistic – Z[t-bar]	3.03	4.43	2.70
p-value	1.00	1.00	1.00

3) EMU

Table 3.13 and 3.14 display the results obtained for members of the European Monetary Union. In contrast with the Johansen test which showed some common trends among the EMU countries, the panel unit root tests reject any evidence of convergence.

Table 3.13 – Panel unit root tests: cross-sectional independence

	LLC	IPS	Fisher ADF		Fisher PP		Hadri
			Chi-square	Choi-Z	Chi-square	Choi-Z	
Statistic	0.77	1.84	12.79	1.93	21.55	1.62	10.66
p-value	0.22	0.97	0.94	0.97	0.49	0.95	0.00

Table 3.14 – CADF test

	Number of lags		
	k=1	k=2	k=3
Statistic – Z[t-bar]	1.22	1.74	1.26
p-value	0.89	0.96	0.90

4) Cohesion group

In what concerns the sub-sample Greece, Ireland, Portugal and Spain no evidence of convergence was found since all the panel unit root tests reject convergence at the conventional levels of significance. This lack of convergence among the Cohesion countries is in contrast with the time-series cointegration analysis which found a common trend among this set of countries.

Table 3.15 – Panel unit root tests: cross-sectional independence

	LLC	IPS	Fisher ADF		Fisher PP		Hadri
			Chi-square	Choi-Z	Chi-square	Choi-Z	
Statistic	-1.32	0.14	6.35	0.16	12.42	-0.18	5.60
p-value	0.09	0.56	0.61	0.56	0.14	0.43	0.00

Table 3.16 – CADF test

	Number of lags		
	k=1	k=2	k=3
Statistic – Z[t-bar]	0.11	0.72	0.44
p-value	0.54	0.77	0.67

3.5. Conclusions

In general no convergence among EU15 countries was found. Convergence seems to be the exception. Among the 105 pairs of countries analyzed, stronger evidence of catching-up was found for Austria-Belgium, Spain-Austria, Spain-Belgium, Finland-Belgium, Finland-France, Finland-Italy and Germany-Italy. This result was consistent across three different tests, at least one unit root test (ADF, PP or ZA), the stationarity test (KPSS) and the Johansen cointegration test. Since the unit root and the KPSS tests were carried out including a time trend, these results indicate catching-up, which is consistent with β-convergence, rather than convergence in the strict time series sense.

Multivariate cointegrating techniques rejected the hypothesis of group convergence in most cases. The exception is the Cohesion group for which only one common trend was found. It was mentioned that unit root tests and cointegration techniques are less appropriate when countries are in transitional dynamics. The time-varying parameter model is more proper when countries are below their steady-state but its results also failed to find any signs of convergence of the Iberian countries towards the EU15 average. The panel unit root tests confirm the lack of group convergence. The lack of convergence among the EU6 do not support the idea that economic integration facilitates the convergence process. The EU6 countries have joined together when the EEC was created in 1957 and have always moved together in each further step of European integration, including the construction of the European Monetary Union. This chapter was a simple assessment of the convergence level of Portugal and Spain within the EU15. The results show non convergence of the Iberian countries and suggest an ineffective European regional policy since these two countries have benefited in a large extent from the structural funds available to reduce the regional disparities within the EU15.

Although this time-series approach to convergence is not linked to any growth theory, this set of results is a starting point. Convergence is a direct implication of the neoclassical growth model but not of the endogenous growth theory according to which the income per capita disparities might persist and even grow over time.

Appendix to Chapter 3

Table 3.17 – ADF Test

	AT	BE	DK	FI	FR	DE	GR	IE	IT	LU	NL	PT	ES	SE	UK
EU15	-0.59 k=0	-1.33 k=2	-3.05 k=1	-2.74 k=1	-1.00 k=0	-0.54 k=1	-3.35 k=3	-0.74 k=0	-1.04 k=1	-2.11 k=0	-2.23 k=1	-1.34 k=1	-3.17 k=1	-2.14 k=1	-2.41 k=1
AT	-	-3.25 k=1	-1.32 k=0	-2.84 k=1	-3.37 k=0	-2.39 k=0	-2.27 k=3	-0.36 k=0	-2.90 k=0	-1.43 k=0	-1.40 k=0	-2.71 k=1	-4.90** k=0	-0.21 k=0	-1.13 k=0
BE		-	-2.16 k=1	-2.60 k=1	-2.26 k=0	-2.36 k=2	-2.23 k=0	0.66 k=0	-0.38 k=7	-1.88 k=0	-1.92 k=0	-2.03 k=1	-5.15** k=0	0.03 k=0	-1.77 k=0
DK			-	-2.91 k=1	-2.55 k=4	-1.40 k=1	-2.32 k=3	-0.96 k=0	0.84 k=9	-2.31 k=0	-3.06 k=3	-2.04 k=1	-2.88 k=1	-2.25 k=1	-2.88 k=0
FI				-	-3.37 k=1	-2.84 k=1	-3.07 k=1	-1.43 k=1	-2.63 k=1	-1.78 k=0	-2.51 k=1	-2.89 k=5	-3.82 k=1	-2.73 k=1	-2.09 k=1
FR					-	-2.77 k=1	-1.93 k=3	-0.71 k=0	-2.65 k=1	-2.02 k=0	-1.22 k=1	-2.12 k=1	-2.58 k=1	-0.84 k=1	-2.11 k=1
DE						-	-2.11 k=3	-0.19 k=0	-3.85* k=0	-1.39 k=0	-3.15 k=7	-2.63 k=1	-2.63 k=1	-0.89 k=1	-1.35 k=1
GR							-	-2.32 k=0	-3.39* k=7	-2.68 k=0	-1.90 k=3	-1.67 k=3	-2.35 k=1	-2.16 k=1	-2.57 k=1
IE								-	-0.56 k=0	-1.05 k=0	-0.47 k=0	-0.38 k=0	-2.46 k=1	-1.86 k=1	-0.67 k=0
IT									-	-2.03 k=0	-0.97 k=1	-3.11 k=1	-2.04 k=1	0.48 k=0	-1.83 k=0
LU										-	-1.77 k=0	-1.58 k=0	-4.17** k=0	-2.40 k=0	-2.20 k=0
NL											-	-1.52 k=1	-2.53 k=1	-1.40 k=1	-2.75 k=1
PT												-	-1.90 k=1	-1.29 k=1	-1.73 k=1
ES													-	-2.39 k=1	-3.23 k=1
SE														-	-2.39 k=1
UK															-

Notes: The tests were performed in EViews 6 with trend, k - number of lags according with SIC, * and ** - reject the null of a unit root at 5% and 1%, respectively.

Table 3.18 – PP Test

	AT	BE	DK	FI	FR	DE	GR	IE	IT	LU	NL	PT	ES	SE	UK
EU15	-0.65	-0.93	-2.65	-2.01	-0.94	-0.24	-2.44	-0.87	-0.93	-2.11	-2.41	-0.85	-4.79**	-1.66	-2.37
AT	-	-4.26**	-1.67	-2.12	-3.37	-2.39	-2.48	-0.48	-3.12	-1.43	-1.44	-2.07	-4.09*	-0.77	-1.20
BE		-	-1.77	-2.12	-3.09	-2.31	-2.25	-0.74	-1.94	-1.88	-2.02	-1.55	-4.34**	-0.53	-1.76
DK			-	-2.14	-1.61	-1.55	-2.01	-1.11	-1.19	-2.32	-2.46	-1.37	-2.99	-1.89	-2.90
FI				-	-1.63	-2.10	-2.49	-1.18	-1.37	-1.85	-2.16	-0.98	-3.15	-1.57	-1.98
FR					-	-2.69	-2.05	-0.78	-2.05	-2.02	-2.07	-1.31	-3.81*	-0.11	-1.97
DE						-	-2.24	-0.40	-4.09*	-1.39	-1.31	-2.08	-3.58*	-0.50	-0.60
GR							-	-2.16	-1.44	-2.53	-2.58	-1.41	-2.06	-2.00	-2.75
IE								-	-0.68	-1.34	-0.49	-0.34	-2.68	-1.64	-1.02
IT									-	-2.00	-1.68	-2.12	-2.09	0.46	-1.99
LU										-	-1.76	-1.74	-4.10*	-2.40	-2.30
NL											-	-1.01	-5.01**	-1.95	-1.62
PT												-	-2.28	-0.45	-1.17
ES													-	-2.88	-4.46**
SE														-	-3.06
UK															-

Notes: The tests were performed in EViews 6 with trend, Newey-West Bandwidth, * and ** - reject the null of a unit root at 5% and 1%, respectively.

Table 3.19 – KPSS Test

	AT	BE	DK	FI	FR	DE	GR	IE	IT	LU	NL	PT	ES	SE	UK
EU15	0.21*	0.22*	0.07	0.12	0.23**	0.18*	0.18**	0.22*	0.21*	0.20*	0.07	0.19*	0.18*	0.07	0.21*
AT	-	0.13	0.17*	0.07	0.08	0.13	0.15	0.22**	0.09	0.21*	0.18*	0.12	0.12	0.16*	0.22**
BE		-	0.17*	0.06	0.08	0.12	0.15*	0.22**	0.13	0.21*	0.19*	0.14	0.13	0.15*	0.22*
DK			-	0.12	0.19*	0.18*	0.17*	0.21*	0.22**	0.20*	0.08	0.18*	0.16*	0.10	0.21*
FI				-	0.07	0.07	0.15*	0.21*	0.09	0.19*	0.10	0.10	0.10	0.17*	0.19*
FR					-	0.14	0.15*	0.22**	0.14	0.22**	0.20*	0.13	0.12	0.18*	0.22**
DE						-	0.15*	0.21*	0.22**	0.22**	0.15*	0.14	0.13	0.14	0.23**
GR							-	0.22**	0.13	0.20*	0.18*	0.11	0.14	0.19*	0.19*
IE								-	0.22**	0.13	0.22**	0.22**	0.22**	0.21*	0.18*
IT									-	0.23**	0.18*	0.09	0.11	0.18*	0.23**
LU										-	0.19*	0.22**	0.21*	0.18*	0.15*
NL											-	0.21*	0.19*	0.06	0.17*
PT												-	0.11	0.16*	0.21*
ES													-	0.17*	0.19*
SE														-	0.18*
UK															-

Notes: The tests were performed in EViews 6 with trend, Newey-West Bandwidth, * and ** - reject the null of stationarity at 5% and 1%, respectively.

Table 3.20 – ZATest

	AT	BE	DK	FI	FR	DE	GR	IE	IT	LU	NL	PT	ES	SE	UK
EU15	-3.68 (1979) k=0	-3.70 (1980) k=2	-4.19 (1985) k=1	-6.84** (1991) k=1	-3.05 (1977) k=0	-3.39 (1991) k=0	-2.51 (1969) k=0	-3.47 (1983) k=0	-3.61 (1992) k=2	-3.60 (1975) k=0	-3.47 (1979) k=0	-2.17 (1991) k=0	-4.39 (1978) k=1	-3.99 (1991) k=1	-4.39 (1969) k=0
AT	-	-5.27* (1983) k=1	-3.88 (1970) k=0	-5.45* (1991) k=1	-4.04 (1970) k=0	-4.41 (1984) k=0	-2.71 (1999) k=0	-3.36 (1983) k=0	-4.71 (1984) k=1	-4.72 (1975) k=0	-4.00 (1979) k=0	-3.78 (1974) k=1	-5.72* (1979) k=1	-3.21 (1991) k=0	-3.48 (1974) k=0
BE		-	-4.22 (1973) k=1	-5.31** (1991) k=1	-4.11 (1970) k=0	-3.61 (1983) k=0	-2.24 (1999) k=0	-3.00 (1986) k=0	-3.60 (1985) k=1	-4.41 (1975) k=0	-4.06 (1980) k=0	-2.62 (1998) k=0	-3.99 (1979) k=2	-2.64 (1991) k=0	-3.89 (1969) k=0
DK			-	-5.50* (1991) k=1	-4.30 (1982) k=1	-3.16 (1977) k=0	-2.39 (1969) k=0	-4.11 (1983) k=0	-3.22 (1989) k=0	-4.30 (1988) k=0	-5.07* (1982) k=0	-4.31 (1970) k=1	-3.77 (1981) k=1	-4.19 (1992) k=0	-4.08 (1987) k=0
FI				-	-5.82** (1991) k=1	-6.56** (1991) k=1	-4.07 (1979) k=1	-3.76 (1985) k=1	-6.02** (1991) k=1	-2.96 (1991) k=0	-5.28* (1991) k=1	-4.12 (1991) k=1	-4.95 (1979) k=1	-5.90** (1991) k=1	-4.21 (1969) k=1
FR					-	-3.17 (1983) k=0	-2.12 (1999) k=0	-3.12 (1986) k=0	-4.28 (1983) k=1	-4.20 (1975) k=0	-4.00 (1981) k=1	-3.24 (1999) k=1	-3.77 (1979) k=1	-3.23 (1991) k=0	-3.57 (1969) k=0
DE						-	-2.50 (1999) k=0	-3.74 (1983) k=0	-4.59 (1990) k=2	-5.14* (1975) k=0	-3.16 (1978) k=0	-4.43 (1970) k=1	-3.20 (1991) k=1	-4.61 (1991) k=1	-3.17 (1980) k=0
GR							-	-3.29 (1970) k=0	-2.02 (1999) k=1	-2.64 (1970) k=0	-2.32 (1969) k=0	-2.24 (1998) k=0	-3.68 (1987) k=0	-3.94 (1971) k=0	-3.65 (1969) k=1
IE								-	-4.30 (1986) k=0	-3.86 (1986) k=0	-2.88 (1985) k=0	-2.79 (1986) k=0	-2.90 (1986) k=1	-3.66 (1983) k=1	-4.34 (1986) k=1
IT									-	-4.47 (1979) k=0	-3.73 (1979) k=1	-4.58 (1970) k=1	-2.86 (1979) k=1	-3.67 (1991) k=0	-3.66 (1980) k=0
LU										-	-3.48 (1975) k=0	-3.43 (1977) k=0	-3.66 (1975) k=0	-3.69 (1988) k=0	-4.22 (1989) k=0

	AT	BE	DK	FI	FR	DE	GR	IE	IT	LU	NL	PT	ES	SE	UK
NL											-	-3.95 (1991) k=1	-3.33 (1972) k=1	-2.41 (1991) k=1	-3.41 (1969) k=0
PT												-	-4.06 (1999) k=1	-2.22 (1998) k=2	-3.54 (1970) k=1
ES													-	-3.75 (1978) k=1	-4.44 (1974) k=1
SE														-	-2.65 (1969) k=2
UK															-

Notes: The tests were performed in STATA 9.0 with break in both intercept and trend, k - number of lags according with SIC, * and ** - reject the null of a unit root at 5% and 1%, respectively. Time-break year in brackets.

Chapter 4
Growth and convergence in the Portuguese regions: The role of human capital

4.1. Introduction

As discussed before, traditionally there have been two ways of including human capital in growth models. It can be considered an input in the production function, like Mankiw *et al.* (1992) augmented Solow model or the Lucas (1988) endogenous growth model. Alternatively human capital is introduced as a determinant of technological progress in line with the seminal work of Nelson and Phelps (1966) and subsequent endogenous growth models that focus on the role of human capital in the adoption of new technologies [Benhabib and Spiegel (1994)] and innovation [Romer (1990)]. In empirical work these two approaches imply testing different hypotheses about what affects the output growth: changes *versus* levels of human capital stock. At an aggregate empirical level the impact of human capital on growth is ambiguous and not always in accordance with the theoretical predictions, in contrast with micro-studies that usually find a positive impact of schooling on individual returns.

The purpose of this chapter is to study the impact of human capital on the 30 Portuguese NUTS III[12] regions' income per capita convergence over the period 1991-2006. Panel methods are applied to estimate the conditional β-convergence model following Mankiw *et al.* (1992), in contrast with the previous chapter which applied a time series approach. The latter has the advantage of providing precise statistical definitions of convergence but the drawbacks of not being clearly linked with any growth theory and also being inappropriate when the economic units are in transition dynamics [Durlauf *et al.* (2009)]. According to the purpose of studying the effect of human capital on regional growth, the Mankiw *et al.* (1992)' conditional β-convergence model is appropriate since it is directly derived from their augmented Solow growth model which explicitly includes human capital.

[12] NUTS stands for the European Commission's Nomenclature of Units of Territorial Statistics.

There are only a few β-convergence studies of this set of regions, but none have considered the role of human capital due to lack of data at the regional level. For example, Soukiaziz and Proença (2008) worked with tourism as the conditioning factor for the period 1993-2001 and the results show its positive effect on both regional convergence and growth rates.

The structure of the chapter is the following: Section 4.2. presents the Regional Accounts data and a brief profile of the regions. Section 4.3. estimates the regional human capital stock according to both the education and labour-income approaches. Section 4.4. examines the σ-convergence in both human capital and GDP per capita among the regions. The applied β-convergence model is presented in section 4.5. The discussion of the methodology and the results are in sections 4.6. and 4.7., respectively. In Section 4.8. the social returns of education are estimated by applying a Macro-Mincer approach, which regresses the regional average wage on the regional average levels of education and experience. Section 4.9. concludes.

4.2. Data and the Regions' Profile

Data on GDP and population was collected from the Portuguese National Institute of Statistics' (INE) Regional Accounts. The original GDP data provided by the Regional Accounts is in nominal terms and before 1995 the values were expressed in the national currency, Escudos. In order to convert the values into Euros, the respective exchange rate at 31 December 1998 was applied. GDP real values were then obtained using the GDP deflator and 2000 was the base year. Due to the lack of regional GDP deflators, the national one is applied under the assumption that the differentials across regions are small. Despite evidence of regional heterogeneity, the variation of the inflation rate among the Portuguese regions is lower than in other countries of the Euro area [Beck *et al.* (2009)]. Therefore the use of the national deflator to obtain the regional GDP at constant prices is reasonable. The share of the main sectors in the regions' total Gross Value Added (GVA) is also supplied by the Regional Accounts.

Table 4.1 summarizes the main regional economic indicators and the regions are ranked from the highest to the lowest level of GDP per capita in 1991. The richest regions are all located on the coast. Although there is a certain persistency over time, with the poorest regions remaining the same, there are some examples of mobility, for example Madeira jumps from the 17th in 1991 to 3rd richest in 2006 and Peninsula de Setubal which declined from the 10th position to 17th. The capital region, Grande Lisboa, is the richest over the period in terms of GDP per capita.

The production structure has changed across the country over the period. The service sector was the most dynamic, with an annual average growth rate around 4.3%, in contrast with the negative growth rates achieved in the industrial output (-0.1%) and agriculture (-1.1%).

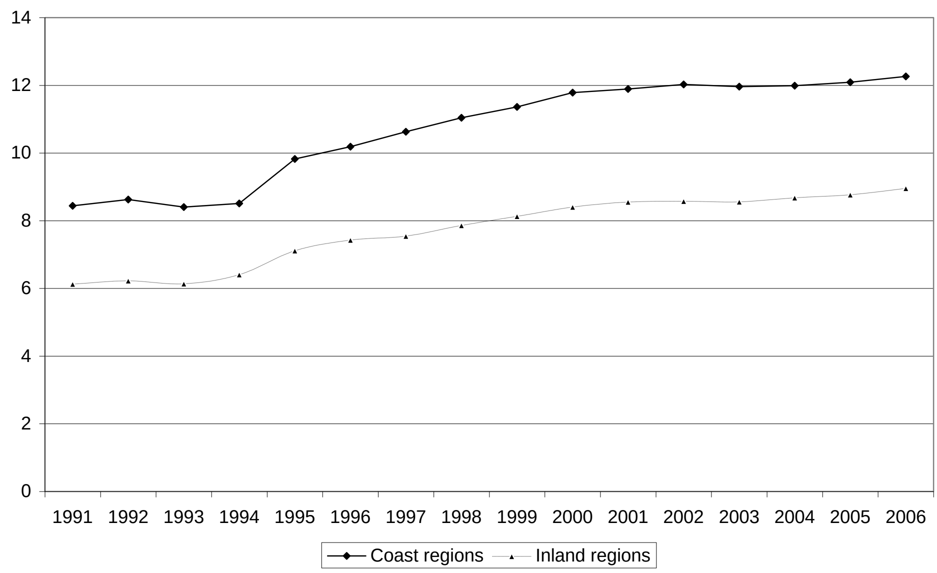
Table 4.1 – The regions' main indicators

Regions	Real GDP pc (1,000 €)		Production structure (%) Agriculture		Industry		Services	
	1991	2006	1991	2006	1991	2006	1991	2006
Grande Lisboa	15.31	20.10	0.34	0.22	26.28	15.26	73.38	84.52
Alentejo Litoral	11.48	17.86	17.52	11.65	54.63	48.54	27.85	39.81
Grande Porto	10.77	12.28	1.25	0.75	40.98	23.58	57.76	75.67
Algarve	9.38	12.84	9.79	5.28	16.93	12.49	73.28	82.23
Baixo Vouga	8.62	11.14	9.25	2.22	51.00	36.67	39.75	61.11
Pinhal Litoral	8.24	12.08	5.21	2.43	47.74	36.56	47.05	61.01
Ave	7.75	8.88	2.82	1.34	70.57	49.09	26.61	49.58
Baixo Mondego	7.68	12.56	6.72	2.07	30.48	20.67	62.80	77.26
Entre Douro Vouga	7.61	9.75	3.17	1.06	67.71	50.38	29.13	48.55
Peninsula de Setubal	7.50	8.89	3.94	1.77	46.88	29.58	49.18	68.65
Oeste	7.49	10.07	14.96	10.17	42.21	25.91	42.83	63.92
Lesiria do Tejo	7.31	10.56	18.49	9.19	32.89	23.82	48.62	66.99
Beira Interior Sul	7.12	10.70	13.27	6.11	31.09	19.72	55.64	74.17
Medio Tejo	6.75	10.34	6.13	3.06	40.22	33.64	53.65	63.30
Alto Alentejo	6.71	10.45	22.70	12.45	25.09	17.86	52.21	69.69
Alentejo Central	6.51	10.26	19.84	8.55	24.17	17.27	55.98	74.18
R.A. Madeira	6.46	15.53	5.31	2.44	21.56	16.49	73.13	81.07
Douro	6.46	8.28	16.83	9.57	45.70	20.20	37.47	70.23
R.A. Acores	6.39	10.95	13.83	11.29	24.11	16.30	62.06	72.41
Baixo Alentejo	6.21	11.24	17.00	12.16	33.75	29.95	49.25	57.89
Cavado	6.19	9.33	5.89	2.88	47.44	36.06	46.68	61.06
Beira Interior Norte	6.16	8.54	17.89	4.80	22.30	18.59	59.81	76.62
Cova da Beira	6.15	8.04	13.42	4.39	35.27	22.38	51.32	73.23
Alto Tras-os-Montes	5.69	8.19	16.63	9.54	33.86	24.12	49.51	66.34
Dao-Lafoes	5.52	8.49	13.60	5.22	31.40	26.34	55.00	68.44
Pinhal Interior Sul	5.37	8.85	16.95	7.94	36.43	30.77	46.62	61.29
Minho-Lima	5.34	7.52	9.88	2.95	33.70	30.63	56.42	66.42
Pinhal Interior Norte	4.91	7.15	14.57	3.97	34.95	31.20	50.49	64.83
Serra da Estrela	4.83	7.35	10.76	3.36	41.19	29.89	48.05	66.75
Tamega	4.27	6.75	9.60	1.85	52.79	44.85	37.61	53.30
National Average	**9.68**	**12.18**	**5.63**	**2.82**	**36.42**	**24.27**	**57.94**	**72.91**

Across the regions there was a decrease in the contribution of agriculture and industry to total output, compensated by a significant increase in the weight of services. Comparing the poorest regions with the richest, the share of the tertiary sector is much higher in the former, above the national average. Alentejo Litoral is an exception, since it concentrates the Portuguese energy industry (electricity and petrol refineries) its secondary sector is the main contributor to total Gross Value Added. In the poorest regions, industrial activity tends to be concentrated in low value added sectors such as the textiles, leather, footwear, clothing, wood/ furniture and cork products. In two of the richest regions, Algarve and Madeira, a strong tourism sector has developed that dominates the tertiary sector both in terms of output and employment. In contrast, the weight of industry in the second city region, Grande Porto, has always been very high in national terms.

Figure 4.1 illustrates the evolution of the average GDP per capita of the regions located on the coast in contrast with the others. The gap between the coast and the inland regions tends to be persistent and increasing since the mid 1990s.

Figure 4.1 – Average regional GDP per capita (in thousands €, 2000 prices)



Shift-Share Analysis

In order to have a better perspective of the regional growth it is interesting to apply a shift-share analysis as a starting point. This technique has been popular for studying regional employment growth disparities because of its simplicity and the fact that it requires only limited amounts of data (see Armstrong and Taylor, 1993, Chapter 5). It can be applied to output growth instead of employment and allows the decomposition of the deviation of a region's output growth rate from the national average into two components: regional (or competitive) and sectoral (or structural). According to the regional data available which is scarce, the lowest level of sectoral disaggregation is considered: Primary (Agriculture), Secondary (Industry) and Tertiary (Services). The results are affected by this, as the magnitude of the sectoral effect tends to rise when the level of disaggregation increases. The regional and the sectoral effect are, respectively, the first and second term on the right-hand-side of the following identity:

$$gr_{it} - gr_{PTt} = \sum_{j=1}^{3}(gr_{ijt} - gr_{PTjt})s_{ij(t-1)} + \sum_{j=1}^{3}(s_{ij(t-1)} - s_{PTj(t-1)})gr_{PTj} \qquad (4.1)$$

where *gr* stands for the Gross Value Added (GAV) growth rate, *i* denotes the region, *PT* stands for Portugal, *j* represents the sector and *t* is time subscript. *s* is the share of the sector *j* in the total GVA of the region *i* (s_{ij}) or at the national level (s_{PTj}). The regional effect is calculated assuming that the production structure of the region is the same as that of the country. It will be positive if the sectors themselves are more dynamic in this particular region comparing to their performance in the rest of the country. On the other hand, the sectoral effect is calculated by assuming that sectors grow in each region at the same rate they do at the national level. A positive sectoral effect means that the region exhibits a better performance comparing to the country due to a specialization in sectors that exhibit a growth rate above the average, this is the region has a favourable production structure. Figures 4.2 to 4.5 exhibit the results of this decomposition for the NUTS III regions. They are organized according to the respective NUTS II level[13] except the last graph that includes all the remaining NUTS III regions. The whole country annual average growth rate was 2.60%.

[13] See Table 4.15 in the chapter's appendix .

Figure 4.2 – "Norte" regions deviation from the national average growth rate

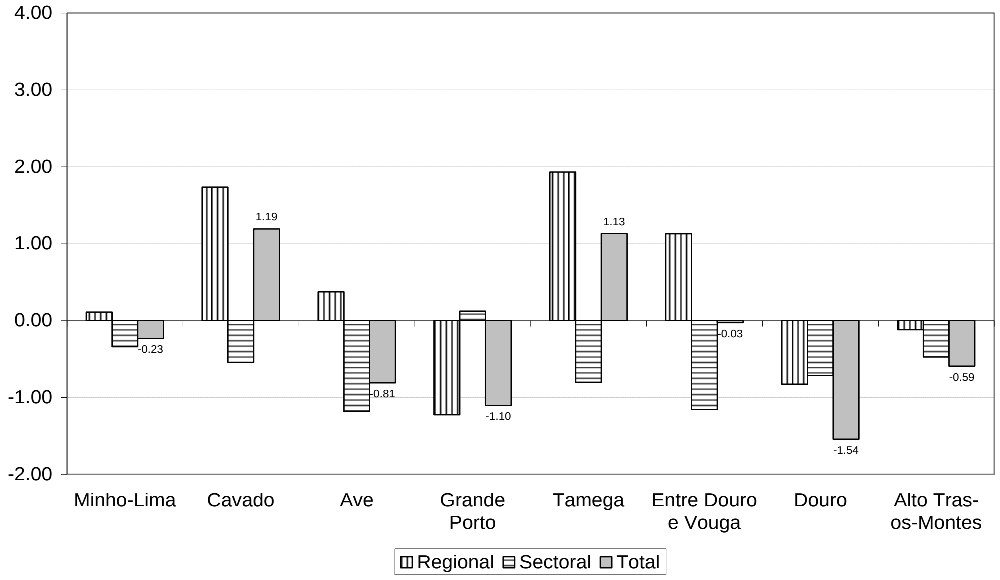


Figure 4.3 – "Centro" regions deviation from the national average growth rate

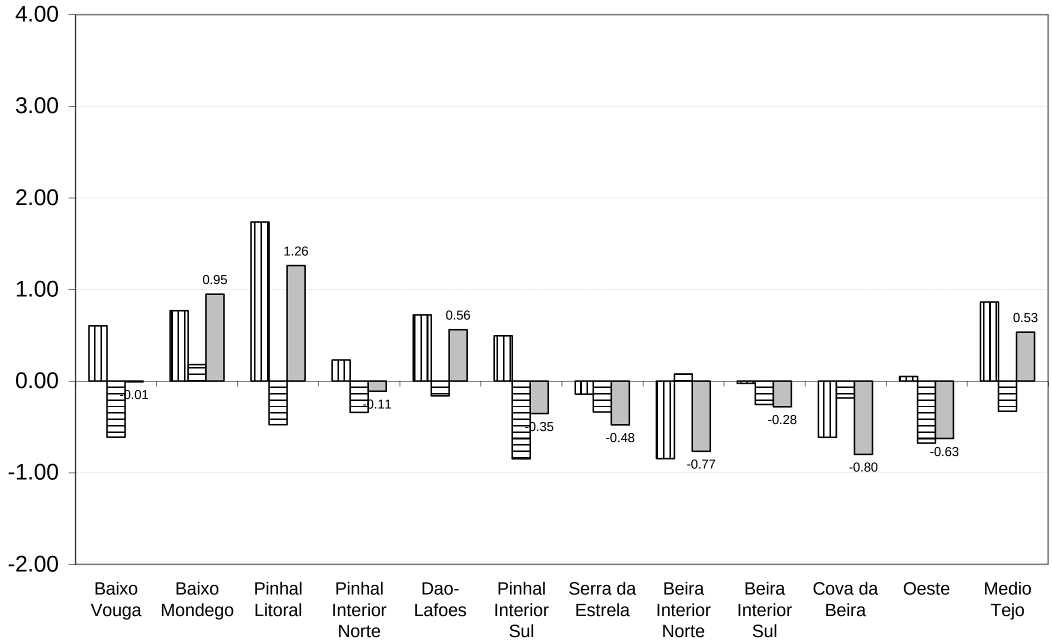


Figure 4.4 – "Alentejo" regions deviation from the national average growth rate

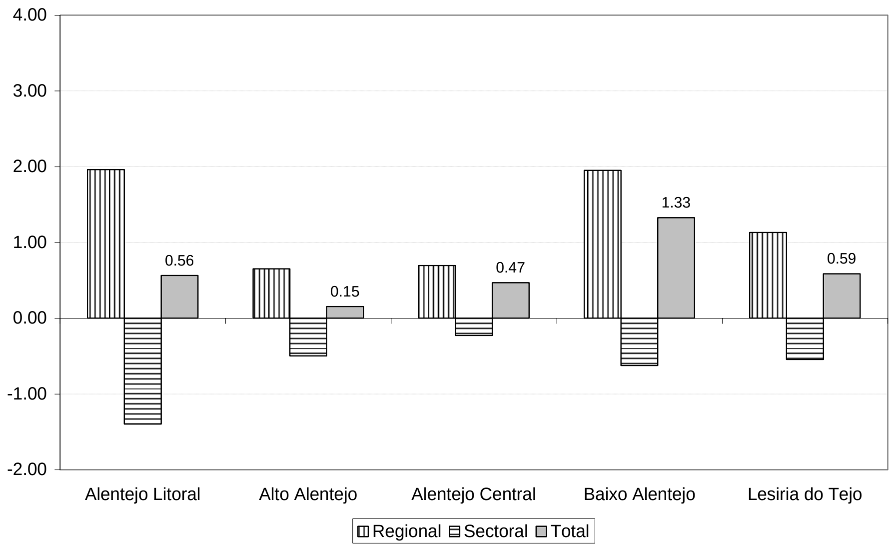
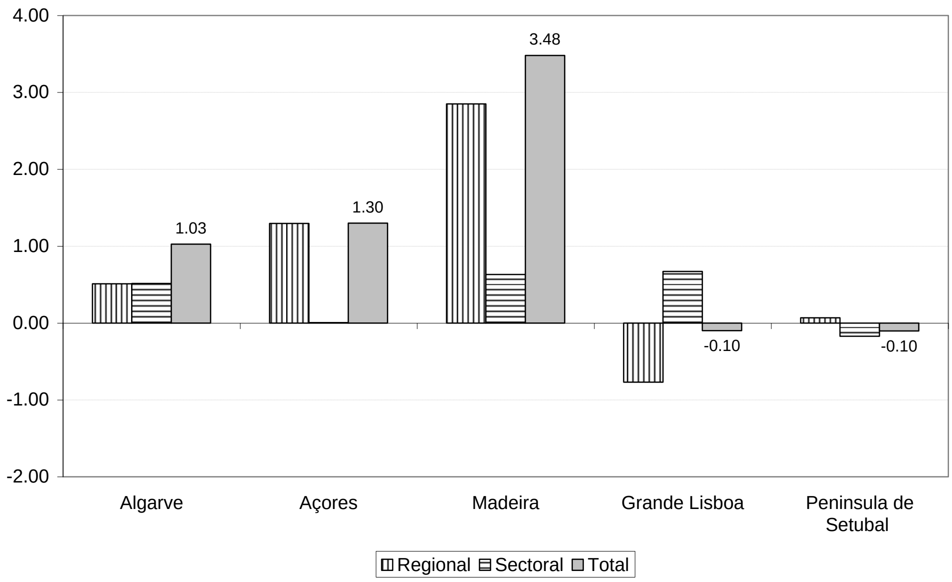


Figure 4.5 illustrates the decomposition for the remaining NUTS III regions. According to the classification, Algarve, Açores and Madeira are simultaneously level II and level III regions. Grande Lisboa and Peninsula de Setubal integrate the NUTS II region called Lisboa.

Figure 4.5 – Other regions deviation from the national average growth rate



In most cases, the regional effect on growth is positive, as depicted by a bar above the zero line. On the other hand, the sectoral impact tends to be negative with some exceptions among the richest regions, like Grande Lisboa, Algarve, Madeira, Baixo

Mondego and Grande Porto. Though in the latter region the sectoral effect is positive, it exhibits the highest negative deviation from the national average growth rate (-1.10%) due to a significant loss of regional competitiveness. In contrast, Madeira is the most dynamic region over the period, with an annual average growth 3.48% above the national average due to a strong regional effect which is reinforced by the structural change in favour of the service sector, tourism in particular. Among the poorest regions in 1991, only Tamega exhibits a positive deviation from the national average growth rate as a result of a strong positive regional effect that more than compensates the negative impact of its production structure characterized by a high weight of the primary sector in the total output.

The shift-share analysis has several limitations, such as the underestimation of the sectoral effect and the loss of information by aggregating regional growth differences in particular industries into a single measure [Armstrong and Taylor (1993)]. Despite this, the results of its application to the Portuguese regions growth over the period 1991-2006 are interesting as a starting point. Overall the regional effect dominates in explaining the regional deviation from the national average growth rate and this result might be related to the regional human capital levels which are the focus of this chapter.

4.3. Regional Human Capital Estimation

Due to the lack of human capital data at this level of regional disaggregation the respective proxies need to be computed. The raw data was taken from *Quadros de Pessoal* (Personnel Records), a dataset that results from an annual compulsory questionnaire that every firm (except family business without employees) must answer. It is applied by the Strategic and Planning Office (GEP) of the Portuguese Ministry of Labour and Social Solidarity (MTSS). This institution provided the data used in this work which consists of the number of workers in each region according to the qualification level and the average monthly wage, excluding social contributions, paid by the firms according to the qualification level as well. The nominal wage was converted into real terms using the Consumer Price Index, for which the base year is 2000. Data on each region's workers average age was also supplied.

The education levels considered in the dataset are the following: no schooling or incomplete primary school, complete primary school (1st cycle), complete 2nd cycle, complete 3rd cycle, complete upper secondary school, lower higher education – *Bacharelato* and higher education - *Licenciatura*. The data is available on an annual basis for the period 1991-2006, except for 2001, which leads to a panel with N=30 and T=15. The dataset excludes the public sector and the self-employed workers. As the public sector is one of the main employers of skilled labour, the series obtained for education proxies may tend to under-estimate the total human capital stock. The exclusion of public employment from the estimation of the human capital series is not considered to be a problem because it is argued that the inclusion of the public sector produces a distortion in the results and education enhances growth only when allocated to innovative sectors [Di Liberto (2007)]. Di Liberto (2007) removed data on the public sector from the human capital indicators and estimated the average years of schooling for the private sector in Spain. Her work shows that the coefficients do not change significantly in comparison with the values obtained when both public and private sector are considered. On the other hand, the dataset only includes employed workers and therefore it is likely to over-estimate the total human capital stock since the unemployment rate among the most qualified workers tends to be lower.[14] Despite these limitations, both an education and an income-based approach are applied to the Personnel Records' data in order to estimate the regional human capital stocks.

4.3.1. Education approach

Though education includes several aspects apart from schooling, due to measurement difficulties usually only formal education is considered in growth empirics. Human capital proxies based on the education output include indicators such as enrolment and dropout rates, literacy rate, test scores and average years of schooling. Despite several criticisms, the latter is one of the most popular in empirical studies and the

[14] OECD (2007), "Tertiary Education in Portugal – Background Report"

main advantage is the fact that reflects the impact on the current labour force of the accumulated investment on education. The main criticisms are related to the fact that this measure ignores the education quality and it does not take into consideration that schooling returns vary greatly according to the level. The most common method applied is the perpetual inventory method that combines data on the enrolment rates with mortality rates to estimate the average years of schooling. One of the main drawbacks of this procedure is the fact that it estimates the schooling acquired in the region which may or may not be present there anymore due to labour mobility between regions. The procedure followed in this section to estimate the Portuguese regional human capital stock is different and estimates directly the average schooling years of the workers present in each region on an annual basis. Before estimating the average years of schooling in each region, the levels of education considered by the GEP/ MTSS need to be converted in schooling years as shown at Table 4.2.

Table 4.2 – Number of schooling years in Portugal

Category	Level of education	Number of schooling years
	0 – No schooling or incomplete primary school	0
Primary	1 - Complete primary school (1st cycle)	4
	2 - Complete 2nd cycle	6
Secondary	3 - Complete 3rd cycle	9
	4 - Complete upper secondary school	12
Tertiary	5 - Lower higher education – *Bacharelato*	15
	6 - Higher education - *Licenciatura*	17

The number of schooling years refers to the highest level achieved. The information provided by the questionnaire is related to all the workers employed by the firms in each year in the month of October. Some of the employees' qualifications are unknown because the respective employer did not answer this particular question. This number of workers varies across regions and years, from a maximum of 9.23% of the total workers in the region Alto-Tras-os-Montes, in 1993, to a minimum in the region Madeira of 0.15% at 1998. According to this, what it is actually estimated for each region is the average years of schooling of the workers for whom the qualification levels are known. In the academic year 1977-1978 the 12th year in secondary school was introduced, which means that workers that concluded upper secondary school before 1978 have a year less than that presented at Table 4.2. As there is no information regarding which year the workers concluded this level of education, it was decided to consider 12 years to complete secondary school. According to the time period, 1991-2006, this is probably the case of the majority of workers. Another problem is the number of workers whose number of schooling years is below 4. Like Mulligan and Sala-i-Martin (1997), the individuals that attended but did not complete primary school qualify for the no schooling category. Before the Bologna process, which started to be implemented in the academic year 2006-2007, the Portuguese higher education system included two degrees: a short (three years) and more practical degree called *bacharelato* which is the OECD "Tertiary-type B" level and the longer *licenciatura* (five years on average) that is equivalent to the OECD "Tertiary-type A".

Both the average years of schooling and the average years by educational level (primary, secondary and tertiary) were calculated. The average years of education (AvEdu) in each region and for each year, was calculated according to the formula:

$$AvEdu = \frac{4E_1 + 6E_2 + 9E_3 + 12E_4 + 15E_5 + 17E_6}{E} \quad (4.2)$$

where E_j is the number of employees whose highest level of completed education is j, which varies from 1 to 6 according to Table 4.2. E is the total number of employees for which the qualification level is known. This average was then decomposed into three different average schooling levels; primary, secondary and tertiary:

$$Av\Pr im = \frac{4E_1}{E} \quad (4.3)$$

$$AvSec = \frac{6E_2 + 9E_3 + 12E_4}{E} \quad (4.4)$$

$$AvTer = \frac{15E_5 + 17E_6}{E} \tag{4.5}$$

As the education level of the total employees increases, E_1 falls and thus the average years of primary schooling declines. Table 4.3 summarizes the values for the beginning and the end of the period. The regions are ranked from the highest to the lowest level of total average years of schooling in 1991. As shown, the average years of schooling increased in all the regions over the period 1991-2006. Although there are some changes in the relative positions the main features remain: the highest levels of human capital are concentrated in the regions of the capital, Lisboa, and Porto, which is the second city.

Table 4.3 – Regional average years of education (AvEdu)

NUTS III region	Position		Total		Primary		Secondary		Tertiary	
	1991	2006	1991	2006	1991	2006	1991	2006	1991	2006
Grande Lisboa	1	1	7.21	9.86	1.54	0.72	4.38	5.92	1.28	3.21
Grande Porto	2	2	6.08	8.80	2.01	0.93	3.41	5.64	0.66	2.24
Algarve	3	5	6.03	8.41	1.89	0.92	3.76	6.12	0.38	1.37
Baixo Mondego	4	4	5.99	8.75	1.99	0.88	3.42	5.82	0.59	2.05
Peninsula de Setubal	5	3	5.90	8.79	2.05	0.83	3.40	6.31	0.46	1.66
R.A. Acores	6	22	5.87	7.67	2.03	1.10	3.50	5.52	0.34	1.05
Baixo Vouga	7	8	5.71	8.21	1.99	0.96	3.26	5.48	0.46	1.76
R.A. Madeira	8	10	5.71	8.13	1.94	0.99	3.47	5.92	0.30	1.22
Beira Interior Sul	9	20	5.62	5.80	2.06	1.24	3.29	5.16	0.26	1.40
Pinhal Litoral	10	7	5.62	8.22	2.07	1.00	3.21	5.66	0.34	1.56
Oeste	11	17	5.61	7.93	2.12	1.05	3.17	5.66	0.32	1.22
Beira Interior Norte	12	16	5.59	7.97	2.48	1.22	2.78	5.14	0.33	1.61
Medio Tejo	13	6	5.57	8.33	2.14	0.96	3.07	5.75	0.35	1.62
Dao-Lafoes	14	11	5.57	8.08	2.22	1.00	3.04	5.55	0.31	1.54
Minho-Lima	15	12	5.56	8.05	2.04	0.81	3.27	5.95	0.25	1.29
Alto Tras-os-Montes	16	9	5.55	8.14	2.36	1.09	2.94	5.49	0.25	1.56
Lesiria do Tejo	17	13	5.55	8.01	2.13	1.07	3.05	5.61	0.36	1.32
Cavado	18	19	5.53	7.91	2.16	0.87	3.10	5.76	0.27	1.28
Douro	19	24	5.47	7.61	2.41	1.33	2.74	4.82	0.32	1.46
Alentejo Litoral	20	14	5.47	8.01	1.92	1.08	3.11	5.62	0.44	1.31
Cova da Beira	21	15	5.36	8.00	2.28	1.16	2.85	5.24	0.23	1.60
Pinhal Interior Norte	22	28	5.23	7.32	2.53	1.36	2.44	4.88	0.26	1.08
Alto Alentejo	23	23	5.23	7.63	2.08	1.24	2.90	5.12	0.25	1.27
Pinhal Interior Sul	24	26	5.22	7.42	2.46	1.32	2.52	5.16	0.24	0.94
Entre Douro e Vouga	25	25	5.18	7.53	2.25	1.13	2.69	5.11	0.23	1.29
Baixo Alentejo	26	21	5.16	7.79	2.20	1.14	2.63	5.32	0.33	1.32
Alentejo Central	27	18	4.97	7.92	2.11	1.15	2.58	5.52	0.27	1.26
Ave	28	27	4.97	7.40	2.34	1.14	2.42	5.24	0.21	1.03
Tamega	29	30	4.80	6.73	2.61	1.36	2.08	4.63	0.11	0.75
Serra da Estrela	30	29	4.78	7.22	2.67	1.65	1.92	4.32	0.19	1.24
National Average	**-**		**6.04**	**8.53**	**1.97**	**0.95**	**3.43**	**5.65**	**0.63**	**1.93**

As with GDP per capita, the regions at the top tend to be located on the coast and the capital city region is the richest. The poorest regions are also the ones that show lower education levels, but in many cases a better position in human capital does not mean higher GDP per capita. As an example, according to the human capital ranking the region Peninsula de Setubal was the 5^{th} in 1991 and became the 3^{rd} region, in 2006. In contrast, its position in terms of GDP per capita was 10^{th} in 1991 and 19^{th} in 2006. The relative position improved in terms of education levels but deteriorated in economic terms. On the other hand, Alentejo Litoral was second richest region in GDP per capita terms in 2006, but was the 14^{th} in terms of average years of education. As it was expected the only regions above the national average in terms of tertiary education are those that exhibit the highest average years of schooling.

Though largely applied in growth empirics, the use of the average years of schooling as a proxy for human capital has several limitations [Rogers (2008), Wößmann, (2003), Pritchett (2001) among others]. Besides ignoring human capital formation outside the education system such as training and experience, it assumes that the formation of human capital per year of schooling is the same across levels of education, regardless the field of study and the quality of the education system. Workers are assumed to be perfect substitutes for each other as long as their years of schooling are equal. With the purpose of overcoming some of these limitations alternative proxies have been proposed by the literature, namely the labour-income measures suggested by Mulligan and Sala-i-Martin (1997). According to the data available it is possible to compute these alternative proxies.

4.3.2. Labour-income approach

This approach is based on the idea that worker quality is somehow related to the respective wage and it is applied following Mulligan and Sala-i-Martin (1997). Their human capital proxy is an index (and not a monetary measure) and the zero-schooling worker's wage is the numeraire. Workers' wages reflect not only the respective human capital but also the other inputs, like the physical capital and technology level. In order to net out the effect of aggregate physical capital on labour income they propose dividing the labour income by the wage of a zero-schooling worker. The aggregate human capital in an economy is defined as "the quality-adjusted sum of labour of all the citizens" and the average stock of human capital in each region *i* at time *t* is the following:

$$h_i(t) = \sum_s \theta_i(t,s)\eta_i(t,s) \tag{4.6}$$

in which θ_i is the efficiency parameter and $\eta_i(t,s)$ is the share of region's *i* population with *s* years of schooling at time *t.* According to these authors the efficiency parameter should be allowed to change across regions and over time because the schooling quality and the relevance of what is taught vary across regions. The zero-schooling worker's wage is proposed as the numeraire, $w(t,0)$, and the efficiency parameter becomes:

$$\theta_i(t,s) = \frac{w_i(t,s)}{w_i(t,0)} \tag{4.7}$$

The explanation is the fact that the wage rate of a worker depends always on two components: the skills and the aggregate stocks. For any given skill, a higher physical capital stock per worker raises the individual productivity and his wage as a result. A proper way to identify the skills in a region and net out the effect of the capital stock on the respective wages is dividing them by the wage of a zero-schooling worker in that region. This is Mulligan and Sala-i-Martin (1997) procedure to obtain their "Labour income-based human capital" proxy (LIHK) which presents several advantages. In contrast with the average years of schooling, it does not assume that workers having the same level of education will have the same skills and allows changes in the relative productivities over time and across economies. As long as factors like health and on-the-job training are reflected in the workers' wages, they are captured by this human capital proxy. The average years of schooling does not take into consideration the relevance of what is taught at school. This labour income-based measure does, in the sense that if what is learnt at school by a worker is irrelevant from a productive perspective, then the respective wage is low and the measured human capital proxy will be as well.

Though all the advantages, namely in comparison with the average years of schooling, this human capital proxy also faces limitations. Mulligan and Sala-i-Martin (1997, 2000) themselves note the main drawbacks. It assumes that the zero-schooling workers have the same amount of skills always and everywhere and are perfect substitutable for the rest of the labour force. This is not realistic since skilled and non-skilled workers are more likely to be complements. If workers with different skills are not substitutes, the labour income human capital measure will increase when the zero-schooling wage falls due to an increase in the number of unskilled workers. Moreover, this measure assumes that physical capital accumulation is equally complementary to skilled and non-skilled workers, which is unlikely. Physical capital accumulation increases workers productivity but this tends to be biased in the sense of increasing more the productivity of the skilled than of the non-skilled workers. If that is the case, the procedure of dividing by the zero-schooling worker wage will not control for the effect of physical capital accumulation on the wages. Another problem is the fact that relative wages among workers might change for other reasons than productivity differences, such as institutional factors like the minimum wage, and this also leads to unrealistic changes in the human capital stock.

The human capital proxy proposed by Mulligan and Sala-i-Martin (1997) will be estimated for the Portuguese regions. In their work, the zero-schooling wage is estimated by the exponential of the constant term from a micro-Mincer wage regression [Mincer (1974)] for each US state at each date, which regresses the log average weekly earnings on a constant, the years of schooling, years of experience, experience squared and then several other individual variables, such as gender, race, marital status and residence. They compare their proxy with others suggested by the literature:

1) Variable weights

This measure restricts the efficiency parameter to be the same across regions but allows it to vary across time:

$$h_i(t) = \sum_S \theta(t,s)\eta_i(t,s) \quad (4.8)$$

in which $\theta(t,s)=\frac{w(t,s)}{w(t,0)}$, it depends on time (*t*) but it is independent of the region (*i*). According to this proxy, all the workers within the same qualification level have the same weight in the total human capital stock. It is appropriate if the variables that matter for individual human capital accumulation are nationwide.

2) Fixed weights

In contrast with the former, in this measure the efficiency parameter does not change either over time or across space:

$$h_i(t)=\sum_S \theta(s)\eta_i(t,s) \tag{4.9}$$

The efficiency parameter $\theta(s)=\frac{w(s)}{w(0)}$ is independent of both time (*t*) and region (*i*). The average years of education (AvEdu) is a particular case of the former. Instead of taking the market wages as the fixed weight, it works with the number of years of schooling, this is, $\theta(s)=s$. In comparison with the others, the Mulligan and Sala-i-Martin (1997) proxy gives each worker a weight that is always proportional to the respective wage.

Due to restrictions on the available micro-data for the Portuguese regions, the zero-schooling wage is computed by calculating the sample mean of the wage of zero-schooling workers in each region *i* at each year *t*, instead of using the Mincer regression. The alternative labour-income measures are computed as well for comparison purposes. For the variable weights proxy, the efficiency parameters are based on the national averages, $\theta(t,s)=\frac{w_{PT}(t,s)}{w_{PT}(t,0)}$.

In the fixed weights measure, the efficiency parameter is fixed over time and 2000 was chosen as the base year. This is:

$\theta(s)=\frac{w_{PT}(2000,s)}{w_{PT}(2000,0)}$.

Using the data on monthly average wage according to the level of qualification, the different labour-income measures were computed. Table 4.4 reports the values for the beginning and the end of the period. The regions are ranked from the richest to the poorest in terms of the Mulligan and Sala-i-Martin (1997) measure in 1991. There are no differences among the three proxies in 1991 at the national level but they are substantial at the regional level. Over the period, there was an increase in human capital stock proxied by the different measures. The number of regions above the national average decreased, from six to three which suggests an increase of regional disparities.

Table 4.4 – Regional labour-income human capital proxies

NUTS III region	Mulligan & Sala-i-Martin				Variable		Fixed	
	Ranking Position		Level		weights		weights	
	1991	2006	1991	2006	1991	2006	1991	2006
Alentejo Litoral	1	2	1.65	1.67	1.27	1.47	1.26	1.48
Grande Lisboa	2	1	1.51	1.97	1.46	1.74	1.44	1.78
Baixo Alentejo	3	8	1.46	1.41	1.23	1.45	1.23	1.47
Alto Alentejo	4	12	1.36	1.38	1.23	1.43	1.22	1.45
R.A. Acores	5	10	1.36	1.39	1.28	1.42	1.27	1.44
Peninsula de Setubal	6	4	1.36	1.52	1.29	1.54	1.28	1.57
Grande Porto	7	3	1.30	1.56	1.31	1.58	1.30	1.62
Lesiria do Tejo	8	17	1.27	1.34	1.25	1.46	1.25	1.48
R.A. Madeira	9	26	1.27	1.28	1.25	1.47	1.25	1.49
Algarve	10	22	1.26	1.32	1.29	1.49	1.28	1.52
Baixo Mondego	11	7	1.23	1.44	1.30	1.56	1.29	1.60
Beira Interior Sul	12	9	1.23	1.39	1.24	1.45	1.24	1.47
Beira Interior Norte	13	18	1.20	1.34	1.24	1.48	1.24	1.50
Baixo Vouga	14	27	1.20	1.27	1.25	1.50	1.25	1.52
Pinhal Interior Norte	15	24	1.17	1.29	1.20	1.40	1.21	1.41
Alto Tras-os-Montes	16	29	1.16	1.23	1.24	1.49	1.24	1.51
Alentejo Central	17	21	1.15	1.32	1.21	1.46	1.21	1.48
Medio Tejo	18	19	1.14	1.33	1.25	1.50	1.24	1.53
Douro	19	28	1.13	1.26	1.24	1.45	1.24	1.47
Cova da Beira	20	5	1.12	1.47	1.21	1.48	1.21	1.50
Serra da Estrela	21	16	1.12	1.35	1.17	1.41	1.18	1.42
Pinhal Interior Sul	22	15	1.11	1.35	1.21	1.39	1.21	1.41
Pinhal Litoral	23	13	1.11	1.36	1.24	1.49	1.24	1.51
Dao-Lafoes	24	11	1.10	1.39	1.22	1.48	1.23	1.50
Oeste	25	6	1.08	1.45	1.24	1.45	1.24	1.47
Ave	26	25	1.08	1.29	1.17	1.39	1.19	1.41
Cavado	27	20	1.07	1.32	1.21	1.44	1.22	1.46
Entre Douro e Vouga	28	14	1.05	1.36	1.18	1.42	1.20	1.43
Tamega	29	30	1.01	1.18	1.14	1.33	1.16	1.33
Minho-Lima	30	23	0.99	1.31	1.21	1.45	1.22	1.47
National average			**1.30**	**1.54**	**1.30**	**1.54**	**1.30**	**1.57**

As with the average years of schooling, Grande Lisboa is the richest in human capital, except in the beginning of the period when Alentejo Litoral came first in the Mulligan and Sala-i-Martin (1997) proxy. This region position is much higher when human capital is proxied by this measure instead of the average years of education and even the other income measures. The efficiency parameter in the Mulligan and Sala-i-Martin (1997) proxy varies not only over time but also across space. This parameter tends to be higher in this region than in the others because there are more large companies than in the rest of the country due to the production structure which is dominated by the energy sector. The gap between the highest and the lowest wages, associated with more and less education respectively, is higher in the large companies than in small and medium enterprises and this explains why the efficiency parameter is superior in Alentejo Litoral leading to a higher level of regional human capital stock.

When human capital is proxied by labour-income measures in general, it is not as clear that the regions located on the coast are the richest in human capital as it was when the proxy was the average years of schooling. In "Alentejo" regions the zero-schooling wage is low and as a result the human capital measure becomes high. On the other hand, in Algarve the zero-schooling wage is much higher since it is a touristic region, and this leads to a lower human capital stock when this proxy is considered. In terms of average years of schooling this region was always among the top five richest contrasting with its position in this ranking.

It is important to note that these values are conditional on the minimum wage. The zero-schooling wage is biased by the fact that in the regions with lower wages it is quite close to the minimum wage and tends to be the same across the workers with low levels of education, primary school (four years) and lower secondary school (nine years). The wage differentials among Portuguese regions is quite high and stable over time with the highest wages for apparently equally-skilled workers found in the richest region, Grande Lisboa [Vieira *et al.* (2006)].

4.3.3. Correlations of the different human capital proxies

Table 4.5 reports the contemporaneous correlation coefficients of the different proxies of human capital in the beginning and at the end of the period. As in Mulligan and Sala-i-Martin (1997) the correlation between their proxy and any other alternative is much lower, in 1991 between 0.47-0.62 and in 2006 between 0.70-0.75. In contrast, the other correlation coefficients are in the range 0.95-0.9(9). The highest correlation is among the variable weights and the fixed weights human capital proxies, which is almost perfect, followed by the average education and the fixed weights. Both are expected results. The average years of schooling is a particular case of fixed weights, the only difference is that in the latter the weights are determined by the labour-market. From the beginning to the end of the period there was a rise in the correlation among all the proxies.

Table 4.5 – Correlation matrix of the different human capital proxies

1991	AvEdu	Mulligan & S.	Variable weights	Fixed weights
AvEdu	1.00	0.47	0.95	0.96
Mulligan & S.		1.00	0.65	0.62
Variable weights			1.00	0.9(9)
Fixed weights				1.00
2006	**AvEdu**	**Mulligan & S.**	**Variable weights**	**Fixed weights**
AvEdu	1.00	0.70	0.97	0.98
Mulligan & S.		1.00	0.75	0.75
Variable weights			1.00	0.9(9)
Fixed weights				1.00

4.4. The regional distribution of GDP per capita and human capital: σ-convergence

As discussed in Chapter 2, section 2.3, the decline of income per capita dispersion across the regions over time evidences σ-convergence and the most common measures are the the standard deviation or the coefficient of variation. Figure 4.6 shows the evolution over time of the standard deviation of GDP per capita. As shown, the standard deviation of GDP per capita declined during the first half of the 1990s, which evidences σ-convergence. Then there is a small increase, followed by a relative stability. The regional distribution of GDP per capita is characterized by persistency.

Figure 4.6 – Standard deviation of the logarithm of regional GDP per capita

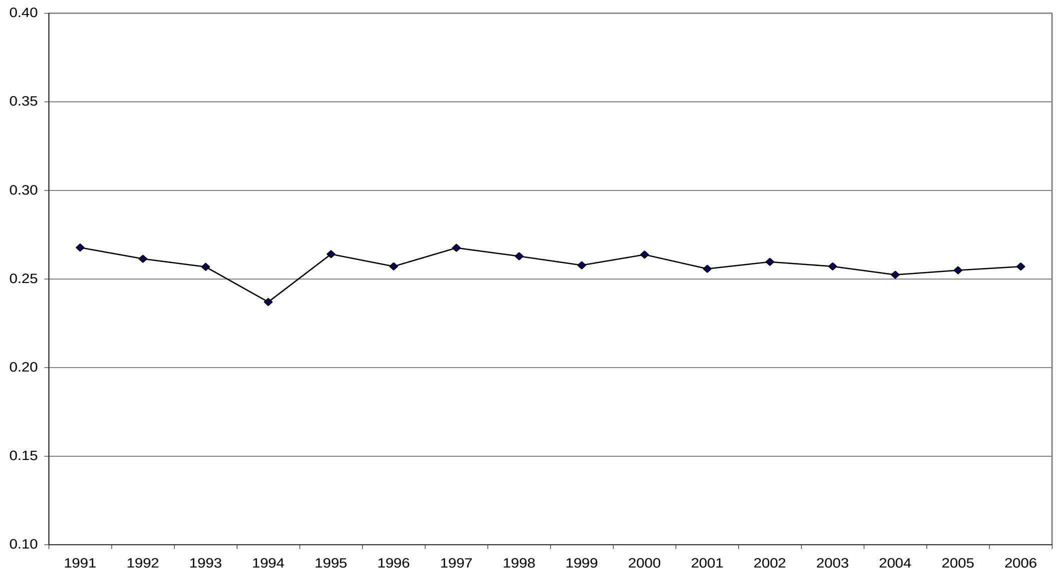
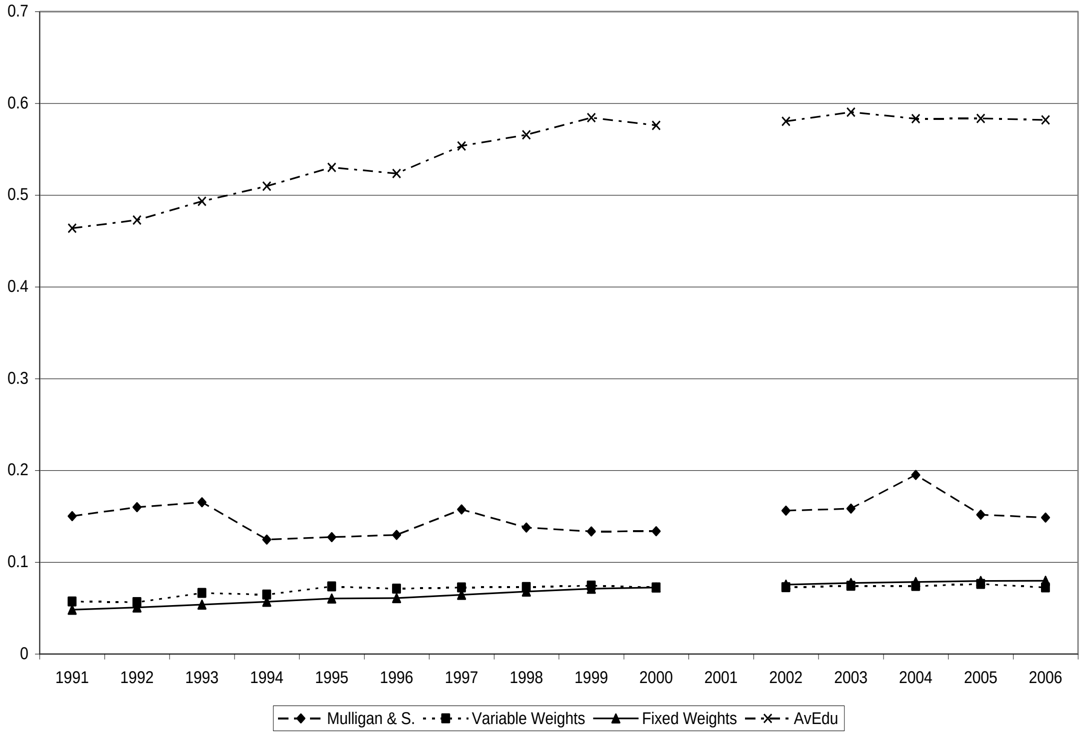


Figure 4.7 illustrates the evolution of the standard deviation of the human capital proxies, the average education and the three different labour-income measures. The data is not available for 2001 which explains the gap in the series. In contrast with GDP per capita, the inequality among the regions in terms of human capital increased over time mainly when the proxy is the average years of schooling. This might look surprising in the sense that education policies are nationwide and even in terms of higher education there has been an effort to spread institutions across the country. One possible explanation is migration between regions. The regional capital stock estimated is measured by those individuals actually working in the region though they might have been educated in a different region. Comparing the labour-income human capital proxies with the average schooling years, the inequality among the regions is much lower. Among them, the Mulligan and Sala-i-Martin (1997) measure exhibits the highest standard deviation and shows a volatile evolution. The variable and fixed weights standard deviation values are very close to each other and the evolution is very smooth showing just a slight increase over time.

Figure 4.7 – Standard deviation of the regional human capital proxies



4.5. β-convergence model

As seen in Chapter 2, section 2.3, the inverse relationship between the initial level of income per capita and the respective average growth rate is known in the literature as β-convergence. Following Barro and Sala-i-Martin (1995), there is absolute β-convergence when the poor regions grow faster than those which are richer without conditioning on any other variables. On the other hand, there is conditional β-convergence among a set of regions when the regression of growth rate on the initial income level, holding constant a number of additional variables, exhibits a negative coefficient. As demonstrated in section 2.2, the standard convergence equation (2.53) was directly derived from the Solow model dynamics around the steady-state by Mankiw *et al.* (1992). Following authors such as Islam (1995) and Caselli *et al.* (1995), this convergence equation can be written for the panel context as:

$$\frac{\ln y_{it} - \ln y_{it-\tau}}{\tau} = \beta \ln y_{it-\tau} + \gamma_1 \ln(s_{it}^K) + \gamma_2 \ln(s_{it}^H) + \gamma_3 \ln(n_{it} + g + \delta) + \eta_i + v_{it} \qquad (4.10)$$

where $\beta = -(1-e^{-\lambda\tau})/\tau$, λ is the convergence coefficient, y is the real GDP per capita, s^K is the investment rate and s^H is the human capital accumulation rate, n is the population growth rate, g is the labour-augmenting technological progress and δ is both the physical and human capital depreciation rate. η_i is the individual specific effect, v_{it} is the idiosyncratic error term and $u_{it} = \eta_i + v_{it}$. The time needed for the economies to reduce half of the deviation from the steady-state is called the half-life and is given by: $-\ln(2)/\ln(1+\beta)$.[15]

As seen in section 2.2, the convergence equation can as well be derived with the level of human capital instead of the respective accumulation rate (Equation 2.52) since the steady-state level of human capital in the Solow model depends on the accumulation rates. According to Mankiw *et al.* (1992) the choice depends if the data available on human capital correspond more closely to the rate of accumulation or to the level.

In order to avoid the business cycle effects on the regional GDP per capita (GDPpc), this variable was replaced by the regional GDP per capita relative to the richest region, Grande Lisboa (L). This is $y_{it} = \frac{GDPpc_{it}}{GDPpc_{Lt}}$. The normalization of GDP per capita on the richest region only controls for the business cycle effects under the assumption that the regional cycles are synchronized, which is a limitation. As the richest region is L in every year, an increase in the ratio always indicates a reduction of the gap between each region i and the capital region. The dependent variable is the change of this ratio, which indicates the improvement relative to the richest region and its lag is one of the explanatory variables. The annual data is applied and τ is equal to 1. Most convergence studies work with five years averages of the GDP per capita in order to control for the business cycle though according to Durlauf *et al.* (2005) there is no natural reason to average the data over this time span.

Since there is no data available for investment at this level of regional disaggregation, the physical capital accumulation rate is not included in the regression. Apart from this practical reason there are some other justifications for excluding physical capital from the growth equation. As Krueger and Lindahl (2001) point out, shocks to output

[15] See Barro and Sala-i-Martin (1997), page 37, for the derivation of the half-life.

are likely to influence the optimal level of investment so it is endogenously determined and captured in the initial GDP per capita level. In addition, and because capital and education are complementary, part of the return to capital might be due to education. Romer (1990) also remarks that physical capital growth can in part capture the effect of endogenous technological change.

As generally assumed in the empirical literature, the sum of the technological progress rate with the depreciation rate is assumed to be equal to 0.05, following Mankiw *et al.* (1992). Thus, the fourth explanatory variable on the right-hand-side of the convergence equation depends only on the regional population growth rate.

Working with the level of human capital (H) proxied by the average years of schooling instead of human capital accumulation rate (s^H) and excluding the physical capital accumulation rate (s^K), the convergence equation estimated becomes:

$$\Delta y_{it} = \varphi_o + \varphi_1 y_{it-1} + \varphi_2 \ln(H_{it}) + \varphi_3 \ln(n_{it} + g + \delta) + \eta_i + v_{it} \tag{4.11}$$

where $\varphi_1 < 0, \varphi_2 > 0, \varphi_3 < 0$. The coefficient φ_1 is expected to be negative to indicate convergence, in the sense that the further is a region from the richest initially, the higher will be the reduction of the GDP per capita gap. The coefficient φ_2 indicates the improvement in the relative GDP per capita of a region as a result of an increase in schooling. It is expected to be positively significant because it enhances the region's ability to adopt and implement new technologies [Nelson and Phelps (1966)] or to innovate [Romer (1990)]. φ_3 is expected to be negative according to the theoretical model, the population growth rate has a negative effect on GDP per capita growth rate, but in most empirical studies' findings it is not significant.

4.6. Methodology

The main advantages of panel data methods over cross-section are the possibility of taking into account the omitted variables and endogeneity problems. According to Temple (1999) panel data methods are the only way to obtain consistent estimates of a conditional convergence equation. Since the unobserved individual specific effects are likely to be correlated with the other explanatory variables, the fixed effects (FE) estimator seems more appropriate than the random-effects, even though it is biased if the regressors are not strictly exogenous. The presence of the lag of the dependent variable in the convergence equation invalidates the strict exogeneity assumption and the FE estimator is biased. Bond *et al.* (2001) demonstrate that the FE estimator is biased downwards and proposed the Generalized Method of Moments (GMM), in general, and the system GMM, in particular, as the most appropriate estimator for the convergence equations. The fact that GMM allows consideration of some of the explanatory variables as endogenous is an important advantage over the alternative panel methods: "The potential for obtaining consistent parameter estimates even in the presence of measurement error and endogenous right-hand-side variables is a considerable strength of the GMM approach in the context of empirical growth research - comparing with other estimators such as maximum-likelihood and bias-corrected FE" [Bond *et al.* (2001), p. 14].

The GMM is an instrumental variables method and in the dynamic panel data context two types of GMM appropriate for growth empirics have been developed: the Difference GMM (Diff-GMM) by Arellano and Bond (1991) and the System GMM (Sys-GMM) by Arellano and Bover (1995) and Blundell and Bond (1998).

The Difference GMM applies first differences to the growth equation in order to remove the unobserved time-invariant individual-specific effect (η_i) and then uses the lagged levels dated (T-2) and earlier as instruments for the equation in the first differences. For example, y_{i1} is the only instrument for the first-differenced $(y_{i3} - y_{i2})$ but for $(y_{i4} - y_{i3})$ there are already two instruments, y_{i2} and y_{i1}, and so on. For the last first-differenced $(y_{iT} - y_{iT-1})$ there will be (T-2) instruments:

$y_{it-2}, y_{it-3}, ..., y_{i1}$. Following Bond (2002), for example, the instrument matrix Z_i takes the form:

$$Z_i = \begin{bmatrix} y_{i1} & 0 & 0 & ... & 0 & ... & 0 \\ 0 & y_{i1} & y_{i2} & ... & 0 & ... & 0 \\ ... & ... & ... & ... & ... & ... & ... \\ 0 & 0 & 0 & ... & y_{i1} & ... & y_{iT-2} \end{bmatrix} \quad (4.12)$$

in which the rows correspond to the first-differenced equations for periods t = 3, 4,…,T for each individual unit *i* and exploit the moment conditions:

$$E\left[Z_i{}' \Delta v_i \right] = 0 \text{ for } i\text{=1,2, …N} \quad (4.13)$$

where $\Delta v_i = (\Delta v_{i3}, \Delta v_{i4}, \Delta v_{i5}, ...\Delta v_{iT})'$ (4.14)

Based on this set of moment conditions, the asymptotically efficient GMM estimator minimizes the objective function:

$$J_N = \left(\frac{1}{N} \sum_{i=1}^{N} \Delta v_i{}' Z_i \right) W_N \left(\frac{1}{N} \sum_{i=1}^{N} Z_i{}' \Delta v_i \right) \quad (4.15)$$

Using the weight matrix:

$$W_N = \left[\frac{1}{N} \sum_{i=1}^{N} \left(Z_i{}' \hat{\Delta} v_i \hat{\Delta} v_i{}' Z_i \right) \right]^{-1} \quad (4.16)$$

where $\hat{\Delta} v_i$ are consistent estimates of the first-differenced residuals obtained from a preliminary consistent estimator. The estimator obtained is the two-step GMM estimator.

In a homoscedastic context, the structure of the first-differenced model implies that an asymptotically equivalent GMM estimator can be obtained in one-step, applying instead the following weight matrix:

$$W_{1N} = \left[\frac{1}{N} \sum_{i=1}^{N} (Z_i{}' H Z_i) \right]^{-1} \tag{4.17}$$

in which *H* is a (T-2) square matrix with 2's on the main diagonal and (-1)'s on the first-off diagonals and zeros elsewhere, that is:

$$H = \begin{bmatrix} 2 & -1 & ... & 0 & 0 \\ -1 & 2 & ... & 0 & 0 \\ ... & ... & ... & ... & \vdots \\ 0 & 0 & ... & 2 & -1 \\ 0 & 0 & ... & -1 & 2 \end{bmatrix} \tag{4.18}$$

W_{1N} does not depend on the estimated parameters. This is considered a reasonable choice for the initial consistent estimator used to obtain the optimal weight matrix W_N and to compute the above two-step estimator. Though the one-step does not allow the errors to be heteroscedastic, large parts of the applied literature just use the one-step estimator because the dependence of the two-step weight matrix on estimated parameters makes the usual asymptotic distribution approximations less reliable for the two-step estimator. The Stata command for the two-steps GMM estimator includes the Windmeijer (2005) correction that solves this problem by including a term based on a Taylor series expansion that accounts for the estimation of the weighting matrix *W*. This procedure makes the two-step GMM estimator more efficient in comparison with the first-step one, especially for the System-GMM [Roodman (2006)].

The <u>System GMM</u> combines the equations in first differences, for which the instrumental variables will be the lagged levels, with equations in levels. For this last set of equations, the lagged first-differences will be the instruments for the variables in levels. The instrument matrix for this system is:

$$Z_i^+ = \begin{bmatrix} Z_i & 0 & 0 & ... & 0 & ... & 0 \\ 0 & \Delta y_{i2} & 0 & ... & 0 & ... & 0 \\ ... & ... & ... & ... & ... & ... & ... \\ 0 & 0 & 0 & ... & 0 & ... & \Delta y_{iT-1} \end{bmatrix} \tag{4.19}$$

The levels of y_{it} are necessarily correlated with the individual-specific effects (η_i) but Δy_{it} are not correlated with η_i [$E(\eta_i \Delta y_{it}) = 0$] and this allows lagged first-differences to be used as instruments. The complete set of second-order moment conditions available is:

$$E\left(Z_i^{+\prime} u_i^+ \right) = 0 \tag{4.20}$$

where $u_i^+ = \left(\Delta v_{i3}, \Delta v_{i4}, ..., \Delta v_{iT,} u_{i3,} u_{i4}, ... u_{iT}\right)'$. (4.21)

Bond *et al.* (2001) show that when the times series are persistent the lagged levels are poor instruments for the first-differenced variables in the sense that the lagged levels of the variables are weakly correlated with the subsequent first-differences. Blundell and Bond (1998, 2000) have demonstrated that in this case the first-differenced GMM estimator suffered from a large downwards bias in particular when the number of time periods is small as in the case of the sample of this chapter. Bond *et al.* (2001) argue that under these conditions the System GMM has superior finite sample properties in terms of bias and root mean squared errors and it is more efficient. According to Bun and Windmeijer (2010) both the System and the Difference GMM might suffer from small-sample bias but the System bias is considerably smaller.

The GMM estimators' consistency depends on two main assumptions: no serial second-order correlation and instrument validity. The first can be tested by the Arellano and Bond (1991) test for autocorrelation based on the *m*-statistics which are moment tests of significance of the average *j*-th order autocovariance r_j with the null $r_j = 0$ [Arellano (2003), p. 121]:

$$r_j = \frac{1}{T-3-j}\sum_{t=4+j}^{T} r_{tj} \tag{4.22}$$

in which $r_{tj} = E\left(\Delta v_{it}\Delta v_{i(t-j)}\right)$. (4.23)

The test statitics is given by:

$$m_j = \frac{\hat{r}_j}{SE(\hat{r}_j)} \tag{4.24}$$

where $\hat{r}_j$ is the sample counterpart of r_j based on the first-difference residuals $\Delta\hat{v}_{it}$, obtained from:

$$\hat{r}_{ij} = N^{-1}\sum_{i=1}^{N}\Delta\hat{v}_{it}\Delta\hat{v}_{i(t-j)} \tag{4.25}$$

and $SE(\hat{r}_j)$ is the respective standard error. m_j follows asymptotically a normal distribution N(0,1). For the second-order serial correlation test $j = 2$. The Arellano-Bond test is applied to the residuals in differences and first-order negative serial correlation is expected [Bond (2002)]. As Roodman (2006) explains, Δv_{it} is mathematically related to $\Delta v_{i,t-1}$ via the shared term $v_{i,t-1}$ and therefore first-order serial correlation in the differences is expected and its evidence is uninformative [Roodman (2006), p. 35].

The instrument validity might be tested through the Sargan (1958) or the Hansen (1982) test of overidentifying restrictions which take the joint hypotheses of correct specification and absence of correlation between instruments and errors as the null. If the null is rejected the instruments are not valid. The *J* statistic of Hansen (1982) is the value of the GMM objective function J_N (equation 5.15) evaluated at the efficient GMM estimator and it has a χ^2 distribution with the degrees of freedom equal to the number of overidentifying restrictions which is (*l*-*k*), where *l* is number of moment conditions and *k* is the number of regressors. The Sargan statistic is a special case of Hansen's J under the assumption of conditional homoscedasticity. In both tests a rejection of the null hypothesis implies that the instruments are not satisfying the orthogonality conditions required for their employment because either they are not exogenous or they are being incorrectly excluded from the regression. The Hansen test is superior to the Sargan test since it is robust to heteroscedasticy, though it can be weakened by too many instruments. According to Roodman (2009) when there are too many instruments there is a potential for false positives in the Hansen test with the implausible *p*-value of 1 being the classic sign that the instrument proliferation reduces the test power to detect the invalidity of the instruments. In order to reduce the number of instruments, the Roodman (2009) collapse procedure is applied. This technique consists into combining instruments through addition into smaller sets [Roodman (2009), p. 148)] and changes the instrument matrix, equations 4.12 and 4.19, by squeezing the matrix horizontally and adding together previously different columns. The new "collapsed" instrument matrixes for the Difference and the System GMM are, respectively:

$$Z_i = \begin{bmatrix} 0 & 0 & 0 & 0 & ... \\ y_{i1} & 0 & 0 & 0 & ... \\ y_{i2} & y_{i1} & 0 & 0 & ... \\ y_{i3} & y_{i2} & y_{i1} & 0 & ... \\ ... & .... & ... & ... & ... \end{bmatrix} \tag{4.26}$$

$$Z_i^+ = \begin{bmatrix} Z_i & 0 \\ 0 & \Delta y_{i2} \\ 0 & \Delta y_{i3} \\ 0 & \Delta y_{i4} \\ ... & ... \end{bmatrix} \tag{4.27}$$

4.7. Results

In the estimation of the conditional β-convergence model (equation 4.11), time dummies were introduced in order to control for technological shocks. The F-test confirms their significance at the conventional levels (1 or 5%). A geographic dummy, taking the value 1 for the regions located on the coast, was also included as a robustness test. This dummy is eliminated when the difference GMM is applied because its first difference is always zero. The relative GDP per capita was considered predetermined and the other explanatory variables as potentially endogenous: human capital, production structure and population growth rate. Subsection 4.7.1 reports and discusses the results for regional convergence conditional on human capital according to the different proxies. In subsection 4.7.2 convergence is conditional on the production structure instead.

The introduction of the two conditional variables together in a single regression led to inconsistent GMM estimators because of either invalid instruments, evidenced by the Hansen test, or second-order serial correlation, evidenced by the Arellano-Bond test. Therefore this set of results is not reported. The GMM problems might be due to multicollinearity among the human capital and the production structure variables.

4.7.1. Convergence conditional on human capital

First, the results when human capital is proxied by education, overall and then decomposed into primary, secondary and tertiary average years of schooling are discussed. Second, the labour-income measures are applied as human capital proxies. The Mulligan and Sala-i-Martin (1997) is the preferable proxy, but the other results are reported as well for comparison purposes.

Education proxies

Table 4.6 reports the results obtained when human capital is proxied by the total average years of education. As seen, the results obtained with the one-step and two-step GMM estimator are quite similar, only the significance level of the education coefficient changes in the case of the Difference estimator results. Both the difference and system GMM estimators are consistent since the Arellano-Bond (1991) test for second order serial correlation [AR(2)] cannot reject the null and the Hansen test confirms the instruments validity (*p*-values are higher than 5%).[16] As expected, the coefficient of the lagged relative GDP per capita is negatively significant, evidencing

[16] In the context of an Arellano-Bond GMM regression, AR(1) is to be expected, and therefore the Arellano-Bond for AR(1) test is usually ignored in the context [Roodman 2006)].

convergence among the Portuguese regions. Comparing the size of this coefficient across the GMM estimators, it is much higher in absolute terms when the Difference GMM is applied (roughly around -0.5) in comparison with the system GMM result (near –0.3) This is consistent with the literature, like Bond *et al.* (2001), that demonstrates that the Difference GMM estimator of the lagged variable coefficient is biased downwards. Therefore the half-life obtained is lower for the difference estimator, less than one year.

Table 4.6 – Average years of total education

Dependent variable: Change in relative GDP per capita (Δy_t)

Regressors	GMM 1			GMM 2		
	Diff	Sys	Sys	Diff	Sys	Sys
Constant	-	0.02 (0.14)	-0.07 (-0.46)	-	-0.04 (-0.24)	-0.12 (-0.78)
y_{it-1}	-0.53*** (-7.07)	-0.28*** (-3.77)	-0.30***, (-4.26)	-0.51*** (-7.38)	-0.27*** (-3.31)	-0.30*** (-3.69)
$\ln(n_{it} + g + \delta)$	0.03 (0.61)	0.03 (0.60)	0.01 (0.17)	-0.00 (-0.03)	0.00 (0.10)	-0.02 (-0.34)
$\ln(AvEdu)$	0.13** (2.34)	0.10** (2.44)	0.11** (2.54)	0.10* (1.69)	0.09** (2.13)	0.10** (2.07)
Coast Dummy	-	-	0.03* (1.98)	-	-	0.03* (1.90)
Half-life	0.92	2.11	1.94	0.97	2.20	1.94
No. Observations	317	376	376	317	376	376
No. Instruments	45	49	50	45	49	50
Arellano-Bond test for AR(2)	0.86 (0.39)	1.18 (0.24)	1.02 (0.31)	0.70 (0.48)	1.01 (0.31)	0.85 (0.39)
Hansen test	23.89 (0.96)	25.72 (0.97)	25.35 (0.97)	23.89 (0.96)	25.72 (0.97)	25.35 (0.97)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

The average years of schooling plays a positive and significant role in the convergence process with a coefficient of 0.10 according to the system GMM results. The effect of the population growth rate is insignificant across the different estimators. The results obtained are robust to the inclusion of the coast dummy.

Though its coefficient is only marginally significant (at 10% level), the addition of this dummy in the regression increases the speed of convergence assessed by the size in absolute terms of the lagged relative GDP per capita which implies a reduction of the number of years needed to eliminate half way towards the steady-state (half-life). A half-life of two years obtained with the System GMM is low relative to many empirical studies but consistent with other results obtained for the Portuguese NUTS III regions, such as Soukiazis and Antunes (2011). They used foreign trade as the conditional variable and found a speed of convergence that leads to a half-life between 2 and 6 years, depending on the trade proxy. A wide range of values for the half-life have been reported by the empirical literature, Abreu *et al.* (2005)' meta-analysis of β-convergence includes studies in which the half-life values vary from 1 to 553 years. On average, the panel data studies that use GMM point out to a half-life of 11 years, such as found by Caselli *et al.* (1996), and this value tends to decrease for intra-national studies and for shorter periods of time [Dobson *et al.* (2006)], which is the case of this chapter.

Next the decomposition of education into the main levels, Primary, Secondary and Tertiary (Higher) is considered. Table 4.7 displays the results obtained when human capital is proxied by the average years of primary education. As shown, the Arellano-Bond test evidences no second order serial correlation and the instruments validity is confirmed by the Hansen test across the different GMM estimators. Again the lagged relative GDP per capita coefficient is negatively significant suggesting regional convergence but the primary education contribution is negative. This is an expected result since a decrease in the average years of primary schooling means an increase in the other levels. The coast dummy is only significant for the two-step system GMM results, but again when it is introduced in the regression the speed of convergence is higher which implies a lower half-life, 1.94 instead of 2.11.

Table 4.7 – Average years of primary education

Dependent variable: Change in relative GDP per capita (Δy_t)

Regressors	GMM 1			GMM 2		
	Diff	Sys	Sys	Diff	Sys	Sys
Constant	-	0.11 (1.03)	-0.07 (-0.50)	-	0.03 (0.31)	-0.16 (-1.05)
y_{it-1}	-0.55*** (-7.29)	-0.28*** (-4.23)	-0.30*** (-5.10)	-0.53*** (-6.56)	-0.29*** (-3.87)	-0.31*** (-5.17)
$\ln(n_{it}+g+\delta)$	0.06 (0.97)	-0.01 (-0.37)	-0.07 (-1.48)	0.04 (0.69)	-0.04 (-1.09)	-0.10* (-1.97)
$\ln(Prim)$	-0.08** (-2.47)	-0.04** (-2.03)	-0.03* (-1.80)	-0.08** (-2.33)	-0.03* (-1.86)	-0.02 (-1.36)
Coast Dummy	-	-	0.05 (3.12)	-	-	0.05*** (2.82)
Half-life	0.87	2.11	1.94	0.92	2.02	1.87
No. Observations	317	376	376	317	376	376
No. Instruments	45	49	50	45	49	50
Arellano-Bond test for AR(2)	0.83 (0.41)	1.05 (0.30)	0.63 (0.53)	0.82 (0.41)	0.77 (0.44)	0.32 (0.75)
Hansen test	25.37 (0.94)	23.78 (0.98)	23.53 (0.99)	25.37 (0.94)	23.78 (0.98)	23.53 (0.99)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

When the other levels of education are considered instead, human capital becomes positively significant as can be seen in Tables 4.8 and 4.9. The estimators are consistent since both the Arellano-Bond test for AR(2) and the Hansen tests *p*-values are higher than 5%. The coefficient of the lagged relative GDP per capita is negatively significant across all the estimators suggesting convergence in the sense that the further is a region from the richest region (Grande Lisboa) initially, the higher will be the increase in the relative GDP per capita. Both secondary and tertiary education have a positive and significant effect on the evolution of the relative regional GDP per capita and this result is robust to the different GMM estimators and in most cases to the inclusion of the geographic dummy. The latter is positive and significant suggesting that location near the coast plays a positive effect on growth.

Table 4.8 – Average years of secondary education

Dependent variable: Change in relative GDP per capita (Δy_t)

Regressors	GMM 1			GMM 2		
	Diff	Sys	Sys	Diff	Sys	Sys
Constant	-	0.16 (0.96)	0.03 (0.23)	-	0.10 (0.60)	-0.03 (-0.18)
y_{it-1}	-0.54*** (-6.93)	-0.18** (-2.50)	-0.28*** (-4.11)	-0.53*** (-7.28)	-0.19** (-2.69)	-0.28*** (-3.98)
$\ln(n_{it} + g + \delta)$	0.02 (0.36)	0.07 (1.35)	0.01 (0.14)	-0.01 (-0.16)	0.04 (0.78)	-0.02 (-0.36)
$\ln(Sec)$	0.06** (2.47)	0.08*** (2.80)	0.07*** (2.99)	0.05* (1.94)	0.07** (2.25)	0.06** (2.10)
Coast Dummy	-	-	0.03** (1.71)	-	-	0.03* (1.85)
Half-life	0.89	3.49	2.11	0.92	3.29	2.11
No. Observations	317	376	376	317	376	376
No. Instruments	45	49	50	45	49	50
Arellano-Bond test for AR(2)	0.73 (0.46)	1.28 (0.20)	0.95 (0.34)	0.61 (0.54)	1.19 (0.23)	0.81 (0.42)
Hansen test	25.07 (0.95)	25.20 (0.97)	25.10 (0.98)	25.07 (0.95)	25.20 (0.97)	25.10 (0.98)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Table 4.9 – Average years of higher education

Dependent variable: Change in relative GDP per capita (Δy_t)

Regressors	GMM 1			GMM 2		
	Diff	Sys	Sys	Diff	Sys	Sys
Constant	-	0.36 (1.83)	0.25 (1.70)	-	-0.30 (1.58)	0.16 (0.97)
y_{it-1}	-0.53*** (-6.96)	-0.20*** (-3.54)	-0.31*** (-4.48)	-0.51*** (-6.02)	-0.20*** (-3.29)	-0.31*** (-3.00)
$\ln(n_{it} + g + \delta)$	0.06 (1.00)	0.09 (1.35)	0.04 (0.75)	0.04 (0.57)	0.07 (1.07)	0.01 (0.l7)
$\ln(Ter)$	0.03** (2.40)	0.02** (2.07)	0.02** (2.08)	0.03* (1.75)	0.02* (1.91)	0.02 (1.47)
Coast Dummy	-	-	0.03** (2.02)	-	-	0.03* (1.91)
Half-life	0.92	3.11	1.87	0.97	3.11	1.87
No. Observations	317	376	376	317	376	376
No. Instruments	45	49	50	45	49	50
Arellano-Bond test for AR(2)	0.92 (0.36)	1.34 (0.18)	1.12 (0.26)	0.80 (0.42)	1.27 (0.20)	0.92 (0.36)
Hansen test	24.27 (0.96)	26.33 (0.96)	24.78 (0.98)	24.27 (0.96)	26.33 (0.96)	24.78 (0.98)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Comparing the coefficients of the two education proxies, the effect of secondary school is larger (in the range 0.06-0.08) than the impact of higher education (0.02-0.03). This might be explained by the level of development of the majority of the Portuguese regions which are well below the European average. At the end of the period, only the richest region (Grande Lisboa) income per capita was above 75% of the European average. It is known in the literature that the effect of different levels of education depends on the level of development of countries or regions [Sianesi and Van Reenen (2003)], higher education matters for growth in OECD countries, in contrast with the less developed countries where primary and secondary schooling are more important [Petrakis and Stamatakis (2002)]. At the Portuguese national level, Pereira and St. Aubyin (2009) found no link between tertiary education and economic growth in Portugal. At the regional level, there are even some studies that found a negative effect of higher education on growth, such as Di Liberto (2008) work on the Italian regional convergence.

The impact of higher levels of education on growth increases as the countries (or regions) become closer to the technological frontier [Vandenbussche *et al.* (2006)] and since Portugal is a follower, the effect of higher education is lower than the impact of the secondary level. The Portuguese innovation levels are quite low in European terms [OECD (2008)] and the technical progress derives mainly from technological adoption for which secondary schooling is probably enough. The lack of science and technology degrees among the Portuguese higher education graduates, in comparison with other OECD countries, which contributes to a lower level of innovation[17], is another possible reason for the lower effect of higher education.

In conclusion, apart from the primary schooling all the education proxies show a positive and significant effect on the reduction of regional income disparities. Secondary school effect is lower than total average education impact, but higher than the tertiary school effect. The negative and significant relative GDP per capita coefficient suggests convergence over the period. The half-life estimated through the System GMM is in the range 2-3 years which is close to the values obtained by Soukiazis and Antunes (2011). The coast effect is always positive and around 0.03 but most times just marginally significant (at 10% level). Though, its inclusion in the estimation tends to increase the size in absolute terms of the lagged relative GDP per capita coefficient suggesting that being close to the coast speeds up regional convergence and reduces the half-life.

When the human capital stock was replaced in the convergence equation by the human capital change, the respective coefficients became insignificant and they are not reported. This is a common result in cross-country literature [Benhabib and Spiegel (1994), Pritchett (2001), Krueger and Lindahl (2001)] and suggests that for the Portuguese regional growth, human capital is more important for technology adoption in the line with Nelson and Phelps (1966) than as an input in the production function [Lucas (1988)].

[17] OECD (2007), “Tertiary Education in Portugal-Background Report”

Labour-income proxies

Table 4.10 reports the results for the convergence equation when human capital is proxied by the Mulligan and Sala-i-Martin (1997) labour-income measure (LIHK). Again the number of instruments was reduced by applying the collapse option [Roodman (2009)].

Table 4.10 – Mulligan and Sala-i-Martin (1997) proxy (LIHK)

Dependent variable: Change in relative GDP per capita (Δy_t)

Regressors	GMM 1			GMM 2		
	Diff	Sys	Sys	Diff	Sys	Sys
Constant	-	0.27* (1.79)	0.24* (1.84)	-	0.18 (1.14)	0.15 (1.08)
y_{it-1}	-0.54*** (-10.36)	-0.31*** (-4.24)	-0.38*** (-5.82)	-0.54*** (-8.50)	-0.30*** (-3.55)	-0.39*** (-5.29)
$\ln(n_{it} + g + \delta)$	0.03 (0.58)	0.04 (0.81)	0.03 (0.58)	-0.01 (-0.31)	0.01 (0.28)	-0.00 (-0.05)
$\ln(LIHK)$	0.05 (1.37)	0.05 (1.35)	0.04 (1.25)	0.02 (0.97)	0.03 (0.81)	0.03 (1.10)
Coast Dummy	-	-	0.05 (1.25)	-	-	0.05** (2.66)
Half-life	0.89	1.87	1.45	0.89	1.94	1.40
No. Observations	317	376	376	317	376	376
No. Instruments	45	49	50	45	49	50
Arellano-Bond test for AR(2)	0.88 (0.38)	1.22 (0.22)	1.06 (0.29)	0.54 (0.59)	1.00 (0.32)	0.83 (0.41)
Hansen test	23.34 (0.97)	25.45 (0.97)	25.34 (0.97)	23.34 (0.97)	25.45 (0.97)	25.34 (0.97)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

The Arellano-Bond test confirms the absence of second-order serial-correlation and the Hansen test indicates the validity of the instruments since the respective *p*-values are higher than 5%. In contrast with the results obtained when human capital was proxied by education, the effect on regional growth of human capital proxied by the LIHK is insignificant across the different estimators. The main advantage of this proxy is the introduction of a measure of quality in the human capital stock by assuming that wages differentials are an outcome of productivity differences among workers. Though, as noted before, in some Portuguese regions the zero-schooling wage tends to be dominated by the minimum wage and this overestimates the respective zero-schooling wage, which is the numeraire. As a consequence, in that set of regions the wage differentials are underestimated and do not reflect properly the productivity differentials. The Mulligan and Sala-i-Martin (1997) proxy also assumes that the zero-schooling worker is a perfect substitute for all the others in every regions which is a strong assumption that might not hold. The quality of the proxy and this limitation might partially explain its insignificance.

The lagged relative GDP per capita coefficient is negatively significant, as expected, and its size is quite similar to what was obtained when human capital is proxied by the average years of schooling. Again, it is much higher in absolute value when the difference-GMM estimator is applied because this estimator is biased downwards. The coast dummy coefficient is positive but only significant in the two-steps GMM results. The two-steps estimator is more efficient [Roodman (2006)] so the respective results are preferable. The inclusion of this geographic dummy increases the speed of convergence assessed by the size in absolute terms of the lagged relative GDP per capita coefficient implying a reduction of the half-life.

For comparison purposes, Tables 4.11 and 4.12 report the results obtained when the alternative labour-income proxies (the variable and the fixed weights) were applied. In both cases, the diagnostic tests confirm the consistency of the estimators. At the conventional levels of significance, the null hypothesis of no second-order serial correlation cannot be rejected by the Arellano-Bond test and the null of correct specification and absence of correlation between instruments and errors is not rejected by the Hansen test.

As the results for convergence conditional on human capital proxied by education, the significant negative coefficient of the lagged relative GDP per capita suggests convergence among the Portuguese regions and the introduction of the coast dummy increases the respective speed. For both the fixed and the variable weights results, the coast dummy is positively significant at 5% suggesting that being located at the coast contributes to reduce the income gap towards the richest region, Grande Lisboa, and accelerates the process. In the variable weights labour-income human capital proxy

(VW) computation, the efficiency parameter (θ) varies over time, but not across space while in the fixed weights proxy (FW) this parameter is both time and space invariant. For both proxies, the results show a positive coefficient when both the one and two-steps difference GMM estimators are applied however it is not significant at the conventional levels. The only exception is the one-step difference GMM results when the FW is applied. As happened with the Mulligan and Sala-i-Martin (1997) proxy, these labour-income human capital measures show no effect on convergence at the conventional levels of significance.[18]

Table 4.11 – Variable weights (VW)

Dependent variable: Change in relative GDP per capita (Δy_t)

Regressors	GMM 1			GMM 2		
	Diff	Sys	Sys	Diff	Sys	Sys
Constant	-	0.20 (1.45)	0.16 (1.35)	-	0.15 (0.91)	0.12 (0.94)
y_{it-1}	-0.63*** (-6.01)	-0.29*** (-3.70)	-0.35*** (-4.76)	-0.61*** (-5.82)	-0.29*** (-3.67)	-0.36*** (-4.57)
$\ln(n_{it} + g + \delta)$	0.03 (0.70)	0.03 (0.58)	0.01 (0.30)	0.02 (0.39)	0.01 (0.16)	-0.00 (-0.08)
$\ln(VW)$	0.24* (1.97)	0.08 (1.35)	0.10 (1.52)	0.21* (1.69)	0.07 (1.20)	0.08 (1.36)
Coast Dummy	-	-	0.04** (2.36)	-	-	0.05** (2.31)
Half-life	0.70	2.02	1.61	0.74	2.02	1.55
No. Observations	317	376	376	317	376	376
No. Instruments	45	49	50	45	49	50
Arellano-Bond test for AR(2)	0.73 (0.46)	1.03 (0.30)	0.92 (0.36)	0.61 (0.54)	0.87 (0.39)	0.81 (0.42)
Hansen test	25.85 (0.93)	25.69 (0.97)	25.52 (0.97)	25.85 (0.93)	25.69 (0.97)	25.52 (0.97)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

[18] The same regressions were done with changes in the labour-income measures of human capital, instead of the stock, and as happened with the education proxies the coefficients were insignificant and the results are not reported.

Table 4.12 – Fixed weights (FW)

Dependent variable: Change in relative GDP per capita (Δy_t)

Regressors	GMM 1			GMM 2		
	Diff	Sys	Sys	Diff	Sys	Sys
Constant	-	0.17 (1.03)	0.15 (0.99)	-	0.12 (0.62)	0.09 (0.57)
y_{it-1}	-0.54*** (-6.50)	-0.28*** (-3.97)	-0.33*** (-4.71)	-0.53*** (-6.39)	-0.28*** (-3.81)	-0.33*** (-4.42)
$\ln(n_{it}+g+\delta)$	0.04 (0.72)	0.03 (0.57)	0.02 (0.37)	0.02 (0.25)	0.01 (0.15)	-0.00 (-0.08)
$\ln(FW)$	0.26** (2.16)	0.15 (1.55)	0.14 (1.46)	0.21 (1.51)	0.14 (1.63)	0.11 (1.31)
Coast Dummy	-	-	0.04** (2.13)	-	-	0.04** (2.08)
Half-life	0.89	2.11	1.73	0.92	2.11	1.73
No. Observations	317	376	376	317	376	376
No. Instruments	45	49	50	45	49	50
Arellano-Bond test for AR(2)	0.86 (0.39)	1.14 (0.25)	1.04 (0.30)	0.74 (0.46)	1.00 (0.32)	0.89 (0.38)
Hansen test	24.86 (0.95)	25.44 (0.97)	25.56 (0.97)	24.86 (0.95)	25.44 (0.97)	25.56 (0.97)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

In terms of the human capital stock, the main conclusion is the effect on the reduction of regional income disparities depends on the proxy chosen. In contrast with the education proxies, the labour-income human capital measures are insignificant in the conditional convergence equation and seem to have no effect on regional growth.

4.7.2. Convergence conditional on the production structure

In order to compare the performance of human capital in the convergence equation with other possible conditioning factors, the production structure was introduced as an alternative conditional variable. The main economic sectors considered are: Primary (Agriculture, forestry and fishery), Secondary (Industry, including energy and civil construction) and Tertiary (Services). The proxy is the share of each economic sector in the regional Gross Value Added. It is not possible to consider the respective weight in employment because data on the sectoral distribution of employment is not available at this level of regional disaggregation.

Economic theory provides support for the inclusion of the production structure in growth regressions. Echevarria (1997), for example, develops a cross-country model including the three economic sectors (agriculture, industry and services), in which the factor intensities and the rate of technological progress differ across the sectors, and shows that the production structure explains a considerable part of the growth rate differences among countries. More recently, Caselli (2005) demonstrates that when the sectoral composition of GDP is taken into account, the income inequality among countries explained by factor endowments decreases substantially. Income differences among countries are mainly explained by differences in total factor productivity which depend on the output sectoral composition. Temple and Wöβmann (2006) develop a two-sector model for a small open economy in which the relationship between growth and the extent of structural change is convex. When the model is applied to cross-country data, they found that the introduction of the structural change term increases the explanatory power of the growth regressions. More specifically dedicated to the tertiary sector, Guerrieri *et al.* (2005) propose a model which focuses on the links between technology diffusion and services in which technological accumulation depends on the imports of services and these are facilitated by low levels of regulation. Their estimation, for a panel of European countries plus Japan and US, shows that output is positively related with both domestic and imported services. In general, the structural change results from the interaction between supply and demand factors.

At an empirical level there is evidence that income per capita growth is associated with a shift from agriculture to the other sectors, both in employment and output shares, followed by a reallocation from industry to services. These changes of each sector share in total output is a result of the Engel's Law, which states that the consumption of agricultural goods increases less than proportionally with GDP per capita growth. Kongsamut *et al.* (2001) named these empirical regularities as the Kuznets facts [Kuznets (1973)]. Eichengreen and Gupta (2009) identify another important fact: the service sector growth during the second half of the 20th Century has been characterized by two-waves. A first wave has occurred in the countries with a low level of GDP per capita, where the increase of the tertiary sector share in GDP is mainly due to the rise of the traditional services produced locally. In contrast, in high income level countries a second wave has happened, with the boom of the modern services that benefit from the application of information technologies, like financial, communication, computer, legal, advertising and business services. Contrary to the traditional services, the modern services are increasingly tradable across borders.

Though in most developed countries the secondary sector share declined steadily during the second half of the 20th Century, the evolution in Portugal was different. The industrialisation process started quite late, in the 1960s. Although there was an increase in the weight of the secondary sector in output and employment, its importance was always lower in Portugal than in other EU15 countries, even the ones which were closer in the stage of development, like Ireland. Several authors [Silva Lopes (1999), Neves (2003), Lains (2008)] have argued that in Portugal there was a significant shift from the primary to the tertiary sector, in contrast with most developed countries. Considering the period of the study 1991-2006 and the level of development of the country, the expansion of the services identified in the Portuguese regions can be classified as second-wave.

Table 4.13 reports the results for Portuguese regional convergence conditional on the share of industry and services, respectively, in the production structure.[19]

[19] When the proxy was the share of agriculture the respective coefficient was insignificant so the results are not reported.

Table 4.13 – Industry and Services share in total output

Dependent variable: Change in relative GDP per capita (Δy_t)

Regressors	GMM 1			GMM 2		
	Diff	Sys	Sys	Diff	Sys	Sys
Constant	-	0.21 (1.62)	0.17 (1.33)	-	0.15 (1.05)	0.11 (0.80)
y_{it-1}	-0.54*** (-5.50)	-0.29*** (-3.57)	-0.35*** (-4.76)	-0.53*** (-5.36)	-0.27*** (-2.92)	-0.33*** (-4.27)
$\ln(n_{it} + g + \delta)$	-0.00 (-0.07)	0.01 (0.27)	-0.01 (-0.14)	-0.02 (-0.33)	-0.00 (-0.05)	-0.02 (-0.44)
Industry	-0.18* (-1.69)	-0.10 (-1.17)	-0.13 (-1.28)	-0.14 (-1.26)	-0.07 (-0.83)	-0.08 (-0.89)
Coast Dummy	-	-	0.05** (2.43)	-	-	0.05** (2.26)
Half-life	0.89	2.02	1.61	0.92	2.20	1.73
No. Observations	317	376	376	317	376	376
No. Instruments	45	49	50	45	49	50
Arellano-Bond test for AR(2)	0.79 (0.43)	1.11 (0.27)	0.97 (0.33)	0.69 (0.49)	0.94 (0.35)	0.82 (0.41)
Hansen test	25.86 (0.93)	26.94 (0.96)	25.93 (0.97)	25.86 (0.93)	26.94 (0.96)	25.93 (0.97)
Constant	-	0.08 (0.66)	0.04 (0.27)	-	0.07 (0.55)	0.02 (0.12)
y_{it-1}	-0.43*** (-5.16)	-0.27*** (-4.57)	-0.32*** (-4.97)	-0.42*** (-5.03)	-0.26*** (-3.71)	-0.33 (-4.51)
$\ln(n_{it} + g + \delta)$	-0.01 (-0.20)	0.03 (0.60)	0.01 (0.12)	-0.02 (-0.50)	0.02 (0.46)	-0.01 (-0.13)
Services	0.12 (1.38)	0.20** (2.35)	0.19** (2.15)	0.09 (1.07)	0.18** (2.08)	0.17* (1.84)
Coast Dummy	-	-	0.04** (2.04)	-	-	0.04* (1.82)
Half-life	1.23	2.20	1.80	1.27	2.30	1.73
No. Observations	317	376	376	317	376	376
No. Instruments	45	49	50	45	49	50
Arellano-Bond test for AR(2)	0.85 (0.39)	1.19 (0.24)	1.02 (0.31)	0.73 (0.47)	1.19 (0.23)	1.00 (0.32)
Hansen test	26.15 (0.93)	27.69 (0.94)	26.95 (0.96)	26.15 (0.93)	27.69 (0.94)	26.95 (0.96)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

The diagnostic tests suggest that both the difference and system GMM estimators are consistent since the Arellano-Bond (1991) test cannot reject the null of no second-order serial-correlation and the Hansen test confirms the instruments validity as the respective *p*-values are higher than 5%. As expected, the coefficient of the lagged relative GDP per capita is negatively significant, evidencing convergence among the Portuguese regions. The values obtained with the System GMM for the half-life is in the range 1-2 years, which are similar to those obtained when the conditional variable was human capital and close to those obtained by Soukiazis and Antunes (2011) for the same set of regions. These results show that the time needed for the Portuguese regions to reduce half of the gap towards their steady-state is very similar across estimations using different conditional variables.

In what concerns the effect of the production structure on regional growth, the effect of the services share is positive and significant according to the system GMM, which is the preferable estimator since the difference is biased. The importance of the tertiary sector in the reduction of the Portuguese regional income disparities was expected and it is in accordance with the empirical stylized facts. Services were the most dynamic sector over the period and its weight in total output increased substantially in national terms, from 58% %, in 1991, to 73%, at the end of the period. According to the regional profile, the services weight in the total output tends to be higher in the richest than in the poorest regions. Though the coefficient of the weight of the industrial sector is negative, it is not significant for the convergence process which shows that in general the Portuguese regions are already at the stage of development for which the secondary sector does not matter for growth. As seen in the regional profile, in the richest regions like Algarve and Madeira which developed a strong tourism sector, the share of the secondary sector in the output is quite low comparing to the other regions.

As in the previous subsection estimations, the results obtained are robust to the introduction of the coast dummy. It is positive and significant at the conventional levels of significance, suggesting that geography matters for the convergence process. The findings indicate that the reduction of the income per capita gap towards the richest region is facilitated by a higher weight of the services in the production structure reinforced by the coast effect. In coastal regions such as Algarve and Madeira, the tertiary sector is dominated by tourism.

Relating the results of the two subsections, there is evidence of a positive role of both human capital proxied by education and the weight of services in the production structure. Among the three economic sectors, services tend to be the most intensive in human capital, especially the modern services associated with the so-called second wave, so the results obtained in the two subsections reinforce each other.

4.8. The Social Returns to Education

In this section a "Macro-Mincer" wage equation is estimated for the Portuguese regions in order to obtain the social returns to education and then compare them with the private returns usually found for Portugal by labour economics studies based on the "Micro-Mincer" equation. By comparing both, it is possible to detect any evidence of external benefits which might be at the production level, such as the increase of productivity of workers that results from their interaction with those with more skills [Lucas (1988)], like a higher and more effective participation of the citizens in the political process [Milligan *et al.* (2004)] or the reduction of crime [Lochner and Moretti (2004)].

The "Macro-Mincer" wage equation was firstly introduced in the literature by Heckman and Klenow (1998). Their objective was to compare social and private returns to education in order to identify possible externalities in a cross-country setup. When they control for life expectancy as a proxy for technology differences, their macro and micro estimates are quite similar suggesting no externalities. Pritchett's review of empirical work [Pritchett (2006)] gives little evidence of positive externalities and even mention cases of education social returns being lower than the private ones (negative externality), mainly among the poor countries. One of the reasons is the fact that in poor countries the public sector tends to absorb great part of the workers with higher levels of education and the effect on productivity is lower than if they were employed in the private sector. On the other hand, the social return can exceed the private return since is important to obtain a more efficient matching between workers and jobs [Temple (2001)] and the individuals do not capture all the benefits their education generate to society (increase in productivity, crime reduction, better democracy). In terms of policy implications, the larger the gap between the social and the private return, the more education and training should be subsidized.

4.8.1. The Micro and Macro-Mincer wage equations

The so-called Mincerian wage equation was developed by Mincer (1974) and it expresses a linear relation between the log of individual earnings (w_i) and the respective years of schooling (*edu*) and experience (*exp*):

$$\ln(w_i) = a_0 + a_1 edu_i + a_2 exp_i + a_3 exp^2 + \varepsilon_i \tag{4.28}$$

where a's are the coefficients and ε is the error term. This is valid under the assumptions that the only cost of attending school an additional year is the opportunity cost of the individual's time and the increase in earnings caused by an extra year of schooling is constant over time. The inclusion of the quadratic term in work experience allows for returns to on-the-job training and the coefficient a_1 can be interpreted as the rate of return to investment in schooling, this is the increase in the wage logarithm as a result of an extra schooling year.

The "Macro-Mincer" wage equation can be obtained by aggregating across individuals and taking the geometric means of the variables [Krueger and Lindahl (2001)]. According to Pritchett (2006) this is the simplest approach and the "Macro-Mincer" wage equation becomes:

$$\ln AvW_{it} = a_0 + a_1 AvEdu_{it} + a_2 AvExp_{it} + \eta_i + v_{it} \tag{4.29}$$

in which the variables for each region *i* are the respective averages in each year *t*: average monthly wage (AvW), average years of education (*AvEdu*) and average years of experience ($AvExp$). η_i denotes the region-specific effect and v_{it} stands for the idiosyncratic error term. The quadratic term of experience disappears as a result of the aggregation process. In the spirit of the original Mincer equation, a_1 can be interpreted as the social return to education.

Usually the "Macro-Mincer" wage equation controls for the physical capital stock per worker [Pritchett (2006)], but due to lack of data on this variable for the Portuguese NUTS III regions, the physical capital stock is not included. This implies assuming perfect capital mobility to identify the social return to education, like Turner *et al.* (2006) did to estimate the social returns to schooling and to potential experience for the US over the period 1840-2000. The assumption of perfect capital mobility seems quite reasonable for the Portuguese regions. Turner *et al.* (2006) found a return to a year of schooling varying from 11% to 15%, quite similar with the micro-estimates and thus indicating no education externalities.

4.8.2. Estimation and Results

In order to estimate Equation (5.29) for the Portuguese regions over the period 1991-2006, the data collected from GEP/MTSS on the average wage and average age of each region's workers is applied. Following Turner *et al.* (2006), the average years of experience is the average age of the workers minus the average years of schooling minus six years of pre-schooling.

The "Macro-Mincer" equation is estimated by the GMM (described in Section 4.6.) in order to control for endogeneity. The results are reported in Table 4.14. As in the convergence equations, the number of instruments was reduced by applying the collapse option [Roodman (2008)]. The Hansen test confirms the validity of the instruments in both the Difference and System GMM. The Arellano-Bond (1991) test indicates second-order serial-correlation, at 5 and 10% level for the one and two-step Difference-GMM respectively, so the estimator is not consistent. Since this estimator is also biased [Bond *et. al* (2001), Bond (2002)] and the System-GMM results show no second order serial- correlation, both with and without the coast dummy, the discussion of the coefficients relies on the System-GMM results.

The social return of an extra year of schooling is 13% according to both the one and two-steps GMM, falling to 12% when the coast dummy is introduced in the two-step estimation. This return is quite close to the individual returns to education in Portugal found by Pereira and Martins (2002), around 11%, and Psacharopoulos and Patrinos (2004), in the range 9-10%. According to Pereira and Martins (2002) meta-analysis using results for Portugal from a large number of studies, the private returns to schooling vary from 3% to 12.4%, depending on the other control variables included in the micro-Mincer equation. The simple comparison between the tendency of the micro estimates and the macro estimate found in this section gives little support to education externalities which is consistent with the weak evidence usually found in the empirical literature [Pritchett (2006)]. Moving to the other explanatory variables, the experience has a positive and significant effect on the average wage as well, but the size is lower than all the other coefficients. The coast dummy is always positive and significant, implying that the log average wage in the regions located at the coast is around 10% higher than in the others.

Table 4.14 – Average Earnings

Dependent variable: $\ln w_{it}$

Regressors	GMM 1			GMM 2		
	Diff	Sys	Sys	Diff	Sys	Sys
Constant	-	4.78^{***} (20.67)	4.91^{***} (27.48)	-	4.79^{***} (19.74)	4.93^{***} (25.26)
AvEdu	0.08^{***} (6.67)	0.13^{***} (6.80)	0.13^{***} (8.61)	0.08^{***} (6.66)	0.13^{***} (6.69)	0.12^{***} (7.68)
AvExp	-0.01 (-1.35)	0.03^{***} (5.55)	0.02^{***} (4.77)	-0.01 (-1.36)	0.03^{***} (4.76)	0.02^{***} (4.19)
Coast Dummy	-	-	0.10^{***} (5.48)	-	-	0.11^{***} (3.63)
No. Observations	390	450	450	390	450	450
No. Instruments	47	51	52	47	51	52
Arellano-Bond test for AR(2)	-2.20 (0.03)	0.74 (0.46)	0.51 (0.61)	-1.78 (0.08)	0.64 (0.52)	0.47 (0.64)
Hansen test	29.36 (0.91)	29.82 (0.95)	29.44 (0.96)	29.36 (0.91)	29.82 (0.95)	29.44 (0.96)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 1%, 5% level and 10% level.

4.9. Conclusion

This work contributes to the literature in the following: First, it introduces two different measurements of the Portuguese regional human capital stocks by applying both an education and an income approach. Secondly, it assesses the effect of human capital on regional growth and convergence in Portugal. In order to compare the role of different conditioning factors, the production structure according to the three main economic sectors was introduced as well.

The effect of human capital on the regional convergence really depends on the proxy considered. The findings suggest a positive role of human capital proxied by education in reducing regional income per capita disparities, but when the labour-income measures are included instead, human capital becomes insignificant. Across the different estimators, the findings support the hypothesis that higher levels of education improved the Portuguese regions' ability to adopt new technologies, which facilitated the catching-up with the capital region, Grande Lisboa. There is empirical evidence of a positive effect of the average years of schooling and the estimation of the Macro-Mincer wage equation confirms the positive impact of education suggesting a social return around 13%. When different levels of education are taken into account mixed results are obtained. In contrast with primary schooling, secondary and tertiary education have played a positive role in the convergence process since the skills needed to adopt the new technologies are provided by higher levels of education.

As regards the production structure, the results indicate a positive effect of services on regional growth and convergence. The tertiary sector, especially the modern services, which rely heavily on human capital, is important for regional growth. There is also evidence that the reduction of income disparities is higher among the regions located on the coast, where the tourism industry is concentrated and accounts for a great share of the tertiary sector output.

Overall, the findings have some policy implications. In the last three decades there has a been a large effort to spread higher education institutions across the Portuguese regions and though the empirical results suggest a positive effect of total education in the decrease of income per capita disparities among the Portuguese regions, the effect of secondary schooling is higher in comparison with the impact of higher education. A possible explanation is the lack of Science and Technology degrees among the Portuguese graduates, therefore future investments on higher education should take into consideration the most relevant academic fields.

Appendix to Chapter 4

Table 4.15 – Portuguese NUTS regions

NUTS II		NUTS III	
PT11	Norte	PT111	Minho-Lima
		PT112	Cavado
		PT113	Ave
		PT114	Grande Porto
		PT115	Tamega
		PT116	Entre Douro e Vouga
		PT117	Douro
		PT118	Alto Tras-os-Montes
PT15	Algarve	PT150	Algarve
PT16	Centro	PT161	Baixo Vouga
		PT162	Baixo Mondego
		PT163	Pinhal Litoral
		PT164	Pinhal Interior Norte
		PT165	Dao-Lafoes
		PT166	Pinhal Interior Sul
		PT167	Serra da Estrela
		PT168	Beira Interior Norte
		PT169	Beira Interior Sul
		PT16A	Cova da Beira
		PT16B	Oeste
		PT16C	Medio Tejo
PT17	Lisboa	PT171	Grande Lisboa
		PT172	Peninsula de Setubal
PT18	Alentejo	PT181	Alentejo Litoral
		PT182	Alto Alentejo
		PT183	Alentejo Central
		PT184	Baixo Alentejo
		PT185	Lesiria do Tejo
PT20	R.A. Acores	PT200	R.A. Acores
PT30	R.A. Madeira	PT300	R.A. Madeira

Chapter 5

The role of human capital in the Spanish regional growth and convergence: a comparative perspective

5.1. Introduction

The purpose of this chapter is to study the effect of human capital on the Spanish NUTS III regions income per capita convergence over the same period considered in the previous chapter (1991-2006) and compare the two Iberian countries regional growth. This is different to the previous studies on Spanish regions which use the NUTS II regions' data. According to the NUTS classification, Spain is divided into 59 NUTS III regions which correspond to the Spanish provinces[20]. In order to compare the results with those obtained for the Portuguese regions, the same model and methodology are applied. As for Portugal, the production structure according to the main economic sectors (agriculture, industry and services) will be considered as an alternative conditional variable.

The role of human capital in Spanish regional convergence has been studied by several authors, but most of them work with the NUTS II level of regional disaggregation.[21] This level corresponds in Spain to the Autonomous Communities which are administrative regions with a high degree of political and financial autonomy. de la Fuente (2002) concluded that the equalization of education levels contributed to the reduction of productivity disparities over the period 1955-1991. Di Liberto (2007) studied the role of human capital in the Spanish NUTS II regions growth over the period 1964-1997 and divided the regions into two clubs according to the level of GDP per capita and human capital. The average years of total education and the average years of secondary schooling played a positive and significant role only in the rich regions club, in contrast with the significant and positive effect of primary schooling in the poor club. For a shorter period, 1995-2000, Galindo-Martín and Álvarez-Herranz (2004) found a positive effect of human capital proxied by the Mulligan and Sala-i-Martin (1997) labour-income measure on regional GDP per capita growth. López-Bazo and Moreno (2007) estimated both the private and social

[20] See Table 5.18 in the appendix to this chapter.
[21] All apart from a recent contribution of Ramos *et. al* (2010).

returns to human capital in the Spanish NUTS II regions for the period 1980-1995 and found higher human capital externalities in the regions with a less favourable position. The same authors [López-Bazo and Moreno (2008)] distinguished the direct effect of human capital on output from its indirect effect of stimulating investment in physical capital and their findings suggest not only a positive effect of human capital on aggregate productivity but also a significant indirect effect through the stimulation of investment in physical capital.

The structure of the chapter is the following: Section 5.2. presents the data and a brief profile of the Spanish provinces including a shift-share analysis. Section 5.3. examines σ-convergence in both human capital and GDP per capita. The β-convergence model is presented in Section 5.4. Section 5.5. discusses the results and Section 5.6. concludes.

5.2. Data and Regions' Profile

5.2.1. GDP and population

Data on these variables was collected from the Spanish National Institute of Statistics' (INE) Regional Accounts. As happened with the Portuguese GDP data, before 1995 the GDP nominal values are provided in the country's national currency, Pesetas, and according to the 1986 accounting system. The nominal regional GDP for 1994 is given for both accounting systems (1986 and 1995), so this common year was used to convert the previous years (1991-93) values into a series closer to the 1995 new accounting system. The second step was to convert the GDP value into Euros by using the respective exchange rate at 31 December 1998 (1 Euro=166.66 Pesetas). GDP real values were then calculated using the GDP deflator and, as for Portugal, 2000 was the base year and the national deflator was applied instead of the regional deflators. As seen in Chapter 4, this procedure results from the absence of regional GDP deflators and implies assuming small differentials in the deflator across the regions. This assumption might not hold and this is a limitation, however to a smaller extent than in other countries since the inflation differentials within Portugal and Spain are lower than in other members of the Euro area such as Italy and Austria

[Beck *et al.* (2009)]. Data on the contribution of each sector (primary, secondary and tertiary) to each province's total Gross Value Added (GVA) was also provided by INE. Due to data unavailability the provinces of the islands (Canarias and Baleares) and the Northern Africa territories are excluded. The panel integrates only the 47 Spanish continental provinces.

Table 5.1 summarizes the main regional economic indicators and the provinces (NUTS III regions) are ranked from the highest to the lowest level of GDP per capita in 1991. Apart from the capital province, Madrid, which is among the richest as expected, all the other provinces located at the top of GDP per capita ranking are in the País Vasco (Basque Country) and Cataluña, which are both in the Northeast. In contrast with Portugal, the richest NUTS III region over all the period is not the capital region but the Basque province of Álava. Madrid's relative position improved over the period, from the 4th in 1991 to the second richest in 2006. The poorest provinces are located in Extremadura, Andalucía and Galicia, have a higher share of agriculture in total Gross Value Added (GVA) and tend to remain poor over the period.

The production structure has changed across the country since 1991, but in contrast with Portugal there is no tendency of the richest NUTS III regions to have a higher share of the tertiary sector. In the richest Spanish province, Álava, the secondary sector contribution to GVA is much higher than the national average and the services share much lower. Provinces with a high share of the services in total GVA are found both at the top and at the bottom of the ranking. Cáceres and Badajoz are among the poorest provinces and exhibit a very high share of the tertiary sector in national terms. Though services were the most dynamic sector, with an annual average growth rate around 3.91%, all the sectors exhibited a positive growth rate, 1.73% in the industrial sector and 0.83% in agriculture.

Across the provinces, there was a decrease in the contribution of agriculture and industry to total output compensated by a significant increase in the weight of services but this evolution is not as striking as in Portugal. There are even some exceptions like Cádiz where the weight of the industrial sector increased over the period. In 1991 the tertiary sector share was almost the same in two Iberian countries, roughly 58%, but has increased much more in Portugal than in Spain, to 73% and 66% respectively.

Table 5.1 – The provinces' main indicators

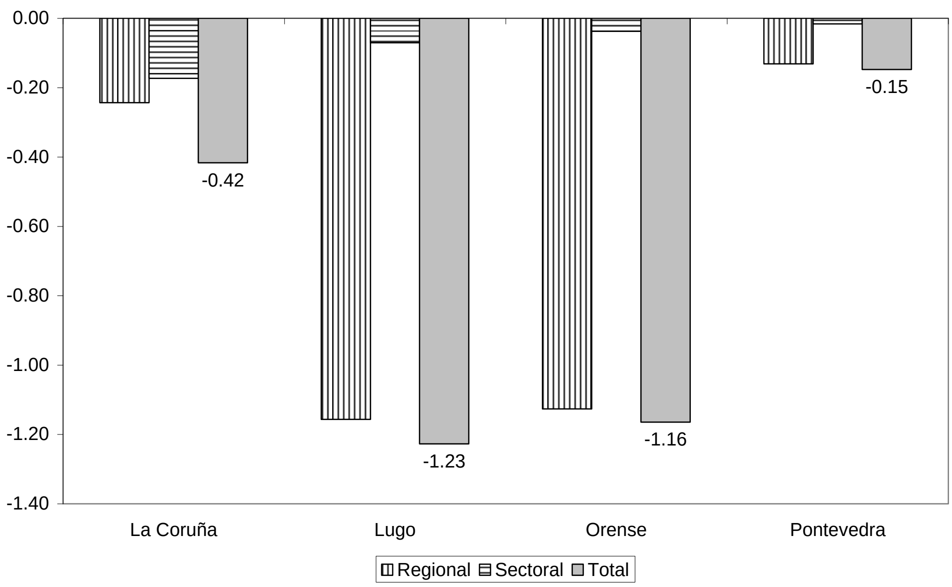
Regions	GDP pc (1,000 €)		Production structure (%) Agriculture		Industry		Services	
	1991	2006	1991	2006	1991	2006	1991	2006
Álava	17.49	24.73	1.74	2.12	54.52	44.82	43.74	53.06
Tarragona	17.16	19.99	3.25	2.39	58.50	35.25	38.24	62.36
Navarra	16.37	21.64	4.74	2.90	47.26	40.48	48.00	56.63
C. Madrid	16.35	22.76	0.18	0.18	29.63	24.25	70.19	75.57
Gerona	15.45	20.70	1.97	2.92	39.00	30.45	59.03	66.63
Guipúzcoa	15.17	22.62	2.24	1.27	46.60	42.37	51.16	56.36
Barcelona	14.82	20.25	0.74	0.66	40.43	33.78	58.83	65.57
Castellón de la Plana	14.76	18.46	6.14	3.58	47.65	42.34	46.20	54.09
Vizcaya	14.75	21.53	2.31	0.85	49.29	36.15	48.41	63.00
Teruel	14.56	18.06	10.32	4.63	38.66	42.56	51.03	52.81
La Rioja	14.42	18.60	8.42	7.44	48.04	37.40	43.54	55.15
Guadalajara	14.41	14.51	6.59	3.42	55.78	37.36	37.62	59.22
Lérida	14.33	20.16	7.68	9.18	37.78	26.58	54.54	64.24
Zaragoza	14.05	19.06	3.47	2.81	39.48	35.70	57.05	61.49
Burgos	13.98	19.51	6.16	5.31	46.62	38.94	47.23	55.75
Soria	13.25	16.24	11.12	14.57	31.20	33.36	57.67	52.08
Valladolid	13.18	18.29	4.63	4.38	44.30	33.73	51.07	61.88
Huesca	12.86	17.17	9.52	12.25	32.32	30.41	58.16	57.34
Segovia	12.81	17.76	9.34	9.00	32.79	25.20	57.88	65.80
Valencia	12.43	15.77	3.43	2.06	39.55	31.15	57.02	66.79
Palencia	12.21	16.76	9.37	11.64	41.62	32.14	49.01	56.22
Cantabria	11.68	17.08	5.16	3.27	35.87	34.31	58.96	62.42
Alicante	11.61	14.67	3.52	1.88	29.58	27.06	66.90	71.06
Toledo	11.35	13.65	9.79	6.89	36.71	36.18	53.50	56.93
Murcia	11.11	14.44	9.00	5.34	36.01	29.87	54.98	64.79
Asturias	10.97	15.57	3.02	2.23	41.54	36.72	55.44	61.05
Almería	10.90	15.64	15.72	10.72	22.99	25.25	61.29	64.03
Ciudad Real	10.57	13.30	7.31	10.60	53.82	35.16	38.86	54.24
La Coruña	10.54	14.97	6.41	4.12	42.56	32.05	51.03	63.83
León	10.46	15.13	4.92	4.96	37.28	32.04	57.80	63.00
Avila	10.45	13.83	9.85	6.60	24.80	30.97	65.35	62.43
Sevilla	10.45	13.74	5.54	3.45	31.49	28.63	62.97	67.92
Huelva	10.36	14.31	13.31	6.70	43.79	32.52	42.90	60.79
Cuenca	10.02	13.46	18.97	15.05	23.09	25.49	57.95	59.45
Lugo	9.96	13.88	11.94	8.62	33.22	29.96	54.84	61.42
Pontevedra	9.94	14.35	12.64	4.75	35.18	35.38	52.18	59.86
Málaga	9.93	13.76	5.14	2.03	26.20	23.14	68.67	74.83
Salamanca	9.85	14.34	5.06	6.13	39.40	25.96	55.55	67.92
Albacete	9.73	12.92	10.47	11.05	29.77	28.60	59.76	60.34
Córdoba	9.63	11.78	11.70	7.19	32.79	26.67	55.51	66.14
Cadiz	9.54	13.70	6.94	2.39	44.68	29.07	48.38	68.54
Jaén	9.35	11.10	17.06	9.23	30.84	26.76	52.10	64.01
Orense	9.08	12.41	6.49	5.89	35.10	32.42	58.41	61.69
Zamora	9.06	13.56	10.82	13.11	28.02	23.85	61.16	63.04
Cáceres	8.92	12.00	8.14	5.22	41.96	29.17	49.89	65.61
Granada	8.71	12.56	9.50	4.45	24.87	23.34	65.63	72.21
Badajoz	7.78	11.57	11.90	10.93	24.70	24.85	63.40	64.22
National Average	12.06	16.22	7.52	5.88	38.03	31.91	54.45	62.21

Shift-Share Analysis

Figures 5.1 to 5.10 exhibit the results of the shift-share decomposition for the Spanish continental provinces (see the description of the technique in the previous chapter, subsection 4.2.). Apart from Figure 5.10, they are organized according to the respective NUTS II level which in Spain corresponds to the Autonomous Communities. Figure 5.10 includes all the units that are simultaneously NUTS II and NUTS III level. The whole country annual average growth rate over the period was 3.00%, in contrast with the Portuguese 2.60%.

Figure 5.1 shows that all the provinces that belong to "Galicia" exhibit a negative deviation from the national growth rate, mainly due to the regional effect but reinforced by a negative sectoral effect as well.

Figure 5.1 – "Galicia" provinces deviation



In the Basque Country (Figure 5.2), the richest Spanish province Álava average growth rate was 0.08% higher than the national average due to a positive regional effect that more than compensates the negative sectoral effect. In contrast, the other two provinces exhibit a negative deviation due to both negative regional and sectoral effects.

Figure 5.2 – “País Vasco” provinces deviation

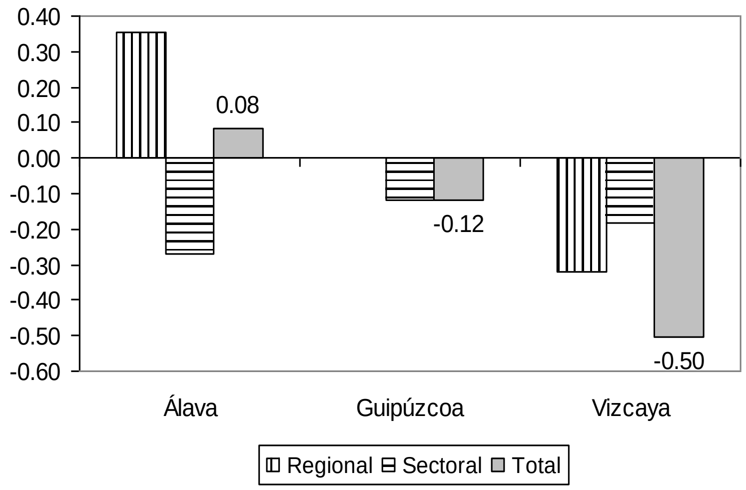
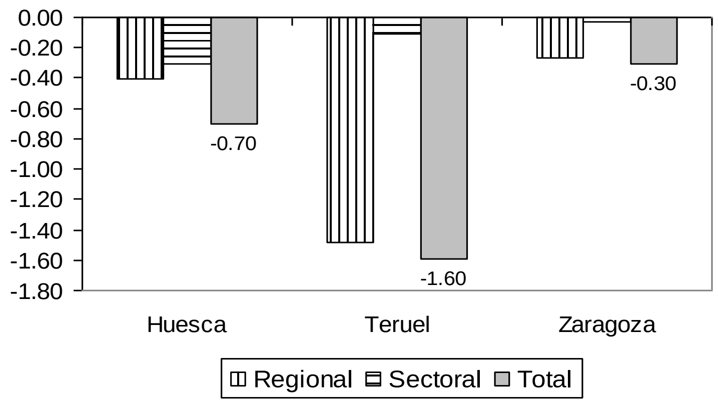


Figure 5.3 shows the results obtained for the provinces that integrate the Autonomous Community of Aragón. All evidence a negative deviation over the period due to both the regional and sectoral effects and the latter is stronger in all the provinces.

Figure 5.3 – “Aragón” provinces deviation



Many more provinces integrate “Castilla Y Leon” as can be seen in Figure 5.4. Apart from Ávila, all the provinces exhibit a negative deviation due to both a negative regional and sectoral effect. In most provinces the regional effect is stronger than the sectoral effect, but the reverse happens in provinces like Burgos and Segovia. Ávila is the only province to have a positive sectoral effect but this is not enough to compensate the significant negative regional effect.

Figure 5.4 – “Castilla Y Leon” provinces deviation

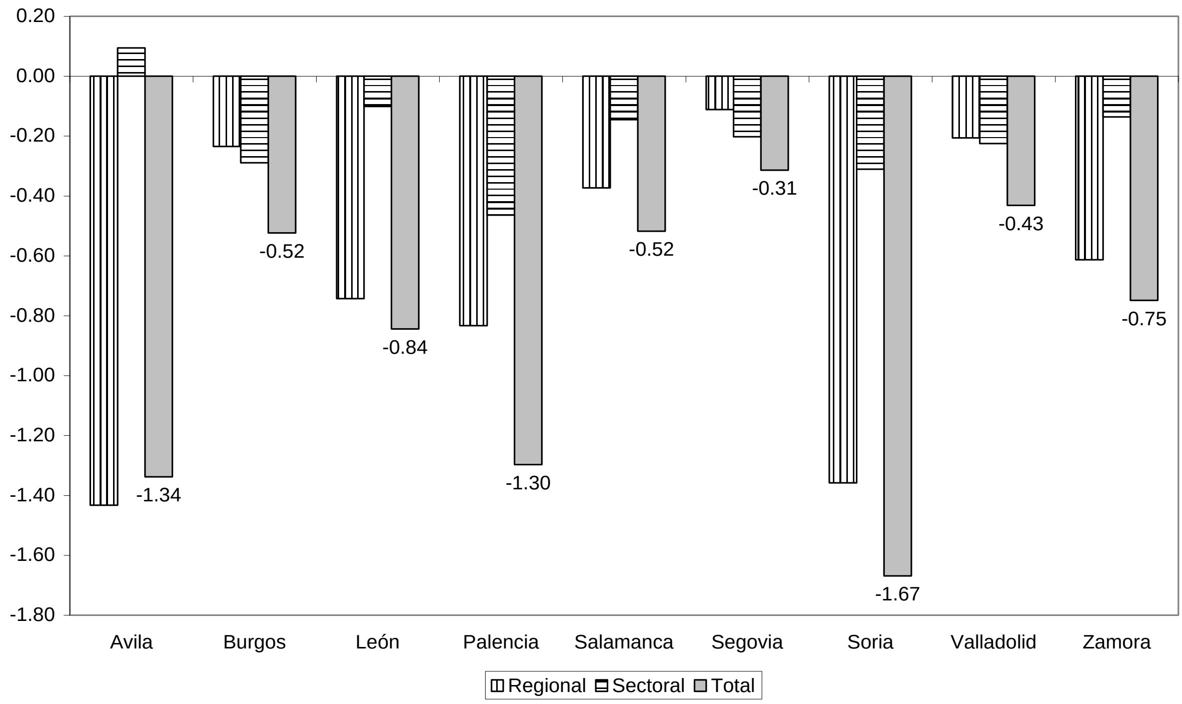
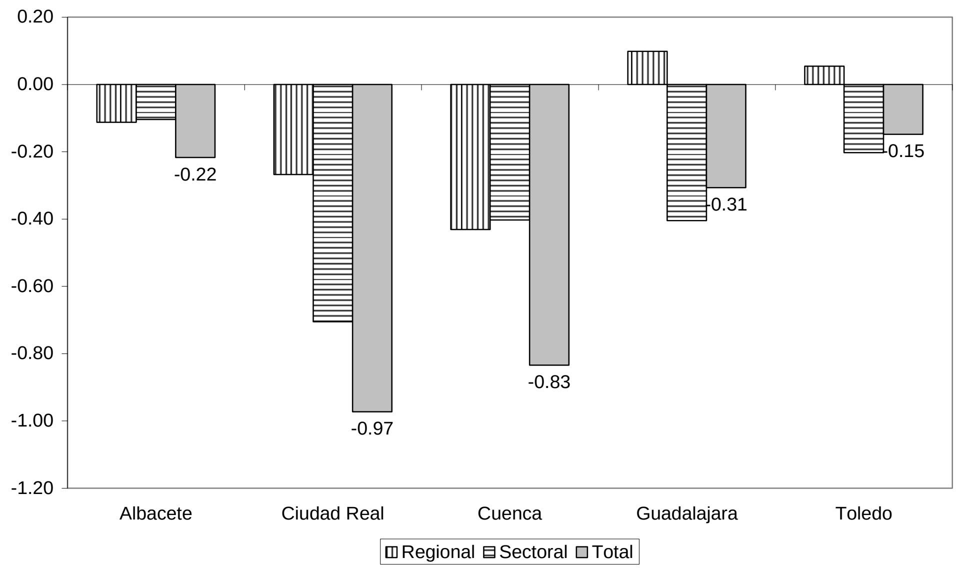


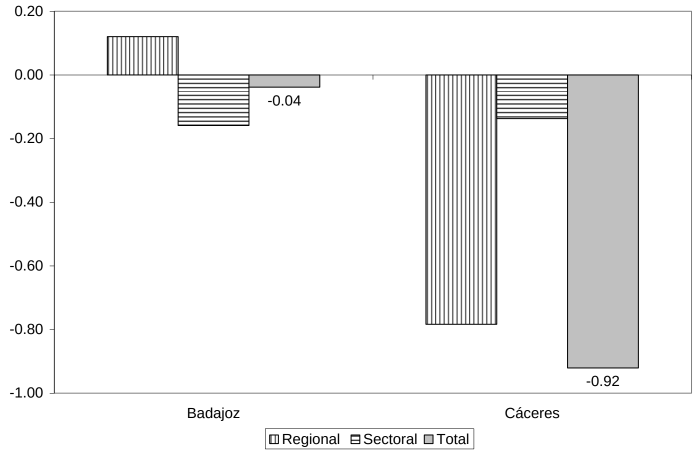
Figure 5.5 shows the results for Castilla - La Mancha provinces. Again all exhibit a negative deviation from the national average, but in contrast with the previous results, in most provinces the sectoral effect tends to be stronger than the regional effect. That is the case of Ciudad Real, Guadalajara and Toledo. Though in the last two provinces the regional effect is positive, it is not sufficient to compensate the negative sectoral effect.

Figure 5.5 – “Castilla - La Mancha” provinces deviation



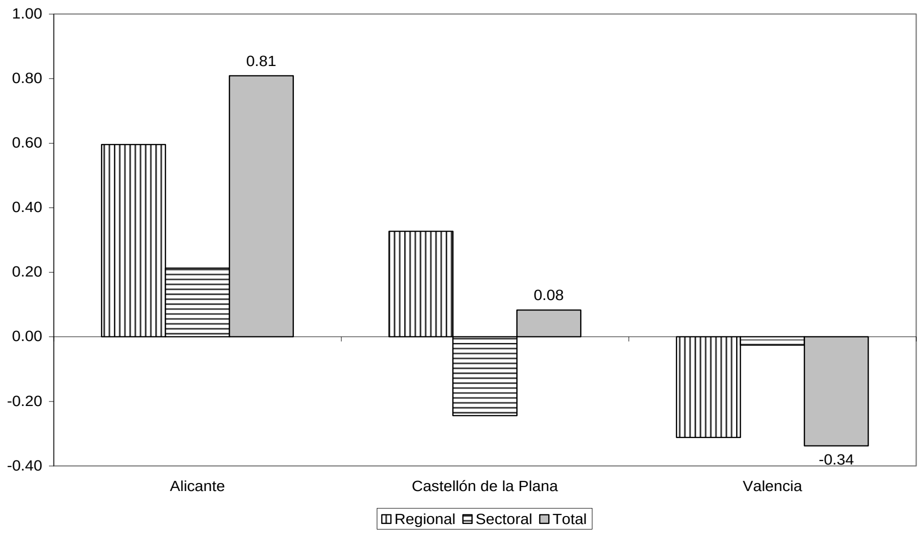
Both provinces in Extremadura (Figure 5.6), which are among the poorest Spanish provinces, exhibit a negative deviation from the national average growth rate but due to different factors. In Badajoz the regional effect is positive but not enough to compensate the negative sectoral effect. In Cáceres the regional effect is stronger than the sectoral effect but both are negative.

Figure 5.6 – "Extremadura" provinces deviation



As can be seen in Figure 5.7, two out three provinces in the Comunidad Valenciana show a positive deviation from the national average. The regional effect is always stronger than the sectoral effect and apart from Valencia, where both effects are negative, the regional effect is positive. In Castellón de la Plana this effect more than compensates the negative sectoral effect.

Figure 5.7 – "Comunidad Valenciana" provinces deviation



As shown in Figure 5.8, the most dynamic NUTS II region over the period 1991-2006 was Cataluña, with all the respective NUTS III units exhibiting a positive deviation from the national average growth rate and apart from Barcelona this is due to a strong positive regional effect. Though in Barcelona the regional effect is negative, it is compensated by a positive sectoral effect that not occurred in the other provinces.

Figure 5.8 – "Cataluña" provinces deviation

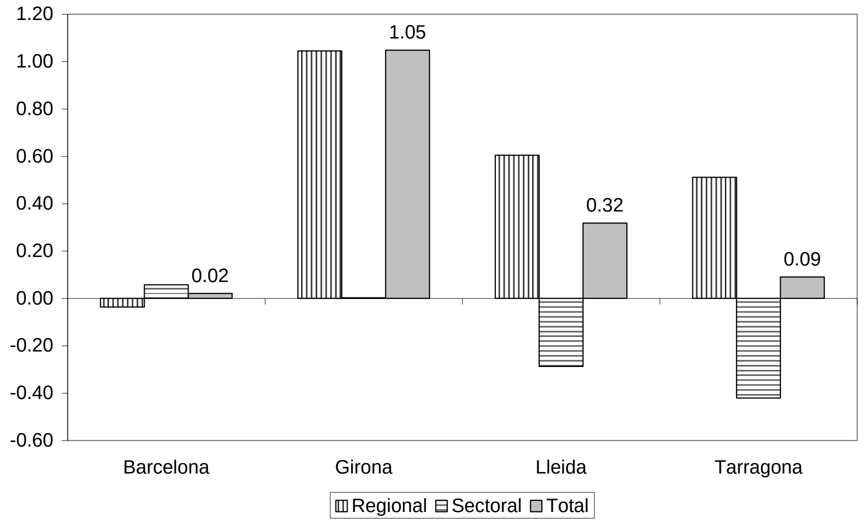
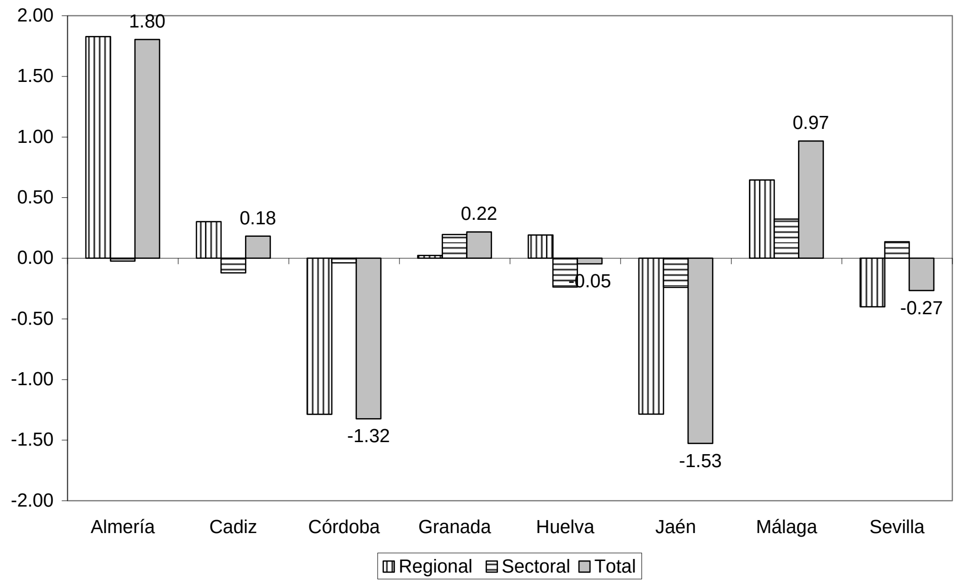


Figure 5.9 displays the results obtained for the provinces that integrate Andalucía which are among the poorest areas of the country.

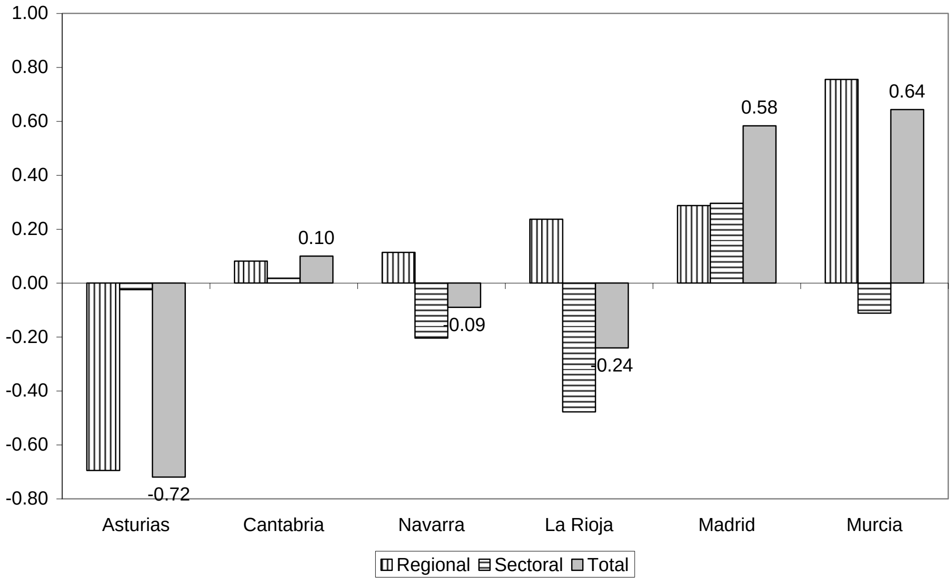
Figure 5.9 – "Andalucía" provinces deviation



As seen above, four out of seven provinces exhibit a positive deviation from the national average and again mainly due to the regional effect. Almería was the most dynamic Spanish province over the period, with the highest positive deviation, 1.80%, due to a very strong regional effect. The sectoral effect is positive in Granada, Málaga and Sevilla probably caused by the expansion of the tourist industry.

Figure 5.10 includes the remaining provinces and shows a variety of situations. The capital province, Madrid, exhibits a significant positive deviation from the national average as a result of both a positive regional and sectoral effects. The same happened in Cantabria but to a lower extent. In Navarra and La Rioja the negative deviation is due to a strong negative sectoral effect.

Figure 5.10 – Other provinces deviation



As happened in the Portuguese NUTS III regions, overall the regional effect tends to dominate in accounting for the regional deviation from the national annual average growth rate over the period 1991-2006. In 33 out of a total of 47 NUTS III regions, the regional effect was stronger than the sectoral effect. One hypothesis is that this is related to the regional human capital levels which are the focus of the chapter.

5.2.2. Physical and Human Capital

In contrast with Portugal, data on these variables at the NUTS III level of regional disaggregation is available from public sources which are the Fundación BBVA (Banco Bilbao-Viscaya)-IVIE (Instituto Valenciano de Investigaciones Económicas) for the investment in physical capital flows and the Fundación Bancaja-IVIE for the regional human capital stock. According to de la Fuente (2002), these regional datasets are unique and have important advantages, namely the fact that the data is fully comparable across regions and over time. For each NUTS III region, the IVIE human capital dataset provides the average years of schooling of the total workers employed[22] and also the number per level of education in each of the following sectors: agriculture, building, energy, industry, trade services and non-trade services. This dataset also provides data for the unemployed workers but only the employed workers are considered since the purpose is to compare the two countries' series. The Spanish data for this period (1991-2006) confirms that human capital stock proxied by the average years of education is lower among the unemployed workers. [23] Therefore the exclusion of this group from the computation of the series tends to over-estimate the regional human capital stocks. The non-trade services sector will be used as a proxy for the public sector. Since the education proxy estimated in the previous chapter for Portugal excludes the public sector, the workers in the non-trade services will be removed from the computation of the average years of education for the Spanish regions. This will allow a more accurate comparison of the results obtained for both countries. The average years of education including the public sector is also applied in the regressions to verify if the results change or not with the inclusion of the public sector.

Table 5.2 describes the education levels and the respective number of schooling years considered by the IVIE according to the Spanish General Law of Education of 1970. The education system looks more complicated than the Portuguese system because there are more choices after primary school, namely the different levels of professional training. In Spain, the compulsory schooling corresponds to 8 years of lower secondary school, one year less than in Portugal. As in Portugal, the Spanish

[22] Población Ocupada
[23] IVIE (2006), "El rendimiento del capital humano en España"

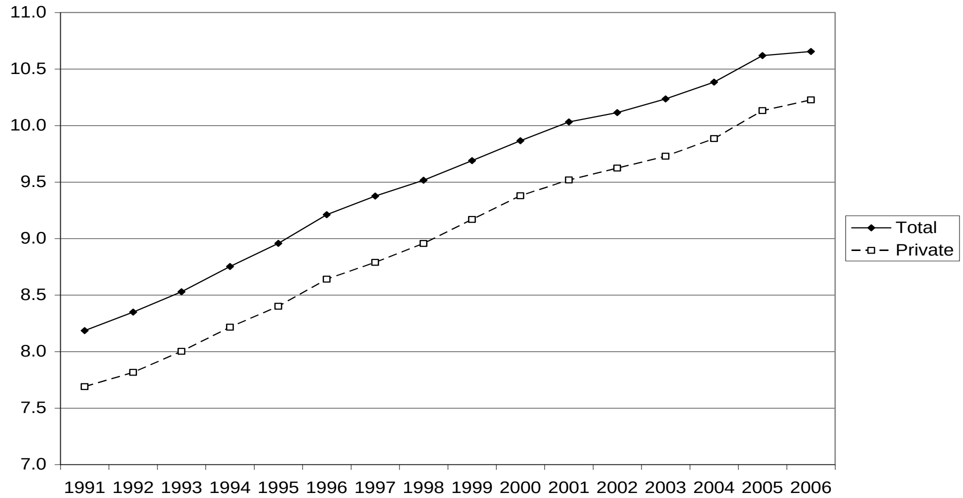
higher education system before the Bologna process was divided in two degrees, the equivalents to the OECD type B (shorter) and A (longer).

Table 5.2 – Number of schooling years in Spain

Category	Level of education	Number of schooling years
	0 – Analphabetism	0
Primary	1 – Primary school	5
Secondary	2 – *Bachiller elemental*	8
	3 – Professional Training 1	10
	4 - *Bachiller Superior*	12
	5 - Professional Training 2	13
Tertiary	6 - Lower higher education – *Ciclo Corto*	15
	7 - Higher education - *Ciclo Largo*	17

Figure 5.11 shows the gap in the average years of schooling of the Spanish NUTS III regions with and without the inclusion of the public sector. As can be seen, the average years of education is around half a year (0.5) higher when the public sector is included although the evolution is quite similar. The increase in both education proxies was around 2.5 years of schooling from 1991 to 2006. The average years of education has always been higher in Spain than in Portugal. Though there is no data available including the public sector for Portugal, a positive deviation between the average years of education with and without the public sector is also expected since the public sector tends to absorb an important share of the higher education graduates.

Figure 5.11 – Average years of education



The IVIE also provides data on the labour-income human capital (LIHK) measure following Mulligan and Sala-i-Martin (1997). Table 5.3 summarizes the data related to human capital proxies collected from the IVIE dataset.

Table 5.3 – The provinces' human capital proxies

Regions	Average Stock				Ranking position			
	Education		LIHK		Education		LIHK	
	1991	2006	1991	2006	1991	2006	1991	2006
Vizcaya	8.94	11.35	2.74	3.24	1	2	1	1
Madrid	8.70	11.32	2.66	3.19	2	3	2	4
Guipúzcoa	8.48	11.38	2.60	3.21	3	1	6	2
Barcelona	8.44	10.58	2.46	2.96	4	7	19	12
Navarra	8.32	10.78	2.58	3.03	5	5	8	7
Álava	8.29	11.22	2.62	3.19	6	4	3	3
Cantabria	8.08	10.36	2.60	3.01	7	9	5	9
Burgos	7.97	10.31	2.56	3.00	8	10	10	10
Zaragoza	7.92	10.66	2.50	3.05	9	6	16	6
Valladolid	7.82	10.50	2.62	3.03	10	8	4	8
Lleida	7.82	9.13	2.52	2.83	11	40	13	25
Valencia	7.70	10.19	2.40	2.84	12	14	24	23
La Rioja	7.67	10.09	2.52	2.94	13	15	12	14
Asturias	7.61	10.20	2.51	2.96	14	12	14	13
Gerona	7.51	9.61	2.25	2.74	15	23	41	37
Tarragona	7.51	9.55	2.36	2.70	16	28	27	41
Huesca	7.47	9.61	2.50	2.90	17	24	15	18
León	7.43	9.84	2.44	2.90	18	21	20	17
Guadalajara	7.37	10.19	2.48	2.89	19	13	18	19
Segovia	7.35	9.84	2.42	2.84	20	22	23	24
Soria	7.28	9.53	2.60	2.92	21	29	7	15
Teruel	7.25	9.57	2.43	2.83	22	27	22	28
Salamanca	7.18	9.96	2.57	3.07	23	17	9	5
Sevilla	7.17	10.02	2.35	2.86	24	16	30	20
Málaga	7.12	9.39	2.27	2.68	25	35	34	44
Pontevedra	7.06	9.86	2.27	2.83	26	20	35	27
Castellón de la Plana	7.06	9.96	2.27	2.77	27	18	37	34
Murcia	7.04	9.45	2.21	2.72	28	33	44	40
Alicante	7.02	9.90	2.16	2.78	29	19	46	31
La Coruña	6.99	10.25	2.35	2.92	30	11	29	16
Palencia	6.98	9.60	2.49	2.96	31	25	17	11
Avila	6.96	9.49	2.38	2.83	32	31	25	26
Zamora	6.95	8.11	2.55	2.73	33	47	11	39
Granada	6.92	9.59	2.43	2.85	34	26	21	21
Córdoba	6.88	9.17	2.29	2.77	35	39	32	32
Jaén	6.87	9.30	2.26	2.78	36	36	40	30
Cadiz	6.86	9.48	2.37	2.77	37	32	26	33
Albacete	6.84	9.06	2.13	2.76	38	43	47	35
Badajoz	6.77	9.27	2.33	2.69	39	38	31	42
Toledo	6.76	9.05	2.23	2.68	40	44	42	43
Cuenca	6.75	8.46	2.35	2.59	41	46	28	45
Almería	6.73	9.12	2.26	2.52	42	41	39	47
Huelva	6.73	9.28	2.27	2.66	43	37	36	45
Ciudad Real	6.72	9.11	2.29	2.74	44	42	33	36
Cáceres	6.52	9.52	2.26	2.84	45	30	38	22
Lugo	6.38	9.04	2.18	2.74	46	45	45	38
Orense	6.29	9.42	2.22	2.80	47	34	43	29
Average	7.33	9.80	2.41	2.86				

The zero-schooling worker used as the numeraire by IVIE to compute the regional human capital stocks is the worker younger than 20 years old who did not attend or complete primary school. The provinces are ranked from the richest to the poorest in terms of education in 1991, the beginning of the period. Both proxies are expressed as the average per worker in each province and the education proxy reported excludes the public sector in order to compare the Portuguese with the Spanish levels. As can be seen, the human capital stock increased over the period according to both proxies and is higher than in Portugal. In Spain there was an increase of the average years of schooling in the private sector from 7.33 in 1991 to 9.80 years in 2006, while in Portugal the evolution over the same period was from 6.04 to 8.53. The situation and evolution of the provinces is quite diverse. Although the richest provinces in terms of GDP per capita tend to be the richest in both proxies of human capital, like Madrid and the Basque provinces of Vizcaya, Guipúzcoa and Álava, there are exceptions. Tarragona is a good example, in the GDP per capita ranking it moved from the second richest in 1991 to the 9th in 2006, but its relative position in terms of human capital is much worse. According to the education proxy this province's position deteriorated from 16th to 27th and in the LIHK ranking the evolution was even worse, Tarragona became one of the poorest among all the Spanish provinces (41st in the ranking). Also provinces like Gerona, Lleida and Teruel are rich in terms of GDP per capita and relatively poor in human capital. Tarragona, Gerona, and Lleida belong to the NUTS II level region of Cataluña which was the most dynamic NUTS II region over the period. Quite the opposite, Cantabria and Valladolid are at the top 10 of the richest provinces in human capital according to both proxies but not in terms of income per capita.

In some provinces there is a significant gap between the two proxies of human capital. Barcelona's position in the ranking is much higher when human capital is proxied by the average years of education than when the proxy is the LIHK measure, though over the period the evolution was opposite. Its relative position improved taking the LIHK as the human capital proxy, from 19th to 12th, and deteriorated in terms of average years of education, from 4th to 7th. In Gerona and Valencia the difference between the two proxies is even greater. There is a significant improvement over the period in both proxies in provinces like Zaragoza, Sevilla, Alicante, La Coruña, Palencia, Cáceres and Orense. In others, like Tarragona, Lleida, Soria and Zamora, the relative position in human capital got worse no matter what is the proxy. It is interesting because Lleida and Zamora's positions in the GDP per capita ranking improved.

As mention in the previous chapter, subsection 4.3.2, this measure has several limitations, such as the assumption of perfect substitution among the zero-schooling workers and the others and also that physical capital complements workers with different skills in the same way. Since these assumptions are unlikely to hold, the obtained labour income measure is biased. Institutional factors as the minimum wage also contributes to this bias.

Table 5.4 reports the contemporaneous correlation coefficients of the human capital proxies in the beginning and at the end of the period. The education proxy considered here does not include the public sector. The correlation among the average years of education and the Mulligan and Sala-i-Martin (1997) labour-income human capital proxy is higher in Spain than in Portugal and also increased from 1991 to 2006.

Table 5.4 – Correlation matrix of the different human capital proxies

1991	AvEdu	Mulligan & S.	2006	AvEdu	Mulligan & S.
AvEdu	1.00	0.79	AvEdu	1.00	0.87
Mulligan & S.		1.00	Mulligan & S.		1.00

5.3. The regional distribution of GDP per capita and human capital: σ-convergence

Figure 5.12 shows the evolution over time of the standard deviation of GDP per capita which is a measure for σ-convergence. Though the variation is low there is evidence of increasing income disparities during the second half of the 1990s, followed by a decline since 2000 suggesting σ-convergence in the beginning of the new century. Authors like de la Fuente (2002) have pointed out that, similar to what happened in other European countries, there was a significant reduction in the Spanish regional disparities till the 1970s and since then the remaining regional disparities tend to persist.

Figure 5.12 – Standard deviation of the logarithm of regional GDP per capita

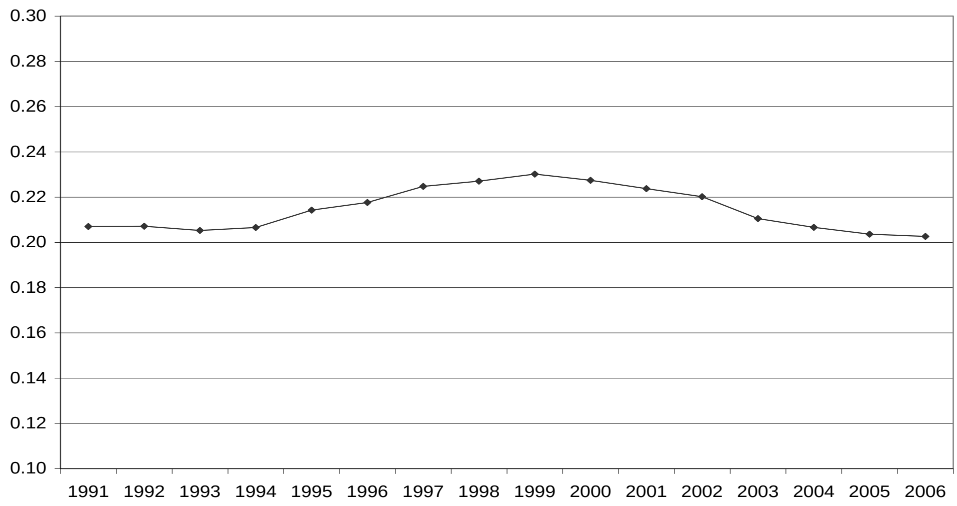
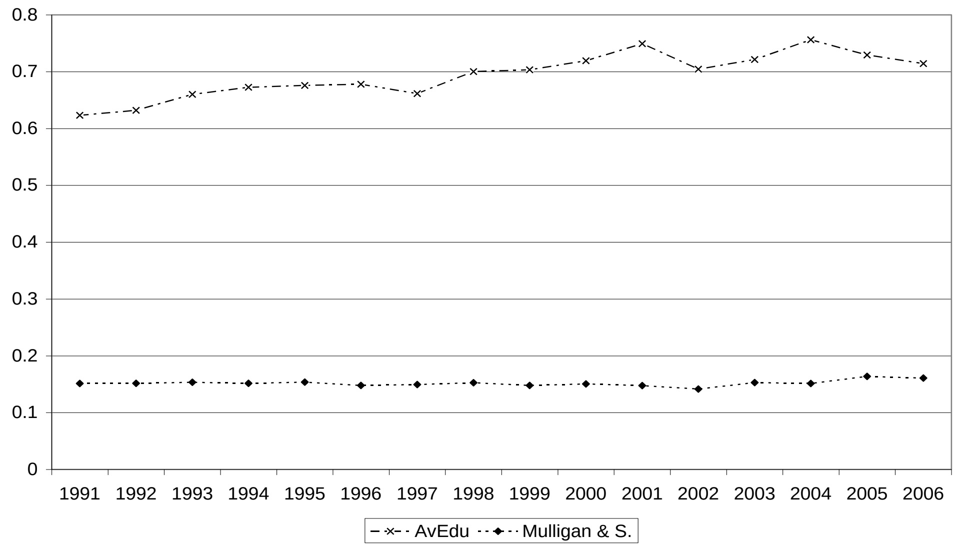


Figure 5.13 illustrates the evolution of the standard deviation of the regional human capital stock proxied by both the average years of education in the private sector and the Mulligan and Sala-i-Martin (1997) labour-income human capital proxy.

Figure 5.13 – Standard deviation of the regional human capital proxies



The inequality among the provinces in terms of human capital is much higher when the proxy is the average years of education. As in the Portuguese NUTS III regions dataset, Spain also shows significant education disparities at this level of regional disaggregation. Apart from a few years that exhibited a decrease of the standard deviation, the tendency is for divergence. The standard deviation increased quite substantially over the period, from 62% in 1991 to around 75% in 2004, only showing some signs of decline since then. As in Portugal, when the proxy is the Mulligan and Sala-i-Martin (1997) LIHK measure the dispersion among the NUTS III regions is much lower and tends to remain constant over time, between 15 and 16%.

5.4. Model and methodology

The same β-convergence model described in section 5.5 of the previous chapter is applied:

$$\Delta y_{it} = \varphi_o + \varphi_1 y_{it-1} + \varphi_2 \ln(s_{it}^K) + \varphi_3 \ln(H_{it}) + \varphi_4 \ln(n_{it} + g + \delta) + \eta_i + v_{it} \qquad (5.1)$$

where y_{it} is the region *i* GDP per capita relative to the richest Spanish province, which is Alava (A), this is $y_{it} = \frac{GDPpc_{it}}{GDPpc_{At}}$; s^K is the investment rate, H is the human capital level, n is the population growth rate, g is the labour-augmenting technological progress and δ is the physical and human capital depreciation rate. η_i is the individual specific effect and v_{it} is the idiosyncratic error term. As in the previous chapter, the normalization of GDP per capita on the richest NUTS III region to control for the business cycle is a limitation since the regional business cycle might not be synchronized in Spain. Like in the previous chapter and generally assumed in the empirical literature, the sum of the technological progress rate with the depreciation rate is equal to 0.05. There will be convergence if the coefficient φ_1 is negative. The coefficient φ_2 indicates the effect of the regional investment rate on the change of its relative GDP per capita and is expected to be positive according to the Solow model. φ_3 represents the effect of the province's human capital stock on the improvement of the relative GDP per capita and it is also expected to be positive according to the human capital literature. A higher human capital stock is expected to reduce the province's income per capita gap towards the richest province by increasing the ability to adopt and implement new technologies, in the line with Nelson and Phelps (1966), or innovate following Romer (1990). Though along with the Solow model the effect of the population growth (φ_4) is expected to be negative, it is usually insignificant in empirical studies.

Since for Spain there is data available for investment at the NUTS III level of regional disaggregation, the physical capital accumulation rate is included proxied by the investment to GDP ratio. In order to compare the results obtained for the two countries, the regressions will be done with and without this variable. This will also allow an evaluation to what extent the exclusion of physical capital accumulation rate from the convergence equation affects the human capital coefficients. As mentioned in the previous chapter, one economic explanation for the exclusion of physical capital is the fact that its stock is already captured by the initial GDP per capita.

As for Portugal, different proxies for human capital (H) will be considered: the average years of schooling, its decomposition into average years of primary, secondary and tertiary education and the Mulligan and Sala-i-Martin LIHK proxy. As mention before, the education proxies for Spain were computed with and without the public sector. It is interesting to see if the inclusion of the public sector affects the results. Again the production structure is chosen as an alternative conditional variable. The convergence equation will be estimated through the GMM estimator which was described in the section 4.6 of Chapter 4.

5.5. Results

Similar to the estimation of the conditional convergence equations for Portugal, time dummies were introduced in order to control for technological shocks. The F-test confirms their significance at the conventional levels (1 or 5%). The relative GDP per capita was considered predetermined and the other explanatory variables as potentially endogenous: human capital, production structure and population growth rate.

Subsections 5.1 and 5.2 report and discuss the results for regional convergence conditional on human capital and the production structure, respectively. All the regressions were run with the collapse command [Roodman (2008)]. In both subsections the convergence equation was estimated excluding and including the physical capital accumulation rate (s_k). The first set of columns in each table exhibit the results obtained without controlling for s_k. These are the results that will be compared with those obtained for Portugal. Then in the right columns of the tables are reported the results when this variable was added to the convergence equation. It is interesting to verify whether the results are robust to the inclusion of physical capital accumulation rate.

As for Portugal, the inclusion of the two conditional variables in a single regression led to inconsistent GMM estimators due either invalid instruments or second-order serial correlation. Hence only the results obtained in separate regressions are reported.

5.5.1. Convergence conditional on human capital

As in the previous chapter, the regressions were done alternatively with the levels of education and the respective growth rates. As before, these correspond to testing two ways of including human capital in growth models: the Lucas approach, which includes human capital in the aggregate production function as an input, and the Nelson-Phelps approach that introduces human capital as a determinant of technological progress [Krueger and Lindahl (2001)].

Education Proxies

The results for regional convergence conditional on human capital proxied by education in levels are reported in the Tables 5.5 to 5.9. First, the total average years of schooling are considered in Table 5.5. Overall, comparing the one-step with the two-step GMM estimator the results are quite similar and the main diagnostic tests suggest consistent estimators. The *p*-values of the Arellano-Bond (1991) test for second-order correlation [AR(2)] are always higher than 10% which indicate no serial correlation across the different estimators and specifications. The Hansen test also confirms that the instruments of both the difference and system GMM are valid since according to the respective *p*-values the null of instruments validity can never be rejected at the conventional levels of significance.

Across the different GMM estimations, the coefficient of the lagged relative GDP per capita is always significant and shows the expected negative sign, evidencing convergence among the provinces. As mentioned in the previous chapter, the Difference GMM estimator is biased downwards and leads to a very low half-life value, around one year. A half-life in the range 5-6 years was obtained by the System GMM which is more plausible but still higher than in other regional convergence studies for Spain. Ramos *et al.* (2010), for example, found that the time needed for the Spanish provinces to eliminate half of the gap towards the steady-state is 12.8 years.

Table 5.5 – Average years of education without the public sector

Dependent variable: Change in relative GDP per capita (Δy_t)

	Without s_k				With s_k			
Regressors	GMM 1		GMM 2		GMM 1		GMM 2	
	Diff	Sys	Diff	Sys	Diff	Sys	Diff	Sys
Constant	-	-0.08 (-1.23)	-	-0.09 (-1.15)	-	0.07 (0.55)	-	0.06 (0.50)
y_{it-1}	-0.46*** (-8.04)	-0.12*** (-4.01)	-0.47*** (-7.29)	-0.12*** (-3.35)	-0.44*** (-6.80)	-0.11*** (-3.13)	-0.45*** (-5.74)	-0.12*** (-2.76)
$\ln(n_{it}+g+\delta)$	0.01** (2.12)	0.01** (2.63)	0.01 (1.44)	0.01** (2.09)	0.01** (2.07)	0.01** (2.45)	0.01 (1.56)	0.01* (1.77)
$\ln(AvEdu)$	0.02 (0.61)	0.08*** (3.24)	0.02 (0.52)	0.09*** (2.95)	0.00 (0.01)	0.04 (1.02)	-0.00 (-0.11)	0.04 (0.88)
$\ln(s_k)$	-	-	-	-	0.03 (1.32)	0.05*** (3.03)	0.03 (1.23)	0.05*** (2.94)
Half-life	1.12	5.42	1.09	5.42	1.20	5.95	1.16	5.42
No. Observations	644	690	644	690	644	690	644	690
No. Instruments	45	49	45	49	59	64	59	64
Arellano-Bond test for AR(2)	-0.85 (0.39)	-1.52 (0.13)	-0.88 (0.38)	-1.47 (0.14)	-0.74 (0.46)	-1.07 (0.29)	-0.80 (0.43)	-1.15 (0.25)
Hansen test	45.11 (0.20)	45.20 (0.30)	45.11 (0.20)	45.20 (0.30)	44.77 (0.72)	44.21 (0.85)	44.77 (0.72)	44.21 (0.85)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

The average years of schooling plays a positive and significant role in the convergence process only when the system GMM is applied without controlling for the physical capital accumulation rate. An increase of 1 in the log of the average years of schooling increases the ratio of the relative GDP per capita in 8-9% according to the system GMM results which is the highest among all the human capital proxies. The fact that the education variable looses significance when s_k is introduced in the convergence equation is common in the literature. Krueger and Lindahl (2001) argue that part of the return to capital might be attributable to education since regions are likely to attract more investment when the education levels are higher. The physical capital accumulation rate has a positive effect on the relative GDP per capita improvement as expected. The coefficient is only significant in the System-GMM results, but this is the preferable estimator since the Difference-GMM is biased. As the results obtained when the average years are computed taking into consideration the public sector are quite similar in terms of sign and significance level of the coefficients, they are only reported in this chapter appendix (Table 5.20).

Table 5.6 displays the results when the average years of primary schooling is taken into consideration. The Arellano-Bond (1991) test evidences no second-order serial correlation, since the *p*-values are always higher than 10% and the Hansen test also confirms the validity of the instruments at the conventional levels of significance. Both diagnostics guarantee the consistency of the estimator across the different specifications. The coefficient of the lagged relative GDP per capita is negative and always significant. Again it is much higher in absolute terms according to the difference GMM and becomes lower when the physical capital accumulation rate is controlled for, which implies an increase in the half-life. Similar to Portugal, the coefficient of primary education proxy is negative, though not significant for Spain at the conventional levels. The results are quite similar when the average years of primary education are computed taking into consideration the public sector (see Appendix to Chapter 5, Table 5.21).

Table 5.6 – Average years of primary education without the public sector

Dependent variable: Change in relative GDP per capita (Δy_t)

	Without s_k				With s_k			
Regressors	GMM 1		GMM 2		GMM 1		GMM 2	
	Diff	Sys	Diff	Sys	Diff	Sys	Diff	Sys
Constant	-	0.20 (5.00)	-	0.20*** (4.01)	-	0.22*** (4.98)	-	0.21*** (4.15)
y_{it-1}	-0.45*** (-8.59)	-0.27*** (-5.49)	-0.45*** (-7.50)	-0.26*** (-4.62)	-0.41*** (-6.09)	-0.19*** (-4.22)	-0.41*** (-5.28)	-0.19*** (-3.84)
$\ln(n_{it}+g+\delta)$	0.01** (2.04)	0.01** (2.55)	0.01* (1.68)	0.01* (1.89)	0.01* (1.93)	0.01** (2.32)	0.01 (1.57)	0.01* (1.71)
$\ln(Prim)$	-0.01 (-1.24)	-0.01 (-1.96)	-0.01 (-1.24)	-0.01* (-1.97)	-0.00 (-0.55)	-0.01 (-1.56)	-0.00 (-0.45)	-0.01 (-1.49)
$\ln(s_k)$	-	-	-	-	0.03 (1.66)	0.06*** (3.90)	0.03 (1.28)	0.05*** (3.05)
Half-life	1.16	2.20	1.16	2.30	1.31	3.29	1.31	3.29
No. Observations	644	690	644	690	644	690	644	690
No. Instruments	45	49	45	49	59	64	59	64
Arellano-Bond test for AR(2)	-0.85 (0.40)	-1.39 (0.16)	-0.83 (0.41)	-1.38 (0.17)	-0.74 (0.46)	-0.83 (0.41)	-0.78 (0.44)	-0.94 (0.35)
Hansen test	45.23 (0.20)	45.51 (0.29)	45.23 (0.20)	45.51 (0.29)	43.93 (0.75)	44.20 (0.85)	43.93 (0.75)	44.20 (0.85)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Moving to the secondary education level, on Table 5.7, the Hansen tests confirms the validity of the instruments in all cases and the Arellano-Bond test for AR(2) evidence no second-order correlation. The lagged GDP per capita coefficient is negatively significant as expected across all the estimators apart from the two-step system GMM. The average years of secondary education is the conditional variable that leads to a higher half-life value, 9.55 when the investment rate is not included and 13.51 years when it is (system GMM results). These values are closer to the 12.8 years found by Ramos *et al.* (2010). The effect of secondary schooling is positive and significant at 1%-5% only according to the system GMM and when the physical capital accumulation rate (s_k) is not included. When the latter is introduced, the average years of secondary education coefficient becomes insignificant across all the estimators. The effect of the investment rate is positively significant according to the system GMM which is the preferable estimator, suggesting an important role of physical capital in the reduction of the income disparities among the Spanish provinces. When the public sector is included in the computation of the average years of secondary school the results are quite alike so they are reported in this chapter appendix (Table 5.22).

Table 5.7 – Average years of secondary education without the public sector

Dependent variable: Change in relative GDP per capita (Δy_t)

	Without s_k				With s_k			
Regressors	GMM 1		GMM 2		GMM 1		GMM 2	
	Diff	Sys	Diff	Sys	Diff	Sys	Diff	Sys
Constant	-	-0.01 (-0.49)	-	-0.01 (-0.49)	-	0.07 (1.51)	-	0.07 (1.32)
y_{it-1}	-0.48*** (-9.05)	-0.07*** (-3.41)	-0.49*** (-8.03)	-0.07*** (-3.41)	-0.44*** (-7.17)	-0.05** (-2.23)	-0.44*** (-6.12)	-0.04 (-1.41)
$\ln(n_{it}+g+\delta)$	0.01** (2.19)	0.01** (2.16)	0.01* (1.85)	0.01** (2.16)	0.01** (2.25)	0.01** (2.18)	0.01 (1.63)	0.01 (1.87)
$\ln(Sec)$	0.01 (0.69)	0.03*** (3.22)	0.01 (0.55)	0.03*** (3.22)	0.01 (0.39)	0.02 (1.64)	0.01 (0.38)	0.02 (2.56)
$\ln(s_k)$	-	-	-	-	0.03 (1.54)	0.04*** (2.85)	0.03 (1.21)	0.04** (2.70)
Half-life	1.06	9.55	1.03	9.55	1.20	13.51	1.20	16.98
No. Observations	644	690	644	690	644	690	644	690
No. Instruments	45	49	45	49	59	64	59	64
Arellano-Bond test for AR(2)	-0.67 (0.51)	-1.90 (0.06)	-0.64 (0.52)	-1.90 (0.06)	-0.47 (0.64)	-1.46 (0.15)	-0.58 (0.56)	-1.50 (0.13)
Hansen test	45.32 (0.19)	44.59 (0.33)	45.32 (0.19)	44.59 (0.32)	44.46 (0.73)	44.87 (0.83)	44.46 (0.73)	44.87 (0.83)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Table 5.8 displays the results obtained when the average years of higher education is the proxy for human capital. Again the diagnostic tests guarantee the consistency of the estimators. The coefficient of tertiary education is positive and significant across all the system estimators, which is preferable relative to the difference GMM, and it remains significant when the investment rate is included. It is slightly lower than the coefficient found for secondary school but the speed of convergence assessed by the lagged relative GDP per capita coefficient is higher which reduces the number of years needed to fill half the gap towards the steady state to the range 4-5 years (case of the system GMM).

Table 5.8 – Average years of tertiary education without the public sector

Dependent variable: Change in relative GDP per capita (Δy_t)

	Without s_k				With s_k			
Regressors	GMM 1		GMM 2		GMM 1		GMM 2	
	Diff	Sys	Diff	Sys	Diff	Sys	Diff	Sys
Constant	-	0.10*** (3.29)	-	0.11*** (2.77)	-	0.14*** (3.74)	-	0.15*** (2.88)
y_{it-1}	-0.43*** (-7.66)	-0.16*** (-4.50)	-0.43*** (-6.90)	-0.16*** (-3.95)	-0.38*** (-5.92)	-0.14*** (-4.25)	-0.39*** (-5.36)	-0.14*** (-3.36)
$\ln(n_{it} + g + \delta)$	0.01* (1.76)	0.01** (2.19)	0.01 (1.58)	0.01 (1.64)	0.01 (1.66)	0.01** (2.14)	0.01 (1.34)	0.01 (1.49)
$\ln(Ter)$	0.01 (0.75)	0.03*** (4.19)	0.01 (0.54)	0.03*** (3.67)	0.01 (0.44)	0.03*** (3.39)	0.00 (0.37)	0.03*** (2.72)
$\ln(s_k)$	-	-	-	-	0.04* (1.75)	0.04*** (2.77)	0.03 (1.46)	0.04** (2.36)
Half-life	1.23	3.98	1.23	3.98	1.45	4.60	1.40	4.60
No. Observations	644	690	644	690	644	690	644	690
No. Instruments	45	49	45	49	59	64	59	64
Arellano-Bond test for AR(2)	-0.92 (0.36)	-1.11 (0.27)	-0.89 (0.38)	-1.10 (0.27)	-0.76 (0.45)	-0.68 (0.50)	-0.74 (0.46)	-0.57 (0.57)
Hansen test	45.16 (0.20)	45.07 (0.31)	45.16 (0.20)	45.07 (0.31)	45.19 (0.70)	45.07 (0.83)	45.19 (0.70)	45.07 (0.83)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Table 5.9 reports the results obtained when the public sector is included in the computation of the education proxy. In the regressions without s_k, the Arellano-Bond (1991) test *p*-values are lower than 10% so the null of no second-order correlation can be rejected at 5% but not at 10% which is a concern in terms of the estimator consistency. Once the investment rate is introduced this problem disappears. It is interesting to notice that there are important changes when the public sector is included in the computation of this education proxy. The coefficient of the average years of tertiary education becomes insignificant and very close to zero according to the system-GMM. In the Difference GMM results, it becomes negative and significant at 10% in most cases and even significantly negative at 5% in the two-step GMM results without s_k. The positive and significant effect of higher education disappears when the public sector is included which suggests some inefficiency when workers with higher qualifications are allocated to this particular sector.

Table 5.9 – Average years of tertiary education with the public sector

Dependent variable: Change in relative GDP per capita (Δy_t)

Regressors	Without s_k				With s_k			
	GMM 1		GMM 2		GMM 1		GMM 2	
	Diff	Sys	Diff	Sys	Diff	Sys	Diff	Sys
Constant	-	0.17*** (3.24)	-	0.18*** (3.11)	-	0.21*** (3.39)	-	0.21*** (2.79)
y_{it-1}	-0.51*** (-8.93)	-0.22*** (-3.99)	-0.52*** (-8.10)	-0.23*** (-3.60)	-0.44*** (-6.29)	-0.17*** (-3.37)	-0.45*** (-5.92)	-0.17*** (-2.91)
$\ln(n_{it}+g+\delta)$	0.01 (1.55)	0.01** (2.28)	0.01 (1.47)	0.01** (2.12)	0.01 (1.50)	0.01** (2.32)	0.01 (1.24)	0.01* (1.95)
$\ln(Ter)$	-0.03* (-1.98)	0.00 (0.29)	-0.03** (-2.08)	0.00 (0.14)	-0.03* (-1.73)	-0.00 (-0.11)	-0.03 (-1.65)	0.00 (0.04)
$\ln(s_k)$	-	-	-	-	0.05* (1.86)	0.06*** (3.59)	0.04 (1.61)	0.06*** (2.76)
Half-life	0.97	2.79	0.94	2.65	1.20	3.72	1.16	3.72
No. Observations	644	690	644	690	644	690	644	690
No. Instruments	45	49	45	49	59	64	59	64
Arellano-Bond test for AR(2)	-1.45 (0.15)	-1.73 (0.08)	-1.39 (0.16)	-1.70 (0.09)	-1.21 (0.23)	-1.02 (0.31)	-1.25 (0.21)	-1.04 (0.30)
Hansen test	44.49 (0.22)	44.71 (0.32)	44.49 (0.22)	44.71 (0.32)	45.40 (0.70)	44.98 (0.83)	45.40 (0.70)	44.98 (0.83)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

The results are affected by the inclusion of the public sector in the computation of human capital only when the proxy is higher education. The coefficient of tertiary education is positive and significant across the system estimators and it remains significant when the investment rate is included, but only when the workers are allocated to the private sector. This gives support to the idea that the public sector in Spain is inefficient, higher levels of education have no significant effect on the reduction of income disparities unless the most qualified workers are allocated to the private sector. As pointed out by Di Liberto (2007), one of the possible explanations for the negative sign on tertiary education commonly found in the empirical literature on the Spanish regions is in fact the tendency of the university educated workers to be employed in the public sector.

Focusing on the results without the public sector, the conclusions about the role of human capital on regional growth depend on the level of education. When the investment rate is controlled for, secondary education contribution is insignificant at the conventional levels of significance but there is evidence of a positive and significant impact of higher education on the evolution of the relative regional GDP per capita. This level of education also increases the speed of regional convergence towards the richest region assed by the size in absolute terms of the lagged relative GDP per capita coefficient. This is in contrast with Portugal, where the effect on the improvement of relative GDP per capita of secondary school was significant and higher than the impact of tertiary education. This might be explained by the level of development of the majority of the Spanish NUTS III regions which tend to be above the Portuguese average and closer to the European frontier.

In contrast with Portugal, when the human capital stock is replaced in the Spanish convergence equation by its growth rate, the respective coefficients are in general significant. The next tables report the results when changes in education levels are considered instead of the levels. Table 5.10 shows the results obtained when the average years of schooling without the public sector was replaced by the respective growth rate. The coefficient of the average years of education growth rate is positive and significant across the different GMM estimators though it was insignificant when this variable was introduced in level. In the model without s_k, the Arellano-Bond test does not reject the null of no second-order correlation for the system GMM since the *p*-value is lower than 5%, but once the physical capital accumulation rate is controlled for this problem disappears and the GMM estimators become consistent. The Hansen test always confirms the validity of the instruments. As before, the lagged relative GDP per capita is negative and significant and in absolute terms is much higher according to the Difference-GMM results. The physical capital accumulation rate is always positive but only significant according to the System GMM which is the preferable estimator. Since the results are quite similar when the proxy includes the public sector they are just reported in the appendix.

Table 5.10 – Change in the average years of education without the public sector

Dependent variable: Change in relative GDP per capita (Δy_t)

Regressors	Without s_k				With s_k			
	GMM 1		GMM 2		GMM 1		GMM 2	
	Diff	Sys	Diff	Sys	Diff	Sys	Diff	Sys
Constant	-	0.11^{***} (3.39)	-	0.11^{***} (2.98)	-	0.17^{***} (4.17)	-	0.17^{***} (3.26)
y_{it-1}	-0.49^{***} (-9.46)	-0.14^{***} (-3.59)	-0.48^{***} (-7.67)	-0.14^{***} (-3.14)	-0.46^{***} (-7.24)	-0.13^{***} (-2.94)	-0.46^{***} (-6.67)	-0.13^{**} (-2.33)
$\ln(n_{it}+g+\delta)$	0.01^{**} (2.03)	0.01^{**} (2.32)	0.01 (1.56)	0.01^{**} (2.05)	0.01 (1.97)	0.01^{**} (2.19)	0.01 (1.64)	0.01 (1.56)
$\Delta\ln(AvEdu)$	0.27^{***} (3.18)	0.18^{**} (2.11)	0.29^{**} (2.54)	0.19^{*} (1.91)	0.27^{***} (2.95)	0.22^{**} (2.32)	0.25^{**} (2.16)	0.23^{*} (1.78)
$\ln(s_k)$	-	-	-	-	0.03 (1.61)	0.06^{***} (3.95)	0.03 (1.46)	0.06^{***} (3.78)
Half-life	1.03	4.60	1.06	4.60	1.12	4.98	1.12	4.98
No. Observations	644	690	644	690	644	690	644	690
No. Instruments	45	49	45	49	59	64	59	64
Arellano-Bond test for AR(2)	-1.21 (0.23)	-2.20 (0.03)	-1.17 (0.24)	-2.09 (0.04)	-1.02 (0.31)	-1.40 (0.16)	-0.92 (0.36)	-1.36 (0.17)
Hansen test	45.24 (0.20)	45.06 (0.31)	45.24 (0.20)	45.06 (0.31)	44.87 (0.71)	44.47 (0.84)	44.87 (0.71)	44.47 (0.84)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Tables 5.11 to 5.15 show the results obtained for each level of education average years of schooling growth rate. As can be seen in Table 5.11, the growth rate of primary schooling years has a negative and significant effect on the reduction of income disparities among the Spanish provinces, in contrast with the respective level coefficient which was insignificant. It is an expected result since this is the lowest level of education. In what concerns the other variables coefficients, the results are quite similar to those previously obtained for the average years of total education and the same comments apply. The diagnostic tests show no second-order serial correlation (Arellano-Bond) and valid instruments (Hansen test).

Table 5.11 – Change in the average years of primary education without the public sector

Dependent variable: Change in relative GDP per capita (Δy_t)

	Without s_k				With s_k			
Regressors	GMM 1		GMM 2		GMM 1		GMM 2	
	Diff	Sys	Diff	Sys	Diff	Sys	Diff	Sys
Constant	-	0.19*** (4.50)	-	0.19*** (3.65)	-	0.22*** (4.72)	-	0.22*** (3.78)
y_{it-1}	-0.49*** (-8.95)	-0.24*** (-4.89)	-0.49*** (-8.57)	-0.25*** (-4.09)	-0.43*** (-6.29)	-0.18*** (-3.60)	-0.45*** (-5.38)	-0.18*** (-2.96)
$\ln(n_{it}+g+\delta)$	0.01 (1.94)	0.01** (2.64)	0.01* (1.71)	0.01** (2.07)	0.01* (1.87)	0.01** (2.38)	0.01 (1.40)	0.01* (1.88)
$\Delta\ln(Prim)$	-0.05** (-2.54)	-0.02** (-2.16)	-0.05** (-2.61)	-0.02** (-2.04)	-0.04* (-2.77)	-0.03** (-2.38)	-0.04* (-2.66)	-0.03** (-2.05)
$\ln(s_k)$	-	-	-	-	0.04* (1.72)	0.07* (4.01)	0.03 (1.35)	0.07* (3.53)
Half-life	1.03	2.53	1.03	2.41	1.23	3.49	1.16	3.49
o. Observations	644	690	644	690	644	690	644	690
No. Instruments	45	49	45	49	59	64	59	64
Arellano-Bond test for AR(2)	-0.82 (0.41)	-1.54 (0.12)	-0.89 (0.37)	-1.55 (0.12)	-0.74 (0.46)	-0.89 (0.37)	-0.74 (0.46)	-0.87 (0.39)
Hansen test	44.90 (0.21)	45.53 (0.29)	44.90 (0.21)	45.53 (0.29)	43.85 (0.75)	44.98 (0.83)	43.85 (0.75)	44.98 (0.83)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Moving to Table 5.12, it reports the results obtained when human capital proxy is the growth rate of the average years of secondary schoolling. The coefficient of the respective growth rate is insignificant across all the estimators. The results might not be consistent since in the system GMM case since the Arellano-Bond test for second-order serial correlation rejects the null at the conventional levels of significance. Even when the physical capital accumulation rate is introduced, the null of absence of serial second order correlation can be rejected at 10% level in the one-step system GMM results.

Table 5.12 – Change in the average years of secondary education without the public sector

Dependent variable: Change in relative GDP per capita (Δy_t)

	Without s_k				With s_k			
Regressors	GMM 1		GMM 2		GMM 1		GMM 2	
	Diff	Sys	Diff	Sys	Diff	Sys	Diff	Sys
Constant	-	0.07*** (2.83)	-	0.07** (2.61)	-	0.11*** (3.58)	-	0.10*** (2.75)
y_{it-1}	-0.50*** (-10.35)	-0.07*** (-3.28)	-0.49*** (-8.80)	-0.07*** (-2.89)	-0.45*** (-7.71)	-0.05** (-2.10)	-0.46*** (-6.38)	-0.04 (-1.39)
$\ln(n_{it}+g+\delta)$	0.01* (1.98)	0.01* (1.84)	0.01* (1.91)	0.01* (1.70)	0.01* (2.01)	0.01* (1.86)	0.01* (1.74)	0.01 (1.40)
$\Delta\ln(Sec)$	0.04 (1.28)	-0.01 (-0.27)	0.04 (1.40)	-0.01 (-0.23)	0.03 (0.86)	-0.00 (-0.09)	0.04 (0.96)	-0.01 (-0.17)
$\ln(s_k)$	-	-	-	-	0.04 (1.66)	0.05*** (3.38)	0.03 (1.36)	0.05*** (3.09)
Half-life	1.00	9.55	1.03	9.55	1.16	13.51	1.12	16.98
No. Observations	644	690	644	690	644	690	644	690
No. Instruments	45	49	45	49	59	64	59	64
Arellano-Bond test for AR(2)	-1.20 (0.23)	-2.44 (0.02)	-1.11 (0.27)	-2.27 (0.02)	-0.82 (0.41)	-1.73 (0.09)	-0.95 (0.34)	-1.59 (0.11)
Hansen test	44.74 (0.21)	45.09 (0.31)	44.74 (0.21)	45.09 (0.31)	43.67 (0.76)	45.10 (0.83)	43.67 (0.76)	45.10 (0.83)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Table 5.13 reports the results obtained when the average years of secondary school is computed taking into consideration the public sector. The respective growth rate coefficient is positively significant in the difference-GMM at the conventional levels without the investment rate and at 10% level when it is included. In the case of the system estimator, the Arellano-Bond test indicates second order serial-correlation problems so the estimator might not be consistent.

Table 5.13 – Change in the average years of secondary education with the public sector

Dependent variable: Change in relative GDP per capita (Δy_t)

Regressors	Without s_k				With s_k			
	GMM 1		GMM 2		GMM 1		GMM 2	
	Diff	Sys	Diff	Sys	Diff	Sys	Diff	Sys
Constant	-	0.09^{***} (2.97)	-	0.09^{***} (2.71)	-	0.10^{***} (3.50)	-	0.11^{***} (3.12)
y_{it-1}	-0.51^{***} (-10.01)	-0.11^{***} (-3.37)	-0.50^{***} (-8.97)	-0.10^{***} (-2.93)	-0.46^{***} (-7.62)	-0.09^{***} (-3.10)	-0.50^{***} (-7.16)	-0.10^{**} (-2.43)
$\ln(n_{it}+g+\delta)$	0.01^{*} (1.99)	0.01^{*} (1.95)	0.01^{*} (1.78)	0.01^{*} (1.86)	0.01^{*} (2.00)	0.01^{**} (2.03)	0.01^{*} (1.74)	0.01^{*} (1.80)
$\Delta\ln(Sec)$	0.10^{**} (2.55)	0.06^{*} (1.69)	0.10^{**} (2.48)	0.07 (1.54)	0.07^{*} (1.93)	0.04 (1.12)	0.08^{**} (2.02)	0.04 (1.78)
$\ln(s_k)$	-	-	-	-	0.03 (1.57)	0.02^{**} (2.11)	0.01 (0.72)	0.02^{*} (1.79)
Half-life	0.97	5.95	1.00	6.58	1.12	7.35	1.00	6.58
No. Observations	644	690	644	690	644	690	644	690
No. Instruments	45	49	45	49	59	64	59	64
Arellano-Bond test for AR(2)	-1.41 (0.16)	-2.57 (0.01)	-1.33 (0.19)	-2.36 (0.02)	-1.08 (0.28)	-2.27 (0.02)	-1.21 (0.23)	-2.14 (0.03)
Hansen test	45.29 (0.19)	44.59 (0.32)	45.29 (0.19)	44.59 (0.32)	44.10 (0.74)	44.89 (0.86)	44.36 (0.77)	44.89 (0.86)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Finally, Table 5.14 exhibits the results for the average years of higher education growth rate. All the estimators are consistent since there is no second-order serial correlation and the Hansen test confirms the instruments validity. As happened when this variable was considered in level, the growth of tertiary average years of schooling also plays an important role in the regional catching-up. Its coefficient is positive and significant across all the GMM estimators and robust to the inclusion of s_k, though it is much lower in comparison with the effect of the total education growth rate.

Table 5.14 – Change in the average years of tertiary education without the public sector

Dependent variable: Change in relative GDP per capita (Δy_t)

Regressors	Without s_k				With s_k			
	GMM 1		GMM 2		GMM 1		GMM 2	
	Diff	Sys	Diff	Sys	Diff	Sys	Diff	Sys
Constant	-	0.16*** (4.74)	-	0.17*** (4.43)	-	0.19*** (4.95)	-	0.20*** (4.14)
y_{it-1}	-0.46*** (-9.88)	-0.22*** (-5.23)	-0.46*** (-8.68)	-0.23*** (-4.91)	-0.40*** (-7.19)	-0.16*** (-4.22)	-0.40*** (-6.16)	-0.17*** (-3.51)
$\ln(n_{it}+g+\delta)$	0.01 (1.55)	0.01 (1.68)	0.01 (1.49)	0.01* (1.73)	0.01 (1.44)	0.01 (1.64)	0.01 (1.12)	0.01 (1.36)
$\Delta\ln(Ter)$	0.03** (2.55)	0.05*** (2.96)	0.03** (2.19)	0.05*** (2.78)	0.03** (2.57)	0.04*** (2.81)	0.03** (2.14)	0.04** (2.30)
$\ln(s_k)$	-	-	-	-	0.04* (1.96)	0.06*** (4.10)	0.03 (1.59)	0.06*** (3.88)
Half-life	1.12	2.79	1.12	2.65	1.36	3.98	1.36	3.72
No. Observations	644	690	644	690	644	690	644	690
No. Instruments	45	49	45	49	59	64	59	64
Arellano-Bond test for AR(2)	-0.62 (0.53)	-1.33 (0.19)	-0.51 (0.61)	-1.25 (0.21)	-0.37 (0.71)	-0.63 (0.53)	-0.61 (0.54)	-0.61 (0.54)
Hansen test	45.11 (0.20)	44.53 (0.33)	45.11 (0.20)	44.53 (0.33)	44.86 (0.72)	44.47 (0.84)	44.47 (0.84)	44.47 (0.84)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

The results obtained including the public sector in the computation of the average years of higher education are displayed in Table 5.15. The coefficient of the respective growth rate looses significance level in the System-GMM results, now it is only significant at 10% level. The effect of higher education growth on the reduction of income disparities is more significant when the workers are allocated to the private sector suggesting certain inefficiency in the public sector.

Table 5.15 – Change in the average years of tertiary education with the public sector

Dependent variable: Change in relative GDP per capita (Δy_t)

	Without s_k				With s_k			
Regressors	GMM 1		GMM 2		GMM 1		GMM 2	
	Diff	Sys	Diff	Sys	Diff	Sys	Diff	Sys
Constant	-	0.19*** (4.61)	-	0.19*** (4.12)	-	0.19*** (4.95)	-	0.24*** (3.85)
y_{it-1}	-0.46*** (-9.21)	-0.24*** (-4.77)	-0.45*** (-8.77)	-0.24*** (-4.37)	-0.40*** (-7.19)	-0.16*** (-4.22)	-0.40*** (-5.80)	-0.20*** (-3.01)
$\ln(n_{it}+g+\delta)$	0.01** (2.08)	0.01** (2.51)	0.01* (1.73)	0.01** (2.13)	0.01 (1.44)	0.01 (1.64)	0.01 (1.42)	0.01** (2.04)
$\Delta\ln(Ter)$	0.03 (1.46)	0.04** (2.01)	0.02 (1.04)	0.04* (1.71)	0.03** (2.57)	0.04* (2.81)	0.03 (1.07)	0.04* (1.73)
$\ln(s_k)$	-	-	-	-	0.04* (1.96)	0.06* (4.10)	0.04 (1.42)	0.06*** (3.70)
Half-life	1.12	2.53	1.16	2.53	1.36	3.98	1.36	3.11
No. Observations	644	690	644	690	644	690	644	690
No. Instruments	45	49	45	49	59	64	59	64
Arellano-Bond test for AR(2)	-0.65 (0.51)	-1.43 (0.15)	-0.63 (0.53)	-1.46 (0.14)	-0.37 (0.71)	-0.63 (0.53)	-0.54 (0.59)	-0.53 (0.60)
Hansen test	45.12 (0.20)	44.14 (0.34)	45.12 (0.20)	44.14 (0.34)	44.86 (0.72)	44.47 (0.84)	44.78 (0.72)	45.27 (0.82)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level

Labour-income proxies

According to the data available only the Mulligan and Sala-i-Martin (1997) labour-income measure (LIHK) is applied. Table 5.16 reports the results for the convergence equation using this human capital proxy. When the physical capital accumulation rate (s_k) is not controlled for, the diagnostic tests confirm the instruments validity but since there is still second-order serial-correlation the estimators are not consistent. Once s_k is introduced in the estimation this problem disappears. In contrast with the results obtained when the proxy for human capital was education, the effect on regional convergence of the labour-income measure is negative across all the estimations however not always significant. The preferable results are obtained with the System-GMM when s_k is controlled for because this estimator is both consistent and unbiased. In this case, the Mulligan and Sala-i-Martin (1997) proxy is not significant. As in Portugal, the Spanish LIHK measure is affected by the minimum wage which does not allow the wage gap to properly reflect the productivity differences among workers. The changes in this proxy are often unrealistic. For example, if there is a reduction in the number of unskilled workers, the wage of the zero-schooling worker tends to increase and the LIHK will fall. However, if this reduction is compensated by an increase in the number of skilled workers, the LIHK measure will reflect a fall in the human capital stock when actually the level of skills is increasing and this might explain the negative coefficient found in these results.

Table 5.16 – Mulligan and Sala-i-Martin (1997) proxy (LIHK)

Dependent variable: Change in relative GDP per capita (Δy_t)

Regressors	Without s_k				With s_k			
	GMM 1		GMM 2		GMM 1		GMM 2	
	Diff	Sys	Diff	Sys	Diff	Sys	Diff	Sys
Constant	-	0.33*** (3.94)	-	0.33*** (3.59)	-	0.35*** (2.96)	-	0.36** (2.48)
y_{it-1}	-0.52*** (-8.75)	-0.24*** (-3.34)	-0.53*** (-7.85)	-0.24*** (-2.95)	-0.47*** (-6.57)	-0.18*** (-2.72)	-0.48*** (-6.00)	-0.19** (-2.41)
$\ln(n_{it} + g + \delta)$	0.01 (1.28)	0.01* (2.01)	0.01 (1.01)	0.01 (1.43)	0.01 (1.33)	0.01* (1.98)	0.01 (0.95)	0.01 (1.63)
$\ln(LIHK)$	-0.20*** (-3.74)	-0.15*** (-3.12)	-0.20*** (-3.69)	-0.15*** (-2.96)	-0.19*** (-2.97)	-0.12 (-1.61)	-0.19*** (-2.84)	-0.12 (-1.34)
$\ln(s_k)$	-	-	-	-	0.04* (1.76)	0.07*** (4.24)	0.04 (1.56)	0.07*** (3.66)
Half-life	0.94	2.53	0.92	2.53	1.09	3.49	1.06	3.29
No. Observations	644	690	644	690	644	690	644	690
No. Instruments	45	49	45	49	59	64	64	64
Arellano-Bond test for AR(2)	-1.73 (0.08)	-2.49 (0.01)	-1.74 (0.08)	-2.51 (0.01)	-1.44 (0.15)	-1.40 (0.16)	-1.36 (0.17)	-1.36 (0.17)
Hansen test	45.15 (0.20)	45.26 (0.30)	45.15 (0.20)	45.26 (0.30)	44.97 (0.71)	45.59 (0.81)	45.59 (0.81)	45.59 (0.81)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

The lagged relative GDP per capita coefficient is negatively significant, as expected, and its size is quite similar to what was obtained when human capital was proxied by the average years of schooling. Again, it is much higher when the difference-GMM estimator is applied because this estimator is biased and this implies a very low half-life, around 1 year. The investment rate coefficient is positively significant suggesting a positive role of physical capital accumulation on the reduction of Spanish regional income per capita disparities. Quite opposite from what happened when human capital was proxied by education, the coefficient of the LIHK growth rate is insignificant so the results are not reported.

5.5.2. Convergence conditional on the production structure

As it was done in the chapter for Portugal, in order to compare the performance of human capital in the convergence equation with other possible conditioning factors, the production structure is introduced as an alternative conditional variable. The same proxies are considered, this is the share of each main economic sector in the regional Gross Added Value. The sectoral classification is the same: Primary (Agriculture, forestry and fishery), Secondary (Industry, including energy and civil construction) and Tertiary (Services). Tables 5.17 and 5.18 report the results for the Spanish regional convergence conditional on the production structure.[24]

Across the system GMM results, when the physical capital accumulation rate (s_k) is not controlled for, the Hansen test confirms the instruments validity but the Arellano-bond (1991) test evidences second order serial-correlation since the respective *p*-values of Hansen test are below 10%. This problem disappears once s_k is introduced in the regression and the results concern the other variables coefficients are robust to its inclusion. The coefficient of the lagged relative GDP per capita is always negatively significant, much higher in absolute terms when the Difference-GMM is applied. Its size is higher in absolute terms when the conditional variable is the share of secondary sector suggesting that industrialization increases the speed of convergence towards the richest province in Spain implying a reduction of the

[24] The effect of the primary sector weight in total output is not significant so the results are not reported.

number of years needed to eliminate the gap towards the steady-state. As in the previous subsection estimations, the coefficient of the physical capital accumulation rate is positive and significant at the conventional levels of significance; except for the Difference-GMM when the production structure is proxied by the industry share, for which it is only significant at 10% level. Since this estimator is biased the System-GMM results are preferable.

Table 5.17 – Industry share in total output

Dependent variable: Change in relative GDP per capita (Δy_t)

	Without s_k				With s_k			
Regressors	GMM 1		GMM 2		GMM 1		GMM 2	
	Diff	Sys	Diff	Sys	Diff	Sys	Diff	Sys
Constant	-	0.15^{***} (2.76)	-	0.15^{***} (2.76)	-	0.18^{***} (3.65)	-	0.18^{***} (2.94)
y_{it-1}	-0.61^{***} (-13.41)	-0.33^{***} (-4.86)	-0.61^{***} (-12.47)	-0.33^{***} (-4.86)	-0.57^{***} (-10.81)	-0.29^{***} (-5.51)	-0.56^{***} (-8.95)	-0.30^{***} (-5.15)
$\ln(n_{it}+g+\delta)$	0.00 (0.21)	0.00 (0.99)	0.00 (0.11)	0.00 (0.99)	0.00 (0.14)	0.00 (0.86)	0.00 (0.04)	0.00 (0.55)
Industry	0.30^{***} (5.24)	0.25^{***} (5.81)	0.30^{***} (5.06)	0.25^{***} (5.81)	0.32^{***} (5.32)	0.26^{***} (5.22)	0.32^{***} (4.73)	0.27^{***} (4.69)
$\ln(s_k)$	-	-	-	-	0.05^{**} (2.05)	0.06^{***} (3.15)	0.05^{*} (1.84)	0.05^{**} (2.31)
Half-life	0.74	1.73	0.74	1.73	0.82	2.02	0.84	1.94
No. Observations	644	690	644	690	644	690	644	690
No. Instruments	45	49	45	49	59	64	59	64
Arellano-Bond test for AR(2)	-1.54 (0.12)	-2.39 (0.02)	-1.52 (0.13)	-2.39 (0.02)	-1.15 (0.25)	-1.55 (0.12)	-1.15 (0.25)	-1.60 (0.11)
Hansen test	45.10 (0.20)	45.58 (0.29)	45.10 (0.20)	45.58 (0.29)	45.42 (0.69)	43.69 (0.86)	45.42 (0.69)	43.69 (0.86)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Table 5.18 – Services share in total output

Dependent variable: Change in relative GDP per capita (Δy_t)

Regressors	Without s_k				With s_k			
	GMM 1		GMM 2		GMM 1		GMM 2	
	Diff	Sys	Diff	Sys	Diff	Sys	Diff	Sys
Constant	-	0.40*** (6.50)	-	0.40*** (6.50)	-	0.46*** (7.43)	-	0.47*** (6.22)
y_{it-1}	-0.63*** (-15.40)	-0.30*** (-5.22)	-0.62*** (-13.59)	-0.30*** (-5.22)	-0.57*** (-11.40)	-0.25*** (-4.63)	-0.56*** (-9.44)	-0.26*** (-4.28)
$\ln(n_{it} + g + \delta)$	0.01* (1.82)	0.01** (2.31)	0.01* (1.80)	0.01** (2.31)	0.01* (1.82)	0.01** (2.15)	0.00 (1.66)	0.01* (1.90)
Services	-0.49*** (-5.27)	-0.28*** (-4.86)	-0.49*** (-5.04)	-0.28*** (-4.86)	-0.51*** (-5.33)	-0.31*** (-4.64)	-0.51*** (-4.78)	-0.32*** (-4.23)
$\ln(s_k)$	-	-	-	-	0.06*** (2.76)	0.07*** (4.08)	0.07** (2.49)	0.07*** (3.80)
Half-life	0.70	1.94	0.72	1.94	0.82	2.41	0.84	2.30
No. Observations	644	690	644	690	644	690	644	690
No. Instruments	45	49	45	49	59	64	59	64
Arellano-Bond test for AR(2)	-1.43 (0.15)	-2.16 (0.03)	-1.37 (0.17)	-2.16 (0.03)	-0.68 (0.50)	-1.14 (0.25)	-0.71 (0.48)	-1.10 (0.27)
Hansen test	45.36 (0.19)	44.94 (0.31)	45.36 (0.19)	44.94 (0.31)	45.66 (0.69)	44.64 (0.84)	45.66 (0.69)	44.64 (0.84)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

As in Portugal, the industrialization process in Spain started late in European terms [de la Escosura and Sanz (2003)]. There was a significant shift from primary to both the secondary and tertiary sector in output and employment. In comparison with Portugal, the Spanish secondary sector has had a higher weight in both output and employment. The expansion of the services in Spain can also be classified as second-wave. Looking at the coefficients of the different sectors shares, the effect of the secondary sector is positively significant across the different estimators while the effect of the service sector on the reduction of income per capita disparities is always negative and significant. It is interesting to see the difference between the two Iberian countries, the sector that has played a positive role in the reduction of income per capita disparities in Spain is industry, in contrast with the services sector in Portugal.

In Spain many of the rich provinces exhibit a share of the industrial sector higher than the national average, namely Álava which is the richest of the country and was chosen as the benchmark. The positive effect of industry on the catching-up towards Álava is in line with the influential work of Kaldor (1957) who views the industrial sector as the engine of growth since it is able to generate significant increasing returns to scale through Verdoorn's Law [Verdorn (1949)][25] and it is the main producer of tradable goods contributing therefore to exports and growth as a result. The automobile sector, for example, was one of the most dynamic industrial sectors in Spain and accounts for more than 15% of the total Spanish exports[26]. Verdoorn's Law was tested in the Spanish NUTS II regions by León-Ledesma (2000) who despite confirming higher increasing returns to scale in the industrial sector relative to the services draws attention to the measurement problems and the high degree of heterogeneity within the tertiary sector.

5.6. Conclusion

This work is a contribution to the study of the effect of human capital, proxied by both educational and labour-income measures, on growth and convergence in Spain. Most empirical studies on convergence in this country are focused on the NUTS II level of regional disaggregation, this chapter works with the NUTS III level which corresponds to the Spanish provinces. In order to compare the results with those obtained for Portugal, the education proxies were computed with and without the public sector.

Overall the results depend on the level of education taken into consideration, the addition or not of the investment rate and even on the inclusion of the public sector in the computation of the proxies. Excluding the public sector, the average years of total education is important as an input, but it is not relevant for technology adoption if the physical capital accumulation is controlled for. In Spain, secondary education is not significant across the different specifications, while in Portugal, secondary school is important for technology adoption and the respective effect is larger than the effect of higher education. On the other hand, Spanish higher education is important as both an

[25] It states that the industrial sector productivity growth is the outcome of output growth.

[26] OECD (2008), "Economic Outlook", No. 86

input in the production function and a vehicle of technological adoption; in Portugal it was just significant as the latest. Spain is closer to the technological frontier than Portugal and this might explain why higher education is the level that matters most for Spanish regional growth.

Human capital proxied by the labour-income measure was insignificant in the conditional convergence equation for Portugal, but shows a negative significant effect on the Spanish regional growth. The poor performance of this human capital proxy in the convergence equation is probably due to the minimum-wage effect on its computation.

In what concerns the production structure, the results show a negative, but not significant, effect of the primary sector weight in total output, a positive and significant contribution of the industrial sector, in the line with the idea of industry as the engine of growth, and a negative and significant impact of the services. These findings contrast with the results obtained for Portugal, where the services sector played a positive role in the reduction of income per capita disparities and the industrial sector was insignificant. Comparing the two Iberian countries experience over the period, the tertiary sector has become more important in Portugal than in Spain (73% of GDP against 66%, in 2006).

Appendix to Chapter 5

Table 5.19 – Spanish NUTS regions

NUTS II		NUTS III	
ES11	Galicia	ES111	La Coruña
		ES112	Lugo
		ES113	Ourense
		ES114	Pontevedra
ES12	Principado de Asturias	ES120	Asturias
ES13	Cantabria	ES130	Cantabria
ES21	País Vasco	ES211	Álava
		ES212	Guipúzcoa
		ES213	Vizcaya
ES22	Comunidad Foral de Navarra	ES220	Navarra
ES23	La Rioja	ES230	La Rioja
ES24	Aragón	ES241	Huesca
		ES242	Teruel
		ES243	Zaragoza
ES30	Comunidad de Madrid	ES300	Madrid
ES41	Castilla y León	ES411	Ávila
		ES412	Burgos
		ES413	León
		ES414	Palencia
		ES415	Salamanca
		ES416	Segovia
		ES417	Soria
		ES418	Valladolid
		ES419	Zamora
ES42	Castilla-La Mancha	ES421	Albacete
		ES422	Ciudad Real
		ES423	Cuenca
		ES424	Guadalajara
		ES425	Toledo
ES43	Extremadura	ES431	Badajoz
		ES432	Cáceres
ES51	Cataluña	ES511	Barcelona
		ES512	Girona
		ES513	Lleida
		ES514	Tarragona
ES52	Comunidad Valenciana	ES521	Alicante
		ES522	Castellón
		ES523	Valencia
ES53	Illes Balears	ES531	Eivissa y Formentera
		ES532	Mallorca
		Es533	Menorca
ES61	Andalucía	ES611	Almería
		ES612	Cádiz
		ES613	Córdoba
		ES614	Granada
		ES615	Huelva
		ES616	Jaén
		ES617	Málaga
		ES618	Sevilla
ES62	Región de Murcia	ES620	Murcia
ES63	Ciudad Autónoma de Ceuta	ES630	Ceuta
ES64	Ciudad Autónoma de Melilla	ES640	Melilla

Spanish NUTS regions (cont.)			
NUTS II		NUTS III	
ES70	Canarias	ES703	El Hierro
		ES704	Fuerteventura
		ES705	Gran Canaria
		ES706	La Gomera
		ES707	La Palma
		ES708	Lanzarote
		ES709	Tenerife

Table 5.20 – Average years of education with the public sector

Dependent variable: Change in relative GDP per capita (Δy_t)

Regressors	Without s_k				With s_k			
	GMM 1		GMM 2		GMM 1		GMM 2	
	Diff	Sys	Diff	Sys	Diff	Sys	Diff	Sys
Constant	-	-0.05 (-0.63)	-	-0.04 (-0.53)	-	0.11 (0.84)		0.10 (0.66)
y_{it-1}	-0.47*** (-8.20)	-0.12*** (-3.52)	-0.48*** (-7.50)	-0.12*** (-3.11)	-0.45*** (-6.78)	-0.11*** (-2.73)	-0.46*** (-6.00)	-0.11** (-2.08)
$\ln(n_{it}+g+\delta)$	0.01** (2.02)	0.01** (2.60)	0.01*** (1.40)	0.01** (2.33)	0.01* (1.97)	0.01** (2.42)	0.01 (1.56)	0.01* (1.82)
$\ln(AvEdu)$	0.00 (0.04)	0.07** (2.28)	-0.00 (-0.03)	0.06** (2.18)	-0.01 (-0.34)	0.02 (0.50)	-0.01 (-0.32)	0.03 (0.51)
$\ln(s_k)$	-	-	-	-	0.03 (1.48)	0.06*** (3.30)	0.03 (1.16)	0.05*** (3.18)
Half-life	1.09	5.42	1.06	5.42	1.16	5.95	1.12	5.95
No. Observations	644	690	644	690	644	690	644	690
No. Instruments	45	49	45	49	59	64	59	64
Arellano-Bond test for AR(2)	-0.94 (0.35)	-1.68 (0.09)	-0.96 (0.34)	-1.62 (0.10)	-0.81 (0.42)	-1.12 (0.26)	-0.88 (0.38)	-1.18 (0.24)
Hansen test	44.88 (0.21)	45.31 (0.30)	44.88 (0.21)	45.31 (0.30)	44.72 (0.72)	44.73 (0.84)	44.72 (0.72)	44.73 (0.84)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Table 5.21 – Average years of primary education with the public sector

Dependent variable: Change in relative GDP per capita (Δy_t)

	Without s_k				With s_k			
Regressors	GMM 1		GMM 2		GMM 1		GMM 2	
	Diff	Sys	Diff	Sys	Diff	Sys	Diff	Sys
Constant	-	0.21*** (5.03)	-	0.21*** (4.30)	-	0.23*** (4.97)	-	0.21*** (3.84)
y_{it-1}	-0.46*** (-8.63)	-0.28*** (-5.48)	-0.45*** (-7.54)	-0.27*** (-4.76)	-0.41*** (-6.11)	-0.20*** (-4.24)	-0.42*** (-5.30)	-0.19*** (-3.73)
$\ln(n_{it}+g+\delta)$	0.01** (2.07)	0.01** (2.61)	0.01* (1.73)	0.01** (2.06)	0.01* (1.97)	0.01** (2.38)	0.01 (1.66)	0.01 (1.66)
$\ln(Prim)$	-0.01 (-1.04)	-0.01 (-1.54)	-0.01 (-1.06)	-0.01 (-1.55)	-0.00 (-0.42)	-0.01 (-1.26)	-0.00 (-0.30)	-0.01 (-1.01)
$\ln(s_k)$	-	-	-	-	0.04* (1.72)	0.06*** (3.92)	0.03 (1.33)	0.06*** (3.01)
Half-life	1.12	2.11	1.16	2.20	1.31	3.11	1.27	3.29
No. Observations	644	690	644	690	644	690	644	690
No. Instruments	45	49	45	49	59	64	59	64
Arellano-Bond test for AR(2)	-0.83 (0.41)	-1.36 (0.17)	-0.80 (0.43)	-1.36 (0.18)	-0.69 (0.49)	-0.79 (0.43)	-0.73 (0.47)	-0.92 (0.36)
Hansen test	45.33 (0.19)	45.19 (0.30)	45.33 (0.19)	45.19 (0.30)	44.03 (0.75)	44.53 (0.84)	44.03 (0.75)	44.53 (0.84)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Table 5.22 – Average years of secondary education with the public sector

Dependent variable: Change in relative GDP per capita (Δy_t)

Regressors	Without s_k				With s_k			
	GMM 1		GMM 2		GMM 1		GMM 2	
	Diff	Sys	Diff	Sys	Diff	Sys	Diff	Sys
Constant	-	-0.03 (0.98)	-	0.03 (0.87)	-	0.09* (1.88)	-	0.10 (1.68)
y_{it-1}	-0.48*** (-8.94)	-0.09*** (-3.60)	-0.49*** (-7.90)	-0.09*** (-3.09)	-0.44*** (-7.09)	-0.07** (-2.63)	-0.45*** (-6.18)	-0.07* (-1.76)
$\ln(n_{it}+g+\delta)$	0.01*** (2.22)	0.01*** (2.31)	0.01** (2.01)	0.01** (2.13)	0.01** (2.22)	0.01*** (2.27)	0.01 (1.59)	0.01* (1.72)
$\ln(Sec)$	0.01 (0.38)	0.03*** (3.59)	0.01 (0.30)	0.03** (2.65)	-0.00 (-0.07)	0.02 (0.28)	-0.00 (-0.01)	0.01 (0.85)
$\ln(s_k)$	-	-	-	-	0.04 (1.63)	0.05*** (3.02)	0.03 (1.33)	0.05*** (2.88)
Half-life	1.06	7.35	1.03	7.35	1.20	9.55	1.16	9.55
No. Observations	644	690	644	690	644	690	644	690
No. Instruments	45	49	45	49	59	64	59	64
Arellano-Bond test for AR(2)	-0.69 (0.49)	-1.83 (0.07)	-0.66 (0.51)	-1.80 (0.07)	-0.49 (0.62)	-1.39 (0.17)	-0.60 (0.55)	-1.41 (0.16)
Hansen test	45.32 (0.19)	45.35 (0.30)	45.32 (0.19)	45.35 (0.30)	44.19 (0.74)	44.67 (0.84)	44.19 (0.74)	44.67 (0.84)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Table 5.23 – Change in the average years of education with the public sector

Dependent variable: Change in relative GDP per capita (Δy_t)

	Without s_k				With s_k			
Regressors	GMM 1		GMM 2		GMM 1		GMM 2	
	Diff	Sys	Diff	Sys	Diff	Sys	Diff	Sys
Constant	-	0.12*** (3.29)	-	0.12*** (3.11)	-	0.17*** (4.17)	-	0.17*** (3.33)
y_{it-1}	-0.48*** (-9.42)	-0.14*** (-3.46)	-0.47*** (-8.14)	-0.14*** (-3.15)	-0.46*** (-7.24)	-0.13*** (-2.94)	-0.43*** (-6.00)	-0.13** (-2.47)
$\ln(n_{it} + g + \delta)$	0.01** (2.19)	0.01** (2.43)	0.01 (1.60)	0.01** (2.15)	0.01** (1.97)	0.01** (2.19)	0.01* (1.70)	0.01 (1.57)
$\Delta \ln(AvEdu)$	0.20** (2.56)	0.21** (2.59)	0.20** (2.23)	0.22** (2.38)	0.27* (2.95)	0.22** (2.32)	0.20* (1.81)	0.24** (2.21)
$\ln(s_k)$	-	-	-	-	0.03 (1.61)	0.06*** (3.95)	0.03 (1.65)	0.06*** (3.54)
Half-life	1.06	1.09	1.09	4.60	1.12	4.98	1.23	4.98
No. Observations	644	690	644	690	644	690	644	690
No. Instruments	45	45	45	49	59	64	59	64
Arellano-Bond test for AR(2)	-0.90 (0.37)	-2.01 (0.04)	-0.93 (0.35)	-1.95 (0.05)	-1.02 (0.31)	-1.40 (0.16)	-0.69 (0.49)	-1.28 (0.20)
Hansen test	45.06 (0.20)	45.22 (0.30)	45.06 (0.20)	45.22 (0.30)	44.87 (0.71)	44.47 (0.84)	44.28 (0.74)	43.74 (0.86)

Notes: t-statistics based on robust standard errors in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Chapter 6
The role of spatial effects on the Iberian countries' regional growth and convergence

6.1. Introduction

The previous chapters have studied the regional growth in Portugal and Spain as a process similar to national growth. The conditional β-convergence model was applied to regional data ignoring possible interactions between regions. As a region's growth depends among other factors on the other regions' growth, the results obtained with methods that ignore spatial effects might be biased. Portugal and Spain are neighbour countries that joined the EU together in 1986 and since then all Portuguese and many Spanish regions have received structural funds to catch-up with the other "Old EU" members. This chapter applies the same β-convergence model and keeps the same conditional variables (human capital and production structure) but builds on the previous chapters by combining the two countries' regions and taking into account possible spatial effects: spatial dependence and spatial heterogeneity. There is spatial dependence (or autocorrelation) when there is a relation between what happens in one region and in the others. It is similar to autocorrelation in the time series context, but more complicated in the sense that there are two directions. What happens at one time period can only be influenced by what has happened in the past. In contrast, what happens in one region is influenced by what happens in the others but also the other way round. Spatial heterogeneity is conceptually different from spatial dependence and it is present when the relationship among economic variables is unstable across the regions.

Although literature on the spatial effects of growth has been mainly empirical, there have been some theoretical developments such as López-Bazo *et al.* (2004) and Ertur and Koch (2007) who integrate the spatial externalities in the augmented Solow model. Most empirical studies on the EU regions consider the NUTS II level of regional disaggregation [López-Bazo *et al.* (2004), Ertur *et al.* (2006), Dall'Erba and Le Gallo (2008), Ramajo *et al.* (2008)] and exclude human capital due to data limitations. Only recently, Arbia *et al.* (2010) included human capital proxied by the tertiary school attainment in a study on the EU27 NUTS II regions within a spatial framework and the findings suggest a positive effect on growth.

In what concerns the individual countries regional studies, there are a couple of papers for the Spanish provinces (which are the NUTS III units in this country) that take into account the spatial effects. For example, Maza and Villaverde (2009) and Villaverde (2006) studied absolute β-convergence in productivity for different time periods and found that though there are spatial effects their relevance for the convergence process is low. Only Ramos *et al.* (2010) focus on the human capital effects on the same set of regions and found a positive impact on productivity growth but no evidence of human capital regional spillovers. With regards to Portuguese regional growth studies applying the β-convergence model there is no work published that takes into account the role of spatial effects. Portuguese and Spanish regions together have never been considered by the literature. Therefore the main contribution is the study of regional growth and convergence clubs in the Iberian NUTS III regions using spatial econometrics.

The chapter is organized as follows: Section 6.2. describes the methodology, Section 6.3. applies the exploratory spatial data analysis in order to describe the space dynamics and detect possible spatial autocorrelation and cases of spatial heterogeneity such as spatial regimes. The latter are then used in Section 6.4. to identify the convergence clubs in the Iberia Peninsula. In section 6.5. the empirical conditional β-convergence model and the respective results are discussed. Section 6.6. adds regional policy to the β-convergence model and Section 6.7. concludes.

6.2. Methodology

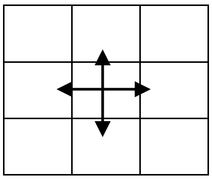
Spatial econometrics can be defined as "a subset of econometric methods that is concerned with spatial aspects present in cross-sectional and space-time observations. Variables related to location, distance and arrangement (topology) are treated explicitly in model specification; estimation; diagnostic checking and prediction. More specifically, spatial econometrics deals with two basic forms of spatial effects in regression models, categorized as spatial dependence and spatial heterogeneity." [Anselin (2006), p. 902].

Spatial autocorrelation is defined by Anselin (1988) as the coincidence of value similarity with location similarity. This is, high or low values for a random variable tend to cluster in space (positive autocorrelation) or locations tend to be surrounded by neighbours with very dissimilar values (negative spatial autocorrelation). The global spatial autocorrelation for each variable is usually measured through the Moran's *I* statistic [Anselin (1995)]:

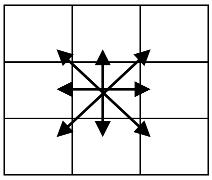
$$I_t = \frac{n}{S_0} \times \frac{z'_t W z_t}{z'_t z_t} \tag{6.1}$$

where *n* is the number of cross-section observations, z_t is the vector of observations for year *t* in deviations from the mean, *W* is the spatial weights matrix and S_0 is the scaling constant, defined as the sum of all spatial elements of *W*, this is $S_0 = \sum_i \sum_j w_{ij}$. Wz_t is the vector of spatially weighted averages of neighbouring values, this is the spatially lagged vector. A positive value of Moran's *I* indicates positive spatial autocorrelation and a negative indicates negative spatial autocorrelation. The spatial weights matrix *W* is a square matrix with *n* rows and columns that correspond to the number of regions and captures their spatial interaction. The diagonal consists of zeros ($w_{ii} = 0$) and each w_{ij} defines the way a region *i* is connected with the region *j*. The most common weights matrixes are based on geographic criteria:

1) The contiguity-based spatial weights matrix, which is constructed by assigning a weight of 1 to all *j* regions that are contiguous to *i*, and zero to all the others. This relies on the regions' depiction on the map. The definition of neighbourhood is sharing a common boundary (Rook-based contiguity, called this way because of this chess piece movements on the board) or common boundaries or corners (Queen-based contiguity):



Rook-based



Queen-based

As seen above, the number of neighbours of region *i* differs according to the matrix applied, from 4 in the Rook's case to 8 in the Queen's. These are the first-order neighbours. It is also possible to consider higher orders of contiguity. For example, when second-order contiguity is considered, the regions that share a border (or border and corners) with the first-order neighbours are also counted as neighbours.

2) The distance-based spatial weights matrix, which is constructed by assigning a weight of the respective distances, e.g. km or travel time, between all regions *j* and region *i* centroids. Following Ertur and Koch (2006), the general form of the *k*-nearest neighbours weight matrix $W(k)$ is:

$$\begin{cases} w_{ij}^{*}(k) = 0 \text{ if } i = j \\ w_{ij}^{*}(k) = 1 \text{ if } d_{ij} \leq d_i(k) \text{ and } w_{ij}(k) = w_{ij}^{*}(k) \Big/ \sum_j w_{ij}^{*}(k) \\ w_{ij}^{*}(k) = 0 \text{ if } d_{ij} > d_i(k) \end{cases}$$

where $d_i(k)$ is the k^{th} order smallest distance between regions *i* and *j* such that each region *i* has exactly *k* neighbours. In this case the definition of neighbour is based on the distance between the region's centroids. In empirical work these matrixes are often applied in the row-standardized form, this is, the elements of a row sum up to one ($w_{ij}^{\text{standardized}} = w_{ij} / \sum_j w_{ij}$).

In the regional growth context, the empirical studies that account for spatial effects usually evolve the following steps:

1) Estimate the convergence equation under consideration using the standard OLS.
2) Apply Moran's *I* statistic to test for spatial autocorrelation in the residuals, with the null of no spatial autocorrelation. Following Anselin (2006), the Moran's *I* statistic for the OLS residuals is formally given by:

$$I = \frac{e'We/S_0}{e'e/n} \tag{6.2}$$

in which e is the $(n \times 1)$ vector of OLS residuals ($Y - X\hat{\beta}$), *W* is the spatial weights matrix and S_0 is the scaling constant. The inference in a test against spatial autocorrelation is based on a normal approximation.
3) If no spatial correlation is detected stick to the OLS results, otherwise decide between the two main spatial dependence models: Spatial Lag Model or Spatial Error Model [Anselin (1988); Anselin and Bera (1998); Rey and Le Gallo (2009)].

In the Spatial Lag Model (SLM), the spatial autocorrelation is modeled through the use of the spatially lagged dependent variable (*WY*) which is added to the right-hand side of the regression specification. The introduction of this extra explanatory variable means that the growth of one region depends, among other factors, on the growth of the neighbours (regional spillovers). In formal terms:

$$Y = \rho WY + X\beta + \varepsilon \tag{6.3}$$

where *Y* is the vector of regional dependent variable, *X* is the matrix of explanatory variables, ρ is the spatial autoregressive parameter and *W* is the standardised (this means the elements of a row sum up to one) spatial weights matrix that captures the spatial interaction between regions described before and ε is the well-behaved error term. Equation (7.3) is called the structural form of the model and the respective reduced form can be directly obtained from it:

$$(I - \rho W)Y = X\beta + \varepsilon$$

$$Y = (I - \rho W)^{-1} X\beta + (I - \rho W)^{-1} \varepsilon \tag{6.4}$$

in which I is the identity matrix. This reduced form shows a model which is no longer linear in the parameters due to the presence of the unknown spatial autoregressive coefficient ρ.

In the Spatial Error Model (SEM), the error term u adopts a spatial structure which means that externalities only come from the shocks, this is:

$$Y = X\beta + u \tag{6.5}$$

$$u = \lambda Wu + \varepsilon \tag{6.6}$$

where Y is the vector of regional dependent variable, X is the matrix of explanatory variables, u is the spatially correlated error, λ is the autoregressive error coefficient, W is the standardised (elements of a row sum up to one) spatial weights matrix and ε is the well-behaved error term. The respective reduced form is obtained by solving (7.6):

$$\begin{aligned} (I - \lambda W)u &= \varepsilon \\ u &= (I - \lambda W)^{-1}\varepsilon \end{aligned} \tag{6.7}$$

and substituting (7.7) into (7.5):

$$Y = X\beta + (I - \lambda W)^{-1}\varepsilon \tag{6.8}$$

Both the SLM and the SEM are estimated by maximum likelihood procedures under the normality assumption. Following Anselin (2006), allowing for heteroskedasticity the error vector is $\varepsilon \approx N(0, \Sigma_\theta)$, the log-likelihood functions for the spatial lag model and spatial error model are given, respectively, by equations (7.9) and (7.10):

$$\begin{aligned} L = &-(N/2)\ln(2\pi) - (1/2)\ln|\Sigma_\theta| + \ln|I - \rho W| \\ &-(1/2)(Y - \rho WY - X\beta)'\Sigma_\theta^{-1}(Y - \rho WY - X\beta) \end{aligned} \tag{6.9}$$

$$L = -(N/2)\ln(2\pi) - (1/2)\ln|\Sigma_\theta| - (Y-\beta)'\Sigma_\theta^{-1}(Y - X\beta) \quad (6.10)$$

and the estimates for the parameters are the solutions for the usual first-order conditions (partial derivatives into respect with each parameter equal to zero).

The decision between the two models is made according to the Lagrange Multiplier (LM) test statistics [Anselin *et al.* (1996), Anselin and Florax (1995), Anselin (2006)]. Following Anselin (2006), the LM test statistics are obtained from the respective log-likelihood functions (7.9 and 7.10) and given by:

$$LM = [d(\theta)]'[I(\theta)]^{-1}[d(\theta)] \quad (6.11)$$

in which $d(\theta)$ is the familiar score and $I(\theta)$ is the information matrix:

$$d(\theta) = \partial L / \partial \theta \quad (6.12)$$

$$I(\theta) = -E[\partial^2 L / \partial\theta\, \partial\theta'] \quad (6.13)$$

This procedure leads to the following LM-lag statistic:

$$LM_{lag} = [e'WY/(e'e/N)]^2 / D \quad (6.14)$$

in which e is the OLS residuals and the denominator D is:

$$D = [(WX\hat{\beta})'[I - X(X'X)^{-1}X'](WX\hat{\beta})/\hat{\sigma}^2] + tr(W'W + WW) \quad (6.15)$$

where $\hat{\beta}$ and $\hat{\sigma}^2$ are from OLS. In the case of the LM-error, the test statistic is:

$$LM_{error} = [e'We/(e'e/N)]^2 / tr[W'W + WW]' \quad (6.16)$$

Setting $d_\rho = (e'WY)/(e'e/N)$, $T = tr[WW + W'W]$ and $d_\lambda = (e'We)/(e'e/N)$, the robust versions of the LM test statistics are given by:

$$Robust\ LM_{lag} = \frac{(d_\rho - d_\lambda)^2}{(D - T)} \tag{6.17}$$

$$Robust\ LM_{error} = \frac{(d_\lambda - TD^{-1}d_\rho)^2}{[T(1 - TD)]} \tag{6.18}$$

The LM-Lag and Robust LM-Lag favour the spatial lag model as the alternative, while the LM-Error and Robust LM-Error suggest the spatial error model as the appropriate specification. All these LM statistics are distributed as a χ^2 with one degree of freedom. The robust versions of the LM statistics should only be considered when both the standard LM-Lag and LM-Error are significant. When both the LM-lag and the LM-error are significant but only the robust LM-lag is significant, the spatial lag model is chosen as the appropriate model. In the rare case that both are highly significant, the model with the largest, most significant, value for the robust test statistic is selected [Anselin (2006), p. 941].

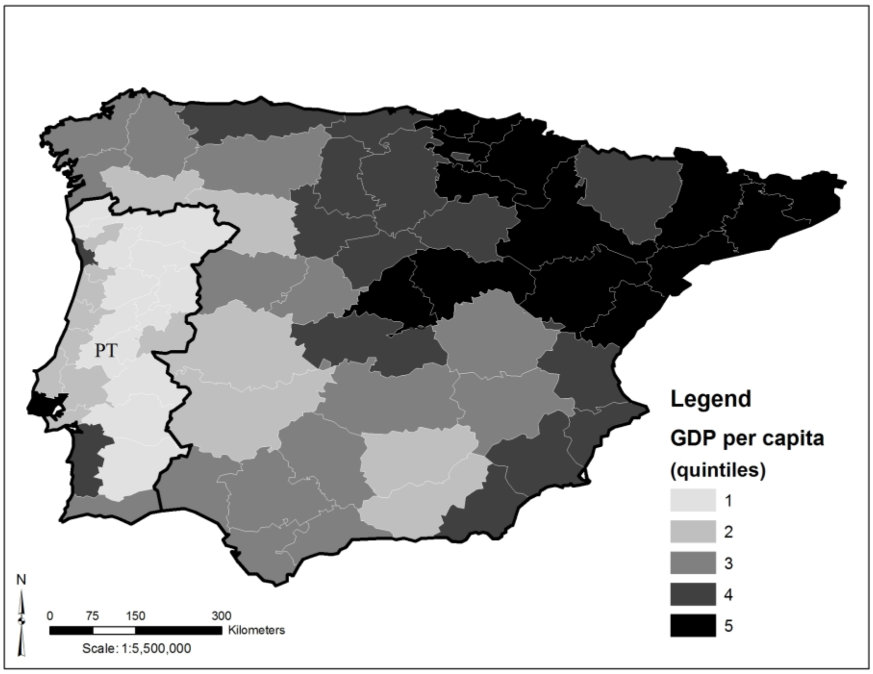
The choice between the SLM and SEM specifications in the regional growth context is very important. The way spatial autocorrelation is included in the spatial lag model has potentially an economic interpretation, while, in the spatial error model it is simple nuisance spatial correlation. It is important to notice that the coefficients of the SLM cannot be directly compared with the coefficients of the SEM or the simple OLS. The coefficients of the SLM reflect a direct marginal effect, this is, the result of changes of the explanatory variables in a region *i*. Differently, the coefficients obtained with the SEM or the simple OLS show a total marginal effect of the explanatory variables, this is, the result of changes in those variables not only in the region *i* but also in the other regions [Rey and le Gallo (2009)].

The spatial autoregressive parameter ρ in the SLM specification can be interpreted as capturing cross-regional spillovers, but with caution since a significant ρ is also likely to reflect the existence of spatially autocorrelated omitted variables and not only cross-regional spillovers [Abreu *et al.* (2005)]. For example, human capital is typically absent from the European regional growth studies, due to lack of data, but if their levels are spatially autocorrelated the omitted variable problem will show up as substantive autocorrelation. In this study human capital is included, but physical capital is omitted since there is no data available for the Portuguese regions at the NUTS III level of regional disaggregation. There is a high probability that physical capital is also spatially correlated so this must be taken into account when the results are interpreted.

6.3. Exploratory Spatial Data Analysis (ESDA)

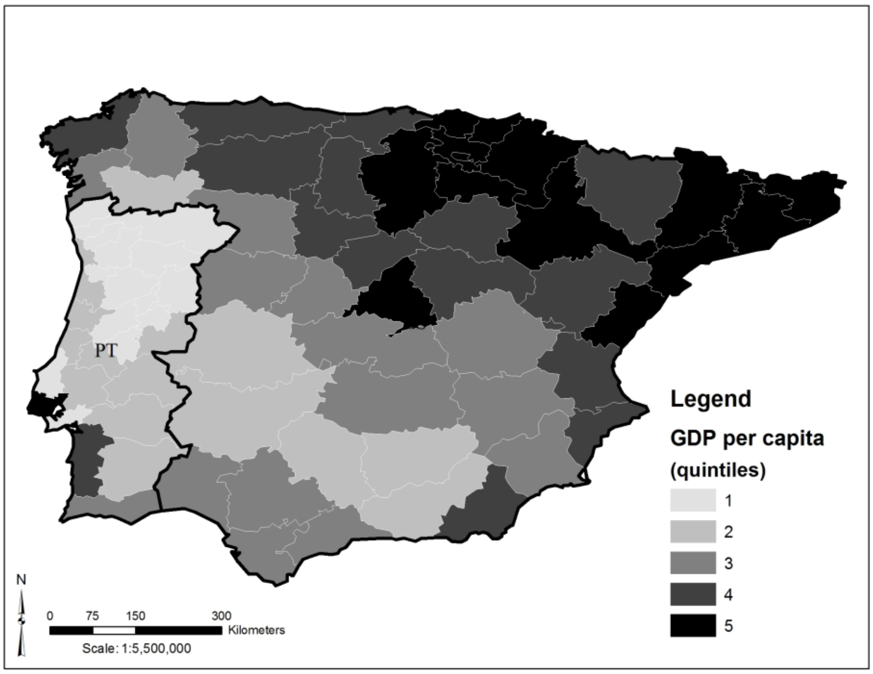
ESDA is defined by Le Gallo and Ertur (2003) as "a set of techniques aimed at describing and visualizing spatial distributions, at identifying atypical localizations or spatial outliers, at detecting patterns of spatial association, clusters or hot spots, and at suggesting spatial regimes or other forms of spatial heterogeneity" [Le Gallo and Ertur (2003), p. 177]. Using GeoDa [Anselin *et al.* (2006)], the ESDA is applied to the regional variables of interest.[27] Figures 6.1 and 6.2 display the quintile map obtained for the regional GDP per capita of the 75 NUTS III Iberian regions at the beginning and at the end of the period.

Figure 6.1 – Regional GDP per capita 1991 quintile map



[27] The maps were edited using ArcView.

Figure 6.2 – Regional GDP per capita 2006 quintile map



The darkest regions represent the richest and are mostly located in the Basque Country and Cataluña, also including the Madrid region. The only Portuguese region that integrates with the richest group is the capital region, Grande Lisboa. The lightest areas correspond to the poorest and contain only Portuguese regions. There are some changes from 1991 to 2006. In Portugal the contrast between the richest and poorest regions was mainly a Coast/ Inland division in 1991, but this is not so striking in 2006. At the end of the period, the quintile map suggests that most poor regions are located in the North while the richest seem to be in the South and then inside these two groups the regions at the coast tend to be better off than inland regions. In Spain there are some changes but the main features remain, with a North-East rich club, which is closer to the European Core, in contrast with a poor South-West.

The spatial distribution of human capital proxied by the average years of education can be seen in the next quintile maps (Figure 6.3 and 6.4). Again the darkest regions are the richest and the lightest correspond to the poorest. It is striking that over the period none of the Portuguese regions integrate with the group of the richest, which reflects the low levels of human capital in Portugal. Among the first and second quintile are all the Portuguese regions apart from the capital (Grande Lisboa).

Madrid, Cataluña and Basque Country are those with a higher level of human capital suggesting a correlation between GDP per capita and average years of education. [28]

Figure 6.3 – Regional Human Capital 1991 quintile map

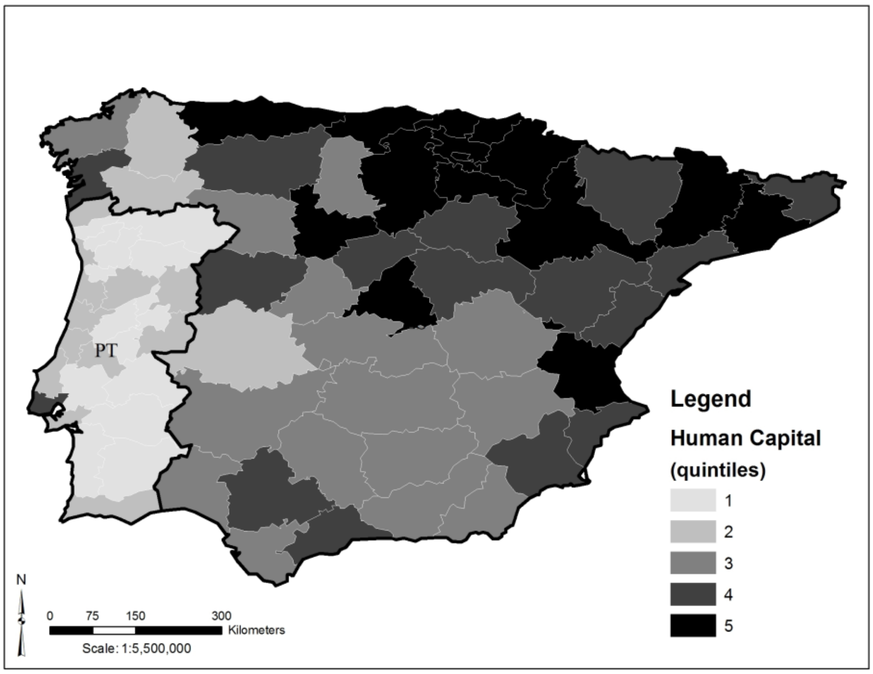
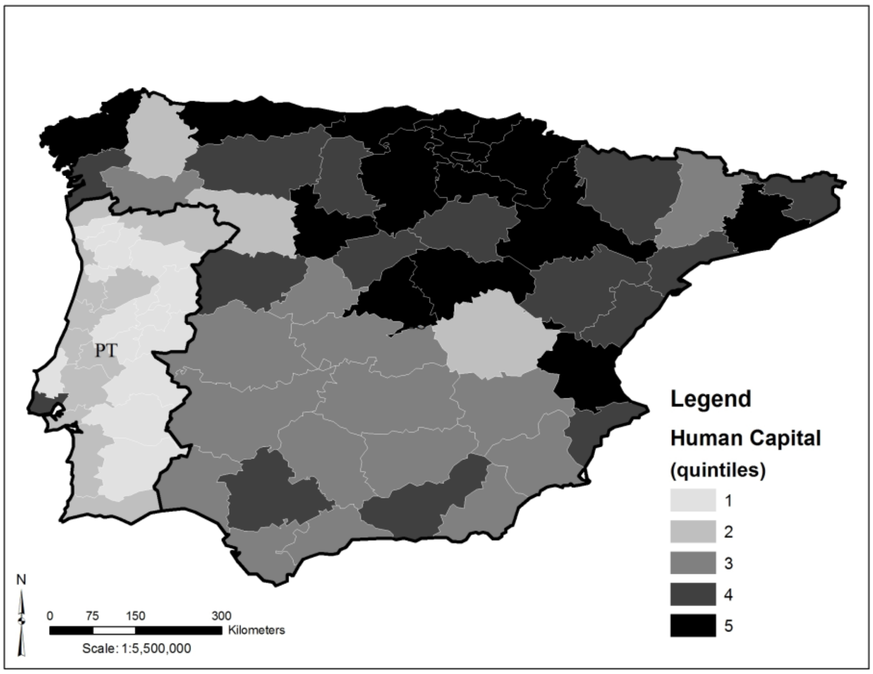


Figure 6.4 – Regional Human Capital 2006 quintile map



[28] In contrast with the previous variables, the production structure does not exhibit any spatial pattern.

The above spatial distribution of the data suggests some spatial patterns in the regional income per capita and human capital. The analysis will proceed with a more formal detection of spatial autocorrelation in the variables of interest, the Moran's *I* and the Moran scatterplot which plots the variable of interest on the x-axis (z_t) against the respective spatial lag on y-axis (Wz_t). The spatial lag of a regional variable is the respective value in the neighbour regions. Since the contiguity matrixes easily satisfy the regularity conditions, in terms of bounds on the weights and sums of the weights, needed to obtain the suitable asymptotic properties for estimators and specification tests [Anselin (2006)], a Rook-contiguity matrix is chosen. This means that the spatial lag of the variable of interest is the average of the values in the regions that have a common boundary with the region of interest. The four quadrants that result from the scatterplot correspond to four types of local spatial association between a region and the respective neighbours:

1) HH – a region with a high value, this is above the mean, is surrounded by regions that have high values as well;
2) HL – a region with a high value surrounded by regions with low values, this is below the mean;
3) LL – a region with a low value surrounded by regions with low values as well;
4) LH – a region with a low value surrounded by regions with high values.

The quadrants HH and LL refer to positive spatial correlation, which indicates clustering of similar values. In contrast, the quadrants LH and HL represent negative spatial autocorrelation, this is spatial clustering of dissimilar values. The Moran scatterplot slope is the Moran's *I* statistic for the variable of interest and since the variables are standardized the scatterplots are comparable over time.

Table 6.1 shows the values of the Moran's *I* statistic using the Rook-contiguity matrix[29] for the regional GDP per capita in levels for the beginning and the end of the period, and also the respective average growth rate. The statistical significance of the Moran's *I* is tested through a permutations procedure which generates a random reference distribution by computing the statistic with a different set of random numbers for the specified number of permutations. The *p*-values are the so-called

[29] Other binary spatial weight matrices (Queen contiguity, *k*-nearest matrices with k=2, 4, 6 and 8) were applied but the results do not change substantially.

pseudo *p*-values since they depend on the number of permutations.[30] As can be seen, the Moran's *I* statistic is positive and significant suggesting that regional GDP per capita both in levels and growth rates is positively spatially correlated.

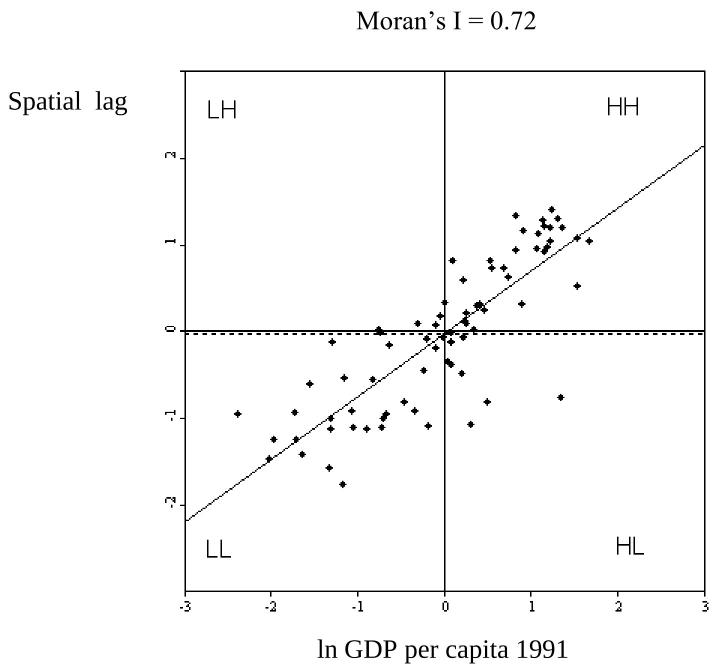
Table 6.1 – Moran's *I* statistic for regional GDP per capita

Year	Moran's *I*	Mean	Std Deviation	*p*-values
Level 1991	0.7249	-0.0095	0.0757	0.0010
Level 2006	0.7043	-0.0134	0.0713	0.0010
Average g.r.	0.2476	-0.0135	0.0719	0.0010

Note: 999 permutations

Figures 6.5 and 6.6 display the Moran scatterplot of the regional GDP per capita (natural logharitm). The spatial lag of this variable is the average regional GDP per capita of the neighbouring regions. As can be seen below, the quadrants are relatively stable over time.

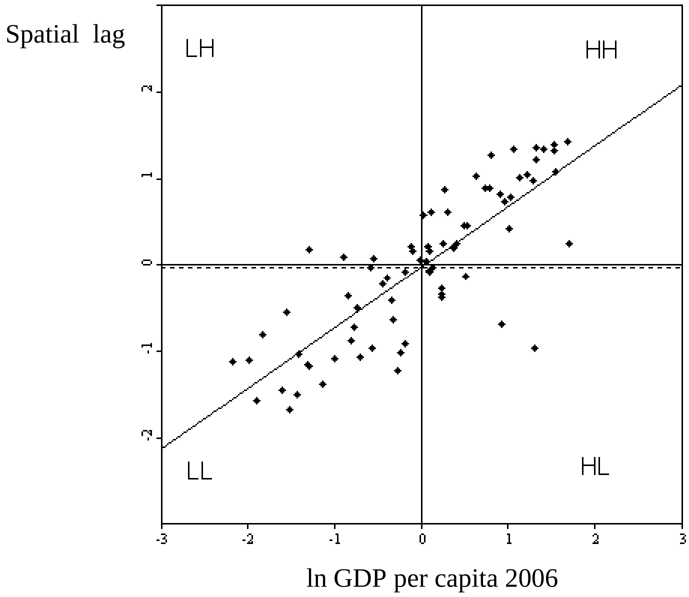
Figure 6.5 – Moran scatterplot for the regional GDP per capita 1991



[30] See GeoDa Center webpage: http//geodacenter.asu.edu for details on this procedure.

Figure 6.6 – Moran scatterplot for the GDP per capita 2006

Moran's I = 0.70

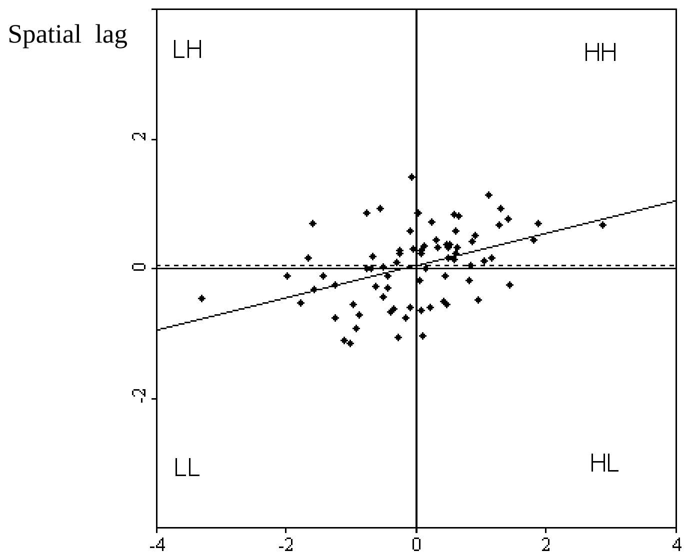


Most regions are located in quadrants HH, rich regions surrounded by rich regions, and LL, poor regions that have poor neighbours. The rich regions in the quadrant HH are the Spanish provinces located in the Basque country, Cataluña and the capital region Madrid. Almost every Portuguese region and the Spanish provinces that integrate Galicia and Extremadura are found in the LL quadrant. The fact that both in 1991 and 2006 most of the regions are located in either quadrant HH or LL suggests two spatial regimes. The atypical regions are located in the quadrants LH, these are poor regions surrounded by rich neighbours, and HL, which are rich regions that have poor neighbours. In the HL quadrant are located the Portuguese richest regions, these are the capital region, Grande Lisboa followed by Alentejo Litoral and Grande Porto. From 1991 to 2006 two Spanish provinces joined this group, like Almería and Huelva which are located in the Mediterrean coast and developed a strong tourist sector.

Moving to the scatterplot for the GDP per capita annual average growth rate over the period in Figure 6.7, there is more spatially instability since more regions are in the quadrants LH and HL, 26% compared with 11% and 19% for GDP per capita in 1991 and 2006, respectively. In the quadrant HH are located the most dynamic regions which are as well surrounded by neighbours with a high average annual growth rate over the period. Around half of them are Portuguese regions which suggest some catching-up since they belong to group of the poorest among all the Iberian regions.

Figure 6.7 – Moran scatterplot for the average GDP per capita growth rate

Moran's I = 0.25



GDP per capita growth rate

Table 6.2 shows the Moran's *I* statistic for log regional human capital proxied by the average years of education excluding the public sector and the respective growth rate over the period. As with regional GDP per capita, there is evidence of positive spatial correlation.

Table 6.2 – Moran's *I* statistic for regional human capital

Year	Moran's *I*	Mean	Std Deviation	*p*-values
Level 1991	0.7765	-0.0146	0.0720	0.0010
Level 2006	0.6553	-0.0161	0.0713	0.0010
Average g.r.	0.5816	-0.0155	0.0700	0.0010

Note: 999 permutations

Figures 6.8 and 6.9 display the Moran scatterplot of the natural log of the regional human capital proxied by education in 1991 and 2006.

Figure 6.8 – Moran scatterplot for the average years of education 1991

Moran's I = 0.78

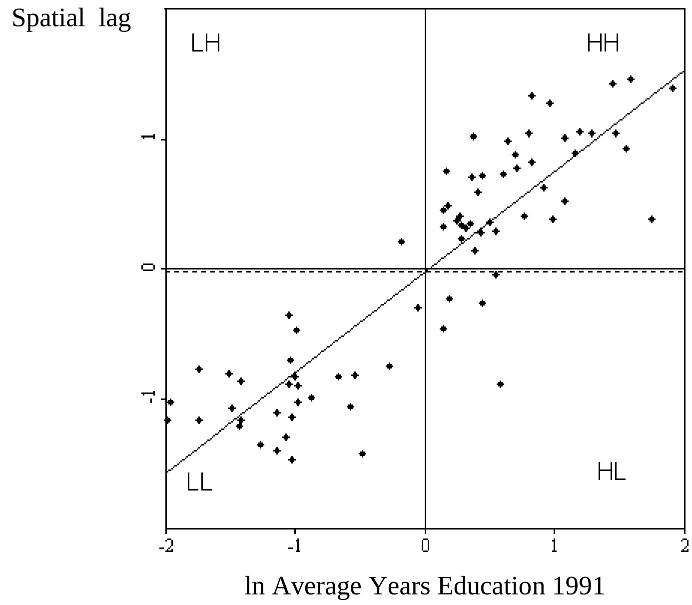
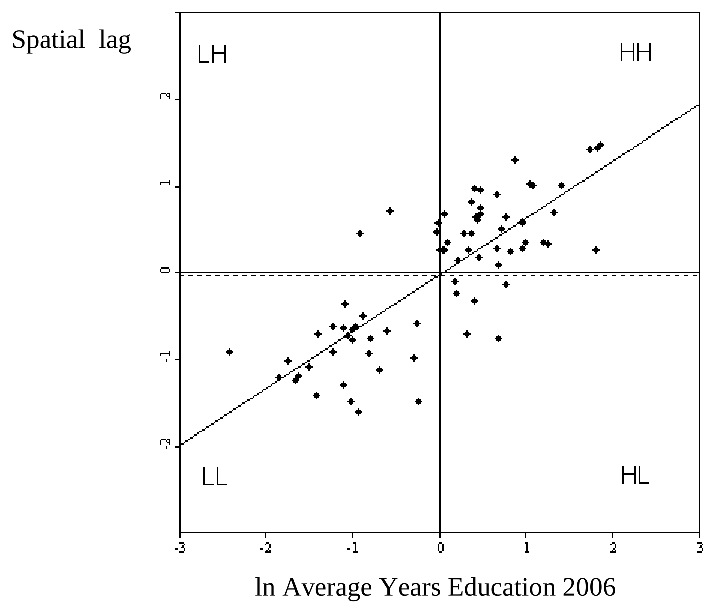


Figure 6.9 – Moran scatterplot for the average years of education 2006

Moran's I = 0.66

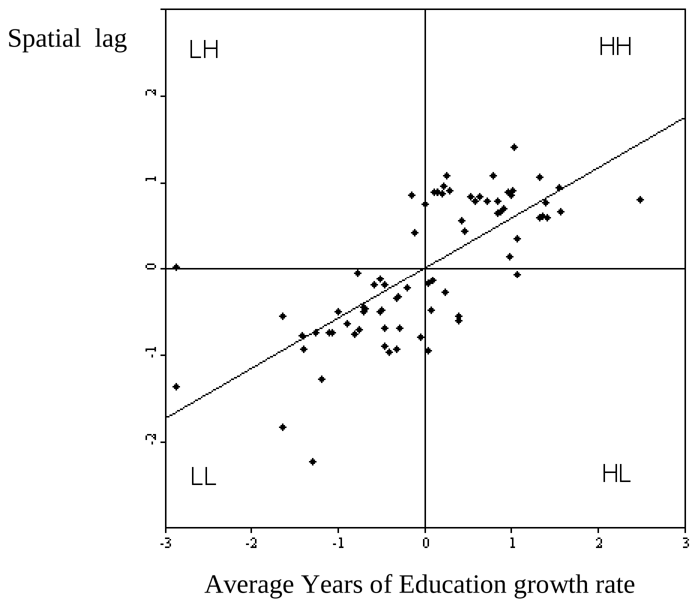


As shown above, the quadrants are relatively stable over time. Similar to regional GDP per capita, most regions are located in quadrants HH, rich regions surrounded by rich regions, and LL, poor regions that have poor neighbours. The rich regions in the quadrant HH are all Spanish. All the Portuguese regions apart from the capital are located in the LL quadrant. In 1991 there was only one Spanish province in the former quadrant, Ourense, but due to a significant improvement in 2006 this region was already in the quadrant of the rich regions with poor neighbours (HL), where the Portuguese capital region Grande Lisboa is located together with some Spanish provinces located on the border such as Salamanca, Badajoz and Huelva.

Moving to the respective annual average growth rate in Figure 6.10, the majority of the regions are located either in quadrant HH or LL suggesting a strong positive spatial correlation of the regional human capital growth rates. The regions found in quadrant HH, higher growth rate in human capital regions surrounded by regions that also have a higher growth, are all Portuguese regions apart from Grande Lisboa and Grande Porto, and the poor Spanish provinces on the border. As happened with GDP per capita, the poor regions tend to have higher growth rates suggesting β-convergence in the human capital levels.

Figure 6.10 – Moran scatterplot for the average years of education growth rate

Moran’s I = 0.58



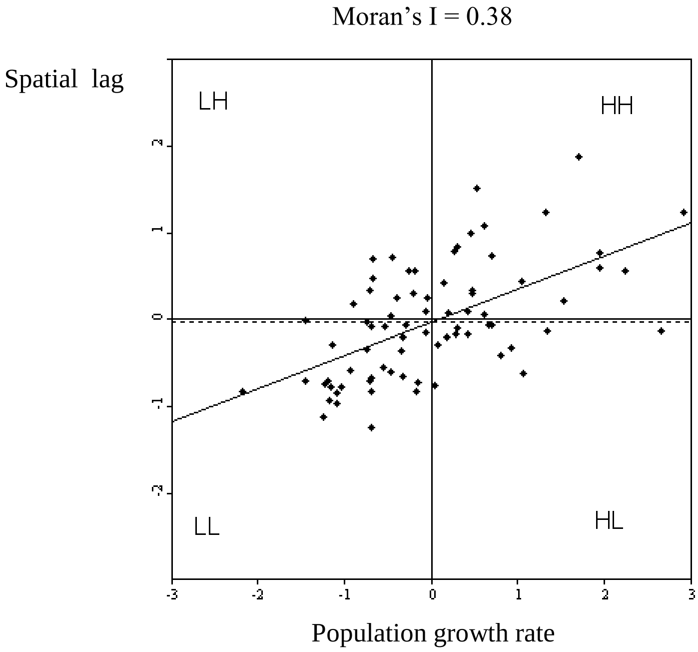
The average population growth rate is also spatially correlated as can be seen in Table 6.3 and Figure 6.11. It was considered the sum $(n + g + \delta) = (n + 0.05)$, since this was the variable used in the estimations of the conditional β-convergence model.

Table 6.3 – Moran's *I* statistic for the regional population growth rate

Time period	Moran's *I*	Mean	Std Deviation	*p*-values
1991-2006	0.3795	-0.0114	0.0701	0.0010

Note: 999 permutations

Figure 6.11 – Moran scatterplot for the average population growth rate



In Tables 6.4 and 6.5 the Moran's *I* statistics for the regional share of industry and services in total GVA are presented. According to the *p*-values, the null of no spatial autocorrelation is not rejected suggesting that the regional production structure is not correlated across space.

Table 6.4 – Moran's *I* statistic for the regional share of industry in total GVA

Year	Moran's *I*	Mean	Std Deviation	*p*-values
1991	0.0108	-0.0148	0.0725	0.3500
2006	0.0056	-0.0101	0.0741	0.3940

Note: 999 permutations

Table 6.5 – Moran's *I* statistic for the regional share of services in total GVA

Year	Moran's *I*	Mean	Std Deviation	*p*-values
1991	-0.0566	-0.0163	0.0719	0.2950
2006	-0.0530	-0.0108	0.0706	0.2970

Note: 999 permutations

Figures 6.12 to 6.15 confirm the lack of spatial correlation since the respective Moran scatterplots are almost flat.

Figure 6.12 – Moran scatterplot for the share of industry 1991

Moran’s I = 0.01

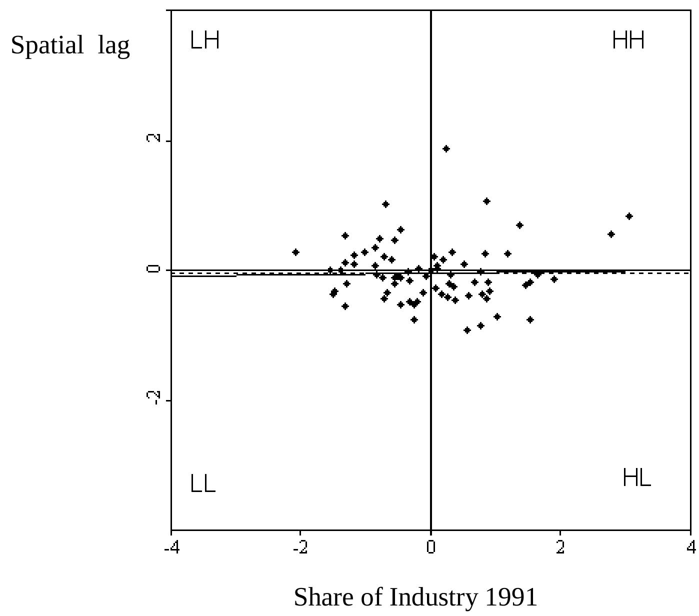


Figure 6.13 – Moran scatterplot for the share of industry 2006

Moran’s I = 0.01

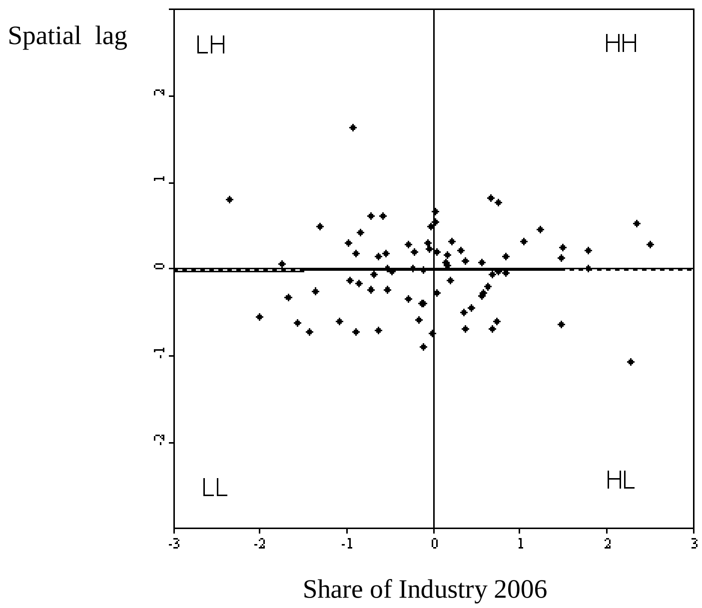


Figure 6.14 – Moran scatterplot for the share of services 1991

Moran's I = -0.06

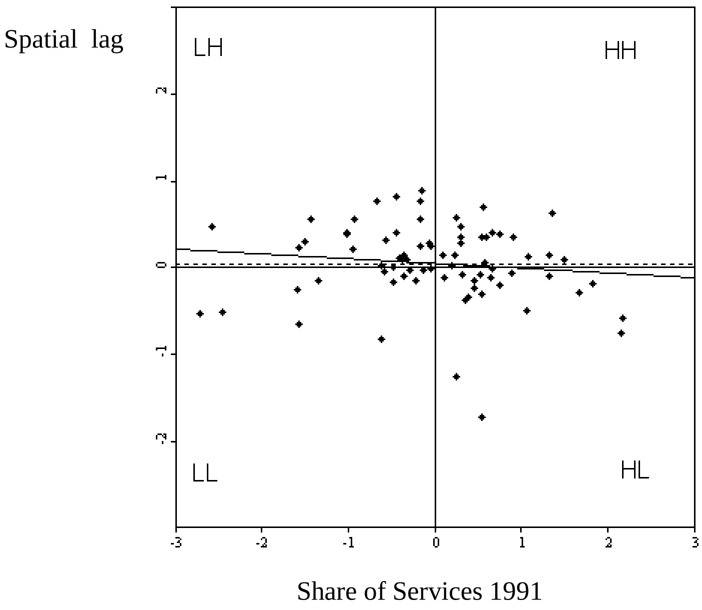
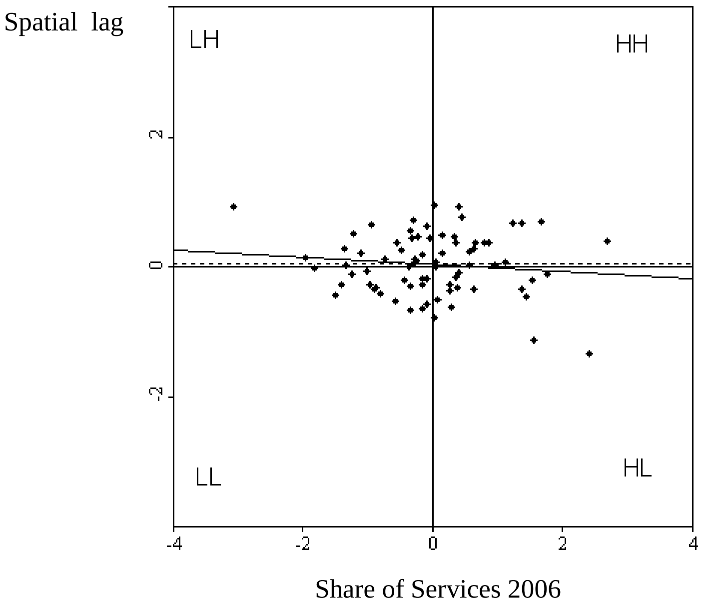


Figure 6.15 – Moran scatterplot for the share of services 2006

Moran's I = -0.05



As shown, the distribution of the regions is all over the four quadrants suggesting no spatial pattern in terms of the production structure. There is no clear tendency for a region with a higher share of industry (or services) to be surrounded by regions with a similar weight of that sector in total Gross Value Added (GVA).

The exploratory spatial data analysis suggests significant positive spatial correlation in the regional GDP per capita and human capital. The rich regions are close to each other and they tend to remain in the same group over time. In terms of the average growth rate over the period the situation is similar which means that the economic growth of a region is correlated with the growth of the neighbours. This evidence of spatial clusters of high and low values for both GDP per capita and human capital can be interpreted as different spatial regimes and suggests spatial heterogeneity. There is spatial heterogeneity when the economic relation among the variables is not stable across space. These spatial regimes can be seen as "convergence clubs" and the convergence process might differ according to the "club".

The identification of convergence clubs in Iberia will be considered in section 6.4. The results obtained for the conditional β-convergence model with methods that ignore spatial dependence and spatial heterogeneity might be biased so in subsection 6.5. the conditional β-convergence model is estimated using the appropriate spatial specification and taking into consideration the different spatial regimes.

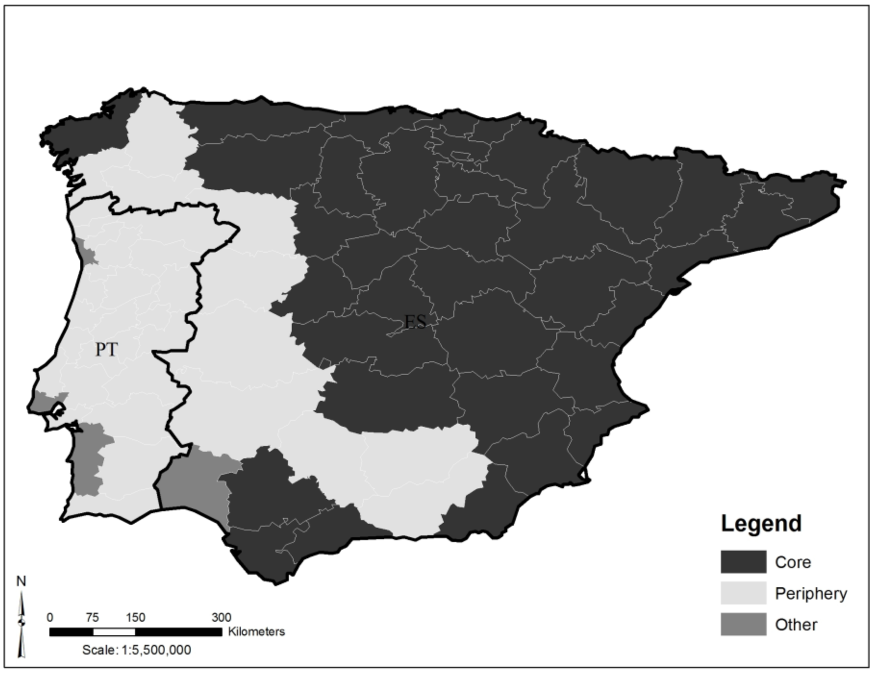
6.4. Convergence clubs within the Iberia Peninsula

The spatial regimes identified in the previous subsection can be interpreted as convergence clubs. As Dall'Erba and Le Gallo (2008) pointed out, regional economies are characterised by strong geographic patterns so it makes sense to detect the convergence clubs using the ESDA which relies on geographic criteria. A convergence club can be defined as a group of regions that subject to some initial sorting based on their structural characteristics converge within their own group. The concept is based on the idea that multiple, locally stable, steady-state equilibrium points are possible [Azariadis and Drazen (1990) and Durlauf and Johnson (1995)]. The particular equilibrium reached by a region depends on the group it belongs to according to the respective initial conditions. The clubs are linked with spatial heterogeneity which must be taken into account otherwise the β-convergence model estimation is unreliable.

In this subsection convergence clubs within the Iberian Peninsula will be identified following the procedure of Ertur *et al.* (2006) who used the Moran scatterplot to determine four spatial clubs among 138 EU15 regions: clusters of rich regions, clusters of poor regions and the two atypical groups formed by rich regions surrounded by poor and the reverse. In their work these atypical groups are dropped out of the sample since they are not numerous enough to form other regimes, only the rich (Core) and poor (Periphery) clubs are considered and the findings show that the convergence process is different across the clubs. According to Rey and Le Gallo (2009), the convergence clubs obtained through this procedure are “semi-endogenous” because the regions are endogenously allocated to the clubs but the number of clubs is predetermined.

The Moran scatterplot for the initial GDP per capita in the Iberian countries in Figure 6.5 showed that most of the Iberian regions are located either in quadrant HH or LL which can therefore be considered as two spatial clubs: the Core, which corresponds roughly to the East of the Iberian Peninsula, and the Periphery, which is mainly constituted by regions located on the West. The Core group is closer to the main EU countries and the Peripheral group is further away. The atypical regions which were notably in the quadrant HL are the richest Portuguese regions (Grande Lisboa, Grande Porto and Alentejo Litoral) and the Spanish province of Huelva. They are dropped since the small number of observations does not allow estimations for this third spatial regime. The other atypical regions are not far from the main spatial regimes (HH or LL) so they were allocated to the club which they are closest to. A different set of coefficients must be estimated for each club since the convergence process might be quite different across the regimes. Figure 6.16 illustrates the two convergence clubs.

Figure 6.16 – Spatial Convergence Clubs in Iberia



Local measures of spatial correlation can also be applied to detect spatial regimes. The Local Indicators of Spatial Association (LISA) are defined by Anselin (1995) as any statistics that satisfy two criteria: the LISA for each observation gives an indication of significant spatial clustering of similar values around that observation; and the sum of the LISA for all observations is proportional to a global indicator of spatial association. The local Moran's *I* statistic for region *i* is given by:

$$I_{i,t} = \frac{(x_{it} - \mu_t)}{m_0} \sum_j w_{ij} (x_{jt} - \mu_t) \qquad (6.19)$$

where x_{it} and x_{jt} are the observation in region *i* and *j*, respectively, for year *t*, μ_t is the mean across regions for year *t* and $m_0 = \sum_i (x_{it} - \mu_t)^2 / n$. A positive value of the local Moran statistic indicates spatial clustering of similar values between a region and the respective neighbours. A negative value suggests a clustering of dissimilar values. According to Anselin (1995) the LISA can indicate local spatial clusters, significant outliers and spatial regimes. The global Moran's *I* statistic is the mean of the local Moran statistics. Spatial clusters are groups of regions that belong to the quadrant HH, rich regions surrounded by rich neighbours, or LL, poor regions with poor neighbours. The outliers are located in HL, rich regions surrounded by poor neighbours, or LH, poor with rich neighbours.

The local Moran statistics cluster map shows not only the significant locations but also the type of spatial autocorrelation which correspond to the quadrants of the Moran scatterplot: HH, LL, HL and LH. The LISA statistic for the GDP per capita is significant in most provinces of Basque country, Cataluña and Madrid, which are rich and have rich neighbours, and regions of Portugal that are poor and have poor neighbours. The local Moran statistics cluster map for GDP per capita in 1991 is not displayed here since it is quite similar with Figure 7.16 and confirms the two convergence clubs in the Iberian Peninsula. The regions called before "Core" coincide with those with a significant LISA and positive autocorrelation (HH quadrant). The regions named Periphery correspond with those for which the LISA is also significant and show a positive autocorrelation (LL quadrant).

6.5. Conditional β-convergence model and results

A cross-section version of the conditional β-convergence model considered in the previous chapters is applied:

$$g_i = \alpha + \beta \ln y_{i,1991} + \gamma_1 \ln(H_i) + \gamma_2 \ln(n_i + g + \delta) + u \qquad (6.20)$$

where the dependent variable g_i is the average GDP per capita growth rate between 1991 and 2006, $y_{i,1991}$ is the initial GDP per capita and H_i and n_i are, respectively, the average human capital level and population growth rate over the same time period. The spatial weight matrix applied is the Rook-contiguity one. The islands are not contiguous to any other region so they are excluded from the study and the total number of Iberian regions included becomes 75 (Spain - 47 and Portugal - 28).

The same model can be specified taking into account the two convergence clubs identified in the previous section [see, for example, Ramajo *et al*. (2008)]. This is:

$$g_i = \alpha_C D_C + \alpha_P D_P + \beta_c D_C \ln y_{i,1991} + \beta_P D_P \ln y_{i,1991} + \gamma_{1C} D_C \ln(H_i) + \\ + \gamma_{1P} D_P \ln(H_i) + \gamma_{2C} D_C \ln(n_i + g + \delta) + \gamma_{2P} D_P \ln(n_i + g + \delta) + u_i \tag{6.21}$$

where the subscripts *C* and *P* stand for the Core and Periphery club, respectively. The dummy *D* takes the value 1 when the region belongs to that club and zero otherwise. In this specification the spatial effects are assumed to be identical in both clubs and all the regions are still interacting in spatial terms with each other no matter to which club they belong.

6.5.1. Absolute convergence

Table 6.6 displays the results for the absolute convergence model. In both models Moran's *I* statistic is significant at 1% or 5% level which indicates strong spatial dependence. Looking at the LM statistics, the results suggest that the Spatial Error model (SEM) is the most appropriate when the spatial regimes are not taken into account since the LM-error statistic is significant at 5% and the LM-lag is only significant at 10%. When the spatial regimes are considered the reverse happens and the Spatial Lag model (SLM) is the most appropriate. Though the OLS results are not reliable due to spatial autocorrelation, they suggest a difference between the core and periphery since the lagged GDP per capita coefficient is only negatively significant in the periphery club. Regional convergence seems to concern only the club of the poor Iberian regions, but this needs to be confirmed by the spatial lag model.

Table 6.6 – OLS results for absolute convergence model in Iberia

Dependent variable: GDP per capita growth rate

Regressors	No Spatial Regimes	Spatial regimes	
		Core	Periphery
Constant	0.04***	0.03	0.05***
	(8.92)	(1.44)	(4.02)
y_{1991}	-0.01***	-0.00	-0.01***
	(-4.17)	(-0.60)	(-2.02)
Tests			
Moran's *I* (error)	2.77	2.40	
	(0.01)	(0.02)	
LM-Lag	3.20	25.04	
	(0.07)	(0.00)	
Robust LM-Lag	1.19	24.64	
	(0.28)	(0.00)	
LM-Error	5.31	3.28	
	(0.02)	(0.07)	
Robust LM-Error	3.30	2.88	
	(0.07)	(0.09)	
Log Likelihood	281.76	258.64	
Akaike	-559.52	-509.27	
Schwarz	-554.89	-500.00	
R-squared	0.19	0.87	

Notes: t-statistics in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Table 6.7 reports the spatial model results for absolute convergence. As shown, in both cases there is an increase of the log-likelihood and a decrease of both the Akaike and Schwarz criteria in comparison with the OLS results which are evidence of an improvement of fit for the spatial models. The likelihood ratio test also rejects the null of the OLS regression against the spatial specifications at the conventional levels of significance. The autoregressive error coefficient (λ) is significant confirming the SEM as appropriate when the spatial regimes are not taken into account, suggesting that a random shock in an Iberian region propagates to all the others [Anselin (2003)], and the initial GDP per capita remains negatively significant confirming convergence at the conventional levels of significance. When the spatial regimes are taken into consideration and the SLM is applied, the spatial lag of the GDP per capita growth rate coefficient is positive (0.31) and significant which indicates that the growth rate of a region is highly influenced by the growth rate of its neighbours. There are though significant differences between the two clubs. Despite the initial GDP per capita coefficient is negative in both clubs it is much lower and insignificant in the Core. In contrast, it is significant at 1% level in the periphery which indicates that convergence is a phenomenon that only concerns the peripheral regions of the Iberia. These results are consistent with those found by Ertur *et al.* (2006), whose procedure was followed, for the EU regions. The constant is also only significant in the Periphery.

Table 6.7 – Spatial Models for absolute convergence

Dependent variable: GDP per capita growth rate

Regressors	No Spatial Regimes SEM	Spatial regimes SLM	
		Core	Periphery
Constant	0.04***	0.01	0.03***
	(7.43)	(0.59)	(2.94)
y_{1991}	-0.01***	-0.00	-0.01***
	(3.65)	(-0.61)	(-2.76)
Autoregressive error (λ)	0.35**		
	(2.37)		
Spatial lag of GDP per capita growth rate (ρ)		0.31***	
		(2.13)	
Tests			
Likelihood ratio test	4.77	3.79	
	(0.03)	(0.05)	
Log Likelihood	284.15	284.27	
Akaike	-564.29	-556.53	
Schwarz	-559.66	-542.62	
R-squared	0.26	0.26	

Notes: z-value in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Though the spatial models can be interpreted as a minimal conditional β-convergence model since spatial autocorrelation can work as a proxy for omitted variables [Le Gallo *et. al* (2003)], in the next subsections are presented the results when the conditional variables are added to the convergence equation.

6.5.2. Convergence conditional on human capital

In this subsection the same education proxies for human capital used in the previous chapters are applied, these are the average years of education and its decomposition into secondary and higher education. The results when human capital is proxied by the average years of primary education are not reported since according to the previous chapters the attention is focused on Secondary versus Higher Education. It is not possible to consider the labour-income proxies because they are computed in a different way for Portugal and Spain and are not directly comparable.

Table 6.8 displays the results obtained for the OLS regression of the β-convergence model conditional on human capital proxied by the average years of education. At the conventional levels of significance (1-5%) the Moran's *I* suggests spatial dependence for the Iberian regions in both models but this is only confirmed in the case of spatial regimes model by the LM tests which favour the Spatial Lag model as the most appropriate. The conflict between Moran's *I* and the LM statistics in the model with no spatial regimes is likely due to the power of Moran's *I* against other alternatives, such as heteroskedasticity and non-normality [Anselin (2005)]. The fact that both human capital and population growth rate are spatially correlated, as seen in section 6.4, might explain why the LM statistics suggest no spatial dependence. It does not necessarily mean that there are no spatial effects which might just be captured by the other conditional variables.

When the spatial regimes are not taken into account, the lagged GDP per capita is negatively significant suggesting conditional convergence, the population growth rate is negatively significant in accordance with the theoretical predictions of the Solow growth model and the effect of human capital is significantly positive. It is quite interesting to see how the coefficients change according to the club in the model with spatial regimes. The lagged GDP per capita is no longer significant and human capital is only marginally significant in the Core group. The population growth rate is not significant in either of the clubs. In the model with no spatial regimes many coefficients are lower than the average of the coefficients obtained for the spatial clubs. The fact that four regions were removed from the sample when the later model was estimated might explain this unexpected result. As seen in the subsection 6.4, these four regions are rich and have poor neighbours (quadrant HL of the Moran scatterplot). They were removed from the spatial clubs because they were not enough to be included in a third spatial regime. However they are in the full sample and might be outliers that affect the OLS coefficients.

Table 6.8 – OLS Regression for convergence conditional on human capital in Iberia

Dependent variable: GDP per capita growth rate

Regressors	No Spatial Regimes	Spatial Regimes	
		Core	Periphery
Constant	-0.04**	-0.08	-0.03
	(-2.12)	(-1.65)	(-0.66)
y_{1991}	-0.01*	-0.02	-0.02
	(-2.99)	(-1.45)	(-1.52)
$\ln(AvEdu)$	0.02**	0.05*	0.02
	(2.12)	(1.87)	(0.75)
$\ln(n_i + g + \delta)$	-0.02***	-0.01	-0.02
	(-3.43)	(-1.22)	(-1.51)
Tests			
Moran's *I* (error)	2.22	26.85	
	(0.03)	(0.00)	
LM-Lag	1.67	26.85	
	(0.20)	(0.00)	
Robust LM-Lag	0.06	25.33	
	(0.81)	(0.00)	
LM-Error	2.67	3.85	
	(0.10)	(0.05)	
Robust LM-Error	1.06	2.32	
	(0.30)	(0.13)	
Log Likelihood	290.17	263.78	
Akaike	-572.35	-511.55	
Schwarz	-563.08	-493.01	
R-squared	0.35	0.89	

Notes: t-statistics in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Table 6.9 reports the Spatial Lag model for the spatial regimes case. Though the likelihood ratio test does not reject the null of OLS regression against the spatial lag model, both the decrease in the Akaike and Schwarz criteria and the increase in the log-likelihood suggest an improvement of fit for this spatial specification. There is evidence of convergence in both clubs though the speed is higher in the periphery club. The human capital coefficient is positive and becomes significant in the Core group at 5% level but it remains insignificant in the periphery. This suggests that the positive effect of human capital on growth concerns the most developed regions. The spatial lag of the GDP per capita growth rate coefficient (ρ) is insignificant suggesting no regional spillovers. It is interesting to notice that when human capital was introduced as a conditional variable ρ became insignificant. This is in accordance with what was pointed out by Abreu *et al.* (2005), who argue that a significant ρ reflects not only cross-regional spillovers but also the existence of spatially autocorrelated omitted variables.

Table 6.9 – Spatial Lag model for convergence conditional on human capital

Dependent variable: GDP per capita growth rate

Regressors	Spatial regimes: Core	Spatial regimes: Periphery
Constant	-0.09*** (-2.97)	-0.05* (-1.77)
y_{1991}	-0.01** (-2.02)	-0.02** (-2.51)
$\ln(AvEdu)$	0.04*** (2.64)	0.02 (1.36)
$\ln(n_i + g + \delta)$	-0.01* (-1.78)	-0.02** (-2.20)
Spatial lag of GDP per capita growth rate (ρ)	0.18 (1.26)	
Tests		
Likelihood ratio test	1.31 (0.25)	
Log Likelihood	293.38	
Akaike	-566.75	
Schwarz	-543.57	
R-squared	0.41	

Notes: z-value in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Average years of Secondary Education

Table 6.10 reports the OLS results obtained when the proxy for human capital is the average years of secondary education. Moran's *I* suggests no spatial dependence which is confirmed by the LM tests in the model with no spatial regimes. In contrast, both Moran's *I* and the LM tests show spatial dependence for the model with spatial regimes. The latter tests suggest the Spatial Lag model as the most appropriate since the respective statistic is significant at 5% level while the LM error is only at 10%.

Table 6.10 – OLS Regression for convergence conditional on secondary education

Dependent variable: GDP per capita growth rate

Regressors	No Spatial Regimes	Spatial Regimes	
		Core	Periphery
Constant	-0.03*	-0.04	-0.03
	(-1.77)	(-0.93)	(-0.65)
y_{1991}	-0.01***	-0.01	-0.01
	(-2.74)	(-0.76)	(-1.64)
$\ln(Sec)$	0.01	0.02	0.01
	(1.64)	(1.02)	(0.67)
$\ln(n_i + g + \delta)$	-0.02***	-0.02	-0.02
	(-3.80)	(-1.53)	(-1.72)
Tests			
Moran's *I* (error)	1.31	2.60	
	(0.19)	(0.00)	
LM-Lag	1.05	26.36	
	(0.30)	(0.00)	
Robust LM-Lag	0.33	26.39	
	(0.56)	(0.00)	
LM-Error	0.73	3.20	
	(0.39)	(0.07)	
Robust LM-Error	0.01	3.22	
	(0.91)	(0.07)	
Log Likelihood	289.26	262.40	
Akaike	-570.52	-508.79	
Schwarz	-561.25	-490.25	
R-squared	0.34	0.88	

Notes: t-statistics in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

When the spatial regimes are not taken into account, all the coefficients apart from the human capital proxy are significant and have the expected signs. The lagged GDP per capita is negative suggesting conditional convergence and the population growth rate has a negative effect on growth in accordance with the theoretical predictions. The secondary school coefficient is positive but not significant. When the spatial clubs are considered, all the coefficients are insignificant but the spatial lag model should be estimated. As in Table 6.8, the coefficients obtained with OLS for the model without spatial regimes are lower than the average of the coefficients obtained for the spatial clubs. The removal of four observations from the sample when the model with spatial clubs was estimated might have affected the results since these observations are possible outliers. Table 6.11 displays the results of the spatial lag model when the spatial regimes are taken into account.

Table 6.11 – Spatial Lag model for convergence conditional on secondary education

Dependent variable: GDP per capita growth rate

Regressors	Spatial regimes	
	Core	Periphery
Constant	-0.05**	-0.05
	(-2.02)	(-1.53)
y_{1991}	-0.01	-0.01**
	(-1.01)	(-2.44)
$\ln(Sec)$	0.02	0.01
	(1.39)	(0.93)
$\ln(n_i + g + \delta)$	-0.01**	-0.02**
	(-2.17)	(-2.49)
Spatial lag of GDP per capita growth rate (ρ)	0.19	
	(1.31)	
Tests		
Likelihood ratio test	1.49	
	(0.22)	
Log Likelihood	290.54	
Akaike	-561.07	
Schwarz	-537.90	
R-squared	0.37	

Notes: z-value in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

As seen above, the decrease in the Akaike and Schwarz criteria favours the SLM but this is not confirmed by the likelihood ratio test. There is evidence of convergence in the periphery group but the average years of secondary education remains insignificant and the spatial lag of the GDP per capita growth rate is also not significant suggesting absence of regional spillovers.

Average years of Higher Education

Table 6.12 displays the OLS results obtained for the models with and without spatial regimes when human capital is proxied by the average years of higher education.

Table 6.12 – OLS Regression for convergence conditional on higher education

Dependent variable: GDP per capita growth rate

Regressors	No Spatial Regimes	Spatial Regimes	
		Core	Periphery
Constant	-0.00 (-0.26)	0.00 (0.06)	0.00 (0.05)
y_{1991}	-0.01^{***} (-2.90)	-0.01 (-1.17)	-0.01 (-1.54)
$\ln(Ter)$	0.00^{*} (1.95)	0.01^{*} (1.69)	0.00 (0.72)
$\ln(n_i + g + \delta)$	-0.02^{***} (-3.40)	-0.01 (-1.53)	-0.02 (-1.44)
Tests			
Moran's *I* (error)	2.34 (0.02)	2.95 (0.00)	
LM-Lag	1.55 (0.21)	27.23 (0.00)	
Robust LM-Lag	0.37 (0.54)	24.80 (0.00)	
LM-Error	3.12 (0.08)	4.41 (0.04)	
Robust LM-Error	1.94 (0.16)	1.99 (0.16)	
Log Likelihood	289.81	263.41	
Akaike	-571.63	-510.82	
Schwarz	-562.36	-492.28	
R-squared	0.35	0.87	

Notes: t-statistics in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

As seen above, Moran's *I* indicates spatial dependence in both cases. In the model with no spatial regimes, the LM tests indicate the Spatial Error model as the most appropriate since the LM-error statistic is significant, even if it is just at 10% level, and the LM-lag is not. In the model with spatial regimes, both LM statistics are significant but when the robust versions are considered only the robust-LM lag is significant which favours the Spatial Lag specification. In the model with no spatial regimes, there is evidence of convergence since the lagged GDP per capita is negatively significant at 5% level, the coefficient of higher education is almost zero and only significant at 10% and the population growth rate has a negatively significant effect on regional growth as expected. When the spatial regimes are taken into account, almost all the coefficients are insignificant but the appropriate spatial model should be analyzed.

Table 6.13 reports the results for the appropriate spatial specifications and there are some changes in comparison with OLS. As shown, for the model with no spatial regimes, the coefficient of the average years of tertiary education becomes significant at 5% level and has a higher value (0.01). Though the Log Likelihood, Akaike and Schwarz criteria suggest an improvement of fit compared to OLS, the likelihood ratio test only rejects the null of OLS against the SEM at 10% level and the autoregressive error coefficient (λ) is also only significant at this level. Looking at the results obtained for the model with Spatial Regimes, there is an improvement of fit suggested by the increase in log likelihood and the decrease in both Akaike and Schwarz criteria, but the likelihood test does not reject the OLS against the SLM. As before, there is only evidence of convergence in the Periphery club. Higher education positive effect on regional growth is only significant in the Core group as in the case with the total average years of education. When a human capital proxy is introduced as a conditional variable, the effect of the growth rate of the neighbours on the region's GDP per capita growth rate becomes insignificant.

Table 6.13 – Spatial Models for convergence conditional on higher education

Dependent variable: GDP per capita growth rate

Regressors	No Spatial Regimes SEM	Spatial Regimes SLM Core	Spatial Regimes SLM Periphery
Constant	-0.00 (-0.02)	-0.02 (-0.65)	-0.01 (-0.43)
y_{1991}	-0.01*** (-3.16)	-0.01 (-1.62)	-0.02** (-2.54)
$\ln(Ter)$	0.01** (2.20)	0.01** (2.38)	0.00 (1.34)
$\ln(n_i + g + \delta)$	-0.02 (-3.20)	-0.01** (-2.18)	-0.02** (-2.06)
Autoregressive error (λ)	0.30* (1.89)		
Spatial lag of GDP per capita growth rate (ρ)		0.20 (1.42)	
Tests			
Likelihood ratio test	3.01 (0.08)	1.64 (0.20)	
Log Likelihood	291.32	292.75	
Akaike	-574.64	-565.51	
Schwarz	-565.37	-542.33	
R-squared	0.39	0.40	

Notes: z-value in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

6.5.3. Convergence conditional on the production structure

Tables 6.14 and 6.15 report the OLS results when the production structure is included as an alternative conditional variable proxied by the share of industry and services, respectively, in the total Gross Value Added. Moran's *I* suggests spatial dependence for the Iberian regions in both models, but the LM tests only confirm it in the case of the spatial regimes model. In the latter both the LM-lag and LM-error statistics are robust at the conventional levels of significance, however only the robust LM-lag is significant indicating the Spatial Lag model as the most appropriate specification for both production structure proxies.

The production structure proxied by both the Industry and Service sector shares in total output is insignificant across all the specifications and the coefficient of the lagged GDP per capita is only significant in the model with no spatial regimes. Even though, it is almost zero suggesting very little evidence of conditional convergence. The population growth rate is significant at the conventional levels (1-5%) and has the expected sign in the model with no spatial regimes and also in the Core for the model with spatial regimes. In the Periphery it is only significant at the 10% level when the industry share is the proxy for the production structure and it is insignificant in the case of the services share.

Table 6.14 – OLS Regression for convergence conditional on the Industry share

Dependent variable: GDP per capita growth rate

Regressors	No Spatial Regimes	Spatial Regimes	
		Core	Periphery
Constant	-0.02 (-0.96)	-0.04 (-1.06)	0.00 (0.09)
y_{1991}	-0.00^{**} (-2.15)	0.07 (0.57)	-0.01 (-1.66)
Industry	-0.01 (-0.98)	-0.03 (-1.13)	-0.01 (-0.81)
$\ln(n_i + g + \delta)$	-0.02^{***} (-3.44)	-0.02^{***} (-2.88)	-0.01^{*} (-1.68)
Tests			
Moran's *I* (error)	2.04 (0.04)	3.07 (0.00)	
LM-Lag	1.45 (0.23)	28.73 (0.00)	
Robust LM-Lag	0.05 (0.82)	25.89 (0.00)	
LM-Error	2.14 (0.14)	4.92 (0.03)	
Robust LM-Error	0.74 (0.39)	2.07 (0.15)	
Log Likelihood	288.36	262.64	
Akaike	-568.72	-509.28	
Schwarz	-559.45	-490.74	
R-squared	0.32	0.88	

Notes: t-statistics in brackets, except for the diagnostic tests which are the p-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Table 6.15 – OLS Regression for convergence conditional on the Services share

Dependent variable: GDP per capita growth rate

Regressors	No Spatial Regimes	Spatial Regimes	
		Core	Periphery
Constant	-0.03	-0.08	-0.01
	(-1.58)	(-1.70)	(-0.25)
y_{1991}	-0.00^{**}	0.00	-0.01^{*}
	(-2.35)	(0.50)	(-1.90)
$Services$	0.01	0.04^{*}	0.02
	(1.63)	(1.85)	(1.34)
$\ln(n_i + g + \delta)$	-0.02^{***}	-0.02^{**}	-0.01
	(-3.67)	(-2.29)	(-1.28)
Tests			
Moran's *I* (error)	2.32	2.82	
	(0.02)	(0.00)	
LM-Lag	1.42	28.75	
	(0.23)	(0.00)	
Robust LM-Lag	0.60	27.42	
	(0.44)	(0.00)	
LM-Error	3.07	3.92	
	(0.08)	(0.05)	
Robust LM-Error	2.25	2.58	
	(0.13)	(0.11)	
Log Likelihood	289.23	264.37	
Akaike	-570.47	-512.75	
Schwarz	-561.20	-494.21	
R-squared	0.34	0.89	

Notes: t-statistics in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Table 6.16 reports the results for the Spatial Lag specification (SLM) of the model with spatial regimes. As seen, there is an improvement of fitness in comparison with OLS suggested by an increase in the log-likelihood and a decrease in both Akaike and Schwarz criteria. The rejection of the null of OLS regression against the spatial lag model by the likelihood ratio test only happens when the proxy for the production structure is the industry share and even though the null can only be rejected at the 10% level. As concerns the coefficients of the explanatory variables, there are some changes compared with OLS. The coefficient of lagged GDP per capita becomes significant for the Periphery group at the 5% level and remains insignificant for the Core, suggesting again that convergence just concerns the club of the poorest regions.

Table 6.16 – SLM for convergence conditional on the sector shares

Dependent variable: GDP per capita growth rate

Regressors	Industry		Services	
	Core	Periphery	Core	Periphery
Constant	-0.06 (-2.37)	-0.02 (-0.54)	-0.10*** (-3.26)	-0.03 (-1.12)
y_{1991}	0.01 (1.18)	-0.01** (-2.49)	0.00 (0.87)	-0.01*** (-2.92)
Industry	-0.03** (-2.13)	-0.01 (-1.09)		
Services			0.04*** (2.97)	0.02** (2.05)
$\ln(n_i + g + \delta)$	-0.02*** (-2.88)	-0.01* (-1.68)	-0.02*** (-3.39)	-0.01* (-1.88)
Spatial lag of GDP per capita growth rate	0.28** (2.01)		0.23* (1.66)	
Tests				
Likelihood ratio test	3.24 (0.07)		2.39 (0.12)	
Log Likelihood	291.92		295.22	
Akaike	-563.84		-570.44	
Schwarz	-540.66		-547.27	
R-squared	0.39		0.44	

Notes: z-value in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

The production structure becomes significant in both spatial clubs when the proxy is the share of services in total output, though the positive effect is much stronger in the Core than in the Periphery group. There is evidence of a negative effect of industry share on the regional GDP per capita growth rate, but it is only significant in the Core. These results are consistent with the Three-Sector Hypothesis, according to which the latter the stages of development, the higher the contribution of the tertiary sector to the value added generated by the region. In the Core, the service sector is also more dominated by the activities that make use of the information and communication technologies and are more likely to generate increasing returns to scale.

The population growth rate is negatively significant in both clubs, though in the Periphery just at the 10% level. The spatial lag of the dependent variable is positively significant when the production structure is proxied by the industry share, which suggests important regional spillovers, but it is only marginally significant (10% level) in the case of the services share. In contrast with the results obtained when human capital was the conditioning variable, there is evidence of spatial effects. This might be explained by the fact that human capital is spatially correlated while the production structure is not.

6.5.4. Conclusions

When the spatial regimes are taken into account in the model, the results obtained for the Core are quite different from those obtained for the Periphery. Both absolute and conditional convergence seems to occur only among the peripheral regions and this result is robust to the different conditional variables and proxies. This finding is in accordance with previous studies for the EU15 NUTS II regions which found that convergence is a phenomenon that mainly concerns the poorest regions club [Ertur *et al.* (2006), Dall'Erba and Le Gallo (2008)]. Ramajo *et al.* (2008) worked with Cohesion *versus* non Cohesion Countries regions as spatial clubs and though convergence was found in both clubs, the speed is faster in the regions that belong to the Cohesion countries (Portugal, Spain, Greece and Ireland). The conditional convergence results obtained in this subsection show a significant positive role of human capital on regional growth only in the Core group and when the proxies are the average years of total and higher education. The effect of secondary school is insignificant. When the production structure is the conditional variable instead, its effect on growth varies according to the spatial club. There is evidence of a negative and positive effect of the share of industry and services, respectively, on the GDP per capita growth rate in both clubs; but this effect is stronger in the Core than in the Periphery. In the model with spatial regimes, the spatial lag model was always the appropriate spatial specification for the β-convergence model and the coefficient of the spatial lag suggests important regional spillovers only when human capital is not the conditional variable. Since human capital is spatially correlated, when it is included, the regional spillovers become insignificant.

6.6. Regional policy

Several studies on the effect of the structural funds on the EU15 regions' convergence suggest no significant effect [Dall'Erba and Le Gallo (2008), Rodriguez-Pose and Fratesi (2004), De la Fuente and Vives (1995)] or extremely small [Bussoletti and Esposoti (2008)]. According to EU regional policy, the regions that are elegible under objective 1 are the NUTS II level regions whose GDP per capita is below 75% of the EU average. The objective 1 of regional policy concerns the development and structural assistance to regions whose development is lagging behind. The time period considered in this study covers three years of the 1989-1993 structural fund programme and the full implementation of the following ones: 1994-1999 and 2000-2006. All the Portuguese regions were and remained objective 1 regions over the period with the exception of the capital area (Lisboa e Vale do Tejo) which lost its elegibility on 1 January 2000, but still received transitional assistance until 2006. In continental Spain, the elegible regions were: Galicia, Asturias, Castilla y León, Castilla-La Mancha, Extremadura, Comunidad Valenciana, Andalucía, Murcia and Cantabria. The latter lost its eligibility on 1 January 2000 but as Lisboa e Vale do Tejo it received transitional assistance until 2006.

It is not possible to find data on the structural funds (SF) allocation by region, as the EU Comission Reports on Economic and Social Cohesion do not provide data on the SF expenditure at the regional level.[31] Therefore, the only way to include a proxy for regional policy is through a dummy variable. For all the NUTS III regions from the sample that belong to a NUTS II which received structural help the dummy takes the value one. As all the regions that benefited from structural funds under the objective 1 belong to the Periphery spatial club, only the model with no spatial regimes is estimated. Table 6.17 displays the results when the regional policy dummy was added to the absolute convergence model. Moran's *I* statistic indicates strong spatial dependence. The LM statistics suggest the Spatial Error model as the most appropriate since the LM-error statistic is significant at 5% and the LM-lag is only significant at 10%. The robust statistics confirm it because only the robust-LM error is significant. There is evidence of convergence, but the inclusion of the regional

[31] The Portuguese Regional Development General-Directorate was contacted to collect information on the payments made to this country regions but no reply was obtained.

policy dummy seems to have a very low negative effect although only significant at 10% level. Therefore regional policy seems to lead to a marginally lower growth rate in GDP per capita.

Table 6.17 – OLS results for absolute convergence model in Iberia

Dependent variable: GDP per capita growth rate	
Regressors	
Constant	0.05*** (7.53)
y_{1991}	-0.01*** (-4.55)
Regional Policy Dummy	-0.00* (-1.86)
Tests	
Moran's *I* (error)	2.91 (0.00)
LM-Lag	3.35 (0.08)
Robust LM-Lag	0.73 (0.39)
LM-Error	5.45 (0.02)
Robust LM-Error	2.83 (0.09)
Log Likelihood	283.52
Akaike	-561.03
Schwarz	-554.08
R-squared	0.23

Notes: t-statistics in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Table 6.18 reports the spatial error model results for absolute convergence with the regional dummy. As shown, there is an increase of the log-likelihood and a decrease of both the Akaike and Schwarz criteria in comparison with the OLS results which evidence an improvement of fit for the spatial error specification. The likelihood ratio test clearly rejects the null of the OLS regression against the spatial error model suggesting the latter as the most appropriate. The autoregressive error coefficient (λ) is significant which indicates that a random shock in an Iberian region propagates to the others. In what concerns the other coefficients, the results confirm those obtained with OLS, this is, regional policy has a very small marginally significant effect on economic growth.

Table 6.18 – Spatial Error Model for absolute convergence

Dependent variable: GDP per capita growth rate

Regressors	
Constant	0.05^{***} (7.07)
y_{1991}	-0.01^{***} (-4.18)
Regional Policy Dummy	-0.00^{*} (-1.84)
Autoregressive error (λ)	0.33^{**} (2.23)
Tests	
Likelihood ratio test	4.60 (0.03)
Log Likelihood	285.81
Akaike	-565.63
Schwarz	-558.67
R-squared	0.29

Notes: z-value in brackets, except for the diagnostic tests which are the p-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Convergence conditional on human capital

Table 6.19 shows the results obtained for the OLS regression of the β-convergence model conditional on human capital. As seen, in terms of spatial dependence test, at the conventional levels of significance (1-5%) Moran's *I* suggests spatial dependence for the Iberian regions across all the education proxies except the average years of secondary schooling. The LM statistics only confirm the spatial dependence when the proxy is higher education and in this case the Spatial Lag model is the most appropriate. Again, in what concerns the other variable of interest, there is evidence of convergence and human capital proxied by the average years of total education played a positive effect on regional growth. When the different levels of education are taken into account mixed results are obtained. The effect of higher education is positively significant but almost zero and the effect of secondary schooling is insignificant. Table 6.20 reports the results for the appropriate spatial specification.

Table 6.19 – OLS Regression for convergence conditional on human capital in Iberia

Dependent variable: GDP per capita growth rate

Regressors	Total	Secondary	Tertiary
Constant	-0.03 (-1.49)	-0.02 (-1.19)	0.00 (0.23)
y_{1991}	-0.01^{***} (-3.42)	-0.01^{***} (-3.16)	-0.01^{***} (-3.36)
$\ln(AvEdu)$	0.02^{**} (2.04)		
$\ln(Sec)$		0.01 (1.53)	
$\ln(Ter)$			0.00^{*} (1.95)
$\ln(n_i + g + \delta)$	-0.02^{***} (-3.38)	-0.02 (-1.65)	-0.02^{***} (-3.33)
Regional Policy Dummy	-0.00^{*} (-1.88)	-0.00 (-1.65)	-0.00^{*} (-1.77)
Tests			
Moran's *I* (error)	2.28 (0.02)	1.59 (0.11)	2.53 (0.01)
LM-Lag	1.95 (0.16)	1.18 (0.28)	1.71 (0.19)
Robust LM-Lag	0.01 (0.92)	0.15 (0.70)	0.34 (0.56)
LM-Error	0.51 (0.48)	1.05 (0.30)	3.39 (0.07)
Robust LM-Error	2.46 (0.29)	0.02 (0.88)	2.02 (0.16)
Log Likelihood	292.02	291.70	291.46
Akaike	-574.05	-571.40	-572.91
Schwarz	-562.46	-559.81	-561.32
R-squared	0.39	0.36	0.38

Notes: t-statistics in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Table 6.20 – Spatial Error model for convergence conditional on higher education

Dependent variable: GDP per capita growth rate	
Regressors	
Constant	0.01 (0.41)
y_{1991}	-0.01^{***} (-3.61)
$\ln(Ter)$	0.01^{**} (2.17)
$\ln(n_i + g + \delta)$	-0.02^{***} (-3.21)
Regional policy dummy	-0.00^{*} (-1.86)
Autoregressive error (λ)	0.28^{*} (1.86)
Tests	
Likelihood ratio test	3.10 (0.08)
Log Likelihood	293.01
Akaike	-576.01
Schwarz	-564.42
R-squared	0.41

Notes: z-value in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

As happened when the regional policy dummy was not introduced, there are some changes in comparison with OLS. The coefficient of the average years of tertiary education becomes significant at 5% level and has a higher value (0.01). The likelihood ratio test only rejects the null of OLS against the SEM at 10% level, but the Log Likelihood, Akaike and Schwarz criteria suggest an improvement of fit comparing to OLS. The autoregressive error coefficient (λ), which represents the propagation of shocks among regions, is only marginally significant. As in the previous estimations, the regional policy dummy coefficient is very low and only significant at 10% level, which confirms a marginal negative effect of regional policy on GDP per capita growth.

Convergence conditional on the production structure

Table 6.21 reports the OLS results when the regional policy dummy was introduced as an additional variable in the convergence equation conditional on the production structure.

Table 6.21 – OLS Regression for convergence conditional on the production structure

Dependent variable: GDP per capita growth rate

Regressors	Industry	Services
Constant	-0.00 (-0.19)	-0.02 (-0.95)
y_{1991}	-0.01^{***} (-3.04)	-0.01^{***} (-3.25)
Industry	-0.01 (-1.37)	
Services		0.01^{*} (1.92)
$\ln(n_i + g + \delta)$	-0.02^{***} (-3.33)	-0.02^{***} (-3.63)
Regional Policy Dummy	-0.00^{**} (-2.20)	-0.00^{**} (-2.22)
Tests		
Moran's *I* (error)	2.15 (0.03)	2.49 (0.01)
LM-Lag	1.83 (0.18)	1.73 (0.19)
Robust LM-Lag	0.02 (0.89)	0.23 (0.63)
LM-Error	2.13 (0.14)	3.19 (0.07)
Robust LM-Error	0.32 (0.57)	1.70 (0.19)
Log Likelihood	290.86	291.79
Akaike	-571.72	-573.58
Schwarz	-560.13	-561.99
R-squared	0.37	0.38

Notes: t-statistics in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

Moran’s *I* suggests spatial dependence for the estimations with both production structure proxies (share of industry and services in total output). The LM tests only confirm it when the production structure is proxied by the share of services. In the latter, the LM-error statistic is significant at 10% level which suggests the Spatial Error model as the most appropriate.

The lagged GDP per capita is negatively significant at the conventional levels, confirming convergence among the Iberian regions when the spatial regimes are not taken into account. The introduction of the regional dummy does not change substantially the results obtained without the dummy.

The industry share coefficient is insignificant and the services share has a positive effect but only significant at 10% level. The population growth rate is significant at the conventional levels and has the expected sign. Though the regional policy effect is negatively significant, its coefficient is almost zero suggesting a very low negative effect on regional income per capita growth.

Table 6.22 reports the estimation of the Spatial Error model when the services share in total output is the conditional variable. There is an improvement of fit relative to OLS since there is an increase in the Log Likelihood and a decrease in both the Akaike and Schwarz criteria. The likelihood ratio rejects the null of OLS against the SEM though just at 10% level and the autoregressive error coefficient (λ) is significant as well at 10% level. It confirms the results obtained with OLS in terms of sign and size of the coefficients, the main difference is that the positive share of services effect becomes significant at 5% level once the spatial dependence is corrected.

Table 6.22 – Spatial Error model for convergence conditional on services share

Dependent variable: GDP per capita growth rate	
Regressors	
Constant	-0.01 (-0.67)
y_{1991}	-0.01^{***} (-3.30)
Services	0.01^{**} (2.10)
$\ln(n_i + g + \delta)$	-0.02^{***} (-3.37)
Regional policy dummy	-0.00^{***} (-2.27)
Autoregressive error (λ)	0.29^{*} (1.89)
Tests	
Likelihood ratio test	3.04 (0.08)
Log Likelihood	293.31
Akaike	-576.62
Schwarz	-565.04
R-squared	0.42

Notes: z-value in brackets, except for the diagnostic tests which are the *p*-values. *, ** and *** indicate statistical significance at 10%, 5% level and 1% level.

6.7. Conclusions

The Exploratory Spatial Data Analysis of the Iberian NUTS III level dataset identified both spatial dependence and spatial regimes. When spatial dependence was corrected by using the appropriate spatial specification for the β-convergence model, the results tend to confirm those obtained with OLS. There are significant differences in the convergence process across the spatial regimes. Convergence, both absolute and conditional, occurs mainly in the periphery group. The effect of the conditional variables on growth varies as well across the spatial regimes. Human capital proxied by the average years of total and higher education plays a positive and significant role in the Core club, but not in the Periphery, which suggests that a certain level of economic development is required to achieve a positive effect of human capital. The effect of secondary schooling on regional growth is insignificant in both clubs. The services share in total output has a positive effect on regional growth which is stronger in the Core than in the Periphery. In contrast, regional policy seems to have a very small negative effect on the income per capita growth rate. This result is likely due to the lack of data since only a dummy variable was used to capture possible effects.

Chapter 7
Conclusions

The purpose of this thesis was the study of growth and convergence in Portugal and Spain with a particular focus on the role of human capital. In order to analyse if Portugal and Spain show any signs of catching-up within the EU15, a time series approach was used to assess the level of convergence in output per capita between each Iberian country and the other EU15 countries since the 1960s. Though several techniques and tests were used, the findings indicate a lack of convergence.

At the regional level, this thesis estimates the Portuguese regional capital stocks for the period 1991-2006 by using both an education and income-based approach. The procedure followed to compute the different human capital proxies uses a firm level dataset which contains information on the qualifications and wages of the workers present in each region. The construction of these human capital series allowed the introduction of human capital proxied by different measures in a study of growth and convergence among the Portuguese regions which is novel. The findings suggest a positive effect of education on the reduction of income per capita disparities, which gives support to the policy of spreading education institutions across the country in the last decades.

The comparison of the effects of human capital on the reduction of income per capita disparities in the Iberian countries indicates some differences. In Spain human capital, proxied by the average years of total and higher education, is also important as an input in the production function, in line with the Lucas's (1988) model, in contrast with Portugal where it is only significant as a vehicle of technology adoption. The higher education role in regional growth has been more important in Spain than in Portugal and one possible explanation is the lack of Science and Technology degrees among the Portuguese graduates. Thus, as a policy recommendation, future investments in the Portuguese higher education system should take into consideration the most relevant academic fields.

By using Exploratory Spatial Data Analysis (ESDA) two convergence clubs within the Iberia Peninsula were identified: the Core, which corresponds roughly to the East of the peninsula, which is closer to the main EU countries; and the Periphery, which is mainly constituted by regions located on the West and is further from the European core countries. The effect of human capital on regional growth is different according to the spatial club. Total and higher education plays a positive and significant role in the Core club but not in the Periphery, which suggests that a certain level of economic development is required to achieve a positive effect of human capital. On the other hand, convergence only occurs among the regions which belong to the Periphery which gives support to policies focused on the reduction of income disparities among the poorest regions. The investment on human capital will reinforce their economic growth after they reach a certain threshold of economic development.

Overall, this thesis contributes to the empirical literature on the effects of human capital on economic growth by presenting original results for Portugal and Spain. The main aim of this thesis was to take advantage of the Iberian countries regional data in order to study the effects of human capital on economic growth. The conditional β-convergence model was estimated through panel data models and the findings indicate a positive effect of human capital proxied by education in Portugal and Spain, in accordance with the theoretical predications. It is known that working with regional instead of cross-country data reduces the measurement error problems and this might explain the positive result obtained.

Nevertheless there are some limitations. Due to the lack of regional data for Portugal before the 1990s, the conditional β-convergence model was estimated for a period of 15 years which is short for growth empirics. The choice of control variables is also limited because of the data constraints. For Portugal, the physical capital stock is not considered as a control variable. Though the lagged income per capita included in the convergence equation can work as a proxy for this variable, this is a drawback that future research will try to overcome by estimating the physical capital stocks for the Portuguese NUTS III regions. Moreover this thesis relies heavily on education as a proxy for human capital. Other dimensions, such as the quality of the education system, health and on-the-job training, were just indirectly considered through the Mulligan and Sala-i-Martin labour-income proxy. Future research will estimate alternative proxies to capture these other human capital dimensions. The European Regional policy was only briefly considered in this work and it constitutes another possible future research direction.

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