Autor(es): Alfredo Moreno Sáez, José Luis Montes Botella y David Trillo del Pozo

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Alfredo Moreno Sáez (Universidad Complutense de Madrid)

José Luis Montes Botella (Universidad Rey Juan Carlos)

David Trillo del Pozo (Universidad Rey Juan Carlos)

MEASURING THE TECHNICAL EFFICIENCY TROUGH MAXIMUM LIKELIHOOD MODELS: A COMPARISON BETWEEN ALTERNA-TIVE SPECIFICATIONS APPLIED TO A UNIVERSITY

Montes Botella, José Luis; Moreno Sáez, Alfredo and Trillo del Pozo, David

jlmontes@poseidon.fcjs.urjc.es ; eciop24@sis.ucm.es ; trillo@poseidon.fcjs.urjc.es

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Keywords: Stochastic frontier. Maximum likelihood. Efficiency. Panel data. Higher education.

Index:

1. INTRODUCTION

The analysis of institutional efficiency is a field of study and interest for researchers in Applied Economics, Statistics, Mathematics and Operational Research. This is partly explained by its analytic complexity that requires powerful and complex statistical tools and, also, because of the importance granted to this topic by economic doctrine, since its origins are to be found in Pareto´s efficiency concept. Farrell´s (1957) work gave birth to the so-called frontier studies, aiming to obtain an "optimal" production or cost function against indexes that measure the difference between the evaluated company or institution function and the optimal one previously adjusted. The reference frontier is calculated by means of two types of approaches: the non-parametric frontier analysis, termed Data Envelopment Analysis[1] (DEA), and the parametric frontier analysis. It is this last method that we apply in this paper, its objectives being technical or productive efficiency evaluation; that is to say, the degree production obtained from a given input level, independent of its cost.

These model specifications are carried out following the production structure:

Y = ¦(X; b) + v – u

Where ¦(X; b) represents the expression to be adjusted, function of an input vector X and a production technology represented by the parameters vector b[2]. The error structure is dual: the term *v* represents the presence of random errors, and follows a normal distribution N(0, s^2). The term *u* stands for company technical inefficiency and assumptions about a behaviour different to the customary N(0, s^2) distribution are made, being the most habitual the half-normality[3]. To be able to consider non-lineal models and split errors we apply a maximum likelihood estimate.

Seminal models, in cross-section applications, were simultaneously proposed by Aigner, Lovell and Schmidt (1977), Batesse and Corra (1977) and Meeusen and Van de Broeck (1977), although their results did not allow for the estimate of an index representing each company's efficiency. To solve this problem, Jondrow, Lovell, Materov and Schmidt (1982) proposed a firm efficiency estimate method. Batesse and Coelli´s (1992, 1995) and Kumbhakar´s works (1990), among others, extended the previous models to include panel data and fixed or time variable effect cases.

In a higher education environment, different applications have been carried out, from the point of view of institutional costs, mainly in theUnited States and the United Kingdom, e.g. Cohn. *et al*. (1989), Groot *et al*. (1991), Glass *et al*. (1995), Johnes (1995, 1997), and Dundar and Lewis, (1995). However, the contribution of literature concerning scientific production of universities is much more developed in the data envelopment analysis domain, where applications either with department data of only one University (Sinuany-Stern, *et al.*, 1994) or with a homogeneous sample of departments of different universities are reported, as in Johnes, G. and Johnes, J. (1993); Beasley (1990) Athanassopoulos and Shale (1997) and Sarrico *et al*. (2000).

In this paper, we study the efficiency of scientific production of the departments at the Polytechnic University of Catalonia (Spain) through stochastic models. We carry out two types of applications: in the first one we use the Jondrow *et al.* cross-section model for efficiency calculation, considering the1995-1998 period averages and, secondly, we apply the panel data model of Battese and Coelli (1992), proposing a change in the model specifications. In both cases an analysis of sensibility, by means of the comparison of different production structures, is carried out. In the panel data models, different hypothesis are tested in relation to the parameters of evolution efficiency over time.

2. METHODOLOGY

Our aim is to discover a functional relationship between the volume (PUBL) of remarkable publications[4] (dependent variable) and the faculty's dedication level[5] (RESTIME), as well as the Department Research Funds [6] (RESFUND). The available information is a panel data, composed of 38 Departments, and four time periods (from 1995 to 1998). The model parameters estimate using Ordinary Least Squares (O.L.S.) will provide inefficient estimators even when all the hypotheses in which the properties of unbiassnes, efficiency and consistency are sustained. For this reason, we propose the following alternatives:

2.1. Static analysis

A first approach to the problem of the panel data estimate is to obtain the four year average for the variables, and to carry out a non-dynamic estimate.

Considering the production function:

$$LPUBL_i = f(LRESTIME_i; LRESFUND_i; \mathbf{b}) + E_i$$

Where $PUBL_i$ represents the points assigned to the remarkable research activity of the *i*th Department. f ($LRESTIME_i$; $LRESFUND_i$; **b**) is a suitable function of the two explanatory variables, representing the factor inputs associated with the *i*th department "remarkable publications". **b** is a vector of unknown parameters. E_{it} is the error term for the *i*th observation. The "stochastic frontier" (also called "composed error") model, introduced by Aigner, Lovell and Schidt (1977) and Meeusen and Van den Broeck (1977), postulates that the error term E_i is made up of two independent components:

$$E_i = V_i - U_i$$

Where V_i that follows a N(0; s_v), is a two-sided error term representing the usual statistical noise found in any relationship, while U_i is strictly positive, and represents the technical inefficiency measures that is the shortfall of output ($PUBL_i$).

Following Aigner, Lovell and Schmidt (1977), the density function of E_i is:

$$f(E_i) = \frac{2}{\sqrt{2\pi(\sigma_u^2+\sigma_v^2)}}\left[1-F\left(E_i\frac{\sigma_u/\sigma_v}{\sqrt{\sigma_u^2+\sigma_v^2}}\right)\right]e^{\frac{-1}{2(\sigma_u^2+\sigma_v^2)}E_i^2}$$

Where F is the standard normal distribution function. Therefore, the likelihood function for a n size sample is:

$$L(\mathbf{X};\mathbf{E}) = \left(\frac{2}{\sqrt{2\pi(\sigma_u^2+\sigma_v^2)}}\right)^N\prod_{i=1}^{N}\left[1-F\left(E_i\frac{\sigma_u/\sigma_v}{\sqrt{\sigma_u^2+\sigma_v^2}}\right)\right]e^{\frac{-1}{2(\sigma_u^2+\sigma_v^2)}\sum_{i=1}^{N}E_i^2}$$

consequently Ln(*L*(X;E)), the second likelihood function is:

$$NLn(2)-NLn\left(\sqrt{2\pi(\sigma_u^2+\sigma_v^2)}\right)+\sum_{i=1}^{N}\left[1-F\left(E_i\frac{\sigma_u/\sigma_v}{\sqrt{\sigma_u^2+\sigma_v^2}}\right)\right]-\frac{1}{2(\sigma_u^2+\sigma_v^2)}\sum_{i=1}^{N}E_i^2 \quad (1)$$

function to be maximized, after considering a functional expression for the model relating PUBL with RESTIME. In this functional expression the residuals are different, depending on the selected function, and therefore the number of parameters as well as the results of the likelihood function maximization are also different.

2.1.1. Considered production functions

a) Cobb-Doublas function:

The main property of this function is the constant marginal substitution rate between inputs, since the partial derivatives are constant.

The first specification to adjust is:

$$PUBL_i = Ln(A) * DEDINV_i^{B1} PPTO_i^{B2}$$

Then the natural logarithm Ln is:

$$LPUBL_i = A + B1{*}LRESTIME_i + B2{*}LRESFUND_i + E_i \quad (2)$$

With $LRESTIME_i$ = Ln($RESTIME_i$) and $LRESFUND_i$ = Ln($RESFUND_i$), while A, B1 and B2 are parameters to estimate.

b) Translogarithmic function:

It is a generalization of Cobb-Douglas´ function, considering the squared variables as regressor. We consider the function to be estimated:

$LPUBL_i$=A+B1*LRESTIME+B2*LRESFUND+

B11*($LRESTIME^2$)+B22*($LRESFUND^2$)+ B12*LRESTIME*LRESFUND (3)

With $LRESTIME_i$ = Ln($RESTIME_i$) and $LRESFUND_i$ = Ln($RESFUND_i$), while A, B1, B2, B11, B22, and B12 are parameters to estimate.

This function is assumed to satisfy monotonicity and convexity conditions. Nevertheless, the partial derivatives are not fixed. This feature makes the translog function more flexible than the Cobb-Douglas function.

c) C.E.S. function:

The third alternative is to use the constant elasticity of substitution (C.E.S.) function, because it allows for the possibility for some firms to produce zero levels of a subset of outputs (thus reducing estimated costs to zero), thus rendering this unappealing**,** as Baumol, Panzar and Willig (1982) suggest. The proposed C.E.S. function is:

$LPUBL_i$=A+(B1*$LRESTIME^{G1}$ +B2*$LRESFUND^{G2}$ $)^{RO}$

With $LRESTIME_i$ = Ln($RESTIME_i$) and $LRESFUND_i$ = Ln($RESFUND_i$), where A, B1, B2, G1, G2, and RO are parameters to estimate.

2.1.2. Expressions of the static model efficiencies

The adjusted models allow us to know the existent causality among the variables of the production frontier. However, it is necessary to use an additional procedure to know the deviation of a concrete firm in relation to the calculated frontier. Lovell *et al.*(1982) proceed by considering the conditional distribution of U_i given E_i. This distribution contains whatever information E_i yields about U_i. For the half-normal assumption for U_i of this paper, the expression of the *i*th department efficiency is:

$$\frac{\sigma_u \sigma_v}{\sigma}\left[\frac{\frac{1}{\sqrt{2\pi}}e^{\frac{-1}{2}\left(E_i\frac{\sigma_u/\sigma_v}{\sqrt{\sigma_u^2+\sigma_v^2}}\right)^2}}{1-F\left(E_i\frac{\sigma_u/\sigma_v}{\sqrt{\sigma_u^2+\sigma_v^2}}\right)}-E_i\frac{\sigma_u/\sigma_v}{\sqrt{\sigma_u^2+\sigma_v^2}}\right]$$

2.2. Dynamic analysis: Treatment of panel data

To use the average of the considered variables in the four available years to estimate the proposed model implies a misuse of the available information, being more appropriate to use the panel of data to carry out the estimate.

Considering a production function:

$LPUBL_{it} = f(RESTIME_{it}; LRESFUND_{i}; \mathbf{b}) + E_{it}$

Where $PUBL_{it}$ represents the “remarkable publications” for the *i*th firm at the *t*th observation period; $f(RESTIME_{it}; LRESFUND_{it}; \mathbf{b})$ is a suitable function of the two explanatory variables representing the factor inputs associated with the “remarkable publications” of the *i*th department in the observation period *t*th; **b** is a vector of unknown parameters; E_{it} is the error term for the *i*th observation in the *t*th period. The error term E_{it} is made up of two independent components:

$$E_{it} = V_{it} - h_{it} U_{it}$$

Where V_{it} is N(0; σ_v^2) distributed, that is a two-sided error term representing the usual statistical noise found in any relationship; U_{it} is assumed to be independent and identically distributed non-negative truncations of N(MU, s^2), following Battese and Coelli (1992), where MU, s and s_v are parameters to be estimated, and h_{it} is a behaviour specification of the department effects over time.

The density function of E_i is:

$$f(E_i) = \frac{\left[1 - F\left(\frac{\eta_i^T E_i \sigma^2 - \mu\sigma_v^2}{\sigma_v \sigma \sqrt{\sigma_v^2 + \eta_i^T \eta_i \sigma^2}}\right)\right] e^{-\frac{1}{2}\left[\frac{E_i^T E_i}{\sigma_v^2} + \left(\frac{\mu}{\sigma}\right)^2 + \left(\frac{\eta_i^T E_i \sigma^2 - \mu\sigma_v^2}{\sigma\sigma_v \sqrt{\sigma_v^2 + \eta_i^T \eta_i \sigma^2}}\right)^2\right]}}{(2\pi)^{S/2} \sigma_v^{S-1} \sqrt{\sigma_v^2 + \eta_i^T \eta_i \sigma^2} \left(1 - F\left(\frac{-\mu}{\sigma}\right)\right)}$$

Where F is the standard normal distribution function, S the number of time periods; $E_i = LPUBL_i - f(RESTIME_{it}; LRESFUND_i; \mathbf{b})$, es a (Sx1) vector and represents the error term for the *i*th department in each of the S considered periods; η_i is a (Sx1) vector and represents the functional specification of firm efficiency evolution over time.

Therefore, the likelihood function for a sample of n departments is:

$$\left[(2\pi)^{S/2} \sigma_v^{S-1} \left(1 - F\left(\frac{-\mu}{\sigma}\right)\right)\right]^{-N} e^{-\frac{1}{2}\sum_{i=1}^{N}\left[\frac{E_i^T E_i}{\sigma_v^2} + \left(\frac{\mu}{\sigma}\right)^2 + \left(\frac{\eta_i^T E_i \sigma^2 - \mu\sigma_v^2}{\sigma\sigma_v \sqrt{\sigma_v^2 + \eta_i^T \eta_i \sigma^2}}\right)^2\right]} \prod_{i=1}^{N}\left[\frac{1 - F\left(\frac{\eta_i^T E_i \sigma^2 - \mu\sigma_v^2}{\sigma_v \sigma \sqrt{\sigma_v^2 + \eta_i^T \eta_i \sigma^2}}\right)}{\sqrt{\sigma_v^2 + \eta_i^T \eta_i \sigma^2}}\right]$$

Consequently, Ln(*L*(**X**;**E**)), the second likelihood function is:

$$-N\frac{S}{2}\mathrm{Ln}(2\pi)-N(S-1)\mathrm{Ln}(\sigma_v)\ -N\left(1-F\left(\frac{-\mu}{\sigma}\right)\right)\ -\frac{1}{2}\mathrm{Ln}\left(\sigma_v^2+\eta_i^T\eta_i\sigma^2\right)+$$

$$+\sum_{i=1}^{N}\mathrm{Ln}\left[1-F\left(\frac{\eta_i^T E_i\sigma^2-\mu\sigma_v^2}{\sigma_v\sigma\sqrt{\sigma_v^2+\eta_i^T\eta_i\sigma^2}}\right)\right]\ -\frac{1}{2}\sum_{i=1}^{N}\frac{E_i^T E_i}{\sigma_v^2}-$$

$$-\frac{1}{2}\sum_{i=1}^{N}\left(\frac{\mu}{\sigma}\right)^2-\frac{1}{2}\sum_{i=1}^{N}\left(\frac{\eta_i^T E_i\sigma^2-\mu\sigma_v^2}{\sigma\sigma_v\sqrt{\sigma_v^2+\eta_i^T\eta_i\sigma^2}}\right)^2$$

which is the function to be maximized

Next we describe the necessary modifications to analyse efficiency evolution considering cases of fixed and variable effects. In the last place, we distinguish different formulations for inefficiency variability over time.

2.2.1. Fixed effects

When $h_{it} = 1$, efficiency effects over time are fixed.

In this case, the E_i density function is:

$$f(E_i) = \frac{\left(1-F\left(\frac{\sum_{t=1}^{S}E_{it}\sigma^2-\mu\sigma_v^2}{\sigma_v\sigma\sqrt{\sigma_v^2+S\sigma^2}}\right)\right)e^{-\frac{1}{2}\left[\frac{\sum_{i=1}^{N}\sum_{t=1}^{S}E_{it}^2}{\sigma_v^2}+\left(\frac{\mu}{\sigma}\right)^2+\left(\frac{\sum_{t=1}^{S}E_{it}\sigma^2-\mu\sigma_v^2}{\sigma\sigma_v\sqrt{\sigma_v^2+S\sigma^2}}\right)^2\right]}}{(2\pi)^{S/2}\sigma_v^{S-1}\sqrt{\sigma_v^2+\sum_{t=1}^{S}S\sigma^2}\left(1-F\left(\frac{-\mu}{\sigma}\right)\right)}$$

And the second likelihood function is the next:

$$-N\frac{S}{2}\mathrm{Ln}(2\pi)-N(S-1)\mathrm{Ln}(\sigma_v)\ -N\left(1-F\left(\frac{-\mu}{\sigma}\right)\right)\ -\frac{1}{2}\mathrm{Ln}\left(\sigma_v^2+S\sigma^2\right)+$$

$$+\sum_{i=1}^{N} \mathrm{Ln}\left[1-F\left(\frac{\sum_{t=1}^{S} E_{it}\sigma^2-\mu\sigma_v^2}{\sigma_v\sigma\sqrt{\sigma_v^2+S\sigma^2}}\right)\right]-\frac{1}{2\sigma_v^2}\sum_{i=1}^{N}\sum_{t=1}^{S}E_{it}^2-$$

$$-\frac{1}{2}\sum_{i=1}^{N}\left(\frac{\mu}{\sigma}\right)^2-\frac{1}{2}\sum_{i=1}^{N}\left(\frac{\sum_{t=1}^{S} E_{it}\sigma^2-\mu\sigma_v^2}{\sigma\sigma_v\sqrt{\sigma_v^2+S\sigma^2}}\right)^2$$

2.2.2. Lineal variable effects

In this case, h_{it} = $1+\eta(t-S)$ is a lineal specification of efficiency evolution, in which technical efficiency must either increase at a positive rate (h>0), or decrease at an negative rate (h>0) or remain constant at a zero rate (h=0).

The E_i density function is:

$$f(E_i) = \frac{\left[1-F\left(\frac{\sum_{t=1}^{S}(1+\eta(t-S)E_i)\sigma^2-\mu\sigma_v^2}{\sigma_v\sigma\sqrt{\sigma_v^2+\sum_{t=1}^{S}(1+\eta(t-S))^2\sigma^2}}\right)\right] e^{-\frac{1}{2}\left[\frac{E_i^T E_i}{\sigma_v^2}+\left(\frac{\mu}{\sigma}\right)^2+\left(\frac{\sum_{t=1}^{S}(1+\eta(t-S)E_i)E_{it}\sigma^2-\mu\sigma_v^2}{\sigma\sigma_v\sqrt{\sigma_v^2+\sum_{t=1}^{S}(1+\eta(t-S))^2\sigma^2}}\right)^2\right]}}{(2\pi)^{S/2}\sigma_v^{S-1}\sqrt{\sigma_v^2+\sum_{t=1}^{S}(1+\eta(t-S))^2\sigma^2}\left(1-F\left(\frac{-\mu}{\sigma}\right)\right)}$$

And the second likelihood function is the following:

$$-N\frac{S}{2}\mathrm{Ln}(2\pi)-N(S-1)\mathrm{Ln}(\sigma_v)\ -N\left(1-F\left(\frac{-\mu}{\sigma}\right)\right)\ -\frac{1}{2}\mathrm{Ln}\left(\sigma_v^2+\sum_{t=1}^{S}(1+\eta(t-S))^2\sigma^2\right)+$$

$$+\sum_{i=1}^{N} Ln\left[1-F\left(\frac{\sum_{t=1}^{S}\left(1+\eta(t-S)E_i\right)\sigma^2-\mu\sigma_v^2}{\sigma_v\sigma\sqrt{\sigma_v^2+\sum_{t=1}^{S}\left(1+\eta(t-S)\right)^2\sigma^2}}\right)\right]-\frac{1}{2\sigma_v^2}\sum_{i=1}^{N}\sum_{t=1}^{S}E_{it}^2-$$

$$-\frac{1}{2}\sum_{i=1}^{N}\left(\frac{\mu}{\sigma}\right)^2-\frac{1}{2}\sum_{i=1}^{N}\left(\frac{\sum_{t=1}^{S}\left(1+\eta(t-S)E_i\right)\sigma^2-\mu\sigma_v^2}{\sigma\sigma_v\sqrt{\sigma_v^2+\sum_{t=1}^{S}\left(1+\eta(t-S)\right)^2\sigma^2}}\right)^2$$

2.2.3. Exponential variable effects

In this case $h_{it} = e^{-\eta(t-S)}$ is an exponential specification of the behavior of the firm effects over time, technical efficiency must either increase at a negative rate (h<0), decrease at an positive rate (h>0) or remain constant at an zero rate (h=0).

Then, the density function of E_i is:

$$f(E_i) = \frac{1-F\left(\frac{\sum_{t=1}^{S}e^{-\eta(t-S)}E_{it}\sigma^2-\mu\sigma_v^2}{\sigma_v\sigma\sqrt{\sigma_v^2+\sum_{t=1}^{S}e^{-2\eta(t-S)}\sigma^2}}\right)e^{-\frac{1}{2}\left[\frac{\sum_{i=1}^{N}\sum_{t=1}^{S}E_{it}^2}{\sigma_v^2}+\left(\frac{\mu}{\sigma}\right)^2+\left(\frac{\sum_{t=1}^{S}e^{-\eta(t-S)}E_{it}\sigma^2-\mu\sigma_v^2}{\sigma\sigma_v\sqrt{\sigma_v^2+\sum_{t=1}^{S}e^{-2\eta(t-S)}\sigma^2}}\right)^2\right]}}{(2\pi)^{S/2}\sigma_v^{S-1}\sqrt{\sigma_v^2+\sum_{t=1}^{S}e^{-2\eta(t-S)}\sigma^2}\left(1-F\left(\frac{-\mu}{\sigma}\right)\right)}$$

And the second next likelihood function:

$$-N\frac{S}{2}Ln(2\pi)-N(S-1)Ln(\sigma_v)\;-N\left(1-F\left(\frac{-\mu}{\sigma}\right)\right)\;-\frac{1}{2}Ln\left(\sigma_v^2+\sum_{t=1}^{S}e^{-2\eta(t-S)}\sigma^2\right)+$$

$$+\sum_{i=1}^{N} \mathrm{Ln}\left[1-F\left(\frac{\sum_{t=1}^{S} e^{-\eta(t-S)} E_{it}\sigma^2 - \mu\sigma_v^2}{\sigma_v \sigma \sqrt{\sigma_v^2 + \sum_{t=1}^{S} e^{-2\eta(t-S)}\sigma^2}}\right)\right] - \frac{1}{2\sigma_v^2}\sum_{i=1}^{N}\sum_{t=1}^{S} E_{it}^2 -$$

$$-\frac{1}{2}\sum_{i=1}^{N}\left(\frac{\mu}{\sigma}\right)^2 - \frac{1}{2}\sum_{i=1}^{N}\left(\frac{\sum_{t=1}^{S} e^{-\eta(t-S)} E_{it}\sigma^2 - \mu\sigma_v^2}{\sigma\sigma_v \sqrt{\sigma_v^2 + \sum_{t=1}^{S} e^{-2\eta(t-S)}\sigma^2}}\right)^2$$

I.1. 2.2.4. Dynamic model efficiencies expressions

Battesse and Coelli (1992) after Lovell *et al.* (1982) adapt the panel database calculation and include the time effects in the efficiency expression. For the *t*th time and *i*th department is:

$$\frac{1-F\left(\frac{\eta_{it}\sigma_v\sigma}{\sqrt{\sigma_v^2+\eta_i^T\eta_i\sigma^2}} + \frac{\eta_i^T E_i \sigma^2 - \mu\sigma_v^2}{\sigma_v\sigma\sqrt{\sigma_v^2+\eta_i^T\eta_i\sigma^2}}\right)}{1-F\left(\frac{\eta_i^T E_i \sigma^2 - \mu\sigma_v^2}{\sigma_v\sigma\sqrt{\sigma_v^2+\eta_i^T\eta_i\sigma^2}}\right)} e^{\eta_{it}\frac{\eta_i^T E_i\sigma^2 - \mu\sigma_v^2}{\sigma_v^2+\eta_i^T\eta_i\sigma^2} + \frac{1}{2}\eta_{it}^2\frac{\sigma_v^2\sigma^2}{\sigma_v^2+\eta_i^T\eta_i\sigma^2}}$$

3. RESULTS

3.1. Static analysis

The O.L.S. regression analysis (chart I) shows a high level of confidence in the LRESTIME variable as an explanatory factor of the “remarkable publications” number, while LRESFUND is significant at 94,8%. The regression analysis is carried out in order to estimate the parameters as initial conditions of the posterior maximum likelihood estimates.

With these results, we proceeded to a maximum likelihood estimate of a Cobb-Douglas´ function adjusted specification, but splitting the residuals in two, a normal and a half-normal component following Aigner, Lovell and Schmidt (1977). In this estimate it can be observed (chart II) that the two variables introduced are clearly explanatory, although the variance of the normal component is not significant, meaning that the residuals follow a half-normal distribution truncated in the zero value. Problems of collineality are not detected among the regressors, since the correlations among the parameters are not excessively large.

As a generalization of the Cobb-Douglas based specification, a translogarithmic function is proposed, under the same assumptions of residual decomposition, and estimated in the same way through maximum likelihood (chart

III), so as to obtain clearly significant parameters, and validating the fact that the variances of both components of the residuals are significantly different from zero, confirming the assumption carried out by its distribution. It was be observed that the correlations among the estimates are larger that in the previous estimate, causing multicollineality problems; that is, imprecision in the estimates of each of the parameters, although the precision of the combined adjustment does maintain its validity, and can be used to carry out predictions concerning the endogenous variable.

The last estimate that is carried out in relation to the average of the four year variables (chart IV) is a C.E.S. function based specification obtaining, in the same way, that all the parameters are significant, including the two error terms standard deviations in which the perturbations are disaggregated. This estimate should be taken with good judgment, since the correlations among parameters are quite large.

3.2. Dynamic analysis

The Panel data estimate allows for the introduction of more information in the model, to test the static model results, and, simultaneously, to establish hypothesis concerning the evolution of technical efficiency.

Using the assumptions of residual desaggregation described in epigraph 2.2, we proceed to estimate panel data maximum likelihood, using a specification based on the Cobb-Douglas function, but assuming fixed effects; that is, the residuals do not suffer an evolution caused by the course of the time. In this estimate (chart V), it is observed that LRESTIME is influential upon the value of the endogenous variable, but LRESFUND is not. It can be also be observed that the average as well as the typical deviation (MU and SIG) of the residual component distributed as a truncated normal significantly equals zero. Thus we can deduce that in this specification an error term division is unnecessary and the usual residual normality assumption is valid. Moreover, the correlations between the parameters are not excessively high, therefore severe multicollineality problems should not exist.

The following analysis consists of relaxing the assumption of invariability of the residuals over time, considering that these evolve linearly (chart VI). In this case LRESTIME is explanatory of LPUBL, but non LRESTIME. On the other hand, by means of the functional specification that represents the evolution of residuals over time, the typical deviation of the residual component, distributed as a truncated half-normal, is significant although its average again equals zero.

The following estimate is identical to the previous one, but assuming that the expression modelling the temporal evolution of residuals is exponential instead of lineal, obtaining a very similar result to the previous analysis, but with the ET parameter positive, a logical result, since, in the exponential specification, the parameter interpretation is of opposite sign to the lineal one (chart VII). The likelihood function value corresponding to the lineal specification is slightly higher than that of the exponential one, suggesting an adjustment better adapted to the first assumption.

As a generalization of this last specification, based on the Cobb-Douglas function, we propose a translogarithmic function, with the assumptions of decomposition as in the previous analysis, considering again that these evolve over time according to an exponential function. The results (chart VIII) of this estimate shows that all the parameters of the proposed function, except those related to the interaction of the two explanatory variables, are 95% significant. It is also observed that, as in previous estimates, the average of the residual component with truncated normal distribution significantly equals zero, although the typical deviation is significantly different to zero, so as to affirm that this component is half-normal adjusted. Given the high correlations between parameters, the values of the individual estimates of parameters should be taken with caution.

3.3. Efficiencies

To conclude, chart IX shows the static model efficiencies and the dynamic model yearly and firm estimates. We use the translog function as a reference, lsince it is the most flexible functional form of those analysed in the dynamic model. To test the homogeneity of both samples we have carried out the Kruskal-Wallis test on the five independent samples of the efficiencies estimates, for each one of the four years panel and the efficiencies corresponding to the static estimate. As chart X shows, the test allows us to accept the null hypothesis of homogeneity of the five studied samples with a level significance of 0,8%**.**

4. CONCLUSIONS

The first aspect to be highlighted is the need to cross the estimates to obtain more reliable results. It is also necessary to prove different functional specifications, since it can aid in knowing the sensibility of the estimated frontier in relation to the functional specification established “a priori”.

In the panel data models it is important to carry out a parameter test on ET to know efficiency evolution. The application of these models would be interesting as an instrument of management, when attempting to motivate positive results in the units in a certain period.

Lastly, the large homogeneity found in the estimates of individual firm efficiencies, in the static model as well as in the dynamic one, allow us to set up groups of units according to their scientific productivity. Departments 2, 6, 13, 20 and 21 are the reference in this aspect, with a level of efficiency superior to 50% in the classification of efficiency. Another group of units (Department 5, 9, 17, 18, 19, 31, 38) has their indexes close to zero. That does not necessarily mean “bad” behaviours. They are atypical units that lack the same productive specialization as the departments better located in the efficiency classification. The interesting thing in this case is that incoherent results are not obtained with the data; that is, none of the units with low scientific productivity in the straightforward analysis of ratios PUBL/RESTIME or PUBL/RESFUND obtain a high score.

An additional study would be to analyse the sensibility of models as proposed in Simar (1992). Another that we seek to carry out is to study the efficiency in Departments, using other variables of production as international congresses (Posters, communications and high-quality reports), thus giving us an idea of the activity of department members and allowing us to test this information with the structure of faculty categories.

Coeficientes[a]

Modelo		Coeficientes no estandarizados		Coeficientes estandarizados	t	Sig.
		B	Error típ.	Beta		
1	(Constante)	-17,405	5,239		-3,322	,002
	LRESTIME	1,570	,474	,465	3,312	,002
	LRESFUND	,597	,297	,282	2,007	,052

a. Variable dependiente: LPUBL

Coeficientes[a]

Modelo		Coeficientes no estandarizados		Coeficientes estandarizados	t	Sig.
		B	Error típ.	Beta		
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	LRESTIME	1,570	,474	,465	3,312	,002
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a. Variable dependiente: LPUBL

Coeficientes[a]

Modelo		Coeficientes no estandarizados		Coeficientes estandarizados	t	Sig.
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1	(Constante)	-17,405	5,239		-3,322	,002
	LRESTIME	1,570	,474	,465	3,312	,002
	LRESFUND	,597	,297	,282	2,007	,052

a. Variable dependiente: LPUBL

Chart I. Lineal regression of LPUBL on LRESTIME and LRESFUND (following Cobb-Douglas function).

Run stopped after 44 major iterations.

Cannot improve on the current point.

Loss function value: -33,429376

			95% Conf. Bounds		95% Trimmed Range	
Parameter	Estimate	Std. Error	Lower	Upper	Lower	Upper
A	-11,499903	,6087069	-12,702716	-10,297090	-13,577833	-10,846109
B1	1,5300815	,0889475	1,3543201	1,7058430	1,4697398	1,5700988
B2	,3792156	,0325455	,3149052	,4435260	,3792021	,4844104
SIGU	2,3666884	,0763336	2,2158522	2,5175246	2,3636049	2,6020859
SIGV	1,000E-11	4,639E-07	-9,166E-07	9,166E-07	1,000E-11	2,608E-10

Bootstrap Correlation Matrix of the Parameter Estimates

	A	B1	B2	SIGU	SIGV
A	1,0000	-,4548	-,6225	-,0847	,2374
B1	-,4548	1,0000	-,4126	,3366	-,9184
B2	-,6225	-,4126	1,0000	-,2369	,5686
SIGU	-,0847	,3366	-,2369	1,0000	-,4836
SIGV	,2374	-,9184	,5686	-,4836	1,0000

Chart II. Maximum likelihood estimate of LPUBL on LRESTIME and LRESFUND, following the function Cobb-Douglas and assuming residual decomposition in normal and a half-normal components.

Run stopped after 96 major iterations.

Cannot improve on the current point.

Loss function value: -45,870154

Parameter	Estimate	Std. Error	95% Conf. Bounds Lower	Upper	95% Trimmed Range Lower	Upper
A	-101,54846	2,3396009	-106,14951	-96,947416	-101,68501	-101,50378
B1	10,4106752	,5113131	9,4051299	11,4162204	10,4010444	10,4445458
B2	7,3813742	,1174762	7,1503463	7,6124022	7,3791505	7,3880815
B11	-1,5237054	,0663737	-1,6542354	-1,3931753	-1,5295489	-1,5218190
B22	-,4167125	,0132200	-,4427109	-,3907141	-,4171151	-,4165761
B12	,0538043	,0023382	,0492060	,0584026	,0537592	,0538695
SIGU	2,2572625	,4310455	1,4095710	3,1049540	2,2563890	2,2650942
SIGV	,0020359	4,985E-04	,0010556	,0030163	1,000E-08	,0020359

Bootstrap Correlation Matrix of the Parameter Estimates

	A	B1	B2	B11	B22	B12	SIGU
A	1,0000	-,9998	-,9991	,9956	,9960	-,9377	,9852
B1	-,9998	1,0000	,9983	-,9965	-,9960	,9436	-,9853
B2	-,9991	,9983	1,0000	-,9922	-,9973	,9313	-,9876
B11	,9956	-,9965	-,9922	1,0000	,9866	-,9559	,9694
B22	,9960	-,9960	-,9973	,9866	1,0000	-,9382	,9946
B12	-,9377	,9436	,9313	-,9559	-,9382	1,0000	-,9187
SIGU	,9852	-,9853	-,9876	,9694	,9946	-,9187	1,0000
SIGV	-,0116	,0113	,0131	-,0119	-,0117	,0101	-,0140

SIGV

A -,0116

B1	,0113
B2	,0131
B11	-,0119
B22	-,0117
B12	,0101
SIGU	-,0140
SIGV	1,0000

Chart III. Maximum likelihood estimate of LPUBL on LRESTIME and LRESFUND, following the translogarithmic function and assuming decomposition of residuals in normal and half-normal components.

Run stopped after 28 major iterations.

Cannot improve on the current point.

Loss function value: -29,134829

			95% Conf. Bounds		95% Trimmed Range	
Parameter	Estimate	Std. Error	Lower	Upper	Lower	Upper
ALPHA	5,6105055	,3051429	5,0104134	6,2105976	4,9355229	6,2442253
B1	,2188026	,0047647	,2094324	,2281728	,2188026	,2188026
G1	-3,7803725	,0331990	-3,8456614	-3,7150835	-3,7803725	-3,7803725
B2	,5382072	,0101054	,5183340	,5580804	,5382072	,5382072
G2	-8,3276349	,0706557	-8,4665861	-8,1886838	-8,3276350	-8,3276349
RO	13,4489531	,1088646	13,2348606	13,6630455	13,4489531	13,4489532
SIGU	3,0255246	,3837597	2,2708251	3,7802241	2,2583250	3,6427886
SIGV	,5927065	,2992198	,0042627	1,1811503	1,000E-08	,9075982

Bootstrap Correlation Matrix of the Parameter Estimates

	ALPHA	B1	G1	B2	G2	RO	SIGU
ALPHA	1,0000	,4534	-,4435	,4527	-,4435	,3554	,5724
B1	,4534	1,0000	-,9759	,9973	-,9759	,8676	,3724
G1	-,4435	-,9759	1,0000	-,9893	1,0000	-,9142	-,3572
B2	,4527	,9973	-,9893	1,0000	-,9893	,8874	,3694
G2	-,4435	-,9759	1,0000	-,9893	1,0000	-,9142	-,3572
RO	,3554	,8676	-,9142	,8874	-,9142	1,0000	,2833
SIGU	,5724	,3724	-,3572	,3694	-,3572	,2833	1,0000
SIGV	-,2860	-,2992	,2870	-,2969	,2870	-,2221	-,2773

SIGV

ALPHA	-,2860
B1	-,2992
G1	,2870
B2	-,2969
G2	,2870
RO	-,2221
SIGU	-,2773
SIGV	1,0000

Chart IV. Maximum likelihood estimate of LPUBL on LRESTIME and LRESFUND, following the C.E.S. function and assuming decomposition of residuals in normal and half-normal components.

Run stopped after 31 major iterations.

Optimal solution found.

Bootstrap statistics based on 210 samples

Loss function value: 239,466732

			95% Conf. Bounds		95% Trimmed Range	
Parameter	Estimate	Std. Error	Lower	Upper	Lower	Upper
A	-25,476619	10,2038596	-45,592298	-5,3609397	-43,120366	-5,3122500
B1	11,7942605	3,1934118	5,4988341	18,0896869	8,2346418	15,6324869
B2	3,0096385	3,3723461	-3,6385353	9,6578122	-3,7715486	9,1144013
SIG	2,3015263	1,9895919	-1,6207142	6,2237668	-3,9422407	5,1509895
SIGV	,8804009	,1582836	,5683638	1,1924379	,6500979	1,1104816
MU	,0997386	8,7421381	-17,134333	17,3338102	-15,981441	24,5728092

Bootstrap Correlation Matrix of the Parameter Estimates

	A	B1	B2	SIG	SIGV	MU
A	1,0000	-,3652	-,8195	,0942	-,0028	-,0601
B1	-,3652	1,0000	-,2253	-,0943	,1485	,0203
B2	-,8195	-,2253	1,0000	-,0706	-,1429	,0739
SIG	,0942	-,0943	-,0706	1,0000	-,0467	-,9617
SIGV	-,0028	,1485	-,1429	-,0467	1,0000	-,0149
MU	-,0601	,0203	,0739	-,9617	-,0149	1,0000

Chart V. Panel data maximum likelihood estimate of LPUBL on LRESTIME and LRESFUND, following the Cobb-Douglas function, assuming fixed effects and decomposition of residuals in normal and truncated components.

Run stopped after 53 major iterations.

Optimal solution found.

Bootstrap statistics based on 280 samples

Loss function value: -232,727306

			95% Conf. Bounds		95% Trimmed Range	
Parameter	Estimate	Std. Error	Lower	Upper	Lower	Upper

A	-4,1904251	5,8920086	-15,788862	7,4080122	-10,904060	7,4614992
B1	1,4671598	,3285499	,8204083	2,1139113	,8130660	2,0159347
B2	,0187315	,1654660	-,3069889	,3444520	-,3303316	,3116943
SIG	1,5877428	,6363900	,3350070	2,8404785	,9818838	3,2475942
SIGV	,8154773	,0750422	,6677564	,9631982	,6262421	,9069653
MU	1,6218525	5,4003293	-9,0087127	12,2524176	-3,9082421	11,3258695
ET	-,1084357	,0439136	-,1948797	-,0219916	-,1943939	-,0282249

Bootstrap Correlation Matrix of the Parameter Estimates

	A	B1	B2	SIG	SIGV	MU	ET
A	1,0000	-,4709	-,4418	-,2462	,0696	,7143	,1349
B1	-,4709	1,0000	-,0450	,0874	-,0323	-,1285	,1670
B2	-,4418	-,0450	1,0000	,0607	,0797	,0030	,0905
SIG	-,2462	,0874	,0607	1,0000	-,2238	-,5831	,2684
SIGV	,0696	-,0323	,0797	-,2238	1,0000	,1793	-,0934
MU	,7143	-,1285	,0030	-,5831	,1793	1,0000	,2984
ET	,1349	,1670	,0905	,2684	-,0934	,2984	1,0000

Chart VI. Panel data maximum likelihood estimate of LPUBL on LRESTIME and LRESFUND, following the Cobb-Douglas function, assuming variable effects of lineal tendency and decomposition of residuals in normal and truncated components.

Run stopped after 20 major iterations.

Cannot improve on the current point.

Loss function value: -232,00619

95% Conf. Bounds

Parameter	Estimate	Std. Error	Lower	Upper
A	-,393243	4,012644	-8,2940836	7,507599
B1	1,444617	0,390915	,6749114	2,214323
B2	,014240	0,166148	-,3129042	0,341384
SIG	1,562559	0,663066	,2569903	2,868129
SIGV	,809561	0,093469	,6255207	0,993602
MU	1,675912	1,102177	-,4942604	3,846084
ET	,100074	0,023884	,0530475	0,147100

Bootstrap Correlation Matrix of the Parameter Estimates

	A	B1	B2	SIG	SIGV	MU	ET
A	1,0000	-,6365	-,7345	-,0447	,0221	,3245	-,0084
B1	-,6365	1,0000	-,0394	,0786	,0228	-,2561	-,0415
B2	-,7345	-,0394	1,0000	-,1080	-,1386	-,0536	-,0177
SIG	-,0447	,0786	-,1080	1,0000	,9504	-,7386	,0520
SIGV	,0221	,0228	-,1386	,9504	1,0000	-,6797	,0349
MU	,3245	-,2561	-,0536	-,7386	-,6797	1,0000	-,3560
ET	-,0084	-,0415	-,0177	,0520	,0349	-,3560	1,0000

Chart VII. Panel data maximum likelihood estimate of LPUBL on LRESTIME and LRESFUND, following the Cobb-Douglas function assuming variable effects of exponential tendency and decomposition of residuals in normal and another truncated components.

Run stopped after 68 major iterations.

Cannot improve on the current point.

Loss function value: -287,34776

95% Conf. Bounds

Parameter	Estimate	Std. Error	Lower	Upper
A	-15,397210	36,032024	-86,2576477	55,4632277
B1	-542,072190	209,241070	-953,5644332	-130,5799468
B2	425,944660	85,858805	257,0953151	594,7940049
B11	272,704490	104,842860	66,5213404	478,8876396
B22	-212,656920	42,976560	-297,1744539	-128,1393861
B12	-,101546	,297546	-,6867001	,4836084
SIG	1,525957	,627161	,2925867	2,7593274
SIGV	0,779088	,084432	,6130509	,9451251
MU	1,734677	1,139141	-,5054432	3,9747980
ET	0,102426	,023586	,0560433	,1488088

Bootstrap Correlation Matrix of the Parameter Estimates

	ALPHA	B1	B2	B11	B22	B12	SIG
ALPHA	1,0000	,0472	,0403	-,0735	-,0625	,9934	-,1343
B1	,0472	1,0000	,9998	-,9996	-,9997	,0635	,0107
B2	,0403	,9998	1,0000	-,9992	-,9998	,0563	,0050
B11	-,0735	-,9996	-,9992	1,0000	,9997	-,0899	-,0072
B22	-,0625	-,9997	-,9998	,9997	1,0000	-,0785	-,0023

B12	,9934	,0635	,0563	-,0899	-,0785	1,0000	-,1248
SIG	-,1343	,0107	,0050	-,0072	-,0023	-,1248	1,0000
SIGV	-,0734	,0 018	-,0062	,0003	,0076	-,0736	,9447
MU	,2983	-,0492	-,0403	,0419	,0343	,2545	-,7273
ET	,0118	,0284	,0192	-,0289	-,0196	,0246	,1083

	SIGV	MU	ET
ALPHA	-,0734	,2983	,0118
B1	,0018	-,0492	,0284
B2	-,0062	-,0403	,0192
B11	,0003	,0419	-,0289
B22	,0076	,0343	-,0196
B12	-,0736	,2545	,0246
SIG	,9447	-,7273	,1083
SIGV	1,0000	-,6478	,0813
MU	-,6478	1,0000	-,4219
ET	,0813	-,4219	1,0000

Chart VIII. Panel data maximum likelihood estimate of LPUBL on LRESTIME and LRESFUND, following the translogarithmic function, assuming variable effects of exponential tendency and decomposition of residuals in normal and truncated components.

Department	**eff.-est. 1**	**eff.-est. 2**	**eff.-est. 3**	**eff.-est. 4**	**eff. static**
1	4.204%	5.675%	7.452%	9.542%	9.177%
2	50.737%	53.872%	56.929%	59.891%	68.848%
3	5.080%	6.732%	8.695%	10.967%	23.207%
4	3.825%	5.212%	6.901%	8.902%	14.429%
5	0.941%	1.470%	2.202%	3.175%	1.532%
6	53.279%	56.324%	59.282%	62.136%	99.545%
7	4.790%	6.385%	8.289%	10.504%	16.815%
8	38.621%	42.049%	45.466%	48.844%	71.915%
9	0.196%	0.357%	0.614%	1.002%	0.207%
10	9.851%	12.241%	14.915%	17.850%	31.205%
11	25.548%	28.935%	32.427%	35.984%	52.165%
12	6.751%	8.703%	10.963%	13.519%	10.760%
13	55.058%	58.035%	60.918%	63.693%	99.005%
14	5.587%	7.336%	9.396%	11.762%	14.223%
15	5.858%	7.657%	9.766%	12.179%	14.657%
16	19.779%	22.965%	26.320%	29.805%	63.507%
17	0.317%	0.551%	0.908%	1.426%	1.200%
18	0.157%	0.292%	0.511%	0.850%	1.035%
19	0.352%	0.606%	0.989%	1.541%	1.837%
20	46.340%	49.610%	52.822%	55.955%	99.475%
21	58.001%	60.857%	63.609%	66.249%	87.869%
22	2.166%	3.119%	4.342%	5.859%	26.525%
23	5.773%	7.556%	9.650%	12.049%	20.731%
24	19.945%	23.138%	26.500%	29.989%	37.413%
25	14.457%	17.305%	20.387%	23.668%	99.239%

26	16.268%	19.251%	22.445%	25.814%	65.307%
27	29.799%	33.253%	36.769%	40.310%	62.832%
28	14.141%	16.964%	20.024%	23.287%	30.586%
29	2.408%	3.432%	4.733%	6.334%	13.616%
30	17.550%	20.616%	23.877%	27.297%	24.050%
31	0.516%	0.854%	1.349%	2.040%	1.711%
32	3.488%	4.795%	6.400%	8.318%	16.465%
33	6.881%	8.855%	11.135%	13.711%	27.403%
34	21.800%	25.074%	28.493%	32.018%	78.550%
35	20.790%	24.022%	27.412%	30.919%	59.426%
36	1.554%	2.311%	3.312%	4.589%	6.317%
37	15.193%	18.098%	21.229%	24.548%	99.459%
38	0.821%	1.299%	1.969%	2.870%	2.664%

Chart IX. Panel data maximum likelihood estimate efficiencies of LPUBL on LRESTIME and LRESFUND, following the translogarithmic function, comparing variable effects of exponential tendency and decomposition of residuals in normal and truncated components, with static estimates of the same variables and functional specification.

Estadísticos de contraste[a,b]

	EFICIENC
Chi-cuadrado	13,861
gl	4
Sig. asintót.	,008

a. Prueba de Kruskal-Wallis

b. Variable de agrupación: AÑO

Chart X. Kruskal-Wallis´ contrast of homogeneity for K samples.

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[1] The analysis DEA uses lineal programming to calculate lineal combinations starting from the best observations of the convex production set.

[2] The strong dependence of the results on the elected production function is one of the main criticism of this model. In this paper alternative specifications will be used to analyse results stability.

[3] It is to consider that the inefficiencies values don't have to group around the observations average. Other common specifications are based on exponential or gamma distribution functions, see Green (1993).

[4] The "remarkable investigation" activity points correspond to published articles cited in the Journal of Citation Report (PUBL), according to the Science Citation Index, since the departments in question form part of a Technical University.

[5] This variable represents the number of teachers classified by faculty categories and multiplied by the legal weekly working time (37,5 hours), discounting effective teaching hours and an estimate of class preparation time (an additional 25% for consolidated teachers and 50% for the teachers with little educational experience e. g. faculty assistants). Other possible explanatory variables as the number of pupils or the educational load have been discarded due to the fact that they present a high correlation with the RESTIME and RESFUND variables.

[6] It is a variable composed of the expense budget data for service maintenance and from the completed investigation projects received income. They are input variables of an intermediate type that logically maintain a certain correlation with the faculty dedication variable. However, this variable as proxy is interesting in that it represents the differences between the departments in relation to production technology (a department with more economic resources can obtain greater quality in its scientific experiments). It should be taken into account than the analyzed departments are largely of engineering, whose research involves an intensive use of technology.