# Efficiency Evaluation in Secondary Schools: the key role of model specification and of *ex post* analysis of results

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ABSTRACT *This paper evaluates the efficiency of a sample of Spanish secondary schools, paying particular attention to the theoretical specification of the measurement model and to the* ex post *analysis of the results, aspects which, despite being of undoubted importance, have nevertheless received little attention in the previous literature on the subject. The paper tries to demonstrate that, in order for a study of this nature to have the minimum solvency, it is the special characteristics of the education production process that must form the basic guidelines to be followed by the researcher. The paper also highlights the characteristics that differentiate the most efficient schools from the least efficient, and emphasises the importance of completing the information supplied by the quantitative methods of educational evaluation (such as data envelopment analysis), with data of a qualitative nature obtained by way of surveys directed at the pupils (customers) and the school decision-makers.*

## Introduction

Over the past 15 years, the economics of education has increasingly directed its efforts towards the study of a topic that had previously received only limited attention, namely the microeconomic evaluation of the internal efficiency of schools, principally those operating in the public sector. In this context, the studies in which the estimations are made using the data envelopment analysis (DEA) method stand out.[1] However, the majority of the works produced to date have concentrated essentially on the measurement methodology itself, to the detriment of a discussion about whether or not this methodology is appropriate for the task and of the care that must be taken when the subject under study is the education sector. This situation, which may be due to the fact that most of these papers have been produced by statisticians and researchers from Schools of Business Studies and Management Science, has given rise, in practice, to the construction of measurement models that are hard to justify from a conceptual point of view, given that they are constructed essentially in function of available data, and whose main objective, as expressly recognised, is to illustrate the most appropriate mathematical treatment in each case.

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The analysis of the specific characteristics presented by the education services production process and of the restrictions that these characteristics impose upon the measurement of the efficiency of education institutions, as well as the discussion of the variables that best represent the teaching activity, have been almost ancillary in these papers, with the exceptions of Thanassoulis and Dunstan (1994) and Lovell *et al.*, (1994). This is somewhat surprising if we bear in mind that their objective is precisely the estimation of the degree of expertise with which the technical process of converting inputs into outputs is carried out.

Against this background, the main object of this paper is to illustrate that measuring the efficiency of the education sector requires a highly detailed breakdown of the education services production process, one which helps to resolve, in a non-arbitrary manner, such important questions as the definition of the most appropriate method to carry out the estimations, the conceptual specification of the measurement model or the interpretation of the rates of efficiency that are obtained. Our view is that the numerous obstacles encountered in the task of evaluating the efficiency of such a particular context can only be successfully overcome on the basis of a thorough knowledge of the reality of the education sector in question. In order to illustrate this point, in this paper, we measure the efficiency of a specific education reality, namely that of the 35 public-sector secondary schools that operate within the province of Zaragoza (Spain) and that taught the University Entrance Exam Course during the academic year 1993–1994.

There are four categories of centres in the sample: on the one hand, rural and urban centres; and, on the other, schools which teach the traditional General Certificate of Education (1970 Law) and those which teach the updated version of this certificate introduced under the terms of the Education Reform Law 1990.[2] This allows us to compare the efficiency between the different groups.

The paper is organised as follows. In the next section, we review the special characteristics of the education services production process and show the restrictions that these impose when trying to evaluate the efficiency of the education sector. The measurement methodology that best adapts to these special characteristics is then discussed in the following section. The subsequent section is devoted to the process of selecting the appropriate variables and the data employed in the empirical study. The results are then presented in the penultimate section. The final section closes the paper with a summary of the main conclusions.

## The Peculiarities of the Education Service's Production Process

One of the most controversial questions in the analysis of the technical efficiency[3] of organisations is the formal characterisation of the production technology of the sector. This task, which is problematic in all areas of application, is particularly difficult in the education sector, given that in this case the technical transformation process is affected by a series of specific circumstances that complicate the explanation of the underlying technical relationships. The aim of this section is to point out these special characteristics and to analyse the restrictions that they impose on the evaluation of education performance. In other words, we seek to establish the basis for the subsequent empirical work.

Although, from a general perspective, the production process that takes place in schools does not differ from that of any other productive unit – a series of physical and human resources being combined to produce an output – a more detailed analysis reveals a set of peculiarities that make this a very particular process. From

among these peculiarities, emphasis should be placed upon the intangible and multiple nature of the output, the time dimension of the production process, the cumulative character of the human learning process, the importance of elements that are exogenous to the education context, the fact that the production process is carried out on the actual pupil, and the heterogeneity of the services transferred to the customer. Let us now consider each one of these in turn.

The first characteristic of the education production process – one which is shared with many service-providing industries, such as health – is the intangible and multiple nature of the output. In fact, the subject of exchange in the education market is not one single good with a physical and directly observable form, but rather an output made up of elements having a diverse nature (knowledge, attitudes, rules of behaviour, values) which are produced in a joint form and are difficult to measure and aggregate. Additionally, the relative importance of each one of these varies in the successive levels of the education pyramid. These characteristics are important because they highlight the aggregation and measurement problems, and they illustrate the difficulty of finding one single representative standard concept of production for all teaching institutions.

Second, many of the components in the production of education only reveal themselves later, once the education years have finished and even throughout the length of an individual's life cycle (attitudes towards life, position on the economic scale, etc.). It is important that we emphasise this circumstance – which adds a time dimension (Woodhall & Blaug, 1968) and, as a consequence, an economic dimension (Cohn & Millman, 1975) to the education production process – because it highlights the impossibility of achieving a complete specification of education production, which must be identified with the complete trajectory of a lifetime.

Third, the production process is cumulative over time so that, as Becker (1964) indicates, the accumulated human capital is converted into an input to produce additional units of capital. This, in turn, has an impact on the afore-mentioned time dimension of the process and complicates the precise delimitation of the net production that is attributable to one education centre or academic level, in that this is contaminated by all the previous years of learning.

Fourth, it must be emphasised that an indeterminate part of the education received by an individual is not the consequence of his passage through the education system, but rather that of his personal experiences, of the communication media or of the relationships that he has had (family, social, friendships). This is known as informal education and, although it does not represent any additional difficulty to the specification of the product, it clearly hampers the exclusive attribution of the changes experienced by the pupil to the education system.

Fifth, we must not lose sight of the fact that the production process is carried out on the customer himself (the pupil), who represents a fundamental input and whose involvement is an authentic determinant of the products obtained (the time dedicated to learning, his interest, his innate capacities). This singularity, which is due, as Becker (1964) states, to the fact that human capital is found incorporated in the person who invests, illustrates the dual role (input and output) of the pupil in the education process; a role that adds an additional complication to the specification of what is truly being provided by the schools. This circumstance, together with the two earlier mentioned characteristics, illustrates the complexity of conceptually delimiting education production. It further shows that a significant effort must be made to filter out what is really provided by each school. Only in this way is it possible to correctly attribute responsibilities in efficiency studies.

Finally, the strategic role of the pupil in the education process reveals the non-homogeneous character of the education process in that, by incorporating the action of the pupil, each 'produced unit' is different from the rest. Furthermore, if it is accepted that different pupils have different learning patterns (Averch *et al.*, 1974), it can immediately be understood that the effects caused by the same education practices and even by the same teacher are different for each pupil, which shows the impossibility of standardising the education production process. These last two properties, heterogeneity and non-standardisation, merit special consideration because they make us aware of the two qualities which, according to Murnane and Nelson (1984), best define education technology, that is to say, its tacit and idiosyncratic character and, as a consequence, the impossibility of finding stable and universal production relationships that are valid for all education institutions.

In summary, these considerations suggest that the education sector has a production process that is hard to disentangle, as well as a multiple and difficult to determine output that is itself influenced by numerous elements which lie outside the formal education context (the socio-economic environment of the family, innate abilities, accumulated human capital, etc.). As a consequence, the attempt to achieve a single, universal and exportable specification of education production technology is shown to be a truly controversial task.

A context as particular as education necessarily conditions the task of measuring the efficiency of its productive units. Specifically, the analysis of the earlier described characteristics allows us to determine a series of basic guidelines, the consideration of which are obligatory if one wishes to correctly understand the scope and limitation of this type of work. First, the intangible character of the production of education and of many of its inputs (the socio-economic environment of the family, the academic quality of the pupil, the quality of the teachers, etc.) requires that we work with proxy variables, therefore renouncing the possibility of measuring the effects exerted by the true variables. Second, the deferred effects of the education process and the cumulative nature of learning eliminates the possibility of defining a complete measurement model that takes all the relevant inputs and outputs into consideration, so that the notion of efficiency must be understood in a relative and partial sense. Third, the idiosyncratic character of the learning process requires a very flexible measurement technique that respects the particular reality of each school. Fourth, the substantial influence that is exerted by elements outside the education context demands that they be incorporated into the evaluation models. At the same time, the specification of education production has to be carried out with great prudence, in an attempt, as we have already mentioned, to measure a net magnitude that exclusively reflects what has actually been contributed by the school under evaluation.

In our view, all these prescriptions, which are derived from the special characteristics of the technology used in the production of education services, must constitute the basic guide when measuring efficiency in the education sphere, and form the basis of the empirical work that we present in the following sections.

## Selection of the Measurement Methodology and Model

One of the first questions to be considered when evaluating efficiency is the definition of the measurement model which best adapts to the peculiarities of the production technology of the sector in question. The aim is to find a method that approximates an empirical production function which can serve as a reference when

making the efficiency estimations. The literature (see Fried *et al.* 1993) distinguishes two basic alternatives for making these estimations. The first, which is parametric in character, bases its calculations on regression techniques. The second, which is non-parametric, rests on mathematical programming. Although both methods seek to identify an empirical production frontier to act as a reference when making these estimations, the restrictions imposed over the technology are different in each case.

The parametric approaches try to explicitly estimate the extreme technical relationship between the inputs and outputs of the decision making units being evaluated, and try to define the residual corresponding to each observation as their inefficiency value. In this way, the estimations depend entirely on the functional form that is assumed. This represents a serious limitation in the education sector where, as we have seen, it is difficult to specify the appropriate model that links the inputs and the outputs. Non-parametric approaches, from among which DEA is the most important, do not impose any functional form. Therefore, the production frontier has a partially implicit character in that, although the productive units that belong to it (i.e. those which obtain an efficiency rate of 100%) are made explicit, the technical relationship that underlies the data is unknown. In this latter case, efficiency scores are obtained by solving a mathematical programming model.[4]

By virtue of its specific characteristics and the peculiarities of the education production process as described earlier, it is our view that DEA is an extremely attractive methodology to employ when making the efficiency estimation of public-sector education centres. We say this essentially for three reasons. First, DEA does not oblige the data to adapt itself to an arbitrary functional form.

Second, DEA respects the individual productive practices of each centre. As Jesson *et al.* (1987) indicate, the importance of DEA lies in the way it allows for local flexibility and choice of objectives, and of the manner in which they are achieved, in assessing efficiency. This is because the envelopment method optimises each observation, i.e. it solves a different problem for each unit–comparing it with those that have similar productive behaviour–and does not impose any subjective and uniform weights structure, i.e. the weights of different inputs and outputs are endogenous. The result is a better fit to each observation, an estimation that is closer to the true but unknown technology that underlies the data, and a more appropriate basis to estimate and identify the sources of inefficiency in each centre (Charnes & Cooper, 1985). While in the case of the parametric methods, single optimisation supposes that the estimated function is applicable to each one of the agencies being evaluated, multiple optimisation permits the underlying production functions to vary between observations.

Third, DEA fits very well with the multiple nature of education production and to the absence of prices that affects public-sector education services. This is due to its capacity to work simultaneously with multiple inputs and outputs without the need to aggregate them into one single variable by way of weights that are hard to justify.

In an idiosyncratic context such as education, in which the differences between the production practices of the organisations could be both important and difficult to understand and standardise, and where, furthermore, there is no consensus on the relative importance of the different productions, the envelopment approach is clearly very appropriate. The imposition of homogeneous and rigid patterns of behaviour, inherent to the parametric approach does not fit well with the nature of education services.

Obtaining efficiency scores by way of DEA can be carried out by solving alternative mathematical programming models that are constructed on the basis of different assumptions on the production frontier. From among these, it is our view that the so-called BCC (Banker, Charnes and Cooper, 1984) model has a structure that is most in accord with the particular education technology. Its analytical structure, in the output orientation[5] version, is as follows:

$$\text{Maximise} \quad \phi_0 + \varepsilon \left( \sum_{i=1}^{m} s_i^+ + \sum_{i=1}^{s} s_r^- \right)$$

$$\text{subject to:} \quad \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^+ = x_{i0} \qquad i = 1, 2, \ldots, m$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^- = \phi_0 y_{r0} \qquad r = 1, 2, \ldots, s$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j \geq 0 \quad s_i^+ \geq 0 \quad s_r^- \geq 0$$

where $x_{ij}$ and $y_{rj}$ represent the quantity of the input $i$ and output $r$, respectively, corresponding to the school $j$ ($j=, 1, 2, \ldots, n$); $\lambda_j$ are, together with $\phi_0$, the variables of the model; $s_i^+$ and $s_r^-$ are the slacks; and $\phi_0$ represents the efficiency score of the unit whose efficiency is being evaluated. Let us now explain the reasons for choosing this model (BCC, output orientation)

The application of the output orientation version indicates that the efficiency of each education centre will be quantified by comparing its activity with other centres that produce higher levels of outputs with the same or fewer resources and the same environmental factors. This version–as compared with that of the input orientation version, which analyses the extent to which the unit being evaluated could reduce its inputs to produce the same output–adapts very well to the characteristics of the public-sector secondary schools, where the degree of control exerted by management over their resources is minimum, being determined by senior levels in the Spanish Public Administration by certain pre-established criteria. Therefore it seems reasonable to suppose that the objectives of school managers will be orientated towards obtaining the best results on the basis of the resources available to them, rather than minimising these resources, over which they exercise no control, a philosophy that is implicit in the output orientation version.

By incorporating the assumption of variable scale returns (the last restriction), the BCC model refers the estimation to a very flexible frontier that gives a high degree of respect of the individual practices of each education centre, at the same time as supplying an estimation of the pure technical efficiency that is not contaminated by the scale of operation. This latter aspect is fundamental in sectors such as education, where there are neither conceptual nor empirical reasons to sustain the assumption of constant, increasing or decreasing returns to scale.

The use of this model implies that the efficiency score ($\phi_0$) will take a value equal to or higher than 1. A score equal to 1, together with nil values for all the slacks, indicates that the centre in question obtains the maximum possible production on the basis of the resources that are available to it and the conditions under which it operates, and, therefore, that it is efficient. A score higher than 1 indicates that the centre in question could increase its production by the proportion

($\phi_0$–1) without altering its current level of resources, under the same external conditions. Thus, an index higher than 1 is an indicator of technical inefficiency.

Really, the two conditions that must be met in order for a centre to be considered efficient are (a) $\phi_0 = 1$ and (b) slacks = 0. This is so because $\phi_0$ only measures the radial efficiency. Thus, it could be the case that a centre could not increase all its outputs radially, but could increase some of them or reduce some of its input, with both of these aspects being reflected by the values of the slacks variables. For more details on these possibilities, see Seiford and Thrall (1990).

## The Selection of the Inputs and Outputs of Secondary Schools

Once the most appropriate measurement technique and mathematical model have been selected, the next stage in efficiency analysis is to define the inputs and outputs to be used when making the estimations. This stage is particularly delicate when the measurement technique is non-parametric given that, in this case, there is no statistical technique available to evaluate the goodness of the selection. The acute sensitivity of the estimations to the variables being incorporated requires that great care be taken in this stage of the process, in an effort to guarantee that the selection properly reflects the productive activity of the centres being evaluated.

### *The Output of Secondary Schools*

The main problems encountered by all studies into education and, above all, by those which seek to evaluate the efficiency of schools, are the conceptualisation and measurement of the output. The peculiarities of education production analysed earlier in this paper demonstrate the impossibility of attaining a single and universal theoretical specification for education production that is valid for all education institutions. For this reason, it seems much more fruitful to consider a partial concept that offers a rigorous representation of the production of a specific education reality and that adapts itself well to the objectives of each specific line of research. The *ad hoc* approach, although less attractive from the formal point of view, appears in this context to be more operative.

When considering secondary education, the specification of education production by reference to the cognitive domain (Bloom *et al.*, 1956) and, particularly, to academic performance in specific subjects, is a very attractive one. This is the case basically for three reasons. First, because the learning of subjects that are proper to the education curriculum itself is supplied almost entirely by the school, as compared with other elements that are representative of the production of education centres, such as the general cognitive (intelligence or creativity) or non-cognitive (sociability, self-respect, etc.) faculties, which are developed both in and outside school.

Second, because the configuration of the product of secondary schools in terms of academic performance fits very well with the activity that is directly carried out in these centres. This activity takes the form of the supply of a set of specific subjects, on the basis of which the pupils directly obtain the knowledge that is related to these subjects; at the same time, they also obtain all the other cognitive and non-cognitive general knowledge provided by schools, albeit as sub-products (Madaus *et al.*, 1979).

Finally, because academic performance correctly reflects one of the main objectives pursued in all secondary schools, namely the preparation of their pupils

for entry into university. In Spain, this requires that the pupils pass an entrance examination that is entirely academic in nature.

Having established the importance of academic performance in the efficiency evaluation of secondary schools, let us now consider its measurement. In this respect, we believe it is fundamental that the selected variables reflect both the quantity and the quality of the academic standards achieved in each centre. With regards to quantity, the most obvious variable is the proportion of pupils who pass the final examination over the total who originally registered for it. We complement this proportion with some other variable that takes into account the quality of what is produced.

With respect to this latter aspect, the variable that finds most support in the literature is the marks obtained by the pupils in the subjects that form the education curriculum. From among the virtues attributed to this measurement, emphasis can be placed on the following: (a) the marks attained represent the best external and independent indicators of what has been learnt and taught in the schools and are, at the same time, important for the pupils when they try to enter higher education levels or the labour market (Marks, 1984); (b) they measure quite precisely two aspects that are of great importance in the evaluation of school and pupil performance, namely the capacity to express oneself in writing, by retaining and appropriately selecting memorised knowledge, and the capacity to apply such knowledge both practically and orally (Fogelman, 1984); (c) they are extremely well regarded by parents, employers, teachers, politicians and pupils (Fogelman, 1984); and (d) they measure the quantity of knowledge that the pupils have obtained in the core subjects of the programme supplied in each school (Madaus *et al.*, 1979).

Despite these advantages, it must nevertheless be said that the marks in themselves do not correctly represent education production. This is so for two reasons: (a) they do not indicate the greater effort involved in educating a larger number of pupils, and (b) to the extent that education expenditures depends on the number of pupils who are registered, their exclusion prejudices larger schools in research devoted to efficiency evaluation.

In summary, all these factors lead us to consider that a correct approach to the production of schools must include information on both the volume and the value of the output, an aspect that has not been taken into account in previous studies that have applied the DEA methodology to the education sphere. The majority of these have concentrated on just one of these variables, thereby providing a partial view of education activity.

In light of all this, we have considered the production of the secondary schools that make up our sample by way of the following variables.

(a) As an approximation of the volume of the output, we define the percentage of pupils who passed the University Entrance Exam, known in Spain as 'selectividad',[6] at the end of the academic year 1993–1994. This percentage is calculated over the number of pupils who registered for the final year of secondary education at the beginning of that academic year. The use of the University Entrance Exam, instead of the examinations set by each centre for their pupils, provides an extremely homogeneous comparison criteria, in that it eliminates the effects of the different pass levels required by each centre. Recourse to a homogeneous test is defended as a generality in all the literature on the evaluation of education. By introducing the total number of registered pupils, rather than those who actually sat the University Entrance Exam, we are seeking, following Thanassoulis and Dunstan (1994), to eliminate possible

strategic behaviour on the part of the centres being evaluated, with these strategies being designed to establish very demanding criteria in the final school year in order to guarantee optimum results in the University Entrance Exam.

(b) As a measure of the quality of what is produced, we take two further variables, namely the ratio between the average mark and the standard deviation in the said University Entrance Exam in the specialities of sciences (mathematics, physics, biology, geology, technical drawing, mechanics, industrial technology and economics) on the one hand, and of arts (language, philosophy, the history of art, Greek, Latin, literature, geography and drawing) on the other.[7]

The incorporation of the standard deviation is designed to give a negative weight to those centres with a greater deviation in the results, and where the average is not representative by virtue of the high dispersion of the marks. This form of considering education production, proposed by Brown and Saks (1975), has not been used in any of the earlier works that have applied DEA to the education context.

*The Determinants of Education Results in Secondary Schools*

The obstacles that must be overcome when specifying the variables of an efficiency model are not limited solely to the production side; rather, they also exert an effect on the determinants of education output. In this case, the main difficulties lie in the isolation of the elements of a truly educational character that have contributed to the formation of the product from those which are exogenous to the school. Although the literature on this is plentiful (see Hanushek, 1986), the conclusions obtained to date are quite contradictory. This is particularly true with respect to the relative importance of the physical and human resources available to the schools, in that the education variables that are regarded as significant in some papers (spending on education, installations, teaching material) are not so regarded in others.

In this regard, the most consistent conclusions emerging from the empirical studies on the determinants of school performance point towards the greater relative importance of human resources, especially the teaching staff, although the results of the works that have tried to give more precision to the qualities (experience, qualification, etc.) that define a good teacher are quite contradictory (Hanushek, 1986). The pre-eminence of the role of the teacher in promoting educational performance is not strange, in the sense that, as Sorensen and Hallinan (1977) indicate, the teacher is the main coordinator of the whole didactic interaction process and the basic determinant of learning opportunities. In any event, and in the sense that the activities of the teachers are highly conditioned by the pupils themselves (Murnane & Nelson, 1984) and are, furthermore, difficult to measure, the identification of their relevance in the education process could have been obscured in applied regression studies, whose objective is to predict general behaviour. However, their importance at a conceptual level is unquestionable.

There is greater consensus with the so-called exogenous inputs, i.e. influences that fall outside the education context under evaluation. In this case, almost all published works confirm their decisive importance in promoting education performance at all levels, with the socio-economic level of the family and the previous education received by the pupil being the prime determinants.

Against this background, what appears to be unquestionable is that, when evaluating the efficiency of education centres, account must be taken not only of the

physical and human resources available to them, but also of the socio-economic situation of the family and the academic quality of their pupils.

The former, called educational inputs, occupy the centre of attention in quantifying the technical efficiency of schools. This is due to the very nature of the idea of efficiency, which relates the resources available to a productive unit with the results obtained, and also to the fact that the true preoccupation of studies that seek to measure efficiency is precisely to detect those educational resources in which each centre could achieve savings without altering its production. This has caused us to incorporate the following two variables into our model:

(a) the operating expenses (excluding personnel costs) per pupil;
(b) the number of teachers per pupil.

Working with relative magnitudes is an attempt to homogenise the size of the centres, as well as to achieve some coherence with the selected output variables, also defined in relative terms.[8]

With respect to the latter (exogenous inputs), i.e. the determinants of education production that fall outside the control of the schools being evaluated here, their incorporation into the evaluation model is obligatory in order to reach estimations that correctly attribute responsibilities. Their exclusion could favour those centres that have a more selective pupil-body and would unfairly prejudice those that operate in a more hostile environment, independent of whether or not their actual efforts respond to this situation. With the inclusion of the external elements, the activity of each school is placed in context, in such a way that only those that achieve the same (higher) production than the rest, with lower (equal) resources and in identical or worse circumstances, are considered as efficient (Banker & Morey, 1986). In the next section, we will analyse the empirical relevance of introducing these context variables in the efficiency evaluation model applied to our sample.

When putting these ideas on the exogenous inputs into practice, we were faced with a lack of adequate disaggregated data that would have allowed us to measure the 'quality' of the pupil-body. For this reason, we carried out a survey of all those pupils coming from the centres under study who could potentially have sat the University Entrance Exam. As a result, we obtained information on a total of 3,189 pupils, who represented more than 65% of those who registered for the final year of secondary education prior to university, a percentage that is high enough for the data obtained to be considered as representative. The questionnaire consisted of 18 questions and its subsequent analysis allowed us to define 12 fundamental variables that are set out in Table 1.

The first four variables try to define the academic quality of the pupil-body (by reference to age, the percentage of pupils not repeating any year in GCE studies, the previous marks and the education aspirations), while the next eight represent the family influence, represented by the proportion of grant-aided pupils (low socio-economic level), the education level and occupation of the parents, the level of studies of older siblings, the education aspirations of the parents and whether or not those surveyed had received additional private tuition. The survey also included questions relative to the degree of satisfaction of the pupils with the school and with the teaching staff, with the answers given to these last questions being commented upon in the section dealing with the interpretation of the results.

**Table 1.** Context variables redefined on the basis of the survey

| Variable | Meaning (percentage of pupils) | Abbreviation |
|---|---|---|
| Academic quality | | |
| Age | Equal to or lower than 18 | AGE |
| Adequate pupil | Has not repeated any year in GCE studies | NOREP |
| Academic record | Has passed the previous course in the June or September exams and with high marks | RECORD |
| Aspirations | Wishes to undertake university studies | ASPIR |
| Socioeconomic level | | |
| Grant | Studies under grant | GRANT |
| Father's occupation | White collar | FAOCCUP |
| Mother's occupation | White collar | MOOCCUP |
| Father's studies | Secondary school or above | FAEDUC |
| Mother's studies | Secondary school or above | MOEDUC |
| Education of older siblings | Has attended university | EDUCSIB |
| Parents' attitude | Want the pupil to study at university | PARATTI |
| Private classes | Receives private classes | PRIVCLASS |

The number of variables in Table 1 is, in any event, very high for inclusion in an envelopment model, given the sample size with which we are working.[9] Therefore, and following the recommendation of Smith and Mayston (1987), we have carried out a principal components analysis, and have thereby identified three factors that together explain more than 74% of the variance of the original data. As can be seen from Table 2, the first of those presents a high positive correlation with the education level and occupation of the parents, and with the

**Table 2.** Correlation coefficients of the variables with the three principal components

| Variable | Factor 1 | Factor 2 | Factor 3 |
|---|---|---|---|
| AGE | −0.21076 | 0.8762 | 0.10236 |
| GRANT | −0.6982 | 0.34731 | 0.17438 |
| RECORD | 0.08308 | 0.77881 | 0.23574 |
| ASPIR | 0.09965 | 0.09041 | 0.92048 |
| PRIVCLASS | 0.31761 | 0.55309 | −0.03653 |
| FAEDUC | 0.9049 | −0.05552 | 0.13435 |
| MOEDUC | 0.84565 | 0.10952 | 0.10851 |
| FAOCCUP | 0.85234 | −0.11754 | 0.14069 |
| MOOCCUP | 0.91122 | 0.28099 | 0.02193 |
| EDUCSIB | 0.78188 | 0.13594 | 0.26217 |
| PARATTI | 0.18789 | 0.30062 | 0.80024 |
| NOREP | −0.07173 | 0.86066 | 0.18538 |
| Explained variance (%) | 38.3 | 25.8 | 10 |

studies of the older siblings, and a negative correlation with the number of grant-aided pupils. These associations therefore indicate that this first factor reflects the overall effect of the socio-economic situation of the family, and thus we have chosen to call it the 'socio-economic component'.

The second factor presents an important positive correlation with the age and the academic record of the pupils, as well as with the proportion of pupils who are not repeating the final year of secondary education. All this reflects the academic quality of the pupil and we have therefore chosen to call it the 'human capital component'.

The third factor distinguishes those centres with a pupil-body that has high education aspirations, which are also encouraged in the family, and we have therefore called this the 'aspirations component'. However, this was eventually eliminated because of the confusing effect that the education literature attributes to the aspirations variable, where it is not clear whether it is an input or an output, and because of its limited contribution to the total variance.

Thus, the variables finally selected to represent the external conditions under which each school carried out its activities were the first two of the aforementioned factors taken from the principal components analysis. This form of incorporating information on variables outside the control of the centre being evaluated, which has not been applied in any of the previous studies on education evaluation using DEA, produces very interesting results in that it allows for the introduction into the analysis of a significant volume of information that is difficult to quantify, but nevertheless fundamental, in an education context. Thus, the estimations will be much richer and will better reflect the reality of each centre being evaluated.

In summary, the efficiency of the secondary school sector operating in the province of Zaragoza was finally estimated on the basis of seven variables. Three of these synthesise production, two the resources available to the school and the other two the socio-economic and academic characteristics of the pupil body. Table 3 summarises the average and standard deviation of all these variables.

**Table 3.** Variables of the efficiency model

| Variable | Average | Standard deviation |
|---|---|---|
| Outputs | | |
| Average mark/standard deviation (sciences) | 2.261 | 0.4653 |
| Average mark/standard deviation (arts) | 2.938 | 0.6929 |
| Percentage of passes over course registration (University Entrance Exam) | 45.02 | 13.27 |
| Inputs | | |
| Operating expenses per pupil | 21,825 | 8,202 |
| Number of teachers per pupil | 0.0774 | 0.0176 |
| Socio-economic factor | 3.7535 | 2.1448 |
| Human capital factor | 3.0817 | 1.7609 |

## Description and Analysis of the Results

In this section, we present and analyse the results obtained from the application of the BCC model to the 35 public-sector secondary schools operating in the province of Zaragoza (Spain) which taught the University Entrance Exam Course during the academic year 1993–1994. Before commenting on them, it should be noted that the selected sample, although meeting all the requirements cited in the DEA literature with respect to the homogeneity of the productive units being evaluated,[10] represents, as we have already mentioned in the introduction, four categories of centres: rural or urban centres, on the one hand, and centres which taught either the traditional general certificate of education (Law 1970) or the updated version introduced under the terms of the Education Reform Law 1990, on the other. This diversity, although small, is nevertheless of great interest, in that it will allow us to compare the efficiency between different groups.

### *The Basic Results of the DEA Model: the efficiency scores*

The first result is obviously the individual efficiency score of each one of the centres being evaluated. In our case, as can be seen in Table 4, the initial resolution of the BCC model confirmed the existence of 23 efficient schools, which represent two-thirds of the total. The average inefficiency of the inefficient schools in higher than 26%, indicating the existence of a significant capacity for potential improvement in the sector.

A first interesting hypothesis to be tested on the basis of these first results is the extent to which the centres identified as inefficient by DEA are perceived as such by their pupils. A comparison of the results of the efficiency model with the answers obtained from the survey of these pupils reveals an interesting result. Of the six most inefficient schools, only one had received favourable answers to the survey questions about the opinion of the pupil body with respect to the school and the teaching staff. In the other five, the majority of the pupils were not satisfied with the school. This result could be very important because it might be indicating that the customers of the education system clearly perceive the realities of their schools. Therefore, evaluation surveys could well be a useful element in the evaluation of education quality.[11]

A second relevant question to be tested is whether there are important divergences between the rates of efficiency in the different types of schools that coexist in the sample, i.e. rural and urban on the one hand, and the two different types of general certificate of education (before and after the 1990 reform) on the other. The result of the comparison is set out in Table 5.

As can be seen, although the efficient and inefficient centres are distributed equally in both the rural and urban areas (67% of the urban centres are efficient, as compared with 64% of the rural centres), the average inefficiency is significantly higher in the rural centres (35% against 20%). This would appear to indicate that although the capacity to work efficiently does not depend upon the location of the centre, the context variables[12] having been introduced, there may nevertheless be differential elements that make the urban centres more efficient. To explain this result, we met with the managers of the Zaragoza Provincial Delegation of the Ministry of Education. Their explanation was that in Zaragoza, the rural centres are much less attractive for the teaching staff than the urban centres, which gives rise to a greater turnover of this teaching staff and, therefore, to unstable teams who are

**Table 4.** Results of the basic DEA model

| DMU | Secondary school | Technical efficiency score | Ranking |
|---|---|---|---|
| 1 | ACTUR | 1 | 1 |
| 2 | ALAGON | 1 | 1 |
| 3 | AVEMPACE | 1 | 1 |
| 4 | AZARA | 1 | 1 |
| 5 | BLECUA | 1 | 1 |
| 6 | BORJA | 1 | 1 |
| 7 | BUÑUEL | 1.0318 | 24 |
| 8 | C.TORRES | 1.075 | 27 |
| 9 | CALATAYUD | 1.0476 | 26 |
| 10 | CARIÑENA | 1 | 1 |
| 11 | CASETAS | 1.122 | 29 |
| 12 | CASPE | 1 | 1 |
| 13 | CINCO VILLAS (EJEA) | 2.3472 | 35 |
| 14 | CORONA DE ARAGON | 1.1767 | 30 |
| 15 | EPILA | 1 | 1 |
| 16 | FUENTES EBRO | 1 | 1 |
| 17 | GARGALLO | 1 | 1 |
| 18 | GOYA | 1 | 1 |
| 19 | GRANDE COVIAN | 1 | 1 |
| 20 | LA ALMUNIA | 1 | 1 |
| 21 | M.MOLINOS | 1 | 1 |
| 22 | MARIA MOLINER | 1 | 1 |
| 23 | MIGUEL CATALAN | 1 | 1 |
| 24 | PEDRO DELUNA | 1 | 1 |
| 25 | PIGNATELLI | 1.2082 | 32 |
| 26 | PILAR LORENGAR | 1 | 1 |
| 27 | PORTILLO | 1.079 | 28 |
| 28 | PUERTA SANCHO. | 1.4246 | 34 |
| 29 | REYES CATOLICOS (EJEA) | 1 | 1 |
| 30 | SERVET | 1 | 1 |
| 31 | TARAZONA | 1.0459 | 25 |
| 32 | TAUSTE | 1.1945 | 31 |
| 33 | VIRGEN DEL PILAR | 1.409 | 33 |
| 34 | ZUERA | 1 | 1 |
| 35 | ZURITA | 1 | 1 |
| | Efficient schools | 23 (67%)* | |
| | Average ratio | 1.0903 | |
| | Minimum value | 1 | |
| | Maximum value | 2.3472 | |

*The number in parentheses indicates the percentage of centres in each category.

less personally involved in the school. According to those surveyed, the rural school is viewed as a transitory professional destination in order to accumulate sufficient points to achieve a transfer to an urban centre. Those aspects highlighted by the literature on effective schools (Reynolds, 1982; Purkey & Smith, 1993; Rutter, 1983) as elements that make good education more difficult, could well explain the lower rates of efficiency obtained by the rural schools in the DEA model.

**Table 5.** Efficiency according to location and pre- and post-1990 Reform GCE

| | Efficient | | Inefficient | | | |
|---|---|---|---|---|---|---|
| | *n* | (%) | *n* | (%) | Average inefficiency* | Total |
| Urban | 14 | (67%) | 7 | (33%) | 20.06% | 21 |
| Rural | 9 | (64%) | 5 | (36%) | 35.14% | 14 |
| Traditional GCE | 19 | (68%) | 9 | (32%) | 13.65% | 28 |
| Reformed GCE | 4 | (57%) | 3 | (43%) | 64.43% | 7 |
| Total | 23 | | 12 | | 26.34% | 35 |

*Calculated over inefficient centres.

The comparison of the rates of efficiency of those centres that taught the traditional general certificate of education and those that taught the up-dated version introduced by the 1990 Law, reveal more important differences, with a distribution that favours the former. The greatest divergence is produced in all cases in the average rates of inefficiency, which are much higher in the centres that taught the new general certificate (64.43% compared with 13.65%). However, when comparing these results, we should not forget the reduced sample size of the centres that taught the up-dated version (only seven), as well as the fact that the academic year being analysed (1993–1994) was the first in which pupils who had studied this new curriculum sat the University of Zaragoza entrance exam. Furthermore, the earlier-mentioned interviews with the managers of the Zaragoza Provincial Delegation indicated that, in this case, the schools that had taught the new curriculum have previously dedicated themselves to vocational training courses rather than academic-based courses and that the majority of their teaching staff had taught subjects that were outside their speciality. This last aspect is important, because it allows us to consider the experience and solidity of the school, and the specialisation of its teaching staff as aspects that favour good performance.

These results must be interpreted with great prudence. We must always bear in mind that although the non-parametric character of the DEA is a great advantage when evaluating performance in the education sector, it does not carry with it any statistic, similar to $R^2$, that allows the goodness of fit of the model to be evaluated *ex post*. The absence of analytical support upon which to base the specification means that the results are highly vulnerable, so that it is fundamental to carry out a sensitivity analysis which confirms their robustness against alternative specifications.[13]

*Analysis of the Sensitivity of the Results*

There are various procedures available to test the consistency of the estimations of efficiency obtained by way of DEA. In this paper, we use two of them, namely the Spearman correlation coefficient and the novel non-parametric test of Pastor *et al.* (1996)-useful to compare nested models, in a complementary manner. The main advantage of the first is its simplicity, although it has the drawback of only providing

information on the variations produced in the ranking and does not consider the individual alterations of the rates of efficiency when making comparisons between different specifications. The second test solves this problem and, indeed, many others posed by non-parametric tests in a DEA context.[14]

The Pastor *et al.* (1996) test compares the estimations of the efficiency of the nested specifications in pairs, and analyses the statistical significance of the divergence between them. In order to do this, it calculates the ratio between these rates ($\rho$) and studies the statistical significance of the divergence of this ratio with respect to 1. Insofar as it is shown that the value $1-\rho$ measures the contribution to efficiency made by the variables contained in the extended model, a value of $\rho$ close to 1 indicates that the additional variables do not significantly change the estimations of the reduced model and, therefore, they can be eliminated. If, by contrast, the values of $\rho$ differ significantly from 1 in a substantial number of cases, then it can be considered that the variables included in the extended model exert a significant influence over the efficiency of the centres being analysed, and therefore must be taken into consideration.

Pursuant to these considerations, and with the objective of evaluating the consistency of our estimations, we propose five alternative specifications of the initial efficiency model (M1). The content of each of these, as well as the results of applying the earlier-described tests, can be found in Table 6.

First, note the decisive influence of the socio-economic and accumulated human capital variables in the estimations of efficiency. The exclusion of the extra-educational variables, reflected in the specification of model M2, leads to a significant change both in the overall ranking (see the reduced Spearman correlation coefficient obtained) and in the individual efficiency scores of a substantial number of centres (as shown by the low *p* value in the Pastor *et al.* test). Furthermore, it is the centres that are confronted with a more hostile environment which experience the greatest falls in individual efficiency rates. This indicates that the extra-educational variables make an important contribution in determining the efficiency

**Table 6.** Alternative specifications of the data envelopment model

| Variable | M1 | M2 | M3 | M4 | M5 | M6 |
|---|---|---|---|---|---|---|
| Expenses/pupil | × | × | × | × | × | × |
| Teachers/pupil | × | × | × | × | × | × |
| Socio-economic factor | × | | × | × | × | × |
| Human capital factor | × | | × | × | × | × |
| Average mark/standard deviation (sciences) | × | × | × | | × | |
| Average mark/standard deviation (arts) | × | × | × | | × | |
| Passes/registrations | × | × | | × | × | × |
| Passes/sat the exam | | | × | | | |
| BCC model (variable returns to scale) | × | × | × | × | | × |
| CCR model (constant returns to scale) | | | | | × | |
| Average mark sciences | | | | × | | |
| Average mark arts | | | | × | | |
| Spearman correlation coefficient | | 0.5083 | 0.8097 | 0.8725 | 0.8454 | 0.6412 |
| *p* value (Pastor *et al.* test) | | 0 | | | 0.5471 | 0.0003 |

This test is only valid for nested models

of the centres being evaluated and, therefore, must be included in the estimation. Otherwise, the estimations of efficiency that are obtained would be contaminated by the different social composition of the pupil body of the different centres.

Second, model M6 reveals the importance of taking into account the marks obtained as an expression of the quality of the education output. Their exclusion from the evaluation model substantially alters the efficiency scores and ranking of schools.

Third, these tests also show the limited relevance for the sample of the percentage of pupils who pass the examination over the number who registered at the beginning of the course, or over those who finally sat the entrance examination (a change reflected in model M3). The high value of the Spearman correlation coefficient in this case shows that the earlier mentioned strategic behaviour does not appear to be important in the public-sector centres being analysed.

Fourth, we can also note the limited role of the standard deviation of the marks in the sample analysed, given that, as the high Spearman correlation coefficient between models M1 and M4 shows, the ranking between centres hardly changes.

The final significant result is the limited importance of the inefficiencies of scale. As the high $p$ value of the Pastor test shows in the comparison of models M1 and M5, a large number of the centres would not alter their efficiency when varying the assumption of returns to scale, i.e. when solving the CCR (Charnes, Cooper and Rhodes, 1978) model, which assumes constant returns.

### *Characteristics of the Best Secondary Schools*

Having confirmed the robustness of the efficiency model applied to the data, it is of interest to determine the main features that characterise the most efficient schools. To that end, we have carried out a series of interviews with the head-teachers responsible for the five best schools detected according to our quantitative analysis. Let us now consider the results that emerge from these conversations.

The objective of these interviews was to capture those features that have a qualitative character–and have not, therefore, been considered in the previous analysis – and that could characterise those centres with a particularly good performance. The head-teachers of each one of the five secondary schools selected were invited to give their opinion on the aspects that they believed could define the good performance of their centre as compared with the rest. We found a significant coincidence in the replies, possibly the fruit of some objective features shared by all of them.

By contrast with those centres that occupy the last places in the efficiency ranking, these five centres have a long experience in the supply of general certificate of education studies and, therefore, have a very stable and highly experienced teaching staff which, in their majority, have fixed and permanent employment at the schools.

A second element, cited very often, was the good working environment or teaching climate, i.e. the good relations between the members of the educational community (between teachers, teachers and pupils, teachers and management, etc.). The lack of pupil conflict, the preoccupation on the part of the centre with results in the University of Zaragoza Entrance Exam (as is shown by the fact that the majority of these centres pay special attention to the teaching staff who teach the final year), the involvement of the management team in the organisation and follow-up of the teaching at the centre, the participation and collaboration of the

Parents Association, the low rates of absenteeism of the teaching staff (in all cases, below average), as well as extra classes for subjects that the pupils have still not passed, were other elements cited in their majority by the head-teachers as being key factors in the success of their schools. Finally, attention should be drawn to the limited importance given to the installations, judged in almost all cases as of low or medium quality. In summary, all these results concur with the conclusions of the line of investigation into effective schools mentioned earlier, and in which emphasis is given to the teaching climate, the continuity of the teaching staff, parental support and limited conflict as decisive factors for the success of the schools.

Finally, we should recall that these centres, again as mentioned earlier, obtained favourable pupil responses to the survey questions on the valuation of the teaching centre and of the teaching staff. Furthermore, the majority of these centres have a pupil body with high educational aspirations, at both personal and family level (the third factor of the principal components analysis), which could also explain their good behaviour on the production side.

## Concluding Remarks

The objective of this paper has been to demonstrate that a correct and useful efficiency estimation of educational institutions – one that goes beyond a mere exercise in the selection of inputs and outputs, and the application of a mathematical technique – requires a highly detailed analysis of the education reality being studied.

On the basis of our study, let us now consider the main conclusions that can be drawn. These refer to two main aspects, namely the specification of the education efficiency model and the results of the empirical study on public-sector secondary schools operating in the province of Zaragoza, Spain.

With respect to the first, we can draw the following conclusions.

- The DEA methodology, and particularly the BCC model, is highly appropriate for measuring efficiency in the education sector. This is so for three reasons: first, its independence from arbitrary functional forms; second, its absolute local flexibility, which respects the individual productive practices of each centre; and, third, its ability to fit itself to the multiple nature of the education output. These three aspects are especially interesting in the education sector, where education technology is truly idiosyncratic.
- With respect to education inputs, we have confirmed the central importance of considering the contextual variables, i.e. the socio-economic situation and the quality of the pupil-body, in any efficiency analysis of schools. The principal components analysis–capable of synthesising a large body of information into a small number of variables–can be very useful in order to put this aspect into practice.
- On the output side, it is vital to take into account, as an expression of production, not only the number or percentage of pupils who successfully pass the examinations, but also the marks obtained. Furthermore, this percentage must be defined in terms of the students who enrol for the course at the beginning of the academic year, something that has not been considered in the majority of previous work on educational evaluation.

Together with these conclusions on the efficiency models in the school context, the empirical analysis carried out on the secondary schools operating in the province of Zaragoza has led to the following conclusions.

- The most inefficient centres, according to the DEA, are held in low esteem by their own pupils.
- The centres located in urban areas are more efficient than those located in rural areas.
- The educational reform of 1990 does not appear to have resulted in greater efficiency at secondary-school level, although this result must be treated cautiously given the reduce number of centres that were affected by this reform when the estimation was made.
- As their head-teachers emphasised, the most efficient centres are characterised by long experience in the supply of general certificate of education studies, the stability and experience of the teaching staff, a good teaching climate, limited conflict and a marked preoccupation for the academic results of their pupils. Furthermore, they enjoy high rates of participation on the part of parents in the relevant associations, low rates of absenteeism from work, do not have better installations than the rest, but do have a pupil body which is very satisfied with the centre. The fact that all these aspects have a qualitative nature highlights the importance of completing a DEA-based quantitative analysis in an educational context with field studies and qualitative techniques that capture the true essence of each school and thereby give greater significance to the evaluations of educational performance.
- Finally, we have seen that it is fundamental to carry out a sensitivity analysis, in order to test the robustness of the model used to obtain the estimations and to confirm that these are not the fruit of a determined specification.

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**Notes**

1. The education sector has been the preferred area of activity for papers on the evaluation of performance that use DEA. Indeed, the history of DEA began with the Doctoral Thesis of Rhodes (1978), who tried to evaluate the efficiency of an education programme created to support disadvantaged pupils in schools in the USA. Since then there have been a number of applications of DEA in the analysis of the internal efficiency of public-sector education centres (see Bessent & Bessent, 1980; Charnes *et al.*, 1981; Bessent *et al.*, 1982, 1984; Jesson *et al.*, 1987; Smith & Mayston, 1987; Mayston & Jesson 1988; Färe *et al.*, 1989; Norman & Stoker, 1991; Ray, 1991; Ganley & Cubbin, 1992; McCarty & Yaisawarng, 1993; Lovell, *et al.*, 1994; Thanassoulis & Dunstan, 1994; Chalos & Cherian, 1995).
2. In 1990, a new law came into effect in Spain which substantially reformed the organisation of the non-university education system. Its main elements were the extension of obligatory education up to the age of 16 (previously it had been to only 14), and the redrafting and updating of some elements of the general certificate of education so that they were more closely linked to the future university studies that the pupil wished to undertake.
3. On the different meanings given to the term efficiency in the economic ambit, see Dunlop (1985). On the relevant categories in the education sphere, the work of Lockheed and

Hanushek (1988) is of interest. In our work, the relevant concept is that of technical efficiency in the sense used by Farrell (1957), which makes reference to the degree of technical exploitation of the resources placed at the service of education production.

4. Although the literature on the DEA technique has its starting point in 1978, with the classic article of Charnes *et al.* (1978), the enormous proliferation of this type of work throughout the 1980s and 1990s has led to the availability of a large variety of specialised texts and articles that can be consulted. The most recent compilation is that of Charnes *et al.* (1994), which also includes numerous empirical applications.
5. Any basic textbook on the envelopment methodology will include the different versions that DEA can adopt. On the mathematical properties of each one of these versions, see Lovell and Pastor (1995) and Pastor (1996).
6. Readers-unfamiliar with the Spanish secondary education system should note that 'selectividad' is the name given to the examination that pupils must pass in order to enter university and is taken at the end of their secondary education.
7. The study of a foreign language was eliminated from the analysis because extra-school coaching of this subject outside the education centre has a large impact on the final results.
8. We should note that the figures for the variables corresponding to education resources refer to the entire school, while the outputs correspond to the final-year pupils. Although from a theoretical point of view this is correct, because in reality the examination results achieved in the final year are determined by the entire schooling process and not by the inputs used only in the final year, this form of defining the outputs could give rise to problems if the school inputs change too much over time or if the school has experienced pupil migrations as a result of which the students of the final year have not studied the previous years in the same school. However, these two aspects have not affected the schools analysed in our empirical study.
9. The literature on DEA advises that, if it is desired that the technique maintains a certain discriminatory power, then the maximum number of variables introduced in the analysis must not exceed the number of centres evaluated by more than a multiple of three. See Banker *et al.* (1989).
10. These requirements, established by Golany and Roll (1989), and generally accepted, are as follows: (a) the units must perform the same tasks and have the same objectives; (b) they must all operate under the same market conditions; and (c) the elements that define their activity must be identical, save for those referring to differences in intensity or magnitude.
11. This conclusion must be interpreted with caution, given that the calculation of the Pearson correlation coefficient between the rates of efficiency and the opinion of the pupils with respect to their school and its teaching staff produced very low values.
12. This allusion to the context variables is fundamental, because we could note that, if they were excluded, then the divergence between the rates of efficiency according to the location of the centre were accentuated. Thus, when eliminating these variables, the average inefficiency of the rural centres became greater than 39%, as compared with the 22% for urban centres, at the same time that the proportion of efficient centres in each one of these categories became 14% and 29%, respectively. This could be due to the fact that the largest divergence between both types of centre is produced in relation to these variables, in such a way that, by introducing them, we further homogenise the sample, as well as place the reality of each centre in a better context.
13. This procedure, suggested at a theoretical level by Nunamaker (1985), has been subsequently applied in various papers. In the education sphere, see Smith and Mayston (1987), Färe *et al.* (1989) and Norman and Stoker (1991).
14. Here, we are thinking in terms of the Kolmogorov – Smirnov test, which is valid only for independent samples and is, therefore, not useful to compare alternative nested specifications in a DEA model where the estimations are correlated, or the Wilcoxon test which, by being based on the study of the differences in signs, is not applicable in the comparison of nested DEA models where the variations in the rate of efficiency, as Nunamaker (1985) notes, are produced in the same direction.

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