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A translog production function for the Spanish provinces: Impact of the human and physical capital in economic growth

M. del P. Pablo-Romero *, M. de la P. Gómez-Calero [1]

Department of Economic Analysis and Political Economy, Avda. Ramon y Cajal, 1 Seville University, E-41018 Seville, Spain

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ABSTRACT

A translog production function and an extended translog production function with third-order terms are estimated for the 50 Spanish provinces in the period 1985–2006. The results show the existence of complementarity relationships between private physical and human capital. Likewise, they show the existence of decreasing returns of private physical and human capital. However, the direction of the decreasing returns of private physical capital is reversed for a high endowment level of this factor. These results suggest the importance of capitalizing the Spanish economy, since it would increase the effect of human capital upon productivity and may also generate positive externalities.

1. Introduction

The effects of human capital on productivity have been analyzed extensively since Lucas (1988), Romer (1990) and Mankiw et al. (1992) revisited the works of Schultz (1960) and Becker (1964). These studies show that human capital has a positive effect on economic growth. However, as these effects differ according to the geographical areas considered, there is renewed interest in analyzing the role of human capital on the productivity of a given territory. These works have considered the possible presence of external economies related to the local human capital stock (Acemoglu and Angrist, 2001; Adsera, 2000; Almond, 1997; Rauch, 1993; Rudd, 2000).

According to Sanromá and Ramos (2007), two explanations have been given. The first is based on the presence of capital external economies associated with local human capital. The development of a new economic geography and, in particular, the economy of cities, considers that cities are places where human capital can generate externalities. Individuals with a high level of education interact among themselves sharing and exchanging knowledge, with the final effect of improving the productivity of the territory. Glaeser and Mare (2001) provided evidence supporting the view that workers learn more quickly in metropolitan areas. In this sense, Glaeser and Resseger (2010) point out that high levels of human capital and city size interact to advance the frontier of knowledge and the level of productivity. Nevertheless, Sanromá and Ramos (2007) consider that this effect might only be intense in small geographical areas or even at industrial plant level.

The second explanation is associated with the relationships of complementarity between various productive factors and, in particular, between human and physical capital. Somehow, the greatest levels of human capital attract the technological and private physical capital, making regions prosper. The greatest human capital endowment favors the generation and absorption of technology making the rate of technological change faster (Acemoglu, 1998, 2003; Benhabib and Spiegel, 1994, 2005; Caselli and Coleman, 2006; De La Fuente and Da Rocha, 1996; Glaeser and Resseger, 2010; Nelson and Phelps, 1966) and if the technological change is linked to intensive investment in new private physical capital with a qualified workforce, then a positive relationship is generated between human capital and that private physical capital. In turn, the new technologies increase the productivity of workers with higher qualification, making this phenomenon more intensive (Ciccone and Papaioannou, 2009).

Thus, the complementarity of these factors, which was first highlighted in Griliches (1969), may be understood as the high endowments of human capital giving a boost to the investments in certain types of private physical capital, making them attractive, counteracting the production decrements related to the endowment increment of this factor, and allowing the accumulation of private physical capital in regions with high levels of it (López-Bazo and

* Corresponding author. Tel.: +34 954 55 7611; fax: +34 954 55 76 29.
E-mail addresses: mpablorom@us.es (M.P. Pablo-Romero), mdepalma@us.es (M.P. Gómez-Calero).
[1] Tel.: +34 954 55 6164; fax: +34 954 55 76 29.

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Moreno, 2008). Likewise, it may be assumed that the greatest levels of that private physical capital will induce the growth of human capital productivity while if the level of the private physical capital is low, the effectiveness of human capital will also be low, yielding low human-capital elasticity in the empirical estimates of the growth regressions (Barro, 1991; Krueger and Lindahl, 2001; Sianesi and Van Reenen, 2003).

The relation between private physical and human capital therefore becomes a critical determinant of the degree to which these factors affect the productivity in different territories. This could lead to a virtuous or vicious cycle that may cause a region to remain under a certain situation for a long time compared to other regions. The growth of regions is not determined so much by the endowments of factors as by the relations between the productive factors and their externalities, which cause the differences of growths between them (Klenow and Rodríguez-Clare, 2005; Mamuneas et al., 2006). In this sense, as stated in Durlauf et al. (2008), the linear growth model, with constant parameters, may be misspecified, which leads to the need for establishing a non-linear model which allows adjustment of the elasticity of factor productivity with time and geography to be considered. In this sense, using semiparametric techniques, Mamuneas et al. (2006) show that the elasticity of human capital vary significantly throughout countries and time, and it also differs according to the existent level of human capital. Likewise, Kalaitzidakis et al. (2001) highlight that there are non-linear relations within the relations between growth and human capital that cannot be detected with linear models.

The aim of this study, using a non-linear model, is to analyze how the relations between physical and human capital, and the factors endowments, affect the degree of impact of each factor on the productivity growth in the Spanish provinces. To do this, an aggregate translog production function is estimated for the Spanish provinces for the period 1985 to 2006. According to Ostbye (2010), the translog function is more convenient than the CES (constant elasticity of substitution) function, because the former is more flexible as it allows the substitution elasticity to vary along with capital intensity. The output elasticities of the productive factors, which vary throughout provinces and time, are calculated from the estimated parameters. These parameters allow an interpretation in terms of the possible complementarity or substitutability between factors, and whether or not there are increasing or decreasing returns to scale of the considered factors.

However, the translog function may not be flexible enough to observe the changes in productivity elasticities of the different types of capital, since with the usual translog function, the elasticity varies with changes in factor endowments. According to Ostbye (2010), it is possible to make the translog function more flexible by adding third-order terms. These, which were used previously, for instance, in studies that analyze the existence of the environmental Kuznet's curve and the relations between energy and economic growth (Luzzati and Orsini, 2009), permit analysis of whether there are differences in the elasticities for different levels of factors endowments and therefore allowing to check if there are increasing, decreasing or constant returns to scale of each factor for each level of that factor. Thus, another aim of this paper is to estimate this extended translog function and, from it, to analyze the variation of the elasticities according to the level of factor endowments reached in the Spanish provinces within the time period considered. This involves analyzing the non-linear relations present in the economic growth and the possible changes in the yield of productive factors by using parametric techniques, instead of the semiparametric techniques previously mentioned.

With this aim, the paper is organized as follows. In Section 2 the translog production function to be estimated is described, as well as the extended function with third-order terms. In Section 3 the statistical information sources used are specified. In Section 4 the results of the estimations of the translog production function and the extended function of all Spanish provinces are presented; the values of the elasticities calculated from these estimations are shown; and there is a discussion of the main results obtained. The results show a clear differentiation of production elasticities between provinces and the presence of complementarity relations between the private physical capital and human capital. Likewise, the results show that the returns of the private physical capital decrease up to a certain level of the per capita private physical capital, above which they reverse direction. Finally, the main conclusions of this paper are given in Section 5.

2. The translog production function and an extended version

The translog production function is a flexible production function, which is obtained by a second-order approximation using Taylor series (Christensen et al., 1973). For the case of four factors and expressing the variables in terms of Napierian logarithms, this function may be written as follows:

$$\begin{aligned} Y_{it} = {} & A_{it} + \beta_l L_{it} + \beta_k K_{it} + \beta_h h_{it} + \beta_p P_{it} + \beta_{kl} K_{it} L_{it} + \beta_{kh} K_{it} h_{it} \\ & + \beta_{kp} K_{it} P_{it} + \beta_{hl} h_{it} L_{it} + \beta_{hp} h_{it} P_{it} + \beta_{lp} L_{it} P_{it} + {}_{1/2}\beta_{kk} K_{it}{}^2 \\ & + {}_{1/2}\beta_{hh} h_{it}{}^2 + {}_{1/2}\beta_{pp} P_{it}{}^2 + {}_{1/2}\beta_{ll} L_{it}{}^2. \end{aligned} \tag{1}$$

where,

Y	gross value added (hereafter *GVA*)
A	exogenous variable that includes other determinant factors of the production
H	human capital indicator
K	private physical capital stock
P	public physical capital stock
L	employed population
I	1, 2, … 50, for the fifty Spanish provinces
T	time in years from 1985 to 2006

$\beta_{k,}$ $\beta_{h,}$ β_p, $\beta_{kh,}$ $\beta_{kp,}$ $\beta_{hp,}$ $\beta_{kk,}$ $\beta_{hh,}$ β_{pp} are the function parameters to be estimated in order to find the elasticities.

Under the assumption that the production function shows constant returns to scale (CRS) within the private and public physical capital and the employment, given the human capital, the function takes the following form, expressed in terms of output per employee, where it is denoted Y, K and P in lower-case letters to show they are per employee values.

$$\begin{aligned} y_{it} = {} & A_{it} + \beta_k k_{it} + \beta_h h_{it} + \beta_p p_{it} + \beta_{kh} k_{it} h_{it} + \beta_{kp} k_{it} p_{it} + \beta_{hp} h_{it} p_{it} \\ & + 1/2\beta_{kk} k_{it}{}^2 + 1/2\beta_{hh} h_{it}{}^2 + 1/2\beta_{pp} p_{it}{}^2. \end{aligned} \tag{2}$$

With the aim of estimating this function properly, the data were converted to deviations from the geometric mean of the sample. Using italics to indicate these deviations, it is possible to rewrite [2], as follows,

$$\begin{aligned} \mathit{y}_{it} = {} & \mathit{A}_{it} + \beta_k \mathit{k}_{it} + \beta_h \mathit{h}_{it} + \beta_p \mathit{p}_{it} + \beta_{kh} \mathit{k}_{it} \mathit{h}_{it} + \beta_{kp} \mathit{k}_{it} \mathit{p}_{it} + \beta_{hp} \mathit{k}_{it} \mathit{p}_{it} \\ & + 1/2\beta_{kk} \mathit{k}_{it}{}^2 + 1/2\beta_{hh} \mathit{h}_{it}{}^2 + 1/2\beta_{pp} \mathit{p}_{it}{}^2. \end{aligned} \tag{3}$$

Likewise, the function was converted to first differences. Using Δ to indicate this, it is possible to rewrite [3] according to De La Fuente (2008), as follows,

$$\begin{aligned} \Delta y_{it} = {} & \Delta A_{it} + \beta_k \Delta k_{it} + \beta_h \Delta h_{it} + \beta_p \Delta p_{it} + \beta_{kh} \Delta k_{it} h_{it} + \beta_{kp} \Delta k_{it} p_{it} \\ & + \beta_{hp} \Delta k_{it} p_{it} + 1/2\beta_{kk} \Delta k_{it}{}^2 + 1/2\beta_{hh} \Delta h_{it}{}^2 + 1/2\beta_{pp} \Delta p_{it}{}^2. \end{aligned} \tag{4}$$

where Δ indicates the change of a variable or the increment in the product of two variables; for instance, $\Delta k_{it} h_{it}$ applies to the change in value of $k_{it} h_{it}$.

Likewise, the evolution of the technological progress is considered to be the sum of a common temporal fixed effect for all the provinces (δ_t) and a technological catch-up term that is proportional to the technological gap between each territory and the province of Madrid (denoted by the subscript M). Thus

$$\Delta A_{it} = \delta_t - l(y_{it} - y_{Mt}) \tag{5}$$

where λ is a parameter to be estimated.

Substituting [5] in [4], Eq. (6) to be estimated is obtained, in which a control variable has been included (ep) that expresses the secondary sector participation in the *GVA* represents the possible effect of the different productive structure of the provinces.

$$\begin{aligned}\Delta y_{it} = {} & \delta_t - \lambda(y_{it} - y_{Mt}) + \beta_k \Delta k_{it} + \beta_h \Delta h_{it} + \beta_p \Delta p_{it} + \beta_{kh} \Delta k_{it} h_{it} \\ & + \beta_{kp} \Delta k_{it} p_{it} + \beta_{hp} \Delta k_{it} p_{it} + 1/2 \beta_{kk} \Delta k_{it}^2 + 1/2 \beta_{hh} \Delta h_{it}^2 \\ & + 1/2 \beta_{pp} \Delta p_{it}^2 + \beta_e ep_{it}.\end{aligned} \tag{6}$$

The parameters in Eqs. (3) and (6) are estimated empirically through panel data techniques using Stata 11. Positive values of the coefficients of terms with cross-products of the variables indicate there is complementarity between the corresponding productive factors, while negative values of those coefficients indicate there is substitutability between them. The coefficients of the quadratic terms characterize the returns to scale. If the factors show decreasing returns to scale, the sign of these coefficients will be negative.

From the estimation of parameters of these equations, it is possible to find the output elasticities of the different factors for each province and year, as follows:

$$\begin{aligned} EKt_{it} & = \beta_k + \beta_{kh} h_{it} + \beta_{kp} p_{it} + \beta_{kk} k_{it} \\ EPt_{it=} & \beta_p + \beta_{hp} h_{it} + \beta_{kp} k_{it} + \beta_{pp} p_{it} \\ Eht_{it=} & \beta_h + \beta_{kh} k_{it} + \beta_{hp} p_{it} + \beta_{hh} h_{it} \end{aligned} \tag{7}$$

where EKt_{it}, EPt_{it} and Eht_{it} are the elasticities of the private physical capital, public physical capital and human capital, respectively.

Likewise, given the assumed constant returns to scale in the private, public and employment capital, and given the level of human capital, the employment elasticity may be found as follows:

$$EL_{it} = 1 - EKt_{it} - EPt_{it}. \tag{8}$$

It should be clear that the elasticities derived from the translog function are neither constant over time nor between provinces (as in Cobb–Douglas), but they depend on the factor endowments existent at each moment and for each province. Thus, the differences in growths in provinces are explained not only by the different endowment of factors that may exist between them, but also by the different output elasticities of the productive factors they show.

The translog function estimated above has the disadvantage that the output elasticities of each factor vary in a constant manner when its endowment increments, if everything else stays constant. Therefore, *ceteris paribus*, if there are constant, decreasing or increasing returns to scale around the central point, this remains the same for any level of factor endowment, without varying those returns with the level.

It is possible to provide this production function with greater flexibility by adding third-order terms to the translog function, as proposed in Ostbye (2010) This production function may be approximated through a Taylor series of third order. If we convert the data again to deviations from the geometric mean and to first differences, and if we consider likewise that the evolution of the technological progress is expressed according to [6], the extended translog production function may be expressed as follows:

$$\begin{aligned}\Delta y_{it} = {} & \delta_t - \lambda(y_{it} - y_{Mt}) + \beta_k \Delta k_{it} + \beta_h \Delta h_i + \beta_p \Delta p_{it} + \beta_{kh} \Delta k_{it} h_{it} \\ & + \beta_{kp} \Delta k_{it} p_{it} + \beta_{hp} \Delta k_{it} p_{it} + 1/2 \beta_{kk} \Delta k_{it}^2 + 1/2 \beta_{hh} \Delta h_{it}^2 \\ & + 1/2 \beta_{pp} \Delta p_{it}^2 + \beta_{khp} \Delta k_{it} h_{it} p_{it} + \beta_{khh} \Delta k_{it} h_{it}^2 + \beta_{hhp} \Delta h_{it}^2 p_{it} \\ & + \beta_{kkh} \Delta k_{it}^2 h_{it} + \beta_{kkp} \Delta k_{it}^2 p_{it} + \beta_{kpp} \Delta k_{it} p_{it}^2 + \beta_{hpp} \Delta h_{it} p_{it}^2 \\ & + 1/3 \beta_{kkk} \Delta k_{it}^3 + 1/3 \beta_{hhh} \Delta h_{it}^3 + 1/3 \beta_{ppp} \Delta p_{it}^3 + \beta_e ep_{it.}\end{aligned} \tag{9}$$

Now the output elasticities of the different factors for each province and year, are found as follows:

$$\begin{aligned} EKtextended_{it} = {} & \beta_k + \beta_{kh} h_{it} + \beta_{kp} p_{it} + \beta_{kk} k_{it} + \beta_{khp} h_{it} p_{it} \\ & + 2\beta_{kkh} k_{it} h_{it} + 2\beta_{kkp} k_{it} p_{it} + \beta_{khh} h_{it}^2 \\ & + \beta_{kpp} p_{it}^2 + \beta_{kkk} k_{it}^2 \\ EPtextended_{it} = {} & \beta_p + \beta_{hp} h_{it} + \beta_{kp} k_{it} + \beta_{pp} p_{it} + \beta_{khp} k_{it} h_{it} \\ & + 2\beta_{hpp} h_{it} p_{it} + 2\beta_{kpp} k_{it} p_{it} + \beta_{kkp} k_{it}^2 \\ & + \beta_{hhp} h_{it}^2 + \beta_{ppp} p_{it}^2 \\ Ehtextended_{it} = {} & \beta_h + \beta_{kh} k_{it} + \beta_{hp} p_{it} + \beta_{hh} h_{it} + \beta_{khp} k_{it} p_{it} \\ & + 2\beta_{hhp} h_{it} p_{it} + 2\beta_{khh} k_{it} h_{it} + \beta_{hpp} p_{it}^2 \\ & + \beta_{kkh} k_{it}^2 + \beta_{hhh} h_{it}^2. \end{aligned} \tag{10}$$

The fact that the productivity elasticities now depend on terms related to the squared value of the factors endowments implies, *ceteris paribus*, that the productivity elasticity of a certain factor do not vary in a constant manner for endowment increments but changes in a different manner according to the endowment level reached by that factor. Thus, it may happen that beyond a certain endowment level, the variation of elasticity reverses its sign, indicating that the returns have now been modified. Analyzing the sign of the elasticity shows whether there are differences in the elasticities for different levels of factor endowments and, therefore, whether there are increasing, decreasing or constant returns of each factor for each level of the factors. That is to say, it may tell us about the possibility that there may be thresholds, beyond which the productive factors may generate positive externalities.

3. Statistical information used

3.1. Gross value added (GVA)

From the homogenous series of the *GVA* at a provincial level to the cost of the factors expressed in millions of common Pesetas from 1985 to 1999 and from the series expressed at basic prices in millions of common Euros from 1995 to 2008 from Alcaide and Alcaide (2000, 2009) and from Alcaide et al. (2004), a new linked series has been obtained for the *GVA* at basic prices for the years 1985 to 2006, expressed in millions of constant Euros of 2000.

3.2. Private and public physical capital stock

The information about these two explanatory variables comes from the new estimations of the stock and the capital services for the Spanish economy given in Mas et al. (2009) available for the period from 1964 to 2006. The provincial data of the actual productive capital stock expressed in thousands of constant Euros of 2000 for the period studied, converted to millions of Euros from that year, were used for both the private and public physical capital.

The data of public physical capital were collected according to their total valuation considering the expenditure functions in *Other constructions* such as various infrastructures for water supply, railways, airports, ports, and urban infrastructure of municipalities. For private physical capital, the private expenditure functions were considered, which are those of *Transport equipment*, *Machinery*, *equipment material and other products*, and *Other products*, plus the rubric *Other constructions n. c. o. p.* which includes private investments.

3.3. Human capital

The frequently used synthetic indicators of human capital are the mean number of schooling years and the percentage of people who have a certain minimum level of education, which in Spain has been generally calculated from the provincial series of population of working age by educational level, as given in Mas et al. (2005).

Recently, Serrano and Soler (2008) have developed two new series of human capital: one in the form of the mean number of completed years of study and the other in terms of an indicator of human capital that combines salary information and personal characteristics, expressed in equivalent workers without training or experience.

The first series mentioned shows an indicator of human capital measured by the mean number of completed years of study. The second series introduces new elements that explain the human capital, e.g. experience, measuring the educational level in a substantially different way, as it incorporates the market value of capabilities acquired by the individuals. The human capital of a person is measured according to the number of "*equivalent workers*" that would be necessary to achieve the same productive capacity. This productive capacity is measured according to the person's educational level and experience.

So, the human capital of an individual is assessed as the number of individuals without human capital (uneducated man, aged less than twenty years) equivalent to the individual's level of education and experience. The relative wage between the different categories of individuals (offered by the E.E.S. 95) is the source of information used to establish that equivalence[2]. Thus, the human capital of a person is equal to that of an uneducated young male worker without studies and experience plus the human capital he/she has for his/her education, plus the human capital he/she has for his/her experience.

The human capital of a person may be expressed as $te_l = 1 + E_l + X_l$, where, te_l is the human capital (in *te*) of an employee; E_l is the human capital (in *te*) of that employee due to his/her education; and X_l is the human capital (in *te*) due to his/her experience.

By adding the human capital of all the employees of the province i, the expression becomes: $Te_i = L_i + \sum_{l=1}^{L_i} E_l + \sum_{l=1}^{L_i} X_l$. Where L_i is the total employed population of the province i and the index *l* refers to each employee of that province in a given period.

If $E(i)$ is defined as the education per employee in terms of equivalent workers in the province *i*, then $\sum_{l=1}^{L_i} E_l = L_i \times E(i)$. Equally, if $X(i)$ is the experience per employee in the province *i* in terms of equivalent workers, then $\sum_{l=1}^{L_i} X_l = L_i \times X(i)$. Thus, $Te_i = L_i + L_i \times E(i) + L_i \times X(i)$.

From the last expression, it is possible to separate the component Employment (L) from the concept of human capital measured in equivalent workers, by simply dividing the function by L. Thus, an index is obtained that shows the educational and experience level of the employed population as an approximation of the human capital. Analytically, the human capital index of the province *i* is expressed as follows:

$$h_i = Te_i / L_i = 1 + E(i) + X(i)$$

For the two series of human capital indicators offered currently by the IVIE (2011), this last procedure has been chosen for measuring the human capital. However, some estimations of this study were recalculated using the first indicator[3].

3.4. Employment

The data about employment come from the series on employees from the series of human capital of Serrano and Soler (2008) at a provincial level from 1964 to 2007, and expressed in thousands of people.

3.5. Descriptive analysis

Fig. 1 shows, from left to right and top to bottom, the evolution of GVA per employee, private and public physical capital stock per employee, and of the human capital indicator for each province (represented by a line of different color), from 1985 to 2006. The values are spread around the thick black line, which represents the average of the values for each year. The graph shows that GVA has a positive growth rate throughout the period, while appreciating the fact that large differences exist between provinces[4].

Private and public physical capital stock per employee also showed a positive growth rate throughout the period, but with a slightly higher rate until 1995. As stated in Perez (2011), during the last decade of the study, European countries suffered a process of slowing capital accumulation due to the decreased use of non-ICT (non Information and Communications Technologies). Spain was not immune to this process, although its decreased rate of capital accumulation was not as evident. The reduction of non-ICT was not as intense and also was offset by a significant increase in ICT (Information and Communications Technologies).

Finally, the indicator of human capital showed almost constant growth with significant differences evident between provinces throughout the period.

Table 1 shows the main descriptive statistics of the variables per employee and of the human capital indicator. The *overall* statistics refer to the whole sample, while the *within* statistics refer to each individual and to the variation from each individual's average. If a variable does not change over time, its *within* standard deviation will be zero. The *between* statistics refer to the standard deviation, and minimum and maximum of the averages for each individual. Table 1 shows that the typical standard deviation of the data is higher across provinces than across time for GVA and private physical capital stock per employee. It can also be seen that the typical standard deviation of the data is quite similar for public physical capital stock per employee and for the indicator of human capital.

Table 2 shows the correlations between these variables. It can be seen that all values are positive. Public capital has the lower values.

4. Results and discussion

The results of the estimation of the translog production function [3] and [6] and its extended version with third order terms [9] are shown in Tables 3 and 4. Likewise, additional estimations are shown in these Tables, with the aim of analyzing the results further.

[2] Thus, the human capital of an individual is equal to the quotient of the salary predicted for that individual, given his/her age (or experience) and educational level, divided by the salary of an uneducated twenty-year-old male. The salaries predicted are obtained from Mincer regressions, using the national data of the Encuesta de Estructura Salarial (Spanish Wage Structure Survey) of 1995 (INE, 2011).

[3] The series of average years of study based on the L.G.E. (Spanish Educational General Law) of 1970 are used in this study.

[4] Changes in the database of Alcaide and Alcaide (2009) in 1995 do not affect data evolution.

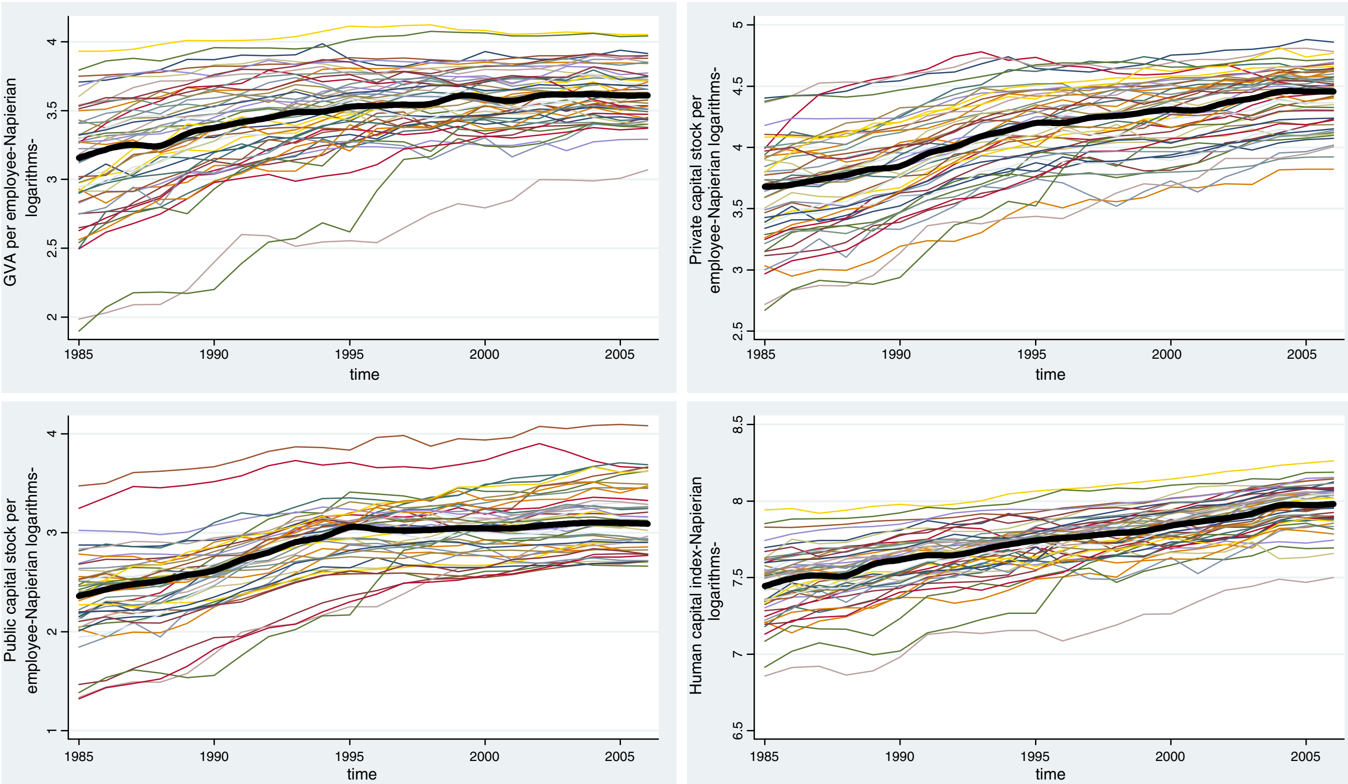

Fig. 1. GVA, private and public physical capital stock per employee and human capital indicator (Spanish provinces). The thick line represents the mean value in each period.

4.1. Translog function

Column (A) in Table 3 shows the results of estimating β_k in [3] by generalized least squares in the presence of heteroskedasticity, autocorrelation and contemporaneous correlation[5], without considering the cross and the squares products. Individual and time dummies are included. The estimated coefficients proved to be all significant, being, for the private physical capital 0.46, the human capital 0.23 and the public physical capital 0.18. Column (B) shows the results of the complete estimation of [3] by using the same procedure as for the previous estimations; but, as it can be seen, not all coefficients are significant. The terms of the cross products between public and private physical capital, and between human and public physical capital, are not significant. Thus, we cannot declare that there are complementarity or substitutability relations between the public physical capital and other productive factors. However, the parameter of the cross product between private physical and human capital, as well as the parameter of the square of private physical and human capital do prove to be significant, which implies that the estimation of a Cobb–Douglas function is not the most appropriate. Column (C) lists the reestimated parameters in [3] but removing those terms that do not prove to be significant. It should be noted that the parameter β_{kh} is positive, which indicates the existence of complementarity relations between human and private physical capital, thus validating the hypothesis in Griliches (1969). Likewise, it may be noted that the parameters of the squared terms have a negative sign, implying decreasing returns. Column (D) shows the estimations of the same function as in column (C) using techniques of instrumental variables in the presence of heteroskedasticity and autocorrelation, because the estimation of the model by generalized least squares is not consistent when the regressors are not exogenous. This suggests the need for modeling the non-exogenous variable as predetermined so that the estimation is unbiased. In order to handle this problem, parameters in [3] were estimated by the generalized method of moments, considering that human and public physical capitals are endogenous variables and taking as instruments the explanatory variables of human and public physical capital at values in first differences. Consistent estimations are obtained, according to the values of the tests performed.[6]

In this estimation, the coefficients β_k, β_h and $\beta_{P,}$ which represent the value of the elasticities of the private, human and public physical capital respectively at the central point of the sample, show values of 0.35, 0.29 and 0.13 respectively. These values are consistent with the values estimated in previous studies in which the elasticities are consistent throughout the years and between the individuals of the sample.

De La Fuente and Doménech (2006) performed a summary of the values shown by the coefficients of human capital in diverse estimations that use different specifications and databases of this factor and which have been developed within the last fifteen years by different researchers for the usual sample of countries in the OECD and the period 1960–1990. The average reported in De La Fuente and Doménech (2006) of the values of these coefficients is 0.348 by fixed-effects, somewhat higher than that obtained in this study. Thus, Mamuneas et al. (2006) states that the Spanish economy has elasticities that are lower compared to those in the other 51 countries within the sample considered in that study, with a value of 0.13, for the period 1971–1987. Meanwhile, Boscá et al. (2010) performed a review of the economic

[5] The null hypothesis of homoscedasticity is rejected according to the modified Wald test proposed in Greene (2000). The null hypothesis of absence of autocorrelation of the Wooldridge test (2002) is rejected and the hypothesis of cross-sectional independence is rejected in the test for the data in the panel proposed in Pesaran (2004).

[6] Underidentification test of Kleibergen-Paap rk (LM statistic = 134.629, P-val = 0.000), identification weakness of Kleibergen-Paap (Wald F statistic = 64.541) and Cragg–Donald (Wald F statistic = 80.150) with minor Stock–Yogo weak ID test critical values, and the Durbin–Wu–Hausman endogeneity test shows a Chi-sq(2) value of 4.436, with an added *pvalue* of 0.0352.

Table 1
Descriptive statistics.

Variable (Napierian logarithms)		Mean	Std. dev.	Min	Max	Observations
y (GVA per employee)	Overall	3.465477	0.335337	1.898249	4.122393	N = 1100
	Between		0.279899	2.593912	4.042522	i = 50
	Within		0.188692	2.578215	4.092556	t = 22
k (Private physical capital stock per employee)	Overall	4.088399	0.410356	2.669136	4.881124	N = 1100
	Between		0.311388	3.430208	4.65121	i = 50
	Within		0.270708	3.11422	4.797435	t = 22
h (Human capital index)	Overall	7.719564	0.233149	6.856845	8.262096	N = 1100
	Between		0.161916	7.170173	8.073437	i = 50
	Within		0.169241	7.218576	8.158485	t = 22
p (Public physical capital stock per employee)	Overall	2.849825	0.436282	1.322947	4.093447	N = 1100
	Between		0.317048	2.201571	3.849527	i = 50
	Within		0.302891	1.893557	3.588743	t = 22

literature which has considered the quantification of the macroeconomic effects of the public infrastructure. These authors state that there is a great gap in those results that tend to measure the contribution of the infrastructure to the growth. However, they consider that for the case of Spanish economy it may be assumed that a reasonable elasticity would be within the range of 0.5 to 10. Thus, the coefficients estimated through this procedure are within expectations.

Column (A) in Table 4 shows the results of estimating β_k in [6] by generalized least squares in the presence of heteroskedasticity, autocorrelation and contemporaneous correlation[7], without considering the cross products, the squares or the term of technological catch-up, although time dummies are included. The estimated coefficients proved to be all significant, being, for the private physical capital 0.53, the human capital 0.15 and the public physical capital 0.18. The coefficient estimated for the control variable is also significant and its value is 0.05. Column (B) shows the results of estimating the previous model, through the same procedure, but also including the technological catch-up, which also proves to be significant. The values of the estimated coefficients barely vary. Column (C) shows the results of the complete estimation of [6] by using the same procedure as for the previous estimations; but, as it can be seen, not all coefficients are significant. Again, the terms of the cross products between public and private physical capital, and between human and public physical capital, are not significant and the parameter of the cross product between private physical and human capital, of the square of private physical and of the square of human capital do prove to be significant. Column (D) lists the reestimated parameters in [6] but removing those terms that do not prove to be significant. All coefficients are significant this time. It should be noted that the parameter β_{kh} is positive and the parameters of the squared terms are negative, again. Column (E) shows the estimation of the same function as in column (D) by using an alternative human capital indicator, with the mean number of schooling years. The signs of all parameters are maintained, as well as their significance. However, the coefficient of human capital is lower than the previous one and the coefficients of the physical capital are somewhat higher. This variation in the value of these coefficients is consistent with the results obtained in previous studies (Pablo-Romero and Gómez-Calero, 2008). Column (F) shows the estimations of the same function as in column (D) using techniques of instrumental variables in the presence of heteroskedasticity and autocorrelation by the generalized method of moments, considering that human and public physical capitals are endogenous[8] variables and taking as instruments the explanatory variables of human and public physical capital at values delayed one and two periods[9].

In this estimation, the signs of the estimated parameters are equivalent to those obtained in the previous estimations. Now, the coefficients β_k, β_h and β_P show values of 0.44, 0.24 and 0.12 respectively.

No major differences in the values of coefficients, estimated by using fixed effects or first differences are evident. It can only be seen that β_k is slightly lower when estimated by fixed effects, while β_h is slightly higher. Nevertheless, in both cases complementarity relations are detected between human and private physical capital and similarly decreasing returns for them.

The elasticities for each province and year were calculated from the results in Table 3 column D and in Table 4 column F, according to [7]. Given that the cross products and the second-order term related to the public physical capital were omitted in both estimations, the elasticity of the productivity of this factor is constant. For the other factors considered, the elasticities vary with time and between provinces, and their values depend not only on the endowments of the respective factors, but also on the endowment of the complementary factor. The evolution of the elasticities is very similar when the results in Table 3 or 4 are used. Only slight changes are apparent in the values of the center point of the sample. We show here the elasticity of the private physical and human capital when it is calculated according to:

$$\mathrm{EKt}_{it} = 0.44 + 0.08h_{it} - 0.14k_{it}$$
$$\mathrm{Eht}_{it} = 0.24 + 0.08k_{it} - 0.05h_{it}$$

Fig. 2 shows the elasticity of the productivity of the private physical capital for each province, represented by a line of a different color. All the elasticities calculated are positive, with values that may be considered to be plausible. These elasticity values are spread around the thick black line, which represents the average of the values for each year. The annual elasticity values for the provinces lie about a percent above and below the average, giving an inter-province difference of up to two percent. This variability of elasticities between provinces shows the heterogeneity between these territories and the difficulty of estimating elasticities that are common to all of them. On the other hand, the general evolution of the elasticities with time shows a decreasing trend from 0.47 to 0.41, approximately. This trend seems to break down around 1995, a year after which these elasticities appear to decrease at a lower rate; which may be explained by the evolution of capital endowments, as shown in Fig. 1, and by the relative variation of its composition.

[7] The null hypothesis of homoscedasticity, absence of autocorrelation and cross-sectional independence is again rejected.

[8] According to the results of the test proposed in Davidson and Mackinnon (1993) to contrast the possible endogeneity of the original regressors, there might be problems of endogeneity regarding the human and public capital, since the *t*-ratio of the auxiliary equation extended with the residue of the first stage is −1.77** for the human capital and 1.73** for the public capital.

[9] Underidentification test of Kleibergen-Paap rk (LM statistic = 153.626, P-val = 0.000), identification weakness of Kleibergen-Paap (Wald F statistic = 65.628) and Cragg–Donald (Wald F statistic = 62.165) with minor Stock–Yogo weak ID test critical values, and Hansen overidentification of instruments (Chi-sq(2) = 3.59, P-val = 0.266). Likewise, the Durbin–Wu–Hausman endogeneity test shows a Chi-sq(2) value of 15.613, with an added *pvalue* of 0.0004.

Table 2
Correlation between variables.

	y	k	h	p
y	1			
k	0.7818	1		
h	0.9039	0.8009	1	
p	0.484	0.6899	0.5341	1

Fig. 3 shows the elasticities for the human capital and it can be seen that they also vary markedly between provinces and with time, which raises the doubt, as stated in Mamuneas et al (2006), about the assumption of constant elasticity between territories. All elasticities are positive, with values that may be considered equally possible. The provincial elasticities range over about a percentage point, but the difference seems to decrease slightly with time. The evolution of its trend is ascendant. This seems to indicate the increasing importance of this factor in the current productive processes.

With the aim of explaining the evolution of the elasticity of the private and human capitals per employee, it is convenient to take into account the increasing evolution of their endowments in the Spanish provinces within the period considered. Since the increment of the private physical capital was greater than that of the human capital, the relation between private and human capital has undergone an increment, which was faster until 1995, and slower since then. The evolution of this relation determines the evolution of the elasticity of both private physical and human capitals. Because of this, since throughout the whole period the relation between private physical and human capital grows, the elasticity of the private physical capital has decreased while the elasticity of the human capital has increased. Besides, the evolution of elasticities shows the change in the intensity of the growth of the relation of the variables that happens from 1995. Within the last two years of the sample, this relation seems to stabilize, and so do elasticities.

The decreasing trend of the elasticity of the private physical capital, along with the increasing evolution of its endowments, suggest that there are decreasing returns, which in turn are consistent with the estimations obtained previously, where the parameter B_{kk} bears a negative sign. The human capital endowments are therefore not sufficient to compensate for the decreasing returns of the private physical capital, and due to this the elasticities are decreasing throughout time. However, it may be noted that since approximately 1995, the increment of human capital affects markedly the elasticity of the private physical capital, halting its decrease or softening its drop in many provinces. In a few provinces it is even noticeable that the increment of the human capital has been sufficient to reverse the decreasing process of this elasticity of the private physical capital.

Table 3
Estimation results. Fixed effects.

Estimated parameters	A	B	C	D	E
β_k	0.46***	0.34***	0.37***	0.35***	0.34***
	(19.88)	(16.41)	(24.94)	(12.39)	(11.76)
β_h	0.23***	0.29***	0.29***	0.29***	0.29***
	(10.95)	(20.22)	(25.24)	(8.91)	(8.81)
β_p	0.18***	0.25***	0.16***	0.13***	0.10***
	(9.45)	(9.58)	(13.26)	(6.06)	(5.70)
β_{kh}		0.10***	0.09***	0.08***	0.12***
		(4.85)	(8.62)	(8.33)	(9.60)
β_{kp}		−0.02			
		(−0.57)			
β_{hp}		−0.04			
		(−1.87)			
β_{kk}		−0.05***	−0.07***	−0.08***	−0.13**
		(−2.31)	(−5.20)	(−8.15)	(−2.38)
β_{hh}		−0.01*	−0.03**	−0.02**	−0.05**
		(−1.72)	(−3.88)	(−2.12)	(−2.04)
β_{pp}		0.03			
		(1.36)			
β_{pkk}					−0.09**
					(−5.82)
β_{pph}					0.02**
					(3.09)
β_{kkk}					0.12***
					(8.46)

Note: *** denotes significance at 1%, ** at 5% and * at 10%. All estimations include individual and time dummies.

On the other hand, the increasing trend of the elasticity of the human capital, consistent with the increasing evolution of its endowments, suggests that there are no decreasing returns of the human capital. However, this is not entirely true, according to estimations previously obtained, where a negative sign appears in the parameter B_{hh}. Actually, the increments of the endowments of human capital generate slightly decreasing returns, consistent with the recent results of López-Bazo and Moreno (2011), which also highlight the presence of decreasing returns in the accumulation of human capital in the Spanish regions. However, the simultaneous capitalization of the economy counteracts these decreasing effects. As is highlighted in the studies in Barro (1991), Sianesi and Van Reenen (2003) and Krueger and Lindahl (2001), the effects of the human capital depend significantly on the increments of the private physical capital. In fact, according to the estimated data, the elasticity of the human capital for all the Spanish provinces will increase as long as the growth rate of the private physical capital per employee is greater than 0.63 times the growth rate of the human capital per employee.[10] Thus, as the economy becomes more specialized in economic activities that require a large presence of qualified personnel per capital unit, the increment of the elasticity of the productivity of the human capital will tend to decline. This explains why the elasticity of the human capital has tended to stabilize since 1995, as the Spanish economy implements investments with greater technological sophistication that require a greater training effort per capital unit.

These conclusions are consistent in turn with those studies that show that the elasticity of the productivity of the human capital varies according to the development level reached (Agiomirgianakis et al., 2002, 2006), since if this development level is associated with the level of capitalization of the economy, when this level is high the elasticity of the human capital is greater. Although, as that development level increases, the increasing trend of that elasticity tends to soften, due perhaps, as we mentioned previously, to the need for increasing markedly the qualification of the working population, which reduces the elasticity of the human capital due to its decreasing returns.

The complementarity relations observed between these two factors, which make the elasticities of private physical and human capital increase as the endowments of the complementary factors increase, make the accumulation of inputs (such as physical and human capital) gain relevance for enhancing the growth, as stated in Papageorgiou and Chmelarova (2005) and Scoppa (2007).

4.2. Extended translog function

With the aim of making the previously estimated translog production function more flexible, it was estimated again [3] and [6] with the addition of third-order terms.

Column E of Table 3 shows the estimated values of parameters in [3] with the addition of third-order terms by the method of moments, in which the terms that were not significant were removed. They are estimated again using instrumental variables. The human and public physical capitals are considered to be endogenous variables and the

[10] Since $\varepsilon K_{it} = \beta_k + \beta_{kh} h_{it} + \beta_{kp} p_{it} + \beta_{kk} k_{it}$, according to the values of the parameters estimated in column F, the $\varepsilon h_{it} = 0.24 + 0.08 k_{it} - 0.05 h_{it}$ thus, differentiating the function $d\varepsilon h_{it} = 0.08 dk_{it} - 0.05 h_{it}$. The elasticity will remain constant if $0.08 dk_{it} - 0.05 h_{it} = 0$ therefore $dk_{it} = 0.05/0.08\ dh_{it}$.

Table 4
Estimation results. First differences.

Estimated parameters	A	B	C	D	E	F	G
β_k	0.53***	0.53***	0.47***	0.49***	0.51***	0.44***	0.40***
	(24.30)	(23.87)	(20.87)	(25.57)	(23.22)	(6.54)	(5.78)
β_h	0.15***	0.15***	0.16***	0.16***	0.13***	0.24***	0.27***
	(12.38)	(12.37)	(10.17)	(10.44)	(10.14)	(5.42)	(5.37)
β_p	0.18***	0.18***	0.22***	0.20***	0.22***	0.12***	0.11***
	(11.46)	(11.34)	(9.96)	(14.06)	(14.47)	(4.14)	(3.70)
β_{kh}			0.10***	0.08***	0.08***	0.08***	0.10***
			(4.11)	(3.78)	(4.29)	(2.78)	(2.94)
β_{kp}			0.05				
			(1.08)				
β_{hp}			−0.06				
			(−1.28)				
β_{kk}			−0.14***	−0.13***	−0.13***	−0.14***	−0.13**
			(−3.33)	(−3.40)	(−3.62)	(−3.11)	(−2.38)
β_{hh}			−0.02*	−0.04**	−0.04**	−0.05***	−0.05**
			(−1.45)	(−2.76)	(−3.22)	(−2.02)	(−2.04)
β_{pp}			0.08				
			(0.16)				
β_{phh}							0.06**
							(2.27)
β_{pph}							−0.05**
							(−2.04)
β_{kkk}							0.18***
							(3.10)
β_{hhh}							−0.07**
							(−2.28)
ep	0.05***	0.06***	0.06***	0.04***	0.03**	0.03**	0.04**
	(6.11)	(5.74)	(5.74)	(2.94)	(2.10)	(1.96)	(2.18)
λ		0.004***	0.004***	0.005**	0.002	0.002	0.002
		(1.44)	(1.44)	(1.85)	(1.26)	(0.78)	(0.87)

Note:*** denotes significance at 1%, ** at 5% and * at 10%. All estimations include time dummies. No individual dummies are included in any case, as in all cases these dummies showed no significance.

variables explanatory of human and public physical capital are taken as instruments at first differences. The estimation obtained is consistent given the values of the tests performed[11]. Comparing the estimated values of parameters in [3] given in column D, the values of the estimated parameters are now slightly lower for the private physical capital (β_k) and lower for the public physical capital (β_p), and equal for the human capital (β_h) and higher for the cross product between private physical and human capital (β_{kh}), and for the squared terms. Thus, the complementarity relations between private physical and human capitals are confirmed again. The third-order estimated coefficient of the private physical capital proved to be significant, which implies that the elasticities of the productivity of the private physical capital will not change in a constant manner when their endowments vary.

Column G of Table 4 shows the estimated values of parameters in [9] by the method of moments, in which the terms that were not significant were removed. They are estimated again using instrumental variables. The human and public physical capitals are considered to be endogenous variables and the variables explanatory of human and public physical capital are taken as instruments at delayed values of one and two periods. The estimation obtained is consistent given the values of the tests performed[12]. Comparing the estimated values of parameters in [6] given in Table 4 column F, the values of the estimated parameters are now lower for the private physical capital (β_k) and for the public physical capital (β_p), and slightly higher for the human capital (β_h) and for the cross product between private physical and human capital (β_{kh}), while the coefficients of the squared terms are nearly equal. The third-order estimated coefficients prove to be significant for private physical capital and human capital, so the elasticities of their productivity will not change in a constant manner when their endowments vary. Likewise, the elasticity of the public physical capital does not remain constant now, but is modified by the endowments of the human capital.

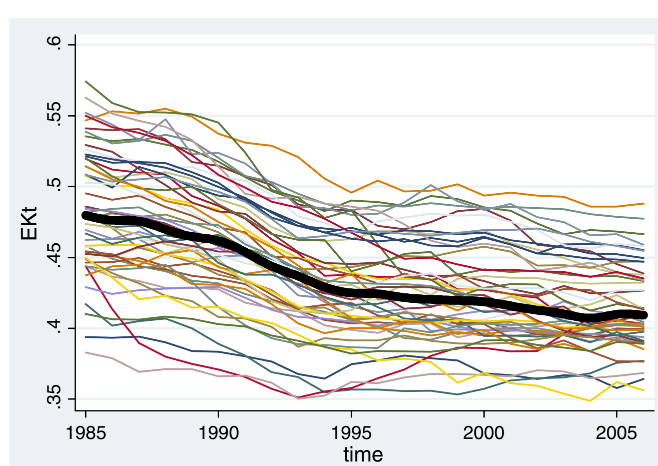

Fig. 2. Elasticity of the productivity of the private physical capital (Spanish provinces).
* The thick line represents the mean value in each period.

[11] Given the values of the underidentification tests of Kleibergen-Paap rk (LM statistic = 145.431, P-val = 0.000), identification weakness of Kleibergen-Paap (Wald F statistic = 78.301 and Cragg–Donald (Wald F statistic = 94.379) with minor Stock–Yogo weak ID test critical values, and the Durbin–Wu–Hausman endogeneity test shows a Chi-sq(2) value of 8.359, with an added *pvalue* of 0.0153.

[12] Given the values of the underidentification tests of Kleibergen-Paap rk (LM statistic = 129.913, P-val = 0.000), identification weakness of Kleibergen-Paap (Wald F statistic = 56.184 and Cragg–Donald (Wald F statistic = 56.954) with minor Stock–Yogo weak ID test critical values, and instrument overidentification of Hansen (2.815 — Chi-sq(2) P-val = 0.244). Likewise, the Durbin–Wu–Hausman endogeneity test shows a Chi-sq(2) value of 14.966, with an added *pvalue* of 0.0006.

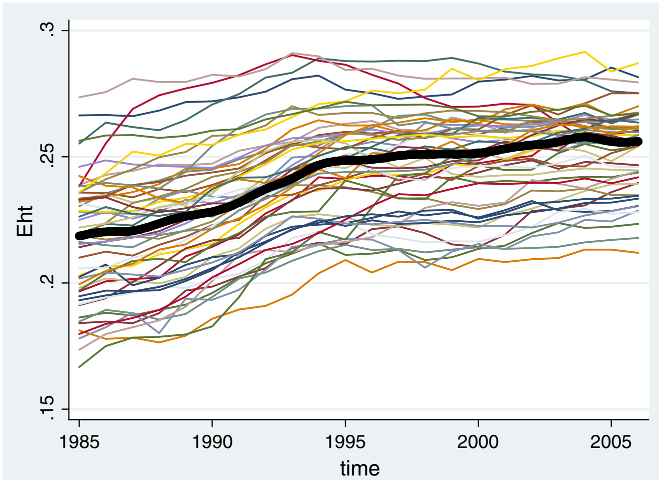

Fig. 3. Elasticity of the productivity of the human capital for each Spanish province. * The thick line represents the mean value of each period.

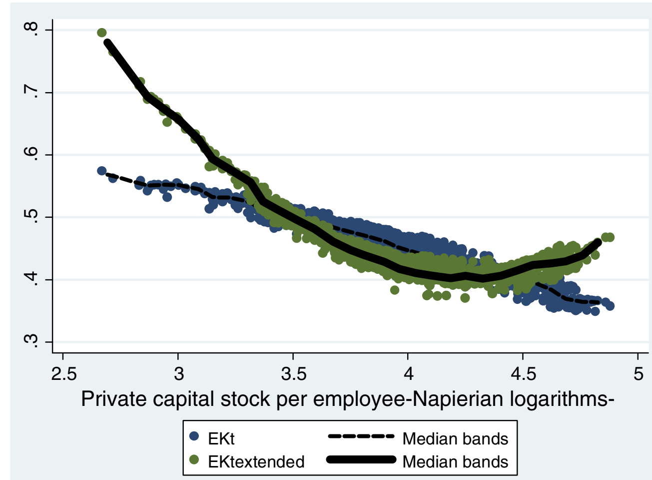

Fig. 4. Elasticity of the private physical capital per level of private physical capital per employee, from the translog function (blue dots, median bands shown by dashed thick black line) and the extended translog function (green dots, median bands shown by thick black line).

Once again, little difference is apparent in the value of the coefficients when they are estimated according to fixed effects or first differences.

We show here the elasticities for each province and time period calculated according to [10], from the values in column G in Table 4. The elasticities of the human capital are quite similar to those obtained previously, so in this respect the introduction of the third-order terms does not seem to affect significantly the previous results. The elasticities of the private physical capital are mostly decreasing until 1995, after which they tend to remain constant or increase slightly at or near a value of 0.4. It is therefore noticeable that this elasticity levels out despite the increases in the per capita endowments of this factor. Finally, it must be said that the elasticity of the public physical capital is no longer constant but varies with time and between provinces. However, except for a few particular cases, the elasticity does not vary markedly, and its value is very close to that at the central point of the sample throughout the considered period.

The introduction of the third-order terms in the translog production function will have a special significance when analyzing the value of such elasticities according to its own endowment per employee. For the elasticity of the private physical capital, it must be emphasized that the sign and the value of the coefficient β_{kkk} are positive and equal to 0.15. Since β_{kk} is negative, this positive value of β_{kkk} implies that beyond a certain level of per capita private physical capital, the elasticity ceases to decrease as the endowment increases and then starts increasing, which shows that there are increasing returns beyond a certain level of private physical capital per employee. This effect may not be observed if this third-order term of the production function is not taken into account.

Fig. 4 shows the value of elasticities of the private physical capital of the endowment of private physical capital per employee, using the elasticities derived from the translog function and from the extended function. It may be observed in the first case how the elasticities decrease as the endowments of the per capita capital increase, while in the second case a turning point occurs. Thus, it may be concluded that above a certain concentration level of the private physical capital, positive externalities are generated, which counteract the decreasing marginal productivities of the capital. In this sense, the greater territorial disaggregation of the sample allows to better observe the effects of these concentrations of capital in some provinces.

Fig. 4 shows that for a private capital endowment per employee equal to 4.4 (in terms of natural logarithms), the elasticity of private capital stops decreasing and it too begins to grow as the endowments of the per capita capital increase. The graph located in the above-right of Fig. 1 shows that only two provinces had endowments of private capital per employee higher than 4.4 at the beginning of the period, these being Alava and Vizcaya, which are both located in the Basque Country region of Spain. In the middle of the period, it can be seen (Fig. 1) that a larger number of provinces exceeded this value, with the provinces of Asturias, Barcelona, Cantabria, Girona, Guipúzcoa and Madrid now added to the list. At the end of the period, more than half of the provinces had reached a value of private capital endowment per employee higher than 4.4. Even so, there were still many provinces that did not have a sufficient level of capitalization to generate positive externalities, which thereby counteracts the decreasing marginal productivities of the capital. Among these are included the provinces of Andalusia, Extremadura, Galicia, Castilla la Mancha, parts of Castilla-León, Murcia and Alicante.

This fact of positive externalities only occurs at high capitalization levels. Therefore, not only the increments in human capital endowments can compensate the decreasing marginal productivity of the capital, but also the concentration of the private physical capital makes that decreasing marginal productivity disappear. In this sense, the accumulation of private physical capital becomes especially relevant, as important economic benefits are generated from a certain level of capitalization; perhaps, as was stated in Bond et al. (2010), because the investments in private physical capital are an important track through which other causes, e.g. technological innovations, may affect the economic growth.

The greatest levels of human capital for specific Spanish provinces favor the absorption of technology, making the rate of technological change faster (Glaeser and Resseger, 2010) due to the ratio between private and human capital stock decreases and the marginal productivity of physical capital increases. The technological innovations are achieved through a process of private investments in new physical capital for high value-added activities, which in turn require a qualified workforce. This generates a positive relationship between human capital and private physical capital, making this phenomenon more intensive and allowing the private accumulation of physical capital in provinces with high levels of it, as has been pointed in López-Bazo and Moreno (2008) for Spanish regions.

Therefore, introducing structural changes in the economies that lead to specialization in activities requiring a greater capitalization will be beneficial for their growth processes. In this sense, as stated in Martínez and Rodríguez (2009), investments in new technologies may help lagging regions or provinces to converge with the richer territories.

Regarding the elasticity of human capital it must be said that, since the coefficients β_{hh} and β_{hhh} are both negative, it is not possible to confirm that the human capital generates positive externalities on its own, as citizens with higher qualifications interact with each other, therefore generating a greater knowledge that may be used and may favor the growth of productivity, as supported by the new theories of geographic economy. This result is consistent with the conclusions of Sanromá and Ramos (2007), in which there is no empirical support for this type of externality either, but it is justified on the grounds that the dimension of provinces hides the reality of the city. Moreover, this type of externality is generated with a strictly local scope within well-defined limits.

5. Conclusions

In this study, a translog production function and an extended translog production function with third-order terms are estimated for the Spanish provinces in the period from 1985 to 2006. The output elasticities of different productive factors which vary throughout time and between provinces are calculated from these estimations.

The results of estimating the translog function shows that there are complementarity relations between the physical and human capital, therefore, the elasticities of each one of these factors depend on the endowment of the other factors. Likewise, it shows the existence of decreasing returns for the productive factors. The elasticities found from this estimation differ markedly among provinces, showing that there is heterogeneity between them. Likewise, they are not constant throughout time. The elasticity of the private physical capital decreases throughout the period of analysis as the endowments of this factor increase. Meanwhile, the elasticity of the human capital increases throughout the period, despite the increment of its endowments. This is due to the complementary effect of the private physical capital, which counteracts these decreasing effects of the human capital. This shows that, consistent with previous studies, the effects of the human capital on the economic growth depend significantly on the increments of the private physical capital. Therefore, the increment of the private physical capital enhanced the effect of the human capital on the economy, highlighting the importance of the accumulation of inputs for enhancing the growth.

In order to make the production function more flexible, an extended translog production function with third-order terms was estimated in this study. This new estimation confirms again the existence of complementarity relations between the human and private physical capital, and the existence of decreasing returns of human capital. In the case of private physical capital, it is noticeable that from a high concentration level of this capital, positive externalities are generated, which counteract the marginal decreasing productivities of the capital. Thus, the high accumulation of private physical capital generates important economic benefits, perhaps because the investments in private physical capital are an important track through which other causes may affect the economic growth. In this sense, the high capitalization of the economies may generate benefits on the growth in two additional ways; on the one hand, intensifying the beneficial effects of the human capital on the growth and, on the other hand, generating positive externalities that allow counteracting the decreasing returns for the capital. In this sense, the territorial scope used in this analysis — at a provincial level — may be an adequate framework for proving the existence of these externalities of private physical capital. In this sense, future research should consider estimating a spatial panel, as there will most likely exist a correlation between geographically close provinces.

For the human capital, there are no thresholds of factor endowment that suggest the existence of positive externalities, perhaps because an even more local territorial scope is necessary in order to prove its existence.

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