PRODUCTIVE CAPITAL AND TECHNICAL EFFICIENCY IN THE UE-15

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ABSTRACT

In this research we examine the capitalization process in the UE-15 with the aim to establish if the evolution manteined in the last two decades for the public and educational capital and its distribution have conditioned the technical efficiency of the European economies. In the analysis we use the frontier function approach that allows to consider an inefficiency use of the productive factors. Specially, we employ the parametric stochastic frontier model from Battese and Coelly (1995) to explore the determinants of the technical efficiency. The results show that larger endowments of public capital and education may facilitate the access to productive activity to the levels of the more efficient members. We also find a limit to the capacity of introducing improvements in the use of productive factors, and it is related to private capital. Then, if the increase of public capital does not lead to an optimal distribution of this factor, the effect on efficiency will be negative.

Key words: Public capital, Capital in education, technical efficiency, Conditioned convergence and Stochastic frontier.

JEL Classification: C23 H54 D24

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1. INTRODUCTION.

The last few years have given rise to a considerable amount of research analyzing the importance of technical efficiency as both a source of output growth and economic convergence. In this research, the efficiency level is determined by the difference between the maximum technically attainable output and that which is actually attained, and its measurement thus involves the estimation of a technological production frontier[1] in order to compare the units studied and contrast the determinants explaining the results. The calculation of technical efficiency has been carried out in firms as well as in the whole of the economy; the former have attempted to identify the conditioning factors of efficiency among the internal and external characteristics of the firm, such as size, degree of market competitiveness, etc., and the latter have mainly aimed at an analysis of the influence of public policy instruments on attained efficiency levels.

As to the latter, infrastructure endowments and human capital must be highlighted, since they receive an outstanding portion of public resources, given the expected economic effects they generate. Public and human capital not only contribute to economic growth as productive factors; in addition, they may also bring about innovation and efficiency gains (due to the dissemination of existing technology and the improvement in resource management). We should highlight the recent publication of studies on the role played by these types of capital, estimating stochastic production frontiers (Puig-Junoy, 2001, with public capital, and Maudos *et al*., 1999, with human capital) and using Malmquist productivity Indexes and DEA analysis (Boisso *et al*, 2000, with public capital and Maudos *et al*., 1998a, with human capital), bringing forth evidence as to its favorable effect on technical efficiency. There are considerably fewer studies that include both types of capital (Maudos *et al.*, 1998b y Pedraja *et al*,. 2002), and their authors have opted for a two-phase

[1] Farrel's seminal study (1957) initiates the considerable amount of literature dealing with the measurement of economic inefficiency and the development of frontier techniques. In non-frontier approximations, it is assumed that all production units are equally efficient, leading to biased estimations in the face of inefficiency.

estimation: regressing the value of efficiency obtained using the Malmquist Index with these variables.[2].

Given the interest in this variable, this paper will attempt to analyze two interrelated questions: in the first place, the behavior of technical efficiency in the European countries between 1980 and 2001. This period coincides with the intensification of the process of economic and monetary integration in the European Union, accompanied not only by an increase in exchanges of goods and services, but also and more importantly, by technological dissemination[3]. With this objective in mind, we opted for the use of a stochastic frontier to measure technical efficiency, introducing public capital and capital invested in education in the function to be estimated, thus avoiding the possible bias derived from the assumption that all economic units are efficient and the omission of relevant inputs. We employed Battese and Coelli's model (1995), enabling us to introduce temporal variation in the inefficiency term and determine the factors that may explain its behavior, focusing in this study on the criteria used to allocate public capital and capital invested in education in European countries.

Moreover, in order to interpret the differences in economic growth among European countries, it is important to confirm to what degree the integration achieved through technological dissemination can alter the dynamics of economic convergence. We shall thus attempt to contrast the existence of a technological catch-up effect[4] among European countries and establish the role of public capital and education endowments in each country. Technological approximation is far from being an automatic process; rather, it is a process that depends upon the capacity of each country to incorporate advanced technologies and adapt them to their productive processes. The existence of conditional convergence could give rise to a situation in which each territory would tend to

[2] The two main objections to these studies are that it is impossible to separate the inefficiency term from the rest of the components of the error term and this contradicts the assumption that the technical efficiency obtained in the first phase is identically distributed and uncorrelated with the error term.

[3] Economic integration during the eighties and nineties was accompanied by a significant increase in flows of direct intra-community investment and merger and takeover processes (European Commission).

[4] An important determinant of the convergence process is the effect of technological catch-up pointed out by Abramovitz (1986), De la Fuente (1995), Paci *et al.* (2002).

converge towards its own stationary state, possibly very different one from the other. Therefore, important differences would be maintained in the face of the persistence of relative positions. Such a situation would justify the maintenance of regional policies that attempt to correct, in the long term, the factors responsible for these differences.

This paper is structured as follows: Section 2 will briefly describe data dealing with public capital and capital invested in education used in this research. In Section 3 the estimation of the model and the results of technical efficiency in European countries are presented, while in Section 4 the catch-up effect is contrasted. The final section summarizes the findings of this research.

2. PRODUCTIVE PUBLIC CAPITAL AND CAPITAL INVESTED IN EDUCATION IN THE EU-15 COUNTRIES.

The Public Administrations of European countries have maintained an active role promoting supply policies for increasing existing endowments in public capital and education. The interest in evaluating such actions in regional policies has resulted in studies that examine the criteria for public investment allocation and evaluate the attained stocks.

Capital endowments have been highlighted in studies on growth, where the attention has largely focused more on private capital than on public and human capital. One of the justifications for this is the lack of compatible series for the three stocks that include a sufficient number of countries and greater periods of time[5]. For this reason, in this paper we have elaborated a homogeneous data base with abundant information concerning European economies during the period 1980-2001. We have used as an estimation method the Permanent Inventory Method, frequently employed in economic capital estimations.

The estimation of productive physical capital and its division into private and public capital has normally been carried out in monetary terms. In this paper we have used investment series by

[5] This situation is changing with the creation of data banks, making it possible to estimate this capital. Among the data bases with information concerning the flows of public and private investment and investment in education is the *Business Sector Data Base* (BSDB), the *National Accounts* and *Economic Outlook, Education at a glance* published by the OECD.

sectors included in the data base NEW CRONOS published by Eurostat. The availability of this data has made it possible to evaluate private and public capital in constant monetary terms, homogenized with the Purchasing Power Parity Standard (dollar PPS) in 1990. In addition, the New Cronos data base also contains information concerning gross value added (GVA) at market prices and in the same terms, an added benefit of the use of this stock data.

As to human capital, most of the analyses carried out have used the school enrolment rate in the different educational levels (Mankiw, Romer y Weil, 1990) and the worker's average number of years of schooling (Benhabib y Spiegel, 1994) as approximations of this stock. In opposition to these alternatives and based on academic findings, in this paper we have elaborated a stock of capital invested in education that attempts to present the investment effort that Public Administrations have carried out in order to obtain a measurement in monetary terms and which may be used as a productive input. In this measurement of stock, we have made use of information regarding spending on education taken from OECD publications[6], expressed in national currency and at current prices, transformed in the same terms as the rest of the variables, using the deflactor of public consumption and the OECD's PPS. The use of this type of data facilitates the homogenization of the different levels of education and introduces information concerning the differences in quality among educational systems. However, a problem arises due to the fact that we are assuming that the spending for each educational level has the same capital endowment[7].

Chart 1 shows the average distribution of public capital and capital invested in education in the EU-15 for the period. The comparison of capital invested is similar in levels and distribution among countries, though following different trajectories[8]. A partial explanation of these differences

[6] Eurostat offers in CD-ROM information concerning the series of investments by sectors. On the contrary, information from the OECD concerning spending on education can be obtained on CD-ROM only for the last few years. Therefore, the information used has been extracted from OECD publications in paper version: Educational Statistics in OECD Countries (1981), Public Educational Expenditure (1992) y Education at a glance (Several years).
[7] This problem is present in many of the indicators elaborated using the aggregation of academic results.
[8] See Alvarez y Delgado, 2002b for details of the estimation and findings obtained.

stems from the role of the Public Administration and the limits established for public deficits, forcing a reduction in the growth of investment during the nineties.

The countries that have maintained greater public investment capacity in relation to their productive activity and population are Austria, Belgium, Luxembourg and Denmark, giving rise to a high public capital/private capital ratio; Ireland, Sweden and the United Kingdom are in a contrary situation. As to average capital invested in education in European countries, the important investment effort that these economies have maintained during the last few decades has allowed them to obtain an important volume of this capital. Among the countries that have obtained greater relative endowments, we find Austria, Belgium, Holland and Denmark, as opposed to Greece, Spain and Portugal which, despite the increase in the last few years in expenditure over GVA for this item, have been unable to situate themselves within the European average.

CHART 1. DISTRIBUTION OF PUBLIC CAPITAL AND CAPITAL IN EDUCATION BY COUNTRY (annual average for the period 1980-2001).

	PUBLIC CAPITAL	%TOTAL	PUBLIC CAPITAL/VAB	PUBLIC CAPITAL/PO	PUBLIC C./ PRIVATE C.	EDUCATIONAL CAPITAL	%TOTAL	EDUC. C. / VAB	EDUC. C./ PO	EDU.EXPEND./ VAB
AUSTRIA	81,186.68	4.08	71.81	10.42	23.31	56,312.59	3.01	44.02	7.09	5.90
GERMANY	485,411.53	24.37	46.66	6.08	17.35	447,062.76	23.89	38.51	5.54	4.51
BELGIUM	61,923.45	3.11	43.14	6.19	19.13	68,601.78	3.67	44.10	6.80	5.48
SPAIN	143,335.93	7.20	34.19	3.68	15.32	112,426.51	6.01	23.54	2.85	4.04
FINLAND	42,722.59	2.15	64.81	8.53	16.35	27,873.57	1.49	37.56	5.47	6.05
FRANCE	336,362.64	16.89	38.48	5.92	15.07	320,808.08	17.14	34.52	5.57	5.65
GREECE	32,134.82	1.61	43.19	3.15	18.85	28,117.24	1.50	34.90	2.66	3.49
IRELAND	6,019.58	0.30	15.90	1.68	7.44	15,206.72	0.81	30.70	4.16	5.51
ITALY	237,340.61	11.92	29.11	4.17	10.88	262,778.99	14.04	29.61	4.58	4.92
LUXEMBOURG	4,446.10	0.22	51.13	11.30	25.39	3,101.19	0.17	29.67	7.61	5.40
NETHERLANDS	76,921.31	3.86	36.50	5.13	14.23	137,853.01	7.37	61.17	9.08	5.97
PORTUGAL	30,913.50	1.55	36.86	3.08	16.45	29,635.24	1.58	29.42	2.92	4.95
DENMARK	50,797.08	2.55	72.03	9.81	28.21	43,867.31	2.34	54.91	8.38	7.71
UNITED KINGDOM	362,995.29	18.23	44.96	6.26	13.11	293,116.91	15.66	33.35	5.00	4.99
SWEDEN	38,966.96	1.96	30.44	4.52	10.66	24,422.99	1.31	17.64	2.80	7.42
UE-15	1,991,478.07	100	40.64	5.62	14.91	1,871,184.90	100.00	34.71	5.29	5.47

NOTE. C : CAPITAL, PO: POPULATION, EDU: EDUCATIONAL, EXPEND: EXPENDITURE.

Source: Alvarez I. y M.J. Delgado (2002), *Estimación del Capital Público, Capital Privado y Capital Humano para la UE-15*, Documento de Trabajo del Instituto de Estudios Fiscales 12/02, Madrid. *www.minhac.es/ief/Publicaciones/Documentos/DOC12/02*.

3. ESTIMATION OF TECHNICAL EFFICIENCY IN EU COUNTRIES.

According to Farrel's classic definition (1957), an economy is considered to be technically efficient if it obtains the maximum attainable output given the inputs used and the technology. Econometrically, several approaches may be used to estimate the production frontier and the inefficiency term. In this paper we have used the parametric and stochastic frontier approach[9], where the deviation between the observed output level and the maximum possible is made up of two components: an error term, $v_{it,}$ that indicates the effect of variables that are not under the control of the analyzed productive unit, errors in the measurement of variables and other statistical noise, that include habitual characteristics iid, $N(0,\sigma^2_v)$ and independently distributed from the second term u_{it}, assuming that it represents the degree of inefficiency, situating the level of production below the maximum output defined by the frontier. For this reason, it is necessary to specify an asymmetric distribution for this term.

In addition, the availability of a data panel for the UE-15 countries makes it possible to develop production frontier applications that solve many of the problems related to earlier models.[10]. In this research, we have used Battese and Coelli's model, (BC from now on) enabling us to analyze the determinants of the evolution of the technical inefficiency of a productive unit in terms of a set of explicative variables that are out of its control and that, in addition, may vary over time.

The functional form of the production frontier adopted is a transcendental logarithmic production function. This choice is based on the flexibility of this function to adapt to any type of productive technology, making it unnecessary to impose restrictions a priori on scale performance. Thus the function that will represent the production of EU countries and the equation of inefficiency for each one of them is as follows:

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[9] See Gumbau y Maudos (1996) y Gumbau (1998a) for a detailed description of the stochastic production frontiers and their main advantages and limitations as compared with other frontier estimation techniques.

$$\ln Y_{it} = b_0 + b_T t + \sum_{j=1}^{4} b_j \ln(X_{jit}) + \sum_{j=1}^{4}\sum_{h=1}^{4} b_{jh} \ln(X_{jit})\ln(X_{hit}) + v_{it} - u_{it} \qquad (1)$$

i = 1, ..., 15 countries
t = 1, ..., 22 years

Where Y_{it} is the product (presented by the Gross Value Added at market prices and in 1990 purchasing power parity) and X_{it} is a vector representing the inputs taken into consideration[11]: j, h = L (employment), KPRIV (private capital), KPUB (public capital) y KEDU (capital invested in education). The statistical source for the GVA pm of the private sector and private employment (excluding final production and employment in the service sector not for sale) is the New Cronos data base, and the variables for capital in this paper are specified in the previous section and can be found in Alvarez y Delgado (2002). Technical progress is included using an additional regressor (t) that represents the temporal tendency, v_{it} is the random error and u_{it} represents the inefficiency term. This is defined in the following equation:

$$u_{it} = d_0 + d_1(KPUB_{it} / KPRIV_{it}) + d_2(EDU_{it} / Y_{it}) + \sum_{j=3}^{16}\sum_{i=1}^{14} d_j D_i \sum_{j=17}^{37}\sum_{t=1}^{21} d_j D_t + W_{it} \qquad (2)$$

i = 1 , ..., 15
t = 1 , ..., 22

Apart from including public capital and capital invested in education as additional explicative factors in the production function, two variables related with capital allocation criteria in European countries have been included in the inefficiency equation: the ratio between stocks of public and private capital (KPU/KPRIV) and the participation of spending on education in the GDP (EDU/Y). European Public Administrations have played an active role promoting public policies to adapt and equate economic conditions in European countries. The effects of these actions on economic efficiency have not usually been taken into consideration, but they may affect aggregate

[10] The assumption of invariant efficiency over time has been one of the most restrictive assumptions in the models developed, giving rise to a series of alternatives to introduce temporal variability in the technical inefficiency term.

[11] The continuous revisions of the New Cronos data base published by Eurostat in an electronic format conditions the presentation and the available information. The changes in the periods taken into consideration have made it necessary to connect the series. See Cordero y Gayoso (1995).

economic growth. Individual and temporal dummies have also been introduced in order to control unobserved differences between countries and time periods, given the fact that these components may also influence efficiency. Finally, the random error, W_{it} , has been introduced.

The equations (1)-(2) have been estimated simultaneously with Maximum Likelihood, using the program Frontier 4.1. (Coelli, 1996). The contrasts of the specification used is presented in Chart 2 and the results obtained in the estimation of the model are shown in Chart 3. The importance of justifying the use of this methodology determined the inclusion of a series of likelihood ratio contrasts (ë[12]), in order to verify the correct functional form. In the first contrast, the null hypothesis that the Cobb-Douglas functional form has advantages over the translogorithmic function is rejected. Subsequently, the inexistence of technical inefficiency in the error term is contrasted; the rejection of the hypothesis that the parameter ã is equal to zero[13] confirms the importance of including technical inefficiency in the production function, in addition to the fact that a function of average production presents an inadequate representation of the data. The third contrast takes into account the fact that the inefficiency equation is not a function of the regressors being considered. Since this hypothesis is rejected, the significance of the variables that explain technical inefficiency is confirmed. The significance of individual and temporal effects is also confirmed, as well as all the determinants of inefficiency as a whole.

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[12] The statistic ë is calculated as:

$$ë = -2\ [\log(f.likelihood(H_0))-\log(f.likelihood(H_1))]$$

, that is distributed by a chi-square with degrees of freedom equal to the number of parameters that are equal to zero in the null hypothesis.

Chart 2: Specification Contrasts.

NULL HYPOTHESIS	LOG.F. LIKELIHOOD	VALUE λ	CRITICAL VALUE	DECISION (90%)
$H_0 : b_{jh} = 0$	487.35	171.56	15.99	REJECTED
$H_0 : g = d_0 = ... = d_{37} = 0$	287.046	572.17	50.105	REJECTED
$H_0 : d_1 = d_2 = 0$	553.42	39.42	4.61	REJECTED
$H_0 : d_3 = ... = d_{37} = 0$	315.47	515.32	51.81	REJECTED
$H_0 : d_1 = ... = d_{37} = 0$	289.22	567.82	51.81	REJECTED

Since all the null hypotheses are rejected, the stochastic frontier model is estimated specifying the proposed translogarithmic production function and the inefficiency equation. The BC model allows us to consider public capital and capital invested in education as inputs of the production function[14] and determine whether the differences in public policy criteria in European countries have conditioned the technical efficiency attained. In the estimation carried out, the translogarithmic function has been considered a second-degree approximation to an arbitrary function, estimating what is known as an approximate form[15]. In this case, the first-degree coefficients are the production elasticities of each input.

The results of the estimation of the model make it possible to test whether public capital is a relevant factor to explain private sector production with an elasticity of 0.128, in accordance with the evidence included in much of the literature that estimates the contribution of this stock[16]. The importance of this result is evident, since the size of the public capital coefficient is an indicator of the effectiveness of this public investment as an instrument of regional policy. One of the main objectives of investment in infrastructures has been precisely its contribution to correct the relative

[13] In the contrast in which the null hipótesis considers $g = 0$, the statistic l follows a mixed chi-square distribution Thus, the critical values are obtained in Kodde and Palm (1986), Table 1, page 1246.

[14] The posible endogeneity of some of the regressors considered in the production function is difficult to contrast in a frontier technique context. Nevertheless, much of the literatura demonstrates that there is no serious simultaneity problem between variables, as long as there is an important sensitivity of the results to the instrument matrix (De Long and Summers, 1991, González Páramo and Martinez, 2002 and Serrano, 1996).

[15] See Boisvert (1982) for a description of this transformation. The advantage of the approximate form over the exact form is that statistics t associated with the first-degree coefficients in the approximate form allow a statistic contrast if the production elasticities are significant.

[16] Revisions of these findings can be found in De la Fuente (2000) and Sturm et al. (1998).

insufficiency of public capital in European economies, as a way of reducing the gap in income levels with respect to wealthier countries.

CHART 3: Translogarithmic Production Function (Battese y Coelli, 1995)

VARIABLE	*PARAMETER*	*COEFFICIENT*	*T-STATISTIC*
Stochastic Frontier			
Constant	β_0	12.00119**	901.567
Tendency	β_T	0.0146**	9.819
LnL	β_L	0.752**	21.318
lnKPRIV	β_{KPRIV}	0.132**	3.443
LnKPUB	β_{KPUB}	0.128**	6.0517
LnKEDU	β_{KEDU}	-0.00768	-0.691
LnL*LnKPRIV	β_{LKPRIV}	0.384**	2.4079
LnL*lnKPUB	β_{LKPUB}	-0.472**	-4.581
LnL*lnKEDU	β_{LKEDU}	-0.0817**	-4.345
LnKPRIV*lnKPUB	$\beta_{KPRIVKPU}$	0.311**	4.876
LnKPRIV*lnKEDU	$\beta_{KPRIVKEDU}$	0.146**	7.175
LnKPUB*lnKEDU	$\beta_{KPUBKEDU}$	-0.0888**	-8.20057
$(LnL)^2$	β_L^2	0.0997	1.146
$(LnKPRIV)^2$	β_{KPRIV}^2	-0.399**	-4.511
$(LNKPUB)^2$	β_{KPUB}^2	0.111**	2.359
$(LnKEDU)^2$	β_{KEDU}^2	-0.00859**	-3.4304
Inefficiency Model with fixed and temporal effects			
Constant	δ_0	0.0922*	1.371
Ratio (KPUB/KPRIV)	δ_1	1.010202**	5.362
Ratio (EDU/Y)	δ_2	-0.00969°*	-1.271
Variance Parameters	s_S^2	0.00289**	9.679
	γ	0.857**	25.931
Log. F. Likelihood		573.13003	

* Parameter significant at 90%.
** Parameter significant at 95%.
°* Parameter significant at 89%. See Fisher y Yates (1938)

The incorporation of human capital as a productive input in the production function is frequent in growth analyses, where both positive and negative evidence as to its impact has been obtained[17]. The findings included in this paper pertain to the latter group: the estimation carried out offers no evidence as to the level effect of human capital. On the contrary, the elasticity of capital

[17] Neoclassic growth models that have included human capital as a productive input (level effect) have obtained as much positive evidence (Mankiw, Romer and Weil, 1992, Barro and Lee, 1996) as negative evidence (Kyriacou, 1991, Benhabib and Spiegel, 1994) as to its impact.

invested in education is not significant, indicating that human capital acquired through the educational system is not relevant when attempting to explain the increase in economic production levels. The arguments most frequently used to justify this type of findings indicate that it may be related to the consideration of variables only related to education as a proxy of human capital (Islam, 1995), that not all the knowledge provided by a formal educational system have the same effect on production (Serrano, 1996) and, as put forth in much research, the way in which human capital affects production is much more complex than its mere inclusion as a productive factor. On the other hand, the elasticities obtained for employment and private capital are in accordance with those obtained in studies carried for European economies.

The inefficiency model with fixed and temporal effects (equation 2) enables us to examine in depth the determinants of efficiency behavior in the European economies. This paper focuses on the influence of public policy in these countries. The two variables analyzed show that inefficiency is positively related to the public capital/ private capital ratio, and negatively related to the investment effort in education. These findings allow us to highlight the following: firstly, and in regard to public capital, its negative effect upon efficiency is compatible with the positive contribution of this stock upon production. This indicates that such endowments, in addition to being a positive externality on economic growth, are conditioned by the availability of private capital for an efficient resource allocation, as well as an improvement in private investment performance[18]. On the other hand, investment effort in education has contributed to the generation of improvements in efficiency levels, in such a way that countries that designate a greater percentage of their production to spending in education will achieve greater efficiency in their productive activity, favouring the adoption of new technologies.

[18] Mulligan and Sala-i-Martín (1993) and Sala-i-Martín (1997) consider that the dynamics of transition is of such a nature that the growth rate is inversely related with the public capital-private capital relation.

The variance of the parameters is expressed as follows: $g = \frac{s^2}{s^2 + s_v^2}$ y $s_s^2 = s_v^2 + s^2$,

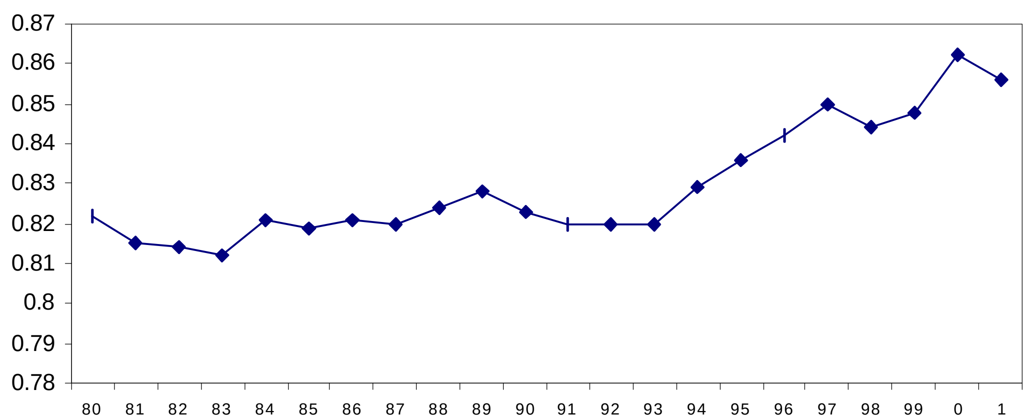
where s_v^2 y s^2 are the variances in distributions of v_{it} y u_{it}, respectively. Thus, the value of the parameter ã indicates that the proportion of the variance of u_{it} on the total compound error is 85.7%, and denotes the error made upon using the average production functions where inefficiency differences are ignored.

The estimation carried out allows us to measure technical efficiency based on output in European countries. The efficiency levels (ET) obtained using the stochastic frontier model and by means of the implementation of expression (3):

$$ET_{it} = \exp(-u_{it}) = \exp\left[-\left(d_0 + d_1 (KPUB_{it} / KPPRI_{it}) + d_2 (EDU_{it} / Y_{it}) + \sum_{j=3}^{16} \sum_{i=1}^{14} d_j D_i \sum_{j=17}^{37} \sum_{t=1}^{21} d_j D_t \right) - W_{it} \right] \quad (3)$$

Thus technical efficiency is calculated as the ratio of the production level obtained with respect to the maximum obtainable, given the quantity of inputs (that is, when $u_{it} = 0$). Its value will oscillate between 0 y 1, being the latter the most favourable case.

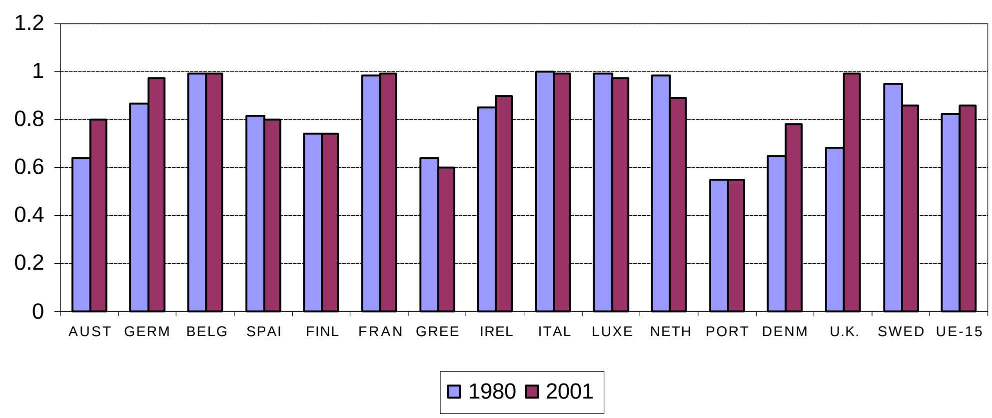
GRAPH 1: Evolution of technical efficiency in the EU-15.



In Graph 1 the evolution of technical efficiency in the EU-15 is presented. The results obtained point to the favourable development experimented by all the European economies, which intensifies in 1993, the moment in which there is a point of inflection, initiating a new economic cycle in Europe, and measures are introduced in order to achieve the economic adjustments necessary for monetary union. In 2001 a technical efficiency of 0.856 is reached, an indication that it is possible to increase production approximately 14 % with the productive inputs used and the available technology.

Technical efficiency for each country is shown in Graph 2, verifying that not all the countries have benefited equally from the improvements in efficiency in European economies. The countries can be classified in three different groups: firstly, Belgium, France, Luxembourg, Holland and Italy are situated near the technological frontier and undergo few variations with respect to this situation. Secondly, Germany and the United Kingdom, despite the fact that they were not among the countries showing greater efficiency at the beginning of the period, have maintained a very favourable evolution, followed by Austria, Ireland and Denmark. Finally, the third group is made up of countries that have maintained reduced levels of efficiency and have not grown like the rest: Spain, Portugal, Greece and Finland.

GRAPH 2: Technical efficiency in the UE-15.



4. EFFICIENCY CONVERGENCE IN EUROPEAN COUNTRIES: THE TECHNOLOGICAL CATCH-UP HYPOTHESIS.

The reduction of inequalities between regions and countries is a goal that has progressively gained in importance in the European Community, though the difficulties related with economic convergence has brought up questions as to the effectiveness of regional policy instruments. The interest in convergence among economies has brought forward studies dealing with this question[19]. Available empirical evidence favours the hypothesis of conditional convergence in European economies. Countries with lower per capita income tend to grow faster than those with greater per capita incomes, once they are controlled by a series of relevant variables[20]. Among convergence mechanisms frequently taken into consideration, we encounter technological dissemination consisting of the transmission of ideas and technology between regions and countries. One way to generate income convergence is to allow the technological level of lower income countries to reach that of higher income countries; when a technological dissemination process exists, sluggish economies will have an advantage in that they can adopt technologies employed in more advanced countries at a low cost.

This section will contrast the existence of a technological catch-up effect among European countries, using as a point of departure the concept of technical efficiency; thus, improvements in a country's efficiency will be linked to the approximation of this country to the efficient frontier and, at the same time, to technological assimilation[21]. The catch-up hypothesis in terms of efficiency convergence will serve to verify whether the process of integration has favoured the access of firms to new technologies, in a market of intense exchanges, making it possible to characterize the

[19] During the eighties and nineties, regional disparities in the European Union have not tended to decrease; on the contrary, they have risen, at the same time that dispersion among countries has decreased (Magrini, 1999, López-Bazo, 1999, Giannetti, 2002).

[20] Barro and Sala-i-Martín's study (1991) and Mankiw, Romer and Weil (1192) initiate a considerable amount of literature explaining the maintenance of international disparities due to the fact that countries possess very different economic principles, and, in accordance with the neoclassic model, they converge in the long term towards remote equilibrium positions.

mechanism of technological dissemination and analyse the capacity of these countries to incorporate new technologies in their productive processes. Moreover, in the framework of the European Union, national institutions have been encouraged to dedicate much of their effort to increasing the economic conditions for infrastructures and education in order to achieve balanced development, on the basis that public policy may affect convergence timing. Thus the incorporation of these instruments as conditioning factors of the process of efficiency convergence is especially interesting for this analysis.

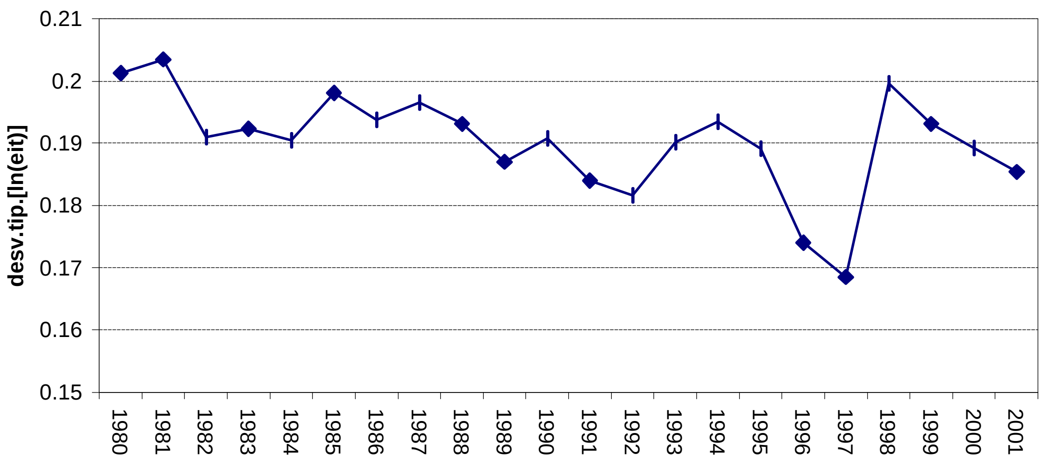
To carry out the analysis of the technological catch-up effect, several notions concerning convergence defined in literature on the subject will be employed: sigma convergence and unconditioned convergence and conditioned beta convergence. The objective is to contribute a greater understanding of the implications of this process for European countries in order to obtain an inference that may be employed in the design of community regional policy.

In the first place, sigma-convergence has been analysed, using as a point of departure the typical deviation of the logarithm of the efficiency indicator, enabling us to extract information concerning existing dispersion over time[22]. Graph 3 shows the temporal course of this dispersion index; over the entire period, the sigma value decreases by approximately 8%, a rather low value although it is a favourable result in that it indicates that inequalities have decreased in the period in question. Nevertheless, we should highlight the fact that there is an intensification in convergence between 1993 and 1997, the year in which this process undergoes a setback, pointing to the difficulty of maintaining a stable trajectory.

[21] In the studies that estimate Malmquist Indexes, the development of new technologies (innovation) displaces the frontier of production possibilities, while the dissemination of this technology contributes to greater efficiency.

[22] Sala-i-Martin (1994, 1996a, 1996b) .

GRAPH 3: Sigma Convergence in Efficiency Levels



Next beta convergence is analysed, enabling us to contrast the hypothesis that the technological diffusion process is related to the previously existing gap. That is, the greater the distance between technology defined on the frontier and the countries' technological level, the greater the innovation dissemination potential, whether technical or organizational. Equation (4) is thus estimated, taking into consideration annual growth rates (T=1).

$$\frac{\ln\left(e_{it}/e_{it-T}\right)}{T} = a - b\ln(e_{it-T}) + e_{i,t,t-T} \qquad (4)$$

Where: $\ln\left(\frac{e_{it}}{e_{it-T}}\right)$ is efficiency growth between t y t-T corresponding to i-ésimo country and $\ln(e_{it-T})$ is the initial level of this growth. In order to confirm the existence of convergence, it is necessary to obtain b>0, where $b = (1 - e^{-l_T})/T$ y l represents the speed of convergence[23] .

To analyze the beta convergence pattern, we shall firstly estimate an unconditioned convergence equation, assuming that the constant term is common for all the regions. Chart 4 shows the results of the estimation of the basic convergence equation (4) for a data pool made up of 15 countries in the period 1980-2001. The estimation for the entire period is presented in column I, the estimation for the entire period including a temporal dummy that covers the period 1980-1992

[23] Islam (1995) and Temple (1998) implement the Mankiw, Romer y Weil model (1992) in the data panel context, highlighting the fact that this makes it possible to show the observable differences between countries in the form of "fixed effects", thus avoiding the possible bias originating in a problem of omitted variables.

and 1993-2001 is presented in column II and, finally, the estimation separated in periods: 1980-1992 is shown in column III and 1993-2001 in column IV. The estimation method in each case is ordinary minimum squares (OMS). The residues do not present auto-correlation problems[24], as can be observed in the contrast carried out and the standard errors have undergone heteroscedasticity correction, using the covariance matrix proposed by White (1980), enabling us arrive at robust inferences even in the presence of heteroscedasticity. At the same time, the Wald test confirms the significance of the model.

The sign of the slope of the line adjusted to regression for the entire period (the results of columns I and II lead to the same results) is negative and significantly different from 0, indicating that less efficient countries are moving closer to the more efficient countries. For the different periods (columns III and IV), it is evident that a convergence process exists, but it has not remained constant over time, producing an increase in convergence between 1993-2001. This demonstrates that when integration increases, there is an intensification in technological dissemination, although the convergence coefficient (that is, the slope of the regression line) suggests that the process of technological assimilation is very slow: the value of this coefficient (0.0105) indicates that each year European countries eliminate only 1.05% of the technological differential existing at the beginning of the period.

Much of the existing literature argues that the appearance of slow convergence towards a single stationary state could be due to the bias induced by an incorrect specification when differences between territories are not included. When a data panel is available, the alternative to avoid this problem is to introduce fictitious variables for each country that show the possible differences in long-term efficiency levels, thus obtaining an unbiased estimator of the speed of convergence.

[24] The auto-correlation test of first and second-degree residues contrasts the existence of a model of mobile averages distributed asyntotically in accordance with a standardized Normal. This test is developed in Arellano and Bond (1991).

CHART 4. Convergence Regression. Dependent Variable: $\ln(e_{it}/e_{it-1})$

	Data Panel Model. OLS "Pooled"			
	1980-2001	1980-2001(D)	1980-1992	1993-2001
Constant	0.00062(0.28)	-0.0014(-0.64)	-0.0014(-0.59)	0.00053(0.22)
$\ln(e_{it-1})$	-0.0105(-1.98)**	-0.011(-1.96)**	-0.0108(-2.019)**	-0.023(-2.63)**
Temporal Dummy		0.00402(1.41)*		
Test Wald Significance	3.92(D.F.=1)	4.32(D.F.=2)	4.077 (D.F.=1)	6.89 (D.F.=1)
Autocorrelation (first and second degree)	-0.002 -0.399	-0.083 -0.434	-0.056 1.432	-0.397 -1.070

D.F. = degree of freedom. T-statistics in brackets.
* parameter significant at 90%.

In the first place, the necessity of controlling the specific effects of each country is tested. To do so, contrast F (individual effects) is applied, consisting of the choice of a constant model (a restricted model) as opposed to an alternative hypothesis that takes into consideration a model with individual effects. In all cases, it allows us to reject the null hypothesis of equality in individual effects and, for this reason, we have opted for estimating the equation with a data panel. The next step is the Hausman test[25] that corroborates the correlation between individual effects and regressors. This is the reason why the estimation of instrumental variables is applied on the model transformed in ortogonal deviations, which is equivalent to the "intra-group" estimator, maintaining the properties of efficiency and consistence when the model, as is our case, is one of "fixed effects". This is a dynamic model, since the regressor is the variable that is dependent on the initial period. For this reason, and following Arellano y Bond's study (1991), we have employed the "optimum estimator of instrumental variables in two phases" or the "generalized estimator of moments in two phases"[26]. With the Wald contrast, we can observe the combined significance of the model. In addition, the residues do not present auto-correlation problems, as demonstrated by the contrast carried out and the standard errors have heteroscedasticity corrections, as previously pointed out.

The results are presented in Chart 5 which is organized in the same way as the previous chart. As is frequent in literature on the speed of technological dissemination, measured by

[25] See Hausman (1978).

coefficient b, it increases considerably, by up to 21% a year. The results of the conditioned convergence equations point towards the convergence of each territory towards its own stationary state. By periods (columns III and IV) , it is evident that convergence becomes more intense in the second period. As in the studies on income convergence, the omission of fixed effects on the model tends to bias the value of β towards zero. In so far as part of the differential of technical progress among countries is due to non-transferable characteristics, or contains important measurement errors, the introduction of dummies allows us to avoid these problems, correcting the bias and elevating the estimated rate of convergence.

CHART 5. Convergence Regression. Dependent Variable: ln(e_{it}/e_{it-1})

	Data Panel Model with Fixed Effects			
	1980	1980-2001 (D)	1980-1992	1993-2001
$\ln(e_{it-1})$	-0.21(-2.58)**	-0.22(-2.79)**	-0.27(-4.86)**	-0.46(-2.76)**
Temporal Dummy		-0.0016(-1.14)		
Test F. Individual effects	F(14,299)=4.29	F(14,298)=5.092	F(14,164)=8.34	F(14,119)=1.86
Test Hausman	$c^{2}(1) = 33.013$	$c^{2}(2) = 40.36$	$c^{2}(1) = 45.613$	$c^{2}(1) = 15.68$
Test Wald Significance	6.65(D.F.=1)	9.291(D.F.=2)	23.59 (D.F.=1)	7.63 (D.F.=1)
Autocorrelation (first and	1.114	1.237	-0.188	1.280
second degree)	0.620	0.726	1.195	-0.592

D.F. = degree of freedom. T-statistic in brackets.
* parameter significant at 90%.
** parameter significant at 95%.

Lastly, in this section, we shall examine the influence of public capital and capital endowments in education on this process of approaching the technological production frontier, attempting to identify the conditioners of this approach. We shall therefore introduce these variables as additional regressors in the convergence equation (4), along with the individual effects, in order to test their influence on convergence intensity. Following the Hausman test, the inexistence of correlation between regressors and individual effects is rejected, and for this reason, the estimation method on the transformed model in ortogonal deviations is maintained, implementing only the initial efficiency level, since the rest of the regressors are considered to be exogenous. The estimated models are, as a whole, significant and their residues do not present auto-correlation problems.

[26] The estimations have been carried out with the D.P.D. package, programmed by Arellano and Bond, 1988.

Chart 6 shows the results after implementing the same estimation method used in previous estimations. In the literature on convergence, we encounter studies that consider that convergence in levels of income per capita, in our case efficiency, is produced among groups of countries whose points of departure are similar. This has given rise to the so-called "convergence clubs". In order to test the robustness of the results, the countries have been divided into three groups, with the same number of countries in each group in accordance with the efficiency level at the beginning of the period. This allows us to test the possibility of detecting differences in the rate of progress of technological dissemination among groups of countries that are initially similar. In order to verify the existence of countries that have shown greater convergence in their efficiency levels, they have been divided into three groups, according to the initial efficiency level. Group I includes France, Luxembourg, Belgium, the Low Countries and Italy, the countries closest to the frontier. Group II is made up of Sweden, Spain, Ireland, Finland and Germany. Finally, Group III includes the countries with lower levels of efficiency: Portugal, Greece, Denmark, the United Kingdom and Austria. The same estimation has been carried out, and in equation (4) we have also included public capital and investment effort in education as variables[27].

CHART 6. Determinants of Convergence. Dependent Variable: $\ln(e_{it}/e_{it-1})$

	Panel Data Model with Fixed Effects			
	UE-15	GROUP I	GROUP II	GROUP III
$\ln(e_{it-1})$	-0.23(-2.59)**	-0.28(-7.59)**	-0.12(-1.11)	-0.25(-3.202)**
$\ln(\text{public capital}_{it})$	-0.015(-0.83)	0.015(1.103)	-0.12(-2.26)**	-0.024(-1.46)*
$\ln(\text{education}_{it})$	0.0042(1.18)	0.000068(0.063)	0.026(2.49)**	0.003003(0.78)
Test F Individual Effects	F(14,297)=4.33	F(4,97)=6.18	F(4,97)=3.089	F(4,97)=4.28
Test Hausman	$c^2(3) = 35.75$	$c^2(3) = 11.901$	$c^2(3) = 11.054$	$c^2(3) = 10.141$
Test Wald Significance	6.76(D.F.=3)	94.14(D.F.=3)	6.24 (D.F.=3)	49.077 (D.F.=3)
Autocorrelation (first and second degree)	1.001 0.878	1.449 1.471	1.399 0.037	-0.156 -0.495

D.F. = degrees of freedom. T-statistic in brackets.
* Parameter significant at 90%.
** Parameter significant at 95%.

[27] There exist a number of studies including public and human capital in the convergence equation of per capita income, obtained using the solution of the stationary state in the Neoclassic Growth Model. This is the case of Mankiw, Romer and Weil (1992), Bajo (2000) and Aschauer (2000), among others.

The results show some improvement in the speed of efficiency level convergence for the entire economy, given the fact that coefficient b continues to be negative and, in addition, increases, perhaps indicating the favourable effects of this capital. However, the role of public capital and capital invested in education as conditioning factors on efficiency convergence in all the countries was not confirmed, since none of the variables were significant.

Groups I and III should be highlighted. These two groups include the countries with greater and lesser efficiency levels, respectively, and they show a greater intensity of convergence, which could perhaps be interpreted as a polarization of convergence at the furthest points. Thus, the countries closer to and farther from the technological frontier show greater technological assimilation. As to the variables introduced as conditions, a favourable effect can be observed. However, capital in education is not significant and, in the case of capital in infrastructures, the effect is irregular due to the fact that in more efficient countries a positive sign is obtained for its coefficient and, in the less efficient countries, the sign is negative. As to the evidence obtained for Group II, the lack of convergence among countries should be highlighted, although it is the only group in which the coefficients of public and human capital are significant.

5. CONCLUSIONES.

The measurement and analysis of technical efficiency in economic activity allow us to extract information concerning the behavior and possibilities of growth in European countries, as well as the factors contributing to its improvement. To carry out this estimation, frontier techniques have been employed, taking into consideration the role of public policies in European countries. The evolution of these policies in the European Union has situated public investment in infrastructures and investment in education as the centre of its action and, at the same time, it has aroused interest in the effects that this capital has had on the economy and the effectiveness of the instruments employed.

Our findings contribute positive evidence as to the effectiveness of public capital as an instrument of public policy. In addition, the difficulty of establishing the ways in which human capital affects production has been highlighted. The process of economic and monetary integration has introduced more competence in economic activities, and, in this context, equating public capital endowments in the European Union should be considered a priority; this indicates that the criteria for implementing public investment policies is related, to a great extent, to equity criteria. The evidence obtained shows the negative effect that the public-private capital ratio has on efficiency. Thus, if the priority is stimulation of economic growth, it will be necessary to allocate public investment with growth and efficiency criteria. On the contrary, investment in education favours technological assimilation and, therefore, efficiency gains, favouring the access of productive activities to technical levels in the most efficient countries.

This paper also presents an empirical analysis to determine the existence of a technological catch-up process among countries, although such a process has been conditioned by factors characteristic of European countries. For this reason, the findings point towards the convergence of each territory to its own stationary state. In addition, the catch-up process has taken place largely in countries situated closer to the efficient frontier.

6.BIBLIOGRAPHY:

Abramovitz M. (1994): "Catch-up and convergence in the postwar growth boom and after", in C*onvergence and Productivity, Cross-national studies and Historical evidence*, 86-125,

Alvarez, I. y M.J. Delgado (2002), *Estimación del Capital Público, Capital Privado y Capital Humano para la UE-15*, Documento de Trabajo del Instituto de Estudios Fiscales 12/02, Madrid.

Barro R.J. and X. Sala--Martin (1992): "Convergence". *Journal of Political Economy*, Vol. 100, n°2, pp 223-251.

Battese G.E. and T.J. Coelli (1993): *A Stochastic Frontier Production Function Incorporating a Model for Technical Inefficiency Effects*. Working Papers in Econometrics and Applied Statistics, number 69, Department of Econometrics. University of New England, Armidale.

Battese G.E. and T.J. Coelli (1995): “A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data”. *Empirical Economics,* Vol. 20, pp. 325-332.

Benhabib J. and M.M. Spiegel (1994): The role of human capital in economic development, evidence from aggregate cross-country data”, *Journal of Monetary Eco*nomics, 34, 143-173.

Boisso D, S. Grosskopf and K. Hayes (2000): “ Productivity and Efficiency in the U.S.: Effects of Business Cycles and Public Capital”. *Regional Science and Urban Economics*, 30, 663-681.

Boisvert R. (1982): *The translog production function: Its properties, its several interpretations and estimation problems,* A.E. Res. 82/28, Dept. of Agricultural Economics, Cornell University.

Coelli T.J. (1996): *A Guide to Frontier Version 4.1. : A Computer Program for Stochastic Frontier Production and Cost Function Estimation.* CEPA Working Paper 96/07.

Cordero, G. and A. Gayoso (1996): *El comportamiento de las economías regionales en tres ciclos de la economía española: primera explotación de una serie (1980-1995) del VAB regional a precios constantes (base 1986).* Contabilidad Regional de España, Dirección de Análisis y Programación Presupuestaria, Ministerio de Economía y Hacienda, Madrid.

Cuadrado J.R., T. Mancha-Navarro and R. Garrido-Yserte (2002) “Regional Dynamics in the European Union: Winners and Losers” in *Regional Convergence in the European Uni*on, Cuadrado-Roura J.R. and M. Parellada (Eds), Heildeberg, Springer.

De la Fuente A. and X. Vives (1995): “Infrastructure and Education as Instruments of Regional Policy: Evidence from Spain”. *Economic Policy*, 20, pp 11-54.

De la Fuente, A. (2000): “Infrastructure and Productivity: A Survey”, Instituto de Análisis Económico, Barcelona (mimeo).

Farrell M.J. (1957): “The Measurement of Productive Efficiency”. *Journal of the Royal Statistical Society*. Vol. 120, Part 3, pp. 253-290.

Gumbau M. (1998): “ La Eficiencia Técnica de la Industria Española”. *Revista Española de Economía,* Vol. 15, nº 1, pp. 67-84.

Gumbau M. and J. Maudos (1996): " Eficiencia Productiva Sectorial en las Regiones Españolas: Una Aproximación Frontera". *Revista Española de Economía,* Vol. 13, number 2, pp. 239-260.

Islam N. (1995): "Growth Empirics: A Panel Data Approach". *Quarterly Journal of Economics*, 110, pp 1127-1170.

Kodde D.A. and F.C. Palm (1986): " Wald Criteria for Jointly Testing Equality and Inequality". *Econometrica*, 54, 1243-1248.

Kyriacou G.A. (1991): " Level and Growth Effects of Human Capital: A Cross-Country Study of the Convergence Hypothesis". Unpublished New York University, June 1991.

Lynde C. and J. Richmond (1999): "Productivity and Efficiency in the UK: A Time Series Application of DEA". *Economic Modelling*, 16, pp. 105-122.

Mankiw N.G., D. Romer and D. Weil (1992): " A Contribution to the Empirics of Economics Growth". *Quarterly Journal of Economics,* CVII, pp. 407-437.

Maudos J., J.M. Pastor and L. Serrano (1998a): *Human Capital in OECD Countries: Technical Change, Efficiency and Productivity*. Documento de Trabajo WP-EC-98-19. Instituto Valenciano de Investigaciones Económicas (IVIE).

Maudos J., J.M. Pastor and L. Serrano (1998b): "Convergencia en las Regiones Españolas: Cambio Técnico, Eficiencia y Productividad". *Revista Española de Economía*, Vol. 15, nº 2, pp. 235-264.

Maudos J., J.M. Pastor and L. Serrano (1999): "Total Factor Productivity Measurement and Human Capital in OECD Countries". *Economic Letters,* 63, pp. 39-44

OCDE (1992): Public Educational Expenditure, Costs and Financing: An Analysis of Trends (1970-1988). París.

OCDE (1996). *Panorama Educativo*. París.

OCDE (Varios Años). Education at a Glance. París.

Pedraja F., J. Ramajo and J. Salinas (1999): "Eficiencia Productiva del Sector Industrial Español: Un Análisis Espacial y Sectorial". *Papeles de Economía Española*, nº 80.

Puig-Junoy J. (2001): “Technical Inefficiency and Public Capital in U.S. States: A Stochastic Frontier Approach”. *Journal of Regional Science*, Vol. 41, number 1, 75-96.

Sala-i-Martin X. (1994): “La Riqueza de las Regiones. Evidencia y Teorías sobre Crecimiento Regional y Convergencia”.*Moneda y Crédito*, 198, pp. 13-80.

Sala-i-Martin X. (1996a): “The Classical Approach to Convergence Analysis”. *Economic Journal*, 106, pp. 1019-1036.

Sala-i-Martin X. (1996b): “Regional Cohesion Evidence and Theories of Regional Growth and Convergence”. *European Economic Review*, 40, pp 1325-1352.

Salinas M.M., F. Pedraja and J. Salinas (2002): “Efectos del Capital Público y del Capital Humano sobre la Productividad de las Regiones Españolas”, *Papeles de Economía Española*, 93, 135-147.

Serrano L. (1996): Indicadores de capital humano y productividad, Revista de Economía Aplicada, 10 (vol. IV), 177-190.

Temple J.R.W. (1998): “Robustness Tests of Augmented Solow Model”. *Journal of Applied* Econometrics, 13(4), July-August, 361-375.