Regional variability in the impact of human capital on regional growth

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Abstract: The first objective of this study is to furnish new evidence concerning the aggregate profitability of the accumulation of human capital. In addition to the traditional measure of the return to human capital, combining the information on its shadow price with the social cost of providing education allows us to confirm the profitability of human capital investments as a tool for promoting economic growth. The possibility of obtaining estimations of these effects for each Spanish region enables us to empirically evaluate the amount of heterogeneity across economies in the effects of human capital. As a second objective, we provide evidence on the indirect effect of human capital in making private capital investment more attractive. Among the main explanations for this process, we observe that higher worker skill levels enable higher returns to be extracted from investment in physical capital.

Keywords : Education, productivity, cost system, returns to capital

JEL Classification :J240, O180, O470, R110

1. INTRODUCTION

The effect that education can have on a society, as a mechanism that generates human capital, has meant that today the principal motivation underpinning human capital theory has been extended from simply accounting for wage differentials between individuals to that of explaining economic growth (Willis, 1986). The macroeconomic evidence presented to-date has been based on the analysis of the aggregate return to human capital, though no definite conclusions have yet been drawn. This evidence has been obtained through the application of a range of specifications centered on a primal approach - in other words, basing the analysis within a production function framework, despite the fact that this approach has given rise to considerable methodological difficulties, including the failure to consider the indirect effects of human capital in the estimate of its return.

Predictions of a range of theoretical models of economic growth (e.g. Lucas, 1988) has given rise to many empirical exercises linking aggregate productivity and growth with the endowment of human capital (e.g. Mankiw et al, 1992; Benhabib and Spiegel, 1994; Bils and Klenow, 2000; Krueger and Lindahl, 2001). Despite recent findings that lend support to a positive effect of human capital based on the use of what is more refined human capital data (de la Fuente and Doménech, 2006a), and to the link between economic performance and non-traditional measures of human capital such as the matching of educational supply and local labor market needs (Rodríguez-Pose and Vilalta-Bufí, 2005), the debate on the real contribution of human capital investments in promoting economic growth is by no means settled, and the evidence from an aggregate perspective on the effects of education on growth remains unclear (Temple, 2001).

Many studies have not only identified human capital as being a major factor in determining a significant part of the levels and growth rates of productivity and per capita income (Mankiw et al, 1992; Barro, 2001), but they have also identified human capital as being a key element in strengthening the effect of other factors considered essential for economic growth, such as investment in technology (Romer, 1990; Aghion and Howitt, 1998). As a result, recent contributions have stressed the role of human capital in explaining growth differences across countries (Krueger and Lindahl, 2001; Bassanini and Scarpetta, 2002; Engelbrecht, 2003) and across regions within countries (Cheshire and Magrini, 2000; Fingleton, 2004). It is of little surprise then that financing the accumulation of human capital in the least developed economies has been suggested as one of the main measures of development policy.

A possible approach to analyze the effect of human capital at the aggregate level —and one that is virtually unexplored— is the one based on the duality theory. Morrison and Siegel (1997) is, to the best of our knowledge, the only study to analyze some of the effects of human capital endowment on production activity by adopting this approach, in a more general context of the study of the effects of the accumulation of knowledge.[1] Yet, this study does not explore the possibility of obtaining an estimate of the return to human capital, or, for that matter, of any other measures of interest in the study of the effect of this capital. With the particular purpose of identifying the impact of the aggregate stock of human capital in the economy, we follow the idea in Morrison and Siegel (1997) that human capital, as an external factor, can cause downward shifts of cost curves, so that their effect on aggregate productivity can be examined through a cost-function approach. This agrees with the statement made by Griliches (1997) in which "*the main, and possibly the only, approach to testing the productivity of schooling directly is to include it as a separate variable in an estimated production function*" —or a cost function, its counterpart in the dual framework. It should then be noted that our approach differs from the one based on estimating human capital externalities from a Mincerian approach (see among others Rauch, 1993; Acemoglu and Angrist, 2001; Ciccone and Peri, 2006). The use of a cost function to analyse the effect of human capital must be understood therefore as parallel 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 lie on the same idea that a higher endowment of human capital in the economy may imply higher productivity growth. In the duality framework, this result implies that additional investment in human capital results in a downward shift in the aggregate cost function.

In this context, the first aim of this study is to show how the use of the duality framework provides with additional evidence concerning the contribution of human capital, acquired in the formal education system, to economic growth. In this sense, besides the traditional measure of its return, the dual framework also allows us obtaining the

[1] The use of the dual approach has been much more frequent in analyzing the effects of investments in infrastructure and public capital (e.g. Nadiri and Mamuneas, 1994; Morrison and Schwartz, 1996).

shadow price of human capital, defined as the price that the firms in the economy would have been willing to pay for an additional year of education of all the employees in the economy. Combining the information on the shadow price with the social cost of providing education in each economy allows us to confirm the profitability of human capital investments as a tool for promoting economic growth.

As far as we know this analysis has not been previously addressed in the literature, and it is possible to deal with it in our case due to the use of the dual approach and the availability of data on the public and private costs of a year of education in the formal educational system in each of the Spanish regions. We believe that the situation in Spain might be paradigmatic when it comes to evaluating the contribution of this type of factor to economic development and to the evolution of regional imbalances. This belief is based on various ideas including: i) the spectacular increase in the level of education in all of the Spanish regions, ii) the persistence of significant inter-regional differences in the level of education, iii) the opening of Spanish regions to competition, and iv) the modernization of the productive and institutional structures which, to a greater or lesser degree, has had an impact on all the regions of Spain.

We thus consider that the setting is ideal for assessing whether human capital can really promote economic growth, especially when this occurs in combination with other elements that might allow both individuals and economies to use this capital in productive activities for which they receive their corresponding return. Actually, we would expect the effect of human capital to be homogenous in all economies in the case that they were also homogenous in other aspects, such as in their productive structure, in their propensity to generate and adopt innovations and in their engagement in trade. Were this not the case, it is possible that the return to human capital would differ between economies, which means that an appraisal of its value as a tool for use in development policy would be particularly useful if information about the distribution of this effect across economies was available. Our empirical approach allows estimating the above-mentioned effect for each of the economies under analysis and, thus, assessing the particular contribution of human capital to economic growth in each of the economies. Thus, we also aim at providing evidence of the heterogeneous profitability of human capital in the Spanish regions.

Besides the direct effect of human capital on economic growth we believe human capital may have an indirect effect through the stimulation of private investment in physical capital. This is an issue which has not received much attention and, where it has, no clear conclusions have been reached. The second main objective of this study consists in providing further stimulating evidence on the issue. Specifically, apart from the analysis of the direct effect of human capital on output, we focus on checking whether the accumulation of human capital stimulates investment in physical capital. This being the case, we try to shed some light on the reasons behind such a relationship. In this sense, our prior assumption is that a higher worker skill level may enable a higher return to be earned from investment in physical capital. In other words, a high endowment of human capital in an economy makes it more attractive for firms to locate, especially for highly capitalised, productive activities which require a highly skilled workforce. We will test that hypothesis.

The rest of this study is organized as follows. In the second section we present the model based on the duality theory that includes the human capital stock as a factor that influences the technology of production in an economy, and describe the empirical specification from which the effects of human capital will be estimated. The third section describes the dataset and the major variables in the empirical analysis, paying special attention to the accumulation of human capital in the Spanish regions over the last decades. The results are reported in the fourth section and the fifth one concludes.

2. THEORETICAL AND EMPIRICAL FRAMEWORK

Consider a production function, where Y is the output and X_i (*i=1,...,r*) the *i*-th input:

$$Y = F(X_1,...,X_r) \tag{1}$$

It is assumed that a typical firm in the economy must accept a vector of input prices, $P_1,..,P_r$, so that the optimization problem consists in determining the amount of inputs that minimizes the cost of producing a given output, Y. Then, the level of optimal cost (C) —the solution to the optimization problem— yields a cost function that is dual to the production function, which is dependent on input prices, output and the technology implicit in the production function:

$$C = C(P_1,...,P_r, Y) \tag{2}$$

We assume that all factors of production can be adjusted within one time period so that the firm instantaneously determines long-run factor demands. As proposed in Brown and Christensen (1981), this can be defined as the full static equilibrium hypothesis (FSE) for production factors. Nevertheless, rather than assume that all inputs adjust instantaneously to their long-run equilibrium values, there are reasons to believe that certain factors do not follow an adjustment mechanism of this kind. These reasons might include price controls and regulations and institutional constraints that are above and beyond the influence of an individual firm in the short-run. The inputs that are in equilibrium are referred to as variable inputs, while those that are not are designated quasi-fixed inputs, a situation known as partial static equilibrium (PSE).

We consider here a framework that distinguishes between variable and quasi-fixed inputs, where the latter adjust only partially to their full equilibrium levels within one time period. This allows us to define a variable cost function which refers to a PSE situation in which the presence of certain inputs fixed at values other than their full equilibrium level implies that there are adjustment costs associated with changing the quasi-fixed factors. These inputs appear in the variable cost function through their amounts and not their prices. Let's define Z the vector of X inputs which are not in equilibrium, with a variable cost function with the following expression:

$$VC = VC\,(P_1,...P_s, Y, Z_1,...Z_m) \tag{3}$$

where $VC = \sum_{i=1}^{s} P_i X_i$ and s+m=r, where r is the total number of inputs. Whereas in the FSE, since all inputs are considered to be variable and the purpose of firms in the economy is to minimize total costs in (2), in a PSE situation the objective is to minimize the cost of variable inputs conditioned to a stock of quasi-fixed inputs and the level of output (Y).

Using both the full and the partial static equilibrium frameworks, cost functions have been widely used to analyze the substitution relationships between production factors. However, the particular purpose of this study is to allow the identification of the impact of the aggregate stock of human capital in the economy, the latter understood as an external factor, that is, one which is not explicitly under the control of the firm. Endogenous growth models emphasize the role of returns to capital that embodies new knowledge, this capital being understood as a general notion that also encompasses aspects of human capital, among others. As stated in Morrison and Siegel (1997) these knowledge factors are hypothesized to be external to the industry, so that the resulting effects on productivity are interpreted as evidence of spillovers which can be considered as efficiency factors. These underlying efficiency factors can cause downward shifts of cost curves, so that their effect on productivity can be examined through a cost-function approach. Although firms pay for the human capital embedded in their employees through their wages, they do not pay for the rest of human capital available in the economy, which is considered as an external environmental variable in our framework.[2]

Therefore, we focus our attention on an aggregate production function expanded with this type of capital. This aspect must be taken into account when obtaining the corresponding PSE model, which presents an associated aggregate variable cost function as follows:

$$VC = VC(P_L, P_M, Y, K, H) \tag{4}$$

where we consider two variable inputs, labor (L) and intermediates (M) which appear in the cost function through their prices, P_L and P_M respectively; a quasi-fixed input, physical capital, K; Y is output and H is human capital. In other words, economies of scale in a cost function are now outlined to include this new argument, so that variations in the human capital stock available in the economy can lead to shifts in cost curves.

Thus, the short-run cost function is the sum of the variable cost and the cost of the services provided by the existing capital:

$$SC = VC(\cdot) + P_K \cdot K \tag{5}$$

By applying Shephard’s lemma, the vector of the different variable inputs that minimize costs (cost-minimizing demands) is obtained:

$$X_i = X_i(P_L, P_M, Y, K, H) = \frac{\partial VC}{\partial P_i} \qquad i = L, M \tag{6}$$

Furthermore, we can calculate each factor share (S_i), that is, the percentage of the cost supposed by the *i*-th input:

$$S_i = \frac{P_i \cdot X_i}{VC} = \frac{\partial \ln VC}{\partial \ln P_i} = \frac{\partial VC}{\partial P_i}\frac{P_i}{VC} \qquad i = L, M \tag{7}$$

Equation set (4) and (7) constitutes the solution to what can be defined as the short-run

[2] Undoubtedly, using data on unskilled and skilled wages separately could also be interesting. The non availability of such information prevents us from doing so.

equilibrium related to variable factors, given the amount of Y, K and H.[3] In other words, the preceding functions, and consequently the short-run solution, are not independent of the stock of the quasi-fixed factor and human capital.

On the other hand, the long-run demand for the quasi-fixed factor is given by minimizing total short-run cost function in (5) with respect to K (the envelope condition):

$$\frac{\partial SC}{\partial K} = \frac{\partial VC}{\partial K} + P_K = 0$$

$$-P_K = \frac{\partial VC}{\partial K} \tag{8}$$

The fixed factor is at its static equilibrium level if and only if the cost savings it generates (shadow price) equal the market rental prices. Solving (8) for capital we obtain its equilibrium stock:

$$K^* = G(P_L, P_M, P_K, Y, H) \tag{9}$$

The optimal demand for K depends not only on its own price but on the prices of variable inputs, the level of output and the fixed quantity of human capital. Thus, equations (4), (6) —or (7)— and (9) characterize the long-run equilibrium.

By substituting (9) into (5) we obtain the long-run cost function, equivalent to that in the full static equilibrium:[4]

$$C = VC(P_L, P_M, Y, K^*, H) + P_K \cdot K^* = C(P_L, P_M, P_K, Y, H) \tag{10}$$

From the functions previously described, a set of measures in relation with the effects of human capital investments can be obtained, as will be shown in section 4.

The functional form chosen for the empirical work is based on a translog cost function, a general second degree polynomial in logs, with the following form:

[3] Either demand functions or factor share functions may be used. So, alternatively, we could talk about set (4) and (6).

[4] It is evident that the FSE can be understood as a specific case of the general model of partial equilibrium; a model in which the quasi-fixed inputs are to be found at all times in their equilibrium quantities.

$$\begin{aligned}
&\ln(VC/P_M) = \beta_0 + \beta_L \ln\frac{P_L}{P_M} + \beta_Y \ln Y + \beta_K \ln K + \beta_H \ln H + \beta_T t + \\
&0.5\left[\beta_{LL}\ln^2\frac{P_L}{P_M} + \beta_{YY}\ln^2 Y + \beta_{KK}\ln^2 K + \beta_{HH}\ln^2 H + \beta_{TT} t^2\right] \\
&+\beta_{LY}\ln\frac{P_L}{P_M}\ln Y + \beta_{LK}\ln\frac{P_L}{P_M}\ln K + \beta_{LH}\ln\frac{P_L}{P_M}\ln H + \beta_{LT}\ln\frac{P_L}{P_M}\, t \\
&+\beta_{YK}\ln Y \ln K + \beta_{YH}\ln Y \ln H + \beta_{YT}\ln Y\, t + \beta_{KH}\ln K \ln H + \beta_{KT}\ln K\, t + \beta_{HT}\ln H\, t
\end{aligned} \tag{11}$$

where t is a time trend which summarizes technological change. For ease of notation, variables in equation (11) onwards do not carry subscripts referring to the observations.

This functional form permits the consideration of a wide range of substitution possibilities and can be accommodated within any production technology without the need to impose a priori restrictions on returns to scale. Intermediate prices are included as a relative factor to ensure that the function is homogeneous of degree one in factor prices and symmetry conditions are imposed (Berndt, 1991). Besides, no kind of a priori returns to scale is imposed.

The share equations for variable inputs on variable costs are obtained through the differentiation of equation (11) with respect to variable input prices, $\partial VC(\cdot)/\partial P_i$, with i=L, M. For the two variable factors we consider here, only one equation is independent, given that factor shares sum to one. Thus, we have:

$$\begin{aligned}
&S_L \equiv \frac{P_L \cdot L}{VC} = \frac{\partial \ln VC}{\partial \ln P_L} = \beta_L + \beta_{LL}\ln\frac{P_L}{P_M} + \beta_{LY}\ln Y + \beta_{LK}\ln K + \beta_{LH}\ln H + \beta_{LT} t \\
&S_M \equiv 1 - S_L
\end{aligned} \tag{12}$$

On the other hand, if fixed inputs are in their long-run equilibrium condition, the following condition holds:

$$-S_K \equiv -\frac{P_K \cdot K}{VC} = \frac{\partial \ln VC}{\partial \ln K} = \beta_K + \beta_{KK}\ln K + \beta_{LK}\ln\frac{P_L}{P_M} + \beta_{YK}\ln Y + \beta_{KH}\ln H + \beta_{KT} t \tag{13}$$

In this situation, the marginal reduction in variable costs due to increases in capital equals this input price, $-\partial VC(\cdot)/\partial K = P_K$.

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

$$S_Y \equiv \frac{P_Y \cdot Y}{VC} = \frac{\partial \ln VC}{\partial \ln Y} = \beta_Y + \beta_{YY} \ln Y + \beta_{LY} \ln \frac{P_L}{P_M} + \beta_{YK} \ln K + \beta_{YH} \ln H + \beta_{YT}\, t \tag{14}$$

The set of expressions (11)-(14) would comprise the framework of the full static equilibrium. By contrast, using the model of partial static equilibrium, the parameters in (13) would not correspond with those in (11).

3. DATABASE

The spatial units considered here correspond to Spanish NUTS II regions[5] and the period analyzed runs from 1980 to 2000. Thus, as stated above we shall consider the influence of human capital in the private productive sector of the Spanish regions during a period in which there was a marked accumulation of education in all the regions, in conjunction with the modernization of the Spanish economy and its opening up to the exterior following integration into the European Union.

The measure used for human capital in this study combines the average number of years in each level of education with the percentage of the population in each of these levels, thereby producing an attractive synthetic indicator of human capital, like that of the average number of years of education of an economy. This type of indicator has been constructed for various samples of economies by, among others, Kyriacou (1991), Barro and Lee (1993, 1996, 2001), and has been used to analyze the contribution of this factor to growth in, for example, Benhabib and Spiegel (1994), Temple (1999), de la Fuente

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

and Doménech (2001, 2006a), del Barrio *et al* (2002).[6] The information required for constructing the indicator was drawn from Mas *et al* (2002).

We have information for five levels of education: no schooling, primary education, secondary education, first level of higher education, and second level of higher education. Given that this information is tabulated for, among other groups, the workers employed in each period, it is possible to obtain the percentage of workers for each of these levels of education, for the period 1964 to 2001. We have followed Serrano (1996) by designating 0 years to workers with no schooling, 3.5 years to the group with primary education studies, 11 years to those having completed secondary education, 16 years to those workers with a first level of higher education and 17 years to those with a second level of higher education.

Figure 1 illustrates the evolution in the education of the population engaged in the private productive sector of the Spanish economy as a whole. It clearly reveals the important growth in the level of education of the working population described above. The group of workers with no schooling virtually disappears and primary education —the preponderant level for much of this period for which data are available— is supplanted by secondary education. Although smaller in number, the increase in the percentage of workers with university studies is notable as well.

Correspondingly, the average years of schooling of workers in the private productive sector of the Spanish economy increased notably throughout the period (Figure 2). In particular, the increase during the period in which this study is focused was even more intense than in earlier periods. Thus, in two decades there was an increase of more than four years, reaching 9.32 years in 2000.

[6] Alternatives, such as the rate of schooling or the literacy rate have been subjected to considerable criticism due to their clear limitations when approximating an economy's human capital stock. They have, however, been used in several studies because of the impossibility of obtaining detailed information about the levels of education of the population.

Figure 1. Employment by education levels in Spain

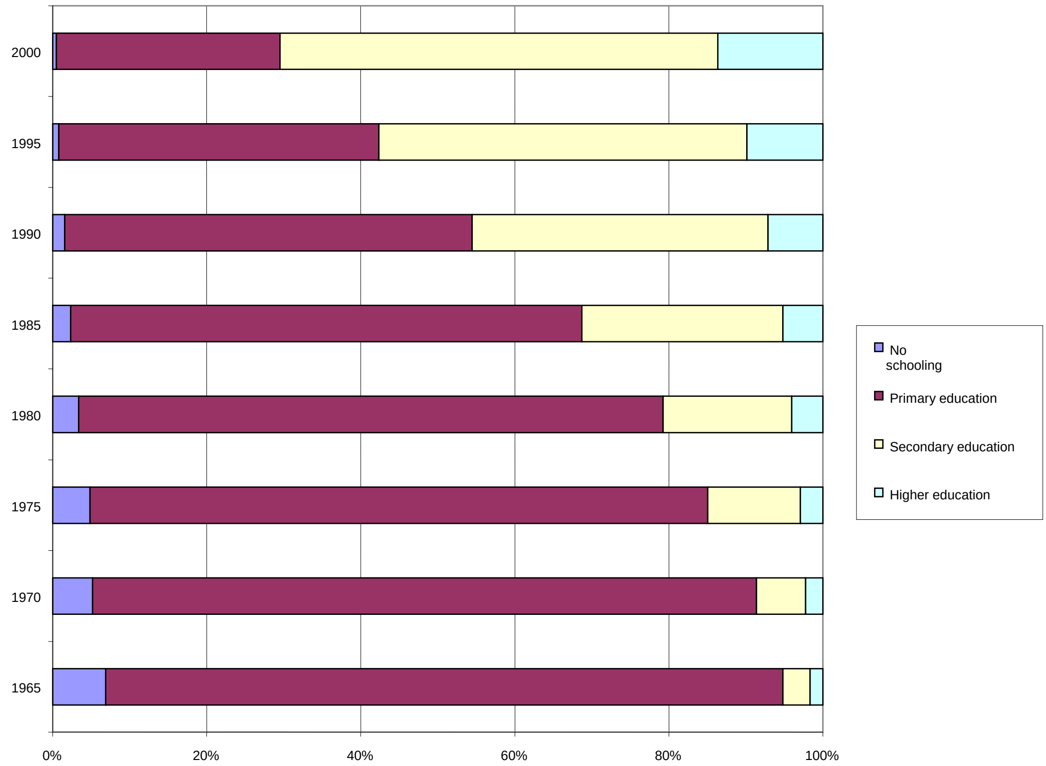
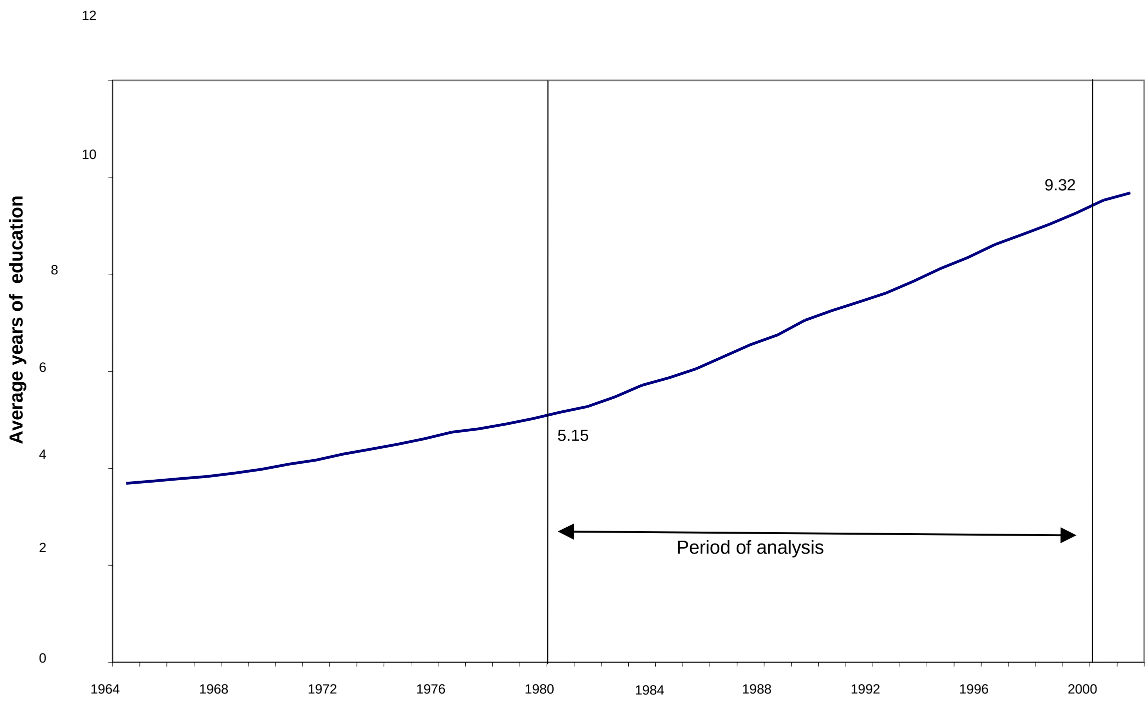
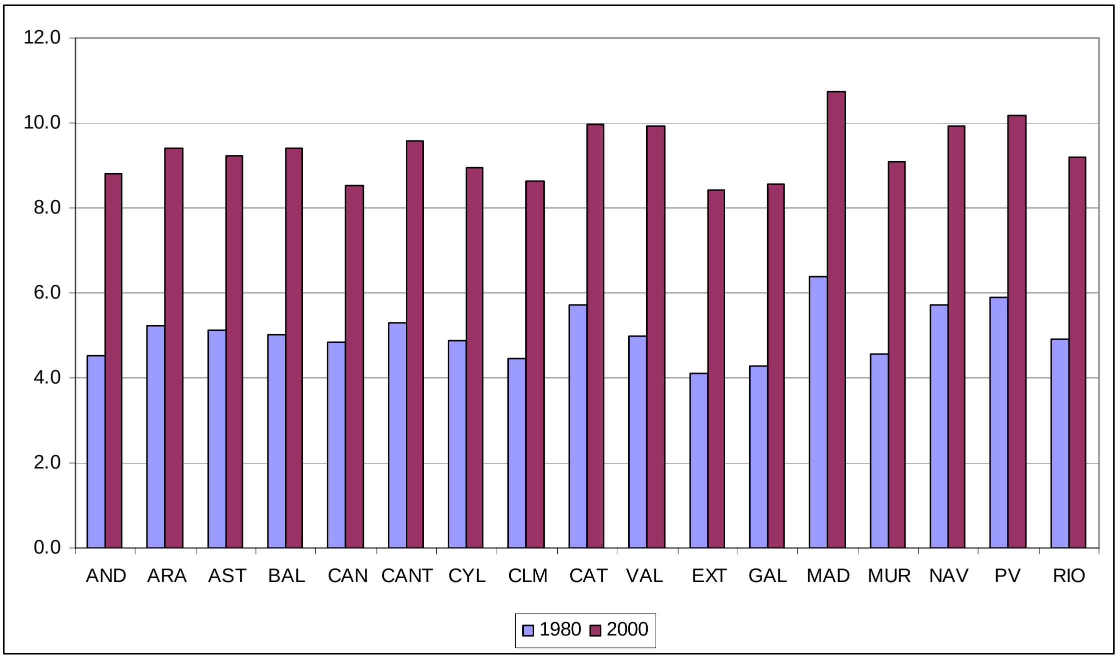


Figure 2. Evolution of the average years of education of employment in Spain



The results obtained for Spain as a whole are reproduced in the case of all the regions, although marked differences persist in the regional endowment of human capital education at the end of the period. Specifically, Figure 3 shows the average years of education of those employed in the private sector in 1980 and in 2000, i.e. the first and last years of the period analyzed in our subsequent study. It can be seen how, despite the convergence in the levels of human capital over the period, marked differences persist across regions. Thus, compared to 10.7 years in Madrid in 2000, Galicia and Extremadura do not reach 8.5 years.

Figure 3. Average years of education in the Spanish regions



Note: Andalucia (AND), Aragon (ARA), Asturias (AST), Baleares (BAL), Canarias (CAN), Cantabria (CNT), Castilla-Leon (CL), Castilla-La Mancha (CM), Catalunya (CAT), Valencia (VAL), Extremadura (EXT), Galicia (GAL), Madrid (MAD), Murcia (MUR), Navarra (NAV), Pais Vasco (PV), Rioja (RIO)

Therefore, the increase in the education stock in all the regions and the existence of marked variability among them should provide us with substantial information for comparing the effect that educational human capital has on aggregate productivity and economic growth which, as discussed above, will enable us to draw conclusions as to the aggregate return to investment in education.

The remaining statistical information has been taken from the BD.MORES database prepared by the Spanish Ministry of Economy and Finance (Dabán et al, 1998). Specifically, of the data provided by the BD.MORES database, we have used the series relating to Gross Added Value at factor prices, employment, wages, private physical capital stock and its cost. Similarly, the data referring to the intermediates are taken from Díaz (1998), so that the output variable chosen is the production value, which is obtained by summing intermediates to value added. The time period for all these series runs from 1980 to 2000.

Table 1. Time evolution of human and physical capital (Spain)

	H	K	K/H	Y/L	K/L
1980	5.06	22017847	255423	2.51	2.19
1981	5.18	22499966	255301	2.56	2.32
1982	5.38	22854075	249971	2.58	2.39
1983	5.59	23167361	243311	2.64	2.45
1984	5.74	23284175	237960	2.77	2.54
1985	5.91	23376304	231440	2.82	2.53
1986	6.16	23678050	225343	2.86	2.53
1987	6.42	24246605	221796	2.89	2.49
1988	6.62	25043141	221658	2.96	2.49
1989	6.90	26117319	221589	3.03	2.53
1990	7.12	27200248	224177	3.05	2.55
1991	7.32	28269177	227057	3.09	2.64
1992	7.51	29236942	228736	3.16	2.80
1993	7.73	29736355	225756	3.19	2.97
1994	7.98	30322707	222601	3.32	3.03
1995	8.18	31219910	222909	3.37	3.07
1996	8.45	32142264	221927	3.41	3.12
1997	8.64	33247770	224033	3.43	3.13
1998	8.86	34560969	227211	3.47	3.12
1999	9.08	36175191	231695	3.49	3.14
2000	9.32	38117427	237483	3.53	3.19
Annual growth [1]					
1980-1985	3.1%	1.2%	-1.9%	2.4%	2.8%
1986-1990	2.9%	2.8%	-0.1%	1.2%	0.1%
1991-1995	2.2%	2.0%	-0.3%	1.7%	3.1%
1996-2000	1.9%	3.4%	1.3%	0.6%	0.4%
1980-2000	3.1%	2.7%	-0.3%	1.7%	1.9%

(1) Annual accumulated growth rate. H refers to human capital stock measured as years of schooling. K is the monetary stock of physical capital, Y is output and L is number of workers.

Table 1 shows the evolution of some of the variables of interest. Physical capital (K) presents positive growth rates throughout the period under analysis, although the interesting point here is that it clearly shows pro-cyclical behaviour. Physical capital experienced slow growth in the period from 1980 to 1985, showed a strong expansion in the late eighties and underwent something of a slowdown in the early nineties that gave way to a growth period at the end of the century. On the contrary, although the educational level (average years of schooling of workers in the private productive sector of the Spanish economy) increased more than four years over the two decades, reaching 9.32 years in 2000, it is interesting to highlight that the growth rate decelerated with time, so that further accumulation of human capital is not expected to continue with the same strength. Specifically, the analysis of the ratio of the two magnitudes leads to the conclusion that the K/H ratio decreased over time with the exception of the last five years, where we observe a notable increment. This would point to the fact that human capital increased at higher rates than those of physical capital, except in the last five years when the reverse occurred. Labour productivity (Y/L) experienced increases throughout the whole period although at different growth rates, which decelerated especially at the end of the nineties. This evolution coincides in time with the capitalisation process of the Spanish economy, as shown by the K/L ratio.

4. RESULTS

4.1. Estimation of the coefficients of the cost system

For purposes of empirical implementation the models discussed in section 2 have to be embedded within a stochastic framework. In order to do this we consider errors in variable costs —eq. 11— and variable factor demands —eq. 12— as being due to errors in optimization in the short-run, while those for the equilibrium relationships (for physical capital —eq. 13— and output —eq. 14) represent unanticipated information that becomes available once the investment and output decision have been taken. To allow for separate elasticities across groups of regions we have included two dummy variables interacting with the linear terms of the variable factor prices, the stock of physical capital and output. Correspondingly, those dummies have been included as well in the factor share equations and in those for the equilibrium conditions of physical capital and output. The first of these dummies (D1) controls for the size of the regional economy, in terms of the share of its output over the one of the country. The second (D2) is included to account for the situation in some regions in which the ratio of physical to human capital was fairly low. The models specified both in the short and long-run are estimated using the iterative Zellner technique for seemingly unrelated regression equations, which converge to the maximum likelihood estimator for models of this type.

To choose the framework for use in computing the elasticities in the section above, we need to determine whether the observed levels of physical capital correspond with their long-term optimal levels. This will allow us to determine the type of framework (FSE or PSE) which best fits the sample under consideration, without any a priori decision as is usually the case in the literature. Therefore, the fixity assumption of K is explicitly tested by applying the test developed by Schankerman and Nadiri (1986).[7] The result of this contrast is shown in the lower panel of Table 2. The result is conclusive: for the sample of Spanish regions in the period between 1980 and 2000, the model that best captures the behaviour of the production technology of the private sector is that of partial static equilibrium. In other words, the assumption that capital stock in this sector adjusts at all times to the optimum in function of the existing production technology is clearly rejected. Consequently, we estimate the PSE model, that is, the set of equations (11)-(14) where the parameters in (13) would not correspond with those in (11) since the restrictions between them are not imposed. The results of the estimation are shown in Table 2. The restrictions between the parameters of equation 11 and those of equations 12 and 14 are imposed (column i, where we only give the estimates of equation 11 to avoid repetition), whereas equation 13 is estimated in the model without imposing restrictions between parameters (column ii). In addition, we show the results obtained from the likelihood-ratio test of the null hypothesis of which the matrix of covariances of the disturbance of the system of equations is diagonal - in other words, the contrast of the fit of the cost system as a model of apparently unrelated equations. The value obtained for the test statistic (115.6) lies clearly within the rejection zone of the null hypothesis, so that the Zellner estimation for the SURE-type estimation is adequate.

[7] In brief, the null hypothesis of long-run equilibrium is tested by applying a standard likelihood ratio test, which in essence compares the estimates from the specification that imposes the constraints in the coefficients across equations with those from the short-run equilibrium model that does not impose any restriction. The constrained estimator is consistent under the null but not under the alternative hypothesis, while the unconstrained estimator is consistent under both the null and the alternative.

It should be pointed out that it is unreasonable to undertake any kind of interpretation or structural analysis directly from the estimated parameters, given that we are using the translog approximation of the unknown functional form underlying the cost system. Similarly, it is worth stressing 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 coefficients of the terms that involve the dummy variables on the one hand, as well as all the variables that describe the effect of human capital, are together significant. Consequently, the Wald test confirms the existence of a significant effect of human capital on costs.

4.2. External returns to human capital

There are various measures easily derived from the estimation of the cost system defined in section 2 that allow us to quantify and evaluate the contribution of investments in human capital to economic growth. The first one is the change in production costs due to a marginal addition to the stock of human capital, the cost elasticity of human capital, defined as:

$$\varepsilon_{SC,H} \equiv \frac{\partial \ln SC}{\partial \ln H} = \frac{\partial SC}{\partial H}\frac{H}{SC} = \frac{\partial VC}{\partial H}\frac{H}{SC} \tag{15}$$

The elasticity in (15) is negative when additions to the stock of human capital save costs of production in a given economy. That is, when they contribute to improve productivity. In connection with the cost elasticity is the traditional elasticity of output to human capital usually obtained in growth studies analyzing the effects of human capital. This measure can be recovered from the dual approach thanks to the envelope theorem (see Chambers, 1988):

$$\varepsilon_{Y,H} = \frac{\partial \ln Y}{\partial \ln H} = \frac{-\dfrac{\partial VC}{\partial H}}{\dfrac{\partial SC}{\partial Y}}\frac{H}{Y} \tag{16}$$

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 SURE –$\chi^2(6)$ –			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: SURE 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 SURE model without imposing restrictions between parameters (column ii).

This relationship provides the connection between the primal (via the production function) and the dual (via the cost function) measurement of the productivity impact of capital stocks. However, in the case of human capital it is more intuitive to analyze the impact of an additional year of education on output. We can define the return to human capital as the increase in output given an increase of one year in the average level of education of the labor force. This semi-elasticity of output with respect to human capital is given by:

$$R_H \equiv \frac{\partial \ln Y}{\partial H} = \varepsilon_{Y,H} \frac{1}{H} \tag{17}$$

The cost elasticity in (15) and the return to human capital in (17) can be estimated for each economy and year by using the parameters estimated in the cost system and the corresponding values for the variables involved. Table 3 summarizes the results, providing the average for each region throughout the period considered and the global average for a representative Spanish region.[8] It can be seen in the first column that the improvements in the endowment of human capital gave rise to a saving in total production costs ($\varepsilon_{SC,H} < 0$), which is true in all the Spanish regions. This confirms that human capital contributed positively to the returns to scale of the private productive activity. Accordingly, the estimation of the returns to human capital is positive and of a sizeable magnitude in all the economies under analysis, with an average return slightly greater than 7%. In other words, for the mean of the period under consideration and in a typical Spanish region, an increase in one year in the average level of education of the labor force gave rise to an increase of 7% in output.[9] This result would therefore justify subsidies being made to the training of human capital, that is the education of individuals, as an effective tool of development policy given that the resources that are diverted for this purpose would be profitably spent, even in comparison with profitability levels of alternative investments.[10]

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[8] The set of effects for each of the regions in each of the years are available upon request.

[9] Although obtained with a different approach, the magnitude of our estimate for the aggregate return to human capital is of the same order of magnitude as that in De la Fuente and Doménech (2006b) for the Spanish economy, and close to the one obtained by Bassanini and Scarpetta (2002) in a sample of OECD countries.

[10] By way of example, estimations of the return on investments in public productive capital on the Spanish economy in a similar period stand at around 3% (e.g. 2.8% in Moreno et al, 2002, 2003, and 2.6% in Boscá et al, 2002).

Yet this global result hides an important regional heterogeneity. Indeed, the mean return to human capital over the period under analysis is very high in the cases of the regions of Aragon, Castilla-Leon, Castilla-La Mancha, Extremadura and Baleares. By contrast, in Galicia, La Rioja, Asturias, Murcia and Andalucía, the return on human capital was considerably lower. Note, for example, that the return in the region in which investments in human capital were most productive (Extremadura) almost doubled the regions with the lowest return (Galicia and La Rioja).

Table 3. Regional and time effects of human capital

	Cost elasticity of human capital ($\varepsilon_{SC,H}$)	**Return to human capital (R_H)**		**Cost elasticity of human capital ($\varepsilon_{SC,H}$)**	**Return to human capital (R_H)**
	(i)	**(ii)**		**(iii)**	**(iv)**
ANDALUCIA	-0.4492	6.6%	**1980**	-0.5515	10.0%
ARAGON	-0.6639	8.4%	**1981**	-0.5282	9.4%
ASTURIAS	-0.4769	6.5%	**1982**	-0.5415	9.1%
BALEARES	-0.653	8.2%	**1983**	-0.5593	9.0%
CANARIAS	-0.5691	7.8%	**1984**	-0.5147	8.0%
CANTABRIA	-0.639	7.8%	**1985**	-0.5078	7.6%
CAST -LEON	-0.5631	8.1%	**1986**	-0.539	7.9%
CAST– LA MANCHA	-0.5306	8.1%	**1987**	-0.5318	7.5%
CATALUNYA	-0.6779	7.7%	**1988**	-0.538	7.3%
VALENCIA	-0.5473	7.1%	**1989**	-0.5455	7.1%
EXTREMADURA	-0.5732	9.8%	**1990**	-0.5546	7.0%
GALICIA	-0.2984	5.0%	**1991**	-0.5663	7.0%
MADRID	-0.7741	7.6%	**1992**	-0.5784	7.0%
MURCIA	-0.4394	6.3%	**1993**	-0.6107	7.1%
NAVARRA	-0.6045	6.7%	**1994**	-0.6055	6.8%
PAIS VASCO	-0.7178	7.9%	**1995**	-0.587	6.4%
RIOJA	-0.3772	5.1%	**1996**	-0.6013	6.4%
			1997	-0.5983	6.2%
			1998	-0.5858	5.9%
			1999	-0.5771	5.7%
			2000	-0.5805	5.6%
Average for Spain	-0.562	7.3%			

The fact that the magnitude of this effect was far from homogenous throughout all the economies could suggest that the return could be related to the level of development attained by each regional economy as well as the existing endowment of human capital. In order to analyze these questions, Figures 4 and 5 show the relationship between the estimation of the return on human capital in each region and year, and its productivity and stock of human capital respectively. A trend is noted for the regions with the lowest levels of productivity to benefit most from the accumulation of this factor (Figure 4).[11] This result supports the idea that, in general terms, investments in education might be an effective tool in enhancing productivity in the less developed economies, and that the social or aggregate return to investments in human capital in those regions might even be larger than in the most productive ones. As expected, the estimated return is negatively related to the existing relative stock of human capital. This is derived from Figure 5 in which the estimated return for each region and year is related to the corresponding ratio of human to physical capital. The negative relationship confirms that the return was higher in those regions in which there was a shortage of human capital in relation to the stock of physical capital, and suggests that investments in human capital should be supported up to the level in which the ratio of human to physical capital is in its equilibrium.

[11] A similar trend is observed when the yearly average for each region is plotted against its average level of productivity over the period.

Figure 4. Returns to human capital with respect to the level of productivity (Y/L)

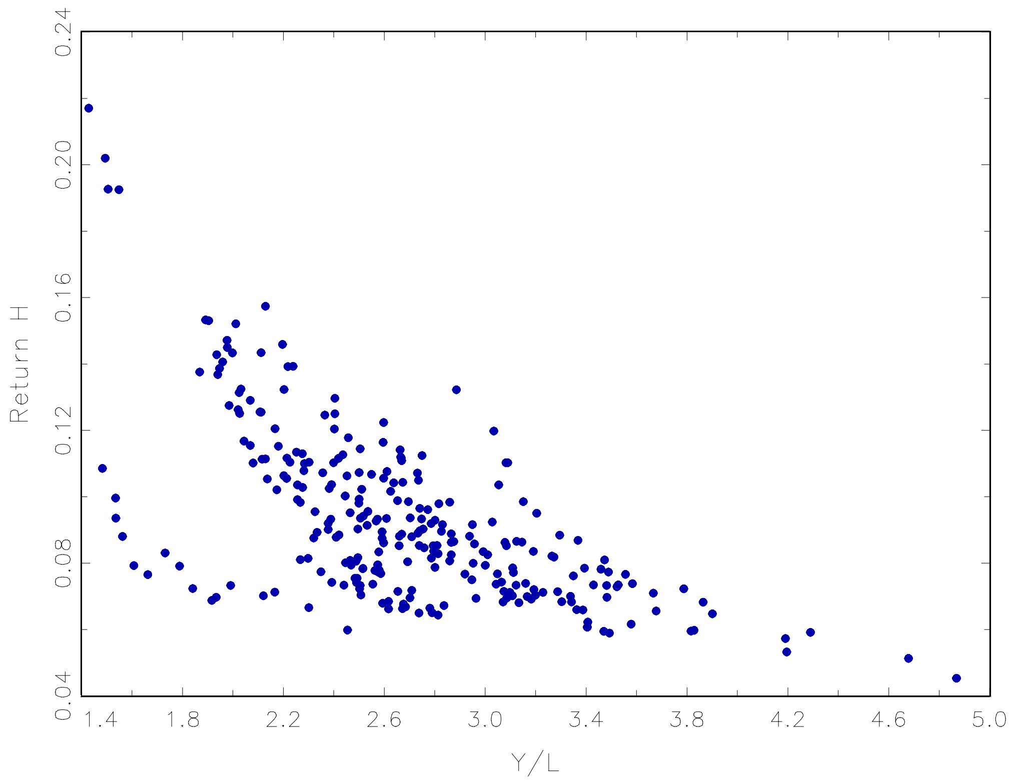
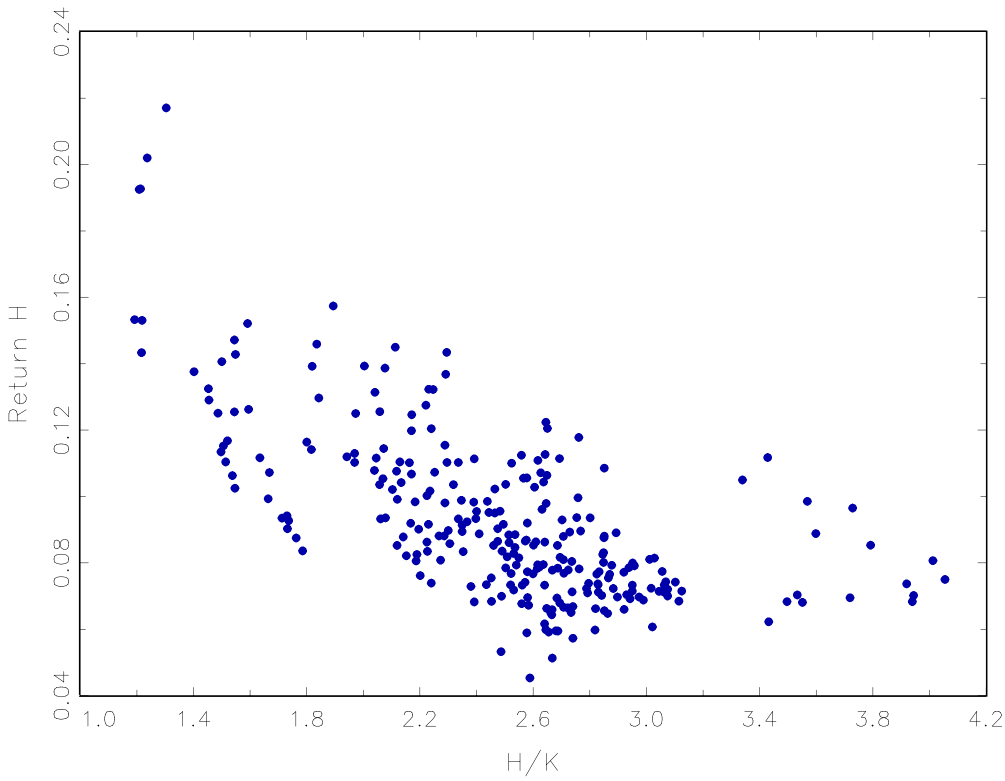


Figure 5. Relationship between returns to human capital and relative stocks of physical and human capital



4.3. Time profile of the returns to human capital

From the above results it can be deduced that, for the whole period under review, investments in human capital were on average profitable in all the Spanish regions, though their effect might have been stronger in those with low initial endowments of such type of capital and low levels of productivity. This evidence points to the presence of decreasing returns to the accumulation of educational human capital. Actually, under the assumption of diminishing returns for the accumulation of this capital, the continuous increase in its stock throughout the period and in all the regions, as described in Section 3 (Figures 2 and 3), could have brought about a decreasing trend in returns, which could even have led to the exhaustion of this resource as a factor that strengthens growth in the Spanish regional economies at the end of this period. In order to verify this, we have calculated the return for each region in each of the years under consideration and that corresponding to the average of all the Spanish regions. For reasons of space, Table 3 only provides information about the latter.[12]

As expected under the assumption of decreasing returns, the most notable feature in the results in the third and fourth columns of Table 3 is the large fall in the returns to human capital. Thus, at the end of the period these returns represented slightly more than 50% of those observed in 1980. However, the return of an extra year of education at the end of the period in a representative Spanish region maintained its importance (5.6%). But interestingly, at the end of the period, the return in some of the regions is rather low (4.3% in La Rioja, around 6% in Catalunya and Madrid) while in some others it remains large enough (6.8% in Extremadura) to strongly support additional investments.

Hence, it could be said that while human capital in the Spanish regions has played a significant role during the period analyzed, this significance has decreased over time in line with the continuous increase in its stock, and its importance is unlikely to persist with the same strength into the future. Thus, investments in human capital seemed to be a highly effective means of increasing productivity and, hence, promoting economic growth even in the mid-nineties. And considering the trend in returns and the current existing stocks, we predict that there is still room for significant returns to human capital investments, particularly in those regions with the smallest endowments.

[12] The same temporal profile was recorded in each of the Spanish regions. Results are available upon request.

4.4. The shadow price and the cost of provision of human capital

Results described so far point to positive aggregate returns to investments in educational human capital. However, to confirm the effectiveness of human capital as a tool for promoting economic growth it would be interesting to relate its effect on productivity, i.e. in saving production costs, with the social cost of provision of additional years of education of the labor force. As far as we know this analysis has not been previously addressed in the literature from an aggregate point of view, and it is possible to deal with it in our case due to the use of the dual approach and the availability of data on the public and private costs of a year of education in the formal educational system in each of the Spanish regions. In brief, we will state that investments in human capital will be socially profitable in a given region when its shadow price, that is the cost saving it causes to the productive sector of that region, exceeds the cost of provision of a year of education for the labor force in the region. We will firstly describe the way in which we compute the above mentioned measures, and then we will discuss the major results for our sample of regions.

If firms in the economy obtain cost reductions due to its aggregate stock of human capital, it can be considered that they will be willing to pay for it up to an amount equal to the savings in cost that this endowment implies. Hence, it is possible to obtain a measure of the implicit willingness of all firms in the economy to pay for human capital - that is, the *shadow price of human capital*:

$$Z_H \equiv -\frac{\partial VC}{\partial H} = \varepsilon_{VC,H}\left(-\frac{VC}{H}\right) \tag{18}$$

where $\varepsilon_{VC,H}$ denotes the elasticity of variable costs with respect to human capital ($\varepsilon_{VC,H} \equiv \frac{\partial \ln VC}{\partial \ln H} = \frac{\partial VC}{\partial H}\frac{H}{VC}$). The shadow price is defined as the reduction in variable costs due to an increase in the human capital stock. As long as this value is positive, human capital will maintain, to a greater or lesser extent, a net substitutability relationship with variable factors, so that investments in this type of capital will imply improvements in efficiency, the latter understood as net savings as a result of decreases in variable input utilization and thus in variable costs. For the sake of convenience we define the shadow price by worker as Z_H/L, where L is the number of workers.

To compare the shadow price of human capital investments with their cost we define a q-Tobin type of measure as $q_H \equiv Z_H/P_H$, where P_H is the cost of an additional year of education for the workers in the economy. Given that we are using the average years of schooling of the labor force as the measure of human capital, we are actually considering that workers accumulated it throughout the formal system of education. The cost of one year in the educational system financed by the government and the households is the measure used to proxy for P_H. Data for the cost of education comes from the report of Uriel et al (1997). It includes the cost per student in the public educational system in the NUTS II Spanish regions for the period 1980 to 1991. It is obtained by adding to the amount financed by different governmental agencies the expenditure made by households in connection with the education (fees, books, transportation, and so on). The cost in the private educational centers is available as well from the same source, but in this case we have decided not to use this information as it was obtained by an indirect estimation, and its quality is much lower than in the case of the public system, as stressed by the authors of the above-mentioned report. Anyway, the cost of the public system is higher for all regions and years, basically due to higher labor costs in the public versus the private centres.

The first column in Table 4 shows the estimates for the shadow price per worker, whereas the cost of one year of education is given in the second column, and finally the results for the q_H are in the third column. It should be noted that, to save space, these figures refer to the average over the period 1980 to 1991 in each of the regions. We find that on average over the period under analysis the firms on a representative Spanish region would have been willing to pay almost 3,000 € for an additional year of education of its labor force. This figure represents the savings in variable costs for an additional year of education. However, and as occurred with the return, we should highlight the significant regional variability in the shadow price of human capital (its standard deviation being greater than 541€). Thus, while Aragon, Cantabria, Pais Vasco and Extremadura exceeded 3,500 €, Galicia did not reach 2,000 €.

Table 4. Shadow price of human capital and its cost of provision (average 1980-1991)

	Shadow price per worker (Z_H/L) (i)	Relative cost of education (P_H) (ii)	q_H—Ratio (iii)
ANDALUCIA	2295	875	2.62
ARAGON	3677	1154	3.19
ASTURIAS	2936	1069	2.75
BALEARES	2965	980	3.02
CANARIAS	2549	1040	2.45
CANTABRIA	3573	1112	3.21
CAST -LEON	3132	1130	2.77
CAST– LA MANCHA	3240	923	3.51
CATALUNYA	3049	985	3.1
VALENCIA	2418	915	2.64
EXTREMADURA	3598	995	3.61
GALICIA	1757	967	1.82
MADRID	2806	1089	2.58
MURCIA	2329	927	2.51
NAVARRA	3149	1108	2.84
PAIS VASCO	3572	1183	3.02
RIOJA	2639	1010	2.61
Average for Spain	2923	1027	2.85

Note: Shadow price per worker (Z_H/L) and cost of education (P_H) are given in Euros. q_H—Ratio is a Tobin type measure obtained as the ratio of the shadow price of human capital and the cost of an additional year of education. The q_H—Ratio is obtained for each region and year and then averaged for the 1980-1991 period, so that it does not correspond to the quotient between the averages given in columns (i) and (ii).

However, figures in the second column of Table 4 show how the cost of education in the Spanish regions is far from homogeneous as well. For instance, the lowest cost is observed in the regions of Andalucia (875 €), Valencia (915 €), Castilla La Mancha (923 €) and Murcia (927€) with an 87% of the average cost in Spain, while the cost in some other regions is more than 10% over the national average, such as in Aragon (1154 €), Pais Vasco (1183 €) and Castilla-Leon (1130 €). This makes it necessary to relate the shadow price of human capital in each region to the cost for its provision. In accordance with the results in the previous sections, the value for the q_H-Tobin measure suggests that investments in educational human capital were very profitable in all the regions. On average, the shadow price almost triplicates the cost of the investment, which suggests that, from a social point of view, human capital was in a shortage over the period under analysis. Actually, regional estimates indicate that this was so in all the regions, although heterogeneity in both the shadow price and the cost of education causes important regional variation in the q_H measure. The largest profitability of investments was reached in the regions of Extremadura and Castilla La Mancha, which combined a high shadow price and a relatively low cost. Interestingly, the lowest profitability was reached in Galicia.

Summing up, investments in human capital, made through the formal system of education, not only contributed to enhance productivity growth in Spain but were also socially profitable, in the sense that the social return they provided were clearly superior to their cost. But this general result should not hide another important feature, that is the existence of noticeable heterogeneity across economies in the aggregate return and social profitability of human capital. Such heterogeneity should be considered when supporting and financing education as a tool for development policy.

4.5. The impact of human capital on physical capital

Bearing in mind that the second main objective is to analyse the extent to which human capital exerts a stimulus on investment in physical capital, we define the semi-elasticity of the optimum demand of physical capital with respect to human capital as follows:

$$\text{Semi} - \varepsilon_{K^*H} \equiv \frac{\partial \ln K^*}{\partial H} = \varepsilon_{K^*H}\frac{1}{H} = -\beta_{KH}\frac{1}{S_K H} \tag{19}$$

This measure indicates the percentage change in the stock of optimum physical capital with respect to a one-year increase in the average education level. In Table 5 we observe that this semi-elasticity is positive in all cases, indicating that human capital seems to have stimulated the stock of physical capital. In addition, the impact is quite significant since, in average terms over the period, an additional year of education meant an increase of around 19% in the optimal stock of capital. The effect, which was more significant at the beginning of the eighties,[13] stabilised at levels near 13% from the second part of the decade. However, the influence of human capital on the optimal amount of physical capital presents an important regional variability. The highest values of the

[13] In fact, the elasticity in 1980 is too high to be credible. This is due to the high value of the price of physical capital given the extremely high interest rates reported in that year in Spain.

semi-elasticity are obtained in the cases of La Rioja, Galicia, Asturias and Murcia, where an additional year of schooling increases the optimal amount of physical capital more than 20%. On the contrary, Extremadura and Baleares offer the lowest values for this elasticity. The same applies to regions with higher development levels but very heterogeneous in their production structures such as Cataluña, Madrid and País Vasco, and low developed regions such as Canarias, Cantabria and Castilla La Mancha.

We now turn to the analysis of the likely reasons that could explain why increases in human capital stimulated investment in physical capital. One possible explanation could be that the improvement in workers' skills would have enabled a higher return from investment in physical capital. In this way, the accumulation of human capital could have offset the neoclassical mechanism of decreasing returns to additional investment in physical capital. The returns to physical capital, defined as its product elasticity, can be calculated similarly to (16), i.e., as the percentage variation in the output as a result of varying the stock of physical capital by 1%:

$$R_K = \varepsilon_{Y,K} \equiv \frac{\partial \ln Y}{\partial \ln K} = \frac{-\dfrac{\partial VC}{\partial K}}{\dfrac{\partial SC}{\partial Y}} \frac{K}{Y} \tag{20}$$

Table 5. Physical capital elascitity of human capital and the return to physical capital

	Physical capital elasticity of human capital (Semi-$\varepsilon_{K^*,H}$)	Return to physical capital (R_K)		Physical capital elasticity of human capital (Semi-$\varepsilon_{K^*,H}$)	Return to physical capital (R_K)
ANDALUCIA	20.2%	6.7%	**1980**	62.8%	6.2%
ARAGON	16.7%	9.4%	**1981**	33.6%	6.6%
ASTURIAS	23.5%	4.1%	**1982**	25.1%	7.5%
BALEARES	14.6%	9.9%	**1983**	26.6%	8.2%
CANARIAS	16.5%	7.5%	**1984**	18.4%	8.2%
CANTABRIA	18.5%	8.3%	**1985**	20.7%	8.2%
CAST -LEON	19.0%	5.3%	**1986**	17.2%	7.2%
CAST– LA MANCHA	17.2%	5.6%	**1987**	13.8%	7.2%
CATALUNYA	17.4%	15.1%	**1988**	16.2%	7.3%
VALENCIA	19.5%	9.7%	**1989**	13.8%	7.7%
EXTREMADURA	15.0%	1.0%	**1990**	12.6%	7.6%
GALICIA	27.2%	2.1%	**1991**	12.6%	7.3%
MADRID	16.8%	16.6%	**1992**	12.1%	6.9%
MURCIA	20.6%	4.5%	**1993**	13.5%	7.2%
NAVARRA	19.8%	12.1%	**1994**	13.5%	7.5%
PAIS VASCO	16.9%	12.8%	**1995**	11.9%	7.9%
RIOJA	26.0%	2.7%	**1996**	12.3%	8.1%
			1997	14.3%	8.2%
			1998	14.9%	7.9%
			1999	15.7%	7.9%
			2000	20.2%	8.8%
Average for Spain	19.1%	7.6%			

According to the results for the returns to physical capital over time (fourth column in Table 5), although not monotonic in nature, we observe an increase in returns in the period (around two points between 1980 and 2000). This is true even after taking into account the constant increase of the factor in the Spanish economy. Thus, the decreasing returns mechanism seems not to be working in the accumulation of physical capital (at least not in net terms). That is, a high endowment of human capital in an economy would make it more attractive for existing firms to continue investing in physical capital and for new firms to locate, given the higher returns they can obtain, especially for high value-added activities which require skilled workers.

All in all, investments in physical capital in Spanish regions presented important profitability levels once discounted the cost associated to this factor. But the magnitude of this effect was far from homogenous throughout all the regions (second column in Table 5). It is interesting to highlight that the regions with the highest returns are precisely those with the lowest ratios of physical to human capital. This would confirm the idea that the regions with low endowments of physical capital in relation to those of human capital obtain higher returns of additional investments in physical capital.

In order to assess the impact of education on the returns to physical capital, we have simulated what would have happened if the stock of human capital had increased at a different pace so that the stock at the end of the period would have been different, all other economic variables being equal. The real figures for the Spanish economy in 2000 show an average number of years of education of 9.3, which enabled returns to physical capital of 8.8% in that year. However, as shown in Table 6, if the growth rate of education in the given period had been lower than the actual one, the returns to physical capital would have also been lower. For instance, with an average stock of human capital in 2000 of 8 years of education, the returns to physical capital would have amounted to 0.9%, or in the case of rising to 8.5 years of education, the returns would have been 4.2%. By contrast, if the growth rate of human capital had been higher, the returns to physical capital would have also been higher. Specifically, for an average stock of human capital of 10 years of education, physical capital returns would have been 12.1%, whereas in the case of an average of the population having completed secondary education (11 years of education), the returns would add up to 16.6%. According to these figures, if the Spanish economy had not made a substantial investment in enhancing educational levels, lower worker skill levels would have led to lower returns from investments in physical capital.

Table 6. Simulated return to physical capital according to different levels of human capital in year 2000

	Average years of education in Spain in 2000						
	8	**8.5**	**9**	**9.3**	**10**	**10.5**	**11**
Simulated R_K	0.9%	4.2%	7.3%	8.8%	12.1%	14.2%	16.6%

To provide additional evidence on the regional 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. As stated above, 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 7, 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. 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.

Table 7. Simulated return to physical capital for various levels of human capital in year 2000

	Actual H	Average H	Max H	Min H
ANDALUCIA	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%
BALEARES	11.1%	10.7%	16.5%	5.9%
CANARIAS	7.9%	11.9%	17.6%	7.2%
CANTABRIA	6.4%	5.1%	11.7%	-0.3%
CAST -LEON	5.2%	7.2%	13.7%	1.9%
CAST– LA MANCHA	8.1%	11.6%	17.3%	6.9%
CATALUNYA	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%
NAVARRA	12.0%	9.3%	15.3%	4.3%
PAIS VASCO	11.5%	7.4%	13.8%	2.0%
RIOJA	2.6%	3.4%	10.1%	-2.2%
Average R_K	8.7%	9.0%	15.1%	3.9%

5. CONCLUSIONS

This study provides a new insight in the analysis of the impact of human capital on economic growth through the use of the duality framework to give evidence concerning the aggregate profitability of the accumulation of human capital. We have described an analytical strategy based on the framework supplied by the duality theory so that not only some of the limitations of the approach based on the estimation of a production function can be overcome but it also allows us to compute the shadow price of human capital. Combining the information on the shadow price with the social cost of providing education in each economy allows us to assess the profitability of human capital investments as a tool for promoting economic growth. From a purely economic perspective, the identification of a positive effect would justify the use of public resources for financing education. Similarly, our results should enable us to assess the use of education as a tool in economic development policy.

We have shown that the return to human capital in Spain was positive throughout the period studied. And this aggregate return is obtained to be superior to the cost of the investments in human capital, made through the formal system of education. This finding would justify the subsidizing of human capital through financing the education of individuals, given that the resources devoted to this purpose would prove profitable. We can affirm, therefore, that it is socially justifiable to dedicate resources to the financing of the accumulation of human capital given that it results in increases in productivity and, consequently, in greater economic growth.

However, our results confirm that the magnitude of the effect of human capital is far from homogenous across economies, even in the case of regions within a country. Relating this effect to the level of development attained by each regional economy as well as the existing endowment of human capital, a trend is observed for the economies with the lowest levels of productivity to benefit most from the accumulation of this factor. Similarly, the negative relationship of the return with the existing stock of human capital suggests that no conflict was caused when using the stimulus for investment in education in the less developed regions as a development policy measure, given that the objectives of efficiency and equity are simultaneously met. Thus, such heterogeneity in the aggregate return and social profitability of human capital should be considered when supporting and financing education as a tool for development policy.

Positive and non-negligible aggregate returns to human capital in the Spanish economy in the last few decades support a direct effect of worker education on aggregate productivity. But in addition, we have also detected a significant indirect effect through the stimulation of private investment in physical capital. From our results, we can conclude that the stock of human capital available in the economy exerts a beneficial effect on returns to physical capital, in such a way that it might well offset the traditional mechanism of decreasing returns. Therefore, improvements in the endowment of human capital in an economy would make investment in physical capital more attractive in such an economy.

The evidence reported in this study reveals that, on average for the last two decades, each additional year in the level of workers' schooling caused a 19% increase in the optimum stock of physical capital in the Spanish economy. Accordingly, we have also shown that returns to physical capital would have been much lower had the endowment of human capital increased at a slower pace. The implications of these results are then obvious. Human capital accumulation in Spain must have stimulated investments in existing firms, and helped improve its ability to attract new business and fight against the process of delocalisation towards economies with lower costs of production.

The *lessons* obtained from the Spanish case can be useful for the design of development and competitiveness policies in other economies. They also support public policies aimed at promoting improvements in human capital endowment, given that individuals are not aware of the indirect effect that their investment in education might have on aggregate productivity, through induced additional investment in physical capital. In the absence of such policies, there is likely to be underinvestment in human capital.

Whatever the case, there are a number of aspects arising from this study which need to be analyzed in greater detail in future studies. First, one could obtain measures of the profitability of investment at different levels of education. Here, we have considered the shadow price as being homogenous for all levels of education; however, it would be interesting to check whether the effects may differ significantly from one level to another. On the other hand, as we have not included the opportunity cost of school attendance (foregone wages), our measure of the cost of education might be underestimating the real price of educational human capital investments. It might be of interest to include this opportunity cost as well as to consider some other elements linked to the level of education that have not been taken into account in the present analysis such as the change in the probability of being employed and the increase in taxes associated to higher wages. Undoubtedly, they might have a role when measuring the aggregate profitability of educational investments.

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