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REGIONAL RETURNS TO PHYSICAL CAPITAL: ARE THEY CONDITIONED BY EDUCATIONAL ATTAINMENT?

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Abstract

This paper provides novel empirical evidence of the indirect effect of educational attainment on regional economic growth, through its influence on the profitability of investment in physical capital. We test the hypothesis that the regional heterogeneity of the return to physical capital can be directly related to the existing heterogeneity in the educational attainment of workers. The results for the Spanish case support our hypothesis that the higher the educational attainment of workers the greater the returns on investment in physical capital. In fact, this effect seems to be sufficiently strong to have counterbalanced the traditional mechanism of decreasing returns to capital accumulation.

Key words: returns to capital, human capital, productivity, cost system

JEL: J24, O11, O47, R11

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1. INTRODUCTION

Although the literature has stressed the importance of other factors (R&D, social and human capital, infrastructures, technical progress, etc) in stimulating productivity and economic growth, the role of investment in private physical capital as a key element of economic development is beyond doubt (Kumar and Russell, 2002; Scoppa, 2007). An economy with sufficiently strong incentives for the accumulation of physical capital will see improvements in the stock of this factor, as it will be able to generate further local investment and attract investment from other areas. In the case of regions within an integrated economy, it can be argued that capital will gravitate to those regions promising the highest return. Furthermore, the neoclassical mechanism of diminishing returns could be counterbalanced by agglomeration economies and an uneven distribution of production amenities across regions. This could cause persistent spatial differences in the return to physical capital which, in turn, would lead to an unequal spatial distribution of the stock of this factor.

Educational human capital is among the elements that might be expected to exert a strong influence on the magnitude of the returns to physical capital accumulation and, as a result, on the existing stock of this type of capital. The role played by human capital in stimulating technical progress and investment in physical capital has been stressed in the economic literature. It can be argued that the stock of human capital in an economy favours the generation and absorption of technology but, at the same time, technical progress will increase the incentive to invest in education. Thus, if technology is linked to investment in physical capital there will be a positive relationship between the two types of capital considered. Additionally, through the stimulus to change the production structure, from sectors with lower to higher capitalisation ratios, we can again see a link between human and physical capital (Tamura, 2002). In fact, this relationship has been used in some empirical studies to justify the minor impact of human capital in growth regressions that control for the accumulation of physical capital. Barro (1991), for instance, argues that a significant proportion of the effect of human capital is channelled through an increase in the investment rate in physical capital. The same point is made by Sianesi and Van Reenen (2003) and Krueger and Lindahl (2001).

According to well-known arguments, additional investment in physical capital in a location with a high existing endowment would lead to congestion problems and the returns to additional investment would decrease as a result. However, these diseconomies of scale in agglomerations could be counterbalanced by certain externalities. For example, one might regard human capital as a factor which facilitates higher returns on investment in physical capital. Therefore, in addition to the impact that physical and human capital have as determinants of regional growth (Fingleton, 2004; Kosfeld et al., 2006), human capital may also have the indirect impact of attracting physical capital. Thus, human capital would increase the capability of a given region to generate and attract economic activity, making the location of physical capital in that economy a more inviting prospect.

In spite of this, few empirical studies to date have examined the influence of educational attainment on the magnitude of returns to physical capital. The primary aim of this paper is to fill this gap in the literature by testing whether endowments of human capital do in fact make investment in physical capital more attractive in regional economies. Specifically, we provide evidence to support the hypothesis that the regional heterogeneity of the return to physical capital can be directly related to the existing heterogeneity in the educational attainment of workers. In other words, we analyse the extent to which improvements in educational attainment may secure higher returns on investment in physical capital. This is a key issue in regional growth and development, as the presence of more highly skilled workers in a region would not only produce higher returns to physical capital but also make the region more attractive to firms looking to relocate.

In addition, and from a methodological point of view, this paper introduces the novel use of the framework established by duality theory, through a cost system in which we incorporate human capital as a factor that can shift the cost function.[2] The main advantage of using the duality framework in this paper is that it enables us to calculate the elasticity of physical capital with respect to human capital in order to analyse the indirect effect of human capital on economic growth through its influence on the optimum stock of physical capital. It is not possible to obtain this measure by the standard practice of estimating a production function including human capital as an additional input.[3]

[2] Morrison and Siegel (1997) is, to the best of our knowledge, the only study that uses this approach to analyse some of the effects of human capital endowment on production activity. However, it does so in a more general context by studying the effects of knowledge accumulation, without analysing the possible increase in physical capital stimulated by human capital.

[3] The use of a cost function to analyse the effect of human capital must therefore be understood as equivalent to the common practice in economic growth literature of using a production function aggregated with the stock of human capital (see, for instance, Topel, 1999). Both frameworks are based on the notion that a greater endowment of human capital in the economy may lead to higher productivity growth.

This methodology is applied to the Spanish regions in recent decades. The situation in the Spanish regions could be paradigmatic since there has been a spectacular increase in educational attainment which coincided with a virtually uninterrupted process in which the regions have opened up and exposed themselves to competition, leading to the subsequent modernisation of production and institutional structures. It seems, therefore, that the situation in Spain is ideal for assessing the impact of human capital and the relationship it maintains with physical capital. In addition, homogeneous and high-quality data on aggregate output, input quantities and prices and educational human capital covering a long period are available for each of the regions. This enabled us to obtain robust estimates of the direct and indirect effects of human capital, in contrast with the evidence provided in most previous studies, which was based on information from samples of heterogeneous economies.

The rest of the paper is organised as follows. In Section 2 we present the empirical framework based on the duality theory and describe the dataset. Section 3 contains the results on the return to physical capital and a first descriptive analysis of its regional heterogeneity. In Section 4 we report different results on the impact that human capital exerts on physical capital. Finally, we conclude with Section 5.

2. EMPIRICAL FRAMEWORK AND DATA

2.1 Empirical framework

This paper follows the duality theory by estimating a cost function augmented with human capital as an additional production input. By taking into account the dual framework through a flexible cost function, it is possible to overcome or at least attenuate the limitations of studies based on the primal approach, while at the same time estimating returns to physical capital in an equivalent form. In addition, with the dual framework it is possible to estimate other interesting effects such as the relationship between inputs.

Briefly, duality theory assumes that the cost minimisation problem that firms face consists in selecting inputs in such a way as to minimise production costs, taking into account certain input prices (of the variable inputs, labour (P_L) and intermediates (P_M), in our case), the level of output (Y) and the form of the production function (Chambers, 1988). Within this framework, labour and intermediates are considered as variable inputs that adjust instantaneously to their long-term equilibrium values. However, it is feasible that certain factors, such as physical capital, do not follow an adjustment mechanism of this type. This may be due to price controls, regulations and institutional constraints that are beyond the influence of an individual firm in the short term. Those inputs that are not in equilibrium are referred to as quasi-fixed inputs (physical capital, K, in our case). Human capital (H) is introduced into this framework in order to take into account the effect of this factor on firm production costs. As stated in Morrison and Siegel (1997), human capital, like certain other knowledge factors, is considered to be external to the industry, so that the resulting effects on productivity are interpreted as evidence of spillovers which can be considered efficiency factors. These underlying efficiency factors can cause downward cost curve shifts. Although firms pay for the human capital embedded in their employees through their wages, they do not pay for the rest of the human capital available in the economy, which is considered in our framework as an external environmental variable.

The functional form selected for the empirical implementation of the variable cost function in this study is the translog function, which is expressed as follows:

$$\begin{aligned}
&\ln (VC/P_M) = \beta_0 + \beta_L \ln\frac{P_L}{P_M} + \beta_Y \ln Y + \beta_K \ln K + \beta_H \ln H + \beta_T t + \\
&0.5\left[\beta_{LL}\ln^2\frac{P_L}{P_M} + \beta_{YY}\ln^2 Y + \beta_{KK}\ln^2 K + \beta_{HH}\ln^2 H + \beta_{TT} t^2\right] \qquad (1)\\
&+\beta_{LY}\ln\frac{P_L}{P_M}\ln Y + \beta_{LK}\ln\frac{P_L}{P_M}\ln K + \beta_{LH}\ln\frac{P_L}{P_M}\ln H + \beta_{LT}\ln\frac{P_L}{P_M}\, t \\
&+\beta_{YK}\ln Y\ln K + \beta_{YH}\ln Y\ln H + \beta_{YT}\ln Y\, t + \beta_{KH}\ln K\ln H + \beta_{KT}\ln K\, t + \beta_{HT}\ln H\, t
\end{aligned}$$

where VC denotes variable costs and t is a time trend which summarizes technological change. Expression (1) imposes on prices the symmetry and homogeneity conditions that all translog functions must fulfil (see Berndt, 1991). We obtain the equations of demand of the cost-minimising variable factors by differentiating the function in (1) with respect to the prices of variable inputs $\partial VC(\cdot)/\partial P_i$, with i = L, M. Given that we only consider two variable factors, the percentage participations of the variable inputs in costs are obtained as:

$$\begin{aligned}
&S_L \equiv \frac{P_L \cdot L}{VC} = \frac{\partial \ln VC}{\partial \ln P_L} = \beta_L + \beta_{LL}\ln\frac{P_L}{P_M} + \beta_{LY}\ln Y + \beta_{LK}\ln K + \beta_{LH}\ln H + \beta_{LT}\, t \\
&S_M \equiv 1 - S_L
\end{aligned} \qquad (2)$$

If the fixed factors are within their static equilibrium levels, the following envelope condition must be fulfilled:

$$-S_K \equiv -\frac{P_K \cdot K}{VC} = \frac{\partial \ln VC}{\partial \ln K} = \beta_K + \beta_{KK} \ln K + \beta_{LK} \ln \frac{P_L}{P_M} + \beta_{YK} \ln Y + \beta_{KH} \ln H + \beta_{KT}\, t \qquad (3)$$

In other words, in this situation the marginal reduction of variable costs due to increases in capital is equal to its price, $-\partial VC(\cdot)/\partial K = P_K$.

Finally, by logarithmically differentiating the function of VC(·) with respect to Y and introducing the condition of equality between the price of the product and the marginal cost, we obtain:

$$S_Y \equiv \frac{P_Y \cdot Y}{VC} = \frac{\partial \ln VC}{\partial \ln Y} = \beta_Y + \beta_{YY} \ln Y + \beta_{LY} \ln \frac{P_L}{P_M} + \beta_{YK} \ln K + \beta_{YH} \ln H + \beta_{YT}\, t \qquad (4)$$

Expressions (1)-(4) make up the framework of full static equilibrium (FSE). However, in view of results obtained elsewhere (Moreno et al., 2002; 2003), this study did not impose the condition of complete equilibrium on the physical capital. In other words, it estimated the returns to physical capital within a framework that was sufficiently flexible to permit partial adjustment processes in the stock of physical capital, in what is known as the partial static equilibrium (PSE) model. In this case, the restrictions of equality between the parameters in (3) and the corresponding ones in (1) were not imposed.[4] By using this framework, we will be able to estimate the return to physical capital and its relationship with human capital, which will be shown in Sections 3 and 4 respectively.

2.2 Database

The statistical information we use in this paper refers to private sector production in the 17 Spanish NUTS II regions[5] between 1980 and 2000. All the variables except for human capital were taken from the BD.MORES database compiled by the Spanish Ministry of Economy and Finance.[6] Specifically, we used the series related to gross added value at factor prices, employment, wages, private physical capital stock and its cost, and intermediates. We chose

[4] Note that, equally, one could question the optimum behaviour on the market of output. In other words, one could question the fulfilment of restrictions between the parameters of Equations (1) and (4). In this exercise, such restrictions became necessary *a priori* to give greater structure to the system under analysis, as is the case in Morrison and Schwartz (1996) and Boscá et al. (2004), among others.

[5] NUTS is the French acronym for Nomenclature of Territorial Units for Statistics, a hierarchical classification established by EUROSTAT that provides comparable regional breakdowns of EU member states. In Spain, the NUTS II regions correspond to the 17 Autonomous Communities, which are historical geographical and administrative regions with a high level of political and financial autonomy.

[6] Free access at http://www.igae.meh.es/SGPG/Cln_Principal/Presupuestos/Documentacion /Basesdatosestudiosregionales.htm

production value as the output variable, which was obtained by adding intermediates to the added value.

The measure used for human capital combines the average number of years in each level of education with the percentage of the population in each of these levels, thereby producing a useful synthetic indicator of human capital as the average number of years of schooling in an economy.[7] The information used to construct the indicator was taken from Mas et al. (2002). For each year and region in Spain, they provide the proportion of workers with each of the following five levels of education: no schooling, primary education, secondary education, first level of higher education, and second level of higher education. We followed Serrano (1996) by assigning 0 years to workers with no schooling, 3.5 years to workers with primary education, 11 years to those who completed secondary education, 16 years to workers who completed the first level of higher education and 17 years to those who completed the second level of higher education.

Physical and human capital in the Spanish economy as a whole showed positive growth rates throughout the period under analysis, although physical capital showed a clear procyclical pattern. Despite a degree of regional convergence in both types of capital, caused by faster growth in regions with lower initial endowments, sizeable spatial disparities were observed. This can be seen in Table 1, which shows the average relative endowment of physical and human capital per worker in each of the regions (K/L and H respectively), and the ratio of the stock of physical capital to that of human capital (K/HL, where HL is the total number of years of schooling). The stock of physical capital per worker in some regions is almost double that of other areas. It is interesting to note that the regions with the highest values for the stock of physical capital per worker were not the advanced industrialised regions but some of the less developed regions (Extremadura and Castile-La Mancha). These figures can be explained by the low levels of employment and the fact that some of the national energy production infrastructure is based in these regions.[8] In terms of human capital, the representative worker in regions with the highest levels had approximately two years more schooling that the average worker in regions with the lowest levels. This difference represented more than 30% of the average years of schooling in the less developed regions.

[7] This type of indicator was constructed for various samples of economies by Kyriacou (1991) and Barro and Lee (2001), among others.
[8] Similar values for the stock of physical capital per worker in the Spanish regions were reported in Tortosa-Ausina et al. (2005).

[Insert Table 1 around here]

Regional imbalances in the stock of the two types of capital cause sharp disparities in the ratio K/HL. These imbalances between physical and human capital were much greater than the national average in less developed regions such as Extremadura and Castile-La Mancha, and in advanced regions like Madrid and Catalonia. However, while human capital fell short of the endowment of physical capital in the less developed regions, the opposite was true of the advanced regions. This is confirmed by the absolute values for the ratio K/HL in each region in 1980, 1990 and 2000 shown in Figure 1. In addition, it can be seen that the accumulation of human capital was faster than that of physical capital in regions with a high ratio at the beginning of the period. The decrease in the ratio is not as strong in those regions in which the stock of both types of capital was more balanced in 1980. As a result, regional dispersion in the ratio K/HL was much lower in 2000.

[Insert Figure 1 around here]

Therefore, the increase in both the physical and human capital stock in all regions in Spain and the existence of marked variability among them should provide us with a substantial body of information from which to analyse the heterogeneity of the impact of physical capital on aggregate productivity and economic growth, and the extent to which this can be related to the heterogeneity of the stock of human capital. In fact, in the regions with low endowments of physical capital in relation to human capital, higher returns on additional investment in physical capital could be expected. Our hypothesis here is that, with the same stock of physical capital, the higher the endowment of human capital in a region, the higher the returns of physical capital.

3. ESTIMATION OF THE REGIONAL RETURNS TO PHYSICAL CAPITAL

3.1 Estimation of the cost system

We estimated the long- and short-term models (Equations 1 to 4) using the iterative Zellner technique for seemingly unrelated regression equations, which converge to the maximum likelihood estimator for models of this type (see Greene, 2001). We included two dummy variables that interact with the linear terms of the variable factor prices, the stock of physical capital and the output. For the sake of consistency, these dummies were also included in the factor share equations and in the expressions for the equilibrium conditions of physical capital and output. The first of these dummies (D1) controls for the size of the regional economy, considered in terms of the share of its output over the national output. The second (D2) dummy was included to account for the situation in some regions in which the ratio of physical to human capital was fairly low.

To choose the framework in which to compute the return to physical capital, it was necessary to determine whether the observed levels of physical capital corresponded to their optimal long-term levels. This enabled us to determine the most suitable framework for the sample under consideration (PSE or FSE), without taking an *a priori* decision, as is usually the case in the literature. Therefore, the fixity assumption of physical capital was explicitly checked, using the test developed by Schankerman and Nadiri (1986). The statistic of this test is shown in the lower panel of Table 3. The result was conclusive: for the sample of Spanish regions in the period under analysis, the model that best fitted the production technology behaviour in the private sector was the PSE model. In other words, our findings clearly rejected the assumption that capital stock in this sector is adjusted to the optimum level in each period according to the existing production technology. Consequently, we estimated the PSE model and used these parameters to calculate the effects relevant to the study.

Table 2 shows the results of the estimation and the results obtained from the likelihood-ratio test of the null hypothesis that the matrix of covariances of the disturbance of the system of equations is diagonal – in other words, the appropriateness of the SUR model for the cost system. The value obtained for the test statistic (108.8) clearly lay within the area of rejection of the null hypothesis, so that the Zellner estimation for the SUR model was appropriate. Since we used the translog approximation of the unknown functional form underlying the cost system, it is unfeasible to undertake any kind of interpretation or structural analysis directly from the estimated parameters. Similarly, it should be stressed that convergence in the estimation was reached with a relatively small number of iterations and, more importantly from an economic point of view, that the dummy variables which account for regional differences in exogenous demands for factors and marginal costs, as well as all the variables that describe the effect of human capital, are jointly significant.

3.2 Estimated returns to physical capital: regional heterogeneity

To quantify and evaluate the contribution of investment in physical capital to economic growth, we derived the elasticity of output with respect to this factor in the cost system given above. Specifically, we used the envelope theorem (Chambers, 1988) to calculate the effect of physical capital on production in the context of the cost system as follows:

$$R_K = \varepsilon_{Y,K} \equiv \frac{\partial \ln Y}{\partial \ln K} = \frac{-\frac{\partial VC}{\partial K}}{\frac{\partial SC}{\partial Y}} \frac{K}{Y} \qquad (5)$$

that is, as the percentage variation in the product as a result of varying the stock of physical capital by 1%.

We used the coefficients estimated in the cost system and Expression (5) to compute the returns to physical capital. Table 3 shows this estimate for each Spanish region and for the country as a whole for representative years and the average value for the entire period under analysis.[9] It can be seen that returns to physical capital are positive and of sizeable magnitude in most regions (with the exception of Galicia) and produce a regional average of approximately 7.6%. In other words, an increase of 1% in the average stock of physical capital led to an increase of 7.6% in output for the period considered and in a typical Spanish region. However, this global result masks a significant degree of regional heterogeneity. Indeed, the mean return to physical capital over the period under analysis was very high in Catalonia, Madrid, Navarre, the Basque Country and Valencia. In contrast, the return was considerably lower than the average value in Andalusia, Asturias, Castile-Leon, Castile-La Mancha, Extremadura, Murcia and La Rioja. The average standard deviation for the entire period was 0.05 (for the average return of 0.076), which indicates the high degree of heterogeneity between regions.

[Insert Table 3 around here]

If we look at the time profile of the returns to physical capital we observe a non-monotonic increase in the return over the period considered (more than two percentage points between 1980 and 2000). This is the case even though the Spanish economy experienced a constant increase of this factor over the period. Therefore, the decreasing returns mechanism generally associated with the accumulation of production factors does not seem to be strong enough in the accumulation of physical capital.

[9] The complete set of estimated effects for each region in each year is available from the authors upon request.

Ultimately, investment in physical capital in Spanish regions showed significant levels of profitability once we had discounted the cost associated with this factor. However, the magnitude of this effect was far from homogenous across all regions and time periods. Interestingly, the regions that showed the highest returns were those with the lowest ratios of physical to human capital. This confirms the hypothesis that the regions with low endowments of physical capital with respect to human capital obtain higher returns to additional investment in physical capital. In the next section we examine the extent to which the higher endowments of human capital in a given region enable it to obtain higher returns from the investment in physical capital.

4. RETURNS TO PHYSICAL CAPITAL AND EDUCATIONAL ATTAINMENT

According to the analysis above, the decreasing returns mechanism does not appear to apply in the accumulation of physical capital. That is, a high endowment of capital in an economy promises higher potential returns, which means that existing firms would continue to invest and new firms would be more likely to relocate there. The hypothesis examined here is that human capital may be the factor behind this phenomenon: a higher skill level among workers in a given region ensures that higher returns can be obtained from investment in physical capital in that area. In other words, human capital stimulates investment in physical capital because the level of educational attainment of the workforce has a positive effect on the profitability of physical capital.

We observe that the correlation coefficient between the stock of human capital and the return to physical capital in all regions has an average value of 0.91 for the period 1980-2000, which we interpret as a tentative confirmation of the hypothesis. The value of the correlation measure remains constant at approximately 0.92 between 1980 and 1991 but decreases to 0.76 by 2000. More interestingly, if we consider the relationship between the returns to physical capital and the ratio K/HL (Figure 2), we clearly see that when human capital is abundant with respect to physical capital, the return to physical capital is much higher than when the stock of physical capital is significantly greater than the stock of human capital.

[Insert Figure 2 around here]

To conduct a more accurate analysis of the extent to which human capital acts as a stimulus for investment in physical capital, we can obtain the semi-elasticity of the optimum demand of physical capital with respect to human capital from the following expression:

$$\text{Semi} - \varepsilon_{K^*H} \equiv \frac{\partial \ln K^*}{\partial H} = \varepsilon_{K^*H} \frac{1}{H} = -\beta_{KH} \frac{1}{S_K H} \quad (6)$$

This measure indicates the percentage change in the stock of optimum physical capital for a one-year increase in the average schooling of the workforce.

Table 4 shows that this semi-elasticity is positive in all cases, which suggests that human capital does stimulate investment in physical capital. In addition, we can see that the effect is relatively strong as an additional year of schooling led to an average increase of approximately 19% in the optimal stock of capital during the period considered. The effect was greater at the beginning of the 1980s[10] and stabilised in the latter part of the decade to levels close to 13%. However, the influence of human capital on the optimal amount of physical capital varies considerably between regions. The highest values of the semi-elasticity measure were obtained in La Rioja, Galicia, Asturias and Murcia, where an additional year of schooling increases the optimal amount of physical capital by more than 20%. In contrast, the lowest semi-elasticity values were found in Extremadura and the Balearic Islands. The same pattern is observed for regions with higher levels of development but very heterogeneous production structures, such as Catalonia, Madrid and the Basque Country, and regions with lower levels of development such as the Canary Islands, Cantabria and Castile-La Mancha.

[Insert Table 4 around here]

To provide additional evidence on the effect of human capital on the return to physical capital we simulated this return for 2000 for a scenario in which all regions had the same endowment of human capital and all other variables were fixed at their real values. The real figures for the Spanish economy in 2000 show an average of 9.3 years of schooling, which led to returns to physical capital of 8.7% in that year. However, as shown in Table 5, if schooling in each Spanish region had amounted to exactly this average value, the return to physical capital would have been approximately 9%, which is slightly higher than the real figure.

[10] In fact, the elasticity value for 1980 is too high to be credible. This is due to the high value of the price of physical capital as a result of the extremely high interest rates reported in Spain that year (see Daban et al., 1998). For example, the average elasticity value for 1981 was approximately 30%, which is substantially lower than the 1980 value.

Additionally, the variation coefficient of this return across regions would have fallen from 0.043 to 0.028, which would indicate a considerable reduction in the regional variability. Specifically, the stock of human capital in regions with above-average values would have reduced and the return to physical capital in these areas would therefore have been much lower. In contrast, the stock of human capital in below-average regions would have increased, as would the returns to physical capital. In other words, if the stock of human capital had been balanced across all of the regions considered, the returns to physical capital would have converged, which would have led to greater investment in this type of capital in regions with lower initial stocks.

We performed the same simulation to analyse the hypothetical scenarios in all regions using highest and lowest recorded values for the endowment of human capital. Thus, for a stock of human capital across all regions of 10.7 years (the value for Madrid, which would imply an average educational attainment across the population of completed secondary studies), the average returns to physical capital would have been 15.1%, with the regions with the lowest real stock showing the greatest increases. In contrast, for a stock of human capital of 8.4 years (the lowest value, recorded in Extremadura), the average returns to physical capital would have been only 3.9%, with the most developed regions showing the greatest decreases.

In summary, these figures confirm that increases in the endowment of human capital would attract greater investment in physical capital. In the case of a regional economy, this effect would stimulate further investment by existing local firms, attract new business from firms based in other regions, and counteract the trend to relocate towards economies with lower production costs.

[Insert Table 5 around here]

5. CONCLUSIONS

This paper provided novel empirical evidence of an indirect effect of educational attainment on regional economic growth, through its influence on the profitability of investment in physical capital. Empirical results support our hypothesis of a positive relationship between the level of educational attainment in a given region and the return to further investment in physical capital in that region. In fact, in the Spanish regions over the last few decades this effect seems to have been strong enough to have counterbalanced the traditional mechanism of decreasing returns to capital accumulation. It also accounts for the high degree of dispersion in the regional distribution of the return to physical capital.

These results have clear implications for regional growth and development. Firstly, human capital, in its capacity as a stimulus of the optimal stock of physical capital in a region, contributes to sustained growth, since investment in physical capital is a key element *per se* and, as argued in the literature, it encourages technical innovation. Secondly, the increase in the return to investment in physical capital stimulated by improvements in the educational attainment of workers in a region should not only stimulate further investment by firms already based in the region but also prevent these firms from relocating to economies with lower labour costs and even improve the capacity of these areas to attract new businesses. In short, human capital endowment could be considered a form of regional insurance against the increasing effects of globalisation.

We focused our research on the effect of regional human capital endowment on the return to investment in physical capital. It can be reasonably argued that a similar relationship could be expected between physical capital and the aggregate regional return to education. Some recent contributions to the literature indirectly support this assumption (e.g. López-Bazo and Moreno, 2007; López-Rodríguez et al., 2007). In fact, it is feasible that the optimal stock of both types of capital will be determined simultaneously within each regional economy, although we consider that the adjustment from observed to optimal stock is faster in the case of physical capital than human capital, which ensures that there is no serious simultaneity problem in our estimates. In any case, future research should be carried out to analyse the sensitivity of regional returns to education to the existing stock of physical capital.

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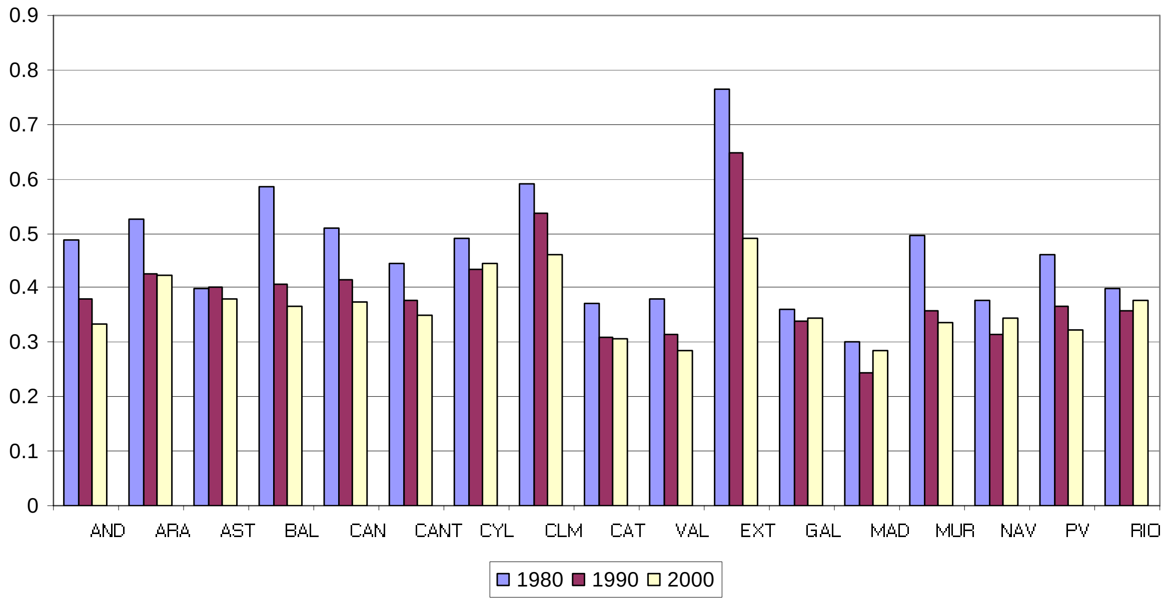
Figure 1. Ratio K/HL in the Spanish regions



Note: Andalusia (AND), Aragon (ARA), Asturias (AST), Balearic Islands (BAL), Canary Islands (CAN), Cantabria (CNT), Castile-Leon (CL), Castile-La Mancha (CM), Catalonia (CAT), Valencia (VAL), Extremadura (EXT), Galicia (GAL), Madrid (MAD), Murcia (MUR), Navarre (NAV), Basc Country (PV), La Rioja (RIO).

Figure 2. Relationship between returns to physical capital and K/HL

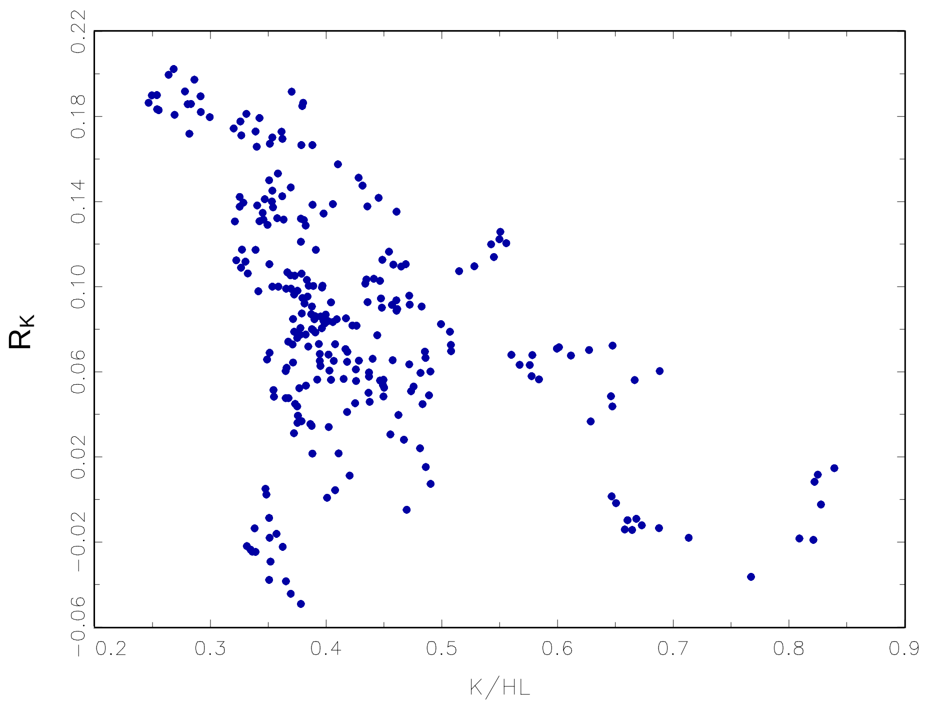


Table 1 . Stock of physical and human capital in the Spanish regions. Averages 1980-2000

	K/L	H	K/HL
ANDALUSIA	98.6	92.6	103.7
ARAGON	123.1	102.7	117.7
ASTURIAS	104.4	98.7	104.2
BALEARIC ISLANDS	117.7	101.8	112.1
CANARY ISLANDS	106.8	96.2	107.9
CANTABRIA	110.6	104.7	103.9
CASTILE—LEON	116.7	96.0	119.8
CASTILE—LA MANCHA	125.7	89.3	138.3
CATALONIA	97.5	110.4	86.3
VALENCIA	87.5	100.5	85.0
EXTREMADURA	146.5	85.3	168.9
GALICIA	79.3	85.3	91.5
MADRID	86.9	121.2	70.7
MURCIA	95.7	93.6	99.2
NAVARRE	100.1	109.8	89.6
BASC COUNTRY	112.4	113.8	96.9
LA RIOJA	97.0	98.2	97.2
Value for SPAIN	2.725[(1)]	7.102	0.39[(2)]

Note: the values for the regions correspond to their percentage with respect to the value in Spain. (1) In millions of pesetas per worker (2) In millions of pesetas per total years of schooling.

Table 2. Estimates of the partial static equilibrium model

	(i)		(ii)	
	Dependent var. : $\ln(VC/P_M)$, S_L, S_Y		Dependent var.: $-S_K$	
Coefficient	**Estimate**	**t-Ratio**	**Estimate**	**t-Ratio**
β_0	-3.835	-7.446	0.061	0.905
β_L	0.300	4.59		
β_Y	-0.219	-2.467		
β_K	1.544	15.289		
β_H	2.636	6.685		
β_T	-0.105	-8.003		
β_{LL}	0.094	14.457		
β_{YY}	-0.022	-3.74		
β_{KK}	-0.056	-7.712	-0.054	-10.435
β_{HH}	-0.992	-9.032		
β_{TT}	-0.001	-5.788		
β_{LY}	-0.137	-15.211		
β_{LK}	0.161	19.669	-0.055	-3.823
β_{LH}	-0.118	-5.573		
β_{LT}	0.000	-0.436		
β_{YK}	0.066	5.995	0.111	9.100
β_{YH}	0.615	22.057		
β_{YT}	-0.015	-15.698		
β_{KH}	-0.623	-16.691	-0.136	-5.579
β_{KT}	0.016	13.173	0.005	5.839
β_{HT}	0.061	8.679		
$D_1\beta_L$	0.003	0.449		
$D_1\beta_Y$	-0.037	-4.302		
$D_1\beta_K$	0.038	4.214		
$D_2\beta_L$	0.023	3.711		
$D_2\beta_Y$	0.039	4.433		
$D_2\beta_K$	-0.041	-4.512		
D_1			0.003	0.357
D_2			0.008	1.171

R^2 of Cost function (Eq 11)	0.998	
R^2 of Labor share (Eq 12)	0.683	
R^2 of Capital share (Eq 13)	0.304	
R^2 of Price = Marginal Cost Equation (Eq 14)	0.710	
# observations (N=17; T=21)	357	
# iterations	22	
LR Test of SUR $-\chi^2(6)$ –	115.6	p-val: 0.000
Wald Test:		
Significance of regional dummies $-\chi^2(8)$ –	65.4	p-val: 0.000
Significance of human capital $-\chi^2(7)$ –	847.1	p-val: 0.000
Shankerman & Nadiri Test $-\chi^2(27)$ –	729.9	p-val: 0.000

Note: SUR estimation of equations 11, 12, 13 and 14 as in the main text. The restrictions between the parameters of equation 11 and those of equations 12 and 14 are imposed (column i), whereas equation 13 is estimated in the SUR model without imposing restrictions between parameters (column ii).

Table 3. Returns to physical capital in Spanish regions

	1980	1985	1990	1995	2000	Average 1980-2000
ANDALUSIA	2.8%	4.8%	6.7%	8.6%	10.1%	6.7%
ARAGON	10.0%	11.4%	8.5%	9.1%	8.8%	9.4%
ASTURIAS	5.2%	5.8%	3.6%	3.3%	4.3%	4.1%
BALEARIC ISLANDS	9.6%	10.4%	9.9%	9.8%	11.1%	9.9%
CANARY ISLANDS	5.6%	6.8%	7.1%	9.2%	7.9%	7.5%
CANTABRIA	9.4%	9.1%	10.1%	8.1%	6.4%	8.3%
CASTILE—LEON	5.1%	7.0%	5.4%	4.8%	5.2%	5.3%
CASTILE—LA MANCHA	2.3%	6.0%	5.7%	5.9%	8.1%	5.6%
CATALONIA	14.6%	17.2%	15.0%	15.0%	15.2%	15.1%
VALENCIA	5.1%	9.3%	9.9%	11.7%	14.5%	9.7%
EXTREMADURA	-1.0%	1.6%	-1.3%	1.0%	4.3%	1.0%
GALICIA	-4.0%	-0.6%	-3.3%	-3.2%	2.0%	-2.1%
MADRID	16.5%	18.3%	16.3%	16.0%	16.6%	16.6%
MURCIA	-0.7%	2.5%	4.3%	5.9%	8.9%	4.5%
NAVARRE	11.2%	12.3%	13.1%	13.8%	12.0%	12.1%
BASC COUNTRY	13.2%	14.7%	13.6%	12.1%	11.5%	12.8%
LA RIOJA	0.3%	2.9%	3.9%	3.6%	2.6%	2.7%
Average	6.2%	8.2%	7.6%	7.9%	8.8%	7.6%

Table 4. Semielasticity of human capital to the optimal stock of physical capital

	1980	1985	1990	1995	2000	Average 1980-2000
ANDALUSIA	66.6%	23.2%	13.7%	12.3%	20.0%	28.6%
ARAGON	48.3%	17.0%	11.9%	11.3%	19.8%	22.6%
ASTURIAS	89.1%	28.1%	13.6%	12.8%	23.0%	35.4%
BALEARIC ISLANDS	41.5%	14.8%	10.2%	9.8%	17.8%	19.4%
CANARY ISLANDS	52.4%	17.6%	11.1%	9.8%	18.0%	22.7%
CANTABRIA	56.9%	20.1%	11.7%	12.0%	22.6%	25.6%
CASTILE—LEON	60.9%	19.8%	12.3%	12.4%	20.9%	26.4%
CASTILE—LA MANCHA	60.2%	18.3%	10.7%	10.7%	17.2%	25.0%
CATALONIA	56.7%	16.4%	12.1%	11.3%	20.0%	24.2%
VALENCIA	69.7%	20.4%	12.8%	11.4%	18.2%	28.1%
EXTREMADURA	48.8%	17.1%	10.4%	9.7%	16.9%	21.4%
GALICIA	91.3%	30.7%	18.2%	16.6%	24.8%	38.5%
MADRID	52.7%	16.7%	12.0%	10.6%	18.2%	22.9%
MURCIA	69.3%	22.4%	14.2%	12.8%	18.9%	29.1%
NAVARRE	62.7%	21.4%	13.0%	11.6%	20.7%	27.5%
BASC COUNTRY	57.1%	16.8%	10.4%	10.8%	20.7%	24.2%
LA RIOJA	82.6%	31.3%	16.3%	16.1%	25.1%	36.6%
Average	62.8%	20.7%	12.6%	11.9%	20.2%	27.0%

Table 5. Simulated return to physical capital for various levels of human capital in year 2000

	Actual H	Average H	Max H	Min H
ANDALUSIA	10.1%	12.7%	18.5%	8.0%
ARAGON	8.8%	8.4%	14.6%	3.3%
ASTURIAS	4.3%	4.8%	11.5%	-0.7%
BALEARIC ISLANDS	11.1%	10.7%	16.5%	5.9%
CANARY ISLANDS	7.9%	11.9%	17.6%	7.2%
CANTABRIA	6.4%	5.1%	11.7%	-0.3%
CASTILE—LEON	5.2%	7.2%	13.7%	1.9%
CASTILE—LA MANCHA	8.1%	11.6%	17.3%	6.9%
CATALONIA	15.2%	12.3%	18.1%	7.4%
VALENCIA	14.5%	11.7%	17.6%	6.9%
EXTREMADURA	4.3%	9.2%	15.1%	4.3%
GALICIA	2.0%	6.6%	13.2%	1.2%
MADRID	16.6%	10.6%	16.6%	5.6%
MURCIA	8.9%	10.1%	16.0%	5.2%
NAVARRE	12.0%	9.3%	15.3%	4.3%
BASC COUNTRY	11.5%	7.4%	13.8%	2.0%
LA RIOJA	2.6%	3.4%	10.1%	-2.2%
Average	8.7%	9.0%	15.1%	3.9%