TESTING THE ACCURACY OF DEA FOR MEASURING EFFICIENCY IN EDUCATION UNDER ENDOGENEITY

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Abstract

DEA is the most common and well known technique to evaluate efficiency in education because it easily allows dealing with a complex multi-output multi-input production framework. After an interesting debate in this journal with Ruggiero (2003), Bifulco and Bretschneider (2001, 2003) concluded that DEA does not perform well to measure efficiency in the presence of endogeneity and measurement error because it leads to quite biased efficiency estimates. However, their experiment was conducted considering a one-output framework, constant returns to scale and a simple Cobb-Douglas specification. Following Bifulco and Bretschneiders' original idea, in this paper we update the adequacy of DEA in the presence of endogeneity and measurement error in a scenario closer to the educational context. To do this we perform a Monte Carlo experimentation in a flexible multi-output multi input *translog* context. Our results point out that DEA obtains quite accurate measures of technical efficiency when the sample size is large enough even in the presence of endogeneity.

Keywords: Efficiency, Educational economics, Simulation.

JEL classification: I2, C9

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1. INTRODUCTION

Since Bessent and Bessent (1980) and Bessent, Bessent, Kennington and Reagan (1982) published the first papers in which nonparametric Data Envelopment Analysis (DEA) was used to measure technical efficiency in the educational sector, this technique has become very popular for this type of evaluation[1]. This fact can be explained because DEA does not require assumptions about the production technology, it easily handles multiple outputs[2] and it does not need input price data. Despite these advantages, DEA has been criticized because it is a non-statistical approach, although the formal statistical foundation provided by Banker (1993) and Korostelev, Simar and Tsybakov (1995) and the bootstrap strategy proposed by Simar and Wilson (1998, 2000) for performing statistical inference have reduced the strength of this criticism.

In order to test its accuracy in measuring technical efficiency, Banker, Gadh and Gorr (1993) and Ruggiero (1999) have used simulated data to evaluate the performance of DEA and compare it with alternative methods. The main conclusion of these simulation studies is that the performance of DEA deteriorates in the presence of measurement error. However, Banker (1993) demonstrates that for large samples the DEA estimators follow the same probability distribution as the true inefficiency random variable. In addition, Gong and Sickles (1992) and Ruggiero (2004) show that the problem of measurement error becomes less significant when efficiency is estimated using panel data, while Ruggiero (2006) concludes that using aggregated data can smooth the influences of measurement error on efficiency estimations.

Most of these simulation studies are focused on frontier and efficiency estimation and do not concern whether or not the method provides measures of

[1] See Worthington (2001) for a review of the literature related to the evaluation of the education sector using efficiency methods.
[2] Seiford and Thrall (1990) consider that using DEA is preferable to other approaches when the aim of the study is to measure the efficiency of a group of units producing several outputs.

efficiency that represent appropriately the characteristics of the educational context (Bifulco and Duncombe, 2002). In particular, they share two main drawbacks: all of them are performed in a single output framework and most of them rely on Cobb-Douglas technology in their data generation process.

In principle, the only exception in the literature in using a multi output framework to simulate an educational production function subject to inefficient behaviours is Bifulco and Bretschneider (2001). In their paper, these authors try to emulate a typical education context by defining a log linear production function with two outputs and three inputs. Through this experiment, they took into account that education is clearly a multi-output activity where it is quite usual to observe students with similar endowments of educational resources but are better prepared, motivated or interested in some of the subjects relative to others. Unfortunately, as remarked by Ruggiero (2003), their generation process was incorrect as Bifulco and Bretschneider (2003) admitted later in a subsequent paper. Hence, they do also assume a single output framework and conclude that the measurements obtained by DEA in the presence of significant amounts of random error and endogeneity can be misleading.

This paper attempts to overcome past drawbacks in the definition of the multi-input multi-output technology and perform a simulation study that can emulate appropriately the particular characteristics of an educational production technology. For this purpose, we use a methodology recently developed by Perelman and Santin (2009) which allows us to generate data simulating this scenario. This methodology follows the framework proposed by Lovell, Richardson, Travers and Wood (1994), i.e., using an output distance function based on a parametric *translog* function. Perelman and Santin (2009) derive the complete set of necessary and sufficient conditions to generate data in a complex multi-output multi-input context that imposes microeconomic behavioral regularity conditions, monotonicity and convexity, to the production technology. In addition, this approach allows us to explore scale efficiency measurement, which can be very useful in our context.

Therefore, in this article we make an effort to simultaneously deal with difficulties encountered in previous works to reproduce the context of school production by expanding the analysis in several directions. First, we perform a simulation study with a data generation process based on a multi-output multi input setting. Second, we use a *translog* function, so that we have a more flexible production technology as in the educational world. Thirdly, we assume decreasing returns to scale in order to adapt our design to this context[3]. Finally, we perform a Monte Carlo experiment to ensure the results are adequately robust and not just the result of a particular case. Under this closer to real educational world hypothesis we re-examine Bifulco and Bretschneiders' (2003) question and conclusions about the accuracy of the efficiency measurements provided by DEA to measure school performance in the presence of noise and endogeneity.

The paper focuses its attention on the data generation process for a multi-output multi-input educational production function and not in the comparison between alternative methods to measure efficiency. Thus, we will only test the adequacy of different models of DEA (Charnes, Cooper and Rhodes, 1978; Banker, Cooper and Rhodes, 1984), since this is the more popular technique to measure efficiency in education contexts. Furthermore, we consider that the comparison between efficiency scores estimated with DEA and those estimated with a parametric or semiparametric approach, such as Corrected Ordinary Least Squares (COLS), would be biased in favor of the latter, since this method shares a similar structure with the methodology used to generate the data.

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[3] Decreasing returns to scale have been imposed in many empirical works in this context since the publication of seminal works by Haley (1976) and Heckman (1976).

The results of our experiment are in accordance with those obtained by Bifulco and Bretschneider (2001, 2003), in the sense that DEA performs well in the presence of endogeneity and moderate noise in data, but its performance deteriorates in the presence of large measurement errors. However, as the design of our experiment is more complex, we can provide additional insights about other conditions under which DEA can be an appropriate instrument for the purposes of performance-based school reforms.

The article is organized as follows. Section II reviews the literature about the production function in education and previous studies that have used simulated data to evaluate methods for estimating efficiency in this context. Section III describes the methodology we use to generate data and the structure of our Monte Carlo experimental design. In Section IV the main results from the simulation analysis are reported and analyzed according to different criteria. The last section presents the main conclusions.

2. PREVIOUS SIMULATION STUDIES IN EDUCATIONAL CONTEXT

Despite the huge number of articles published since the mid-1960s about the assessment of efficiency in education, the production function in the sector is still unknown (Engert, 1996). In fact, the majority of these studies find either no statistically significant relationship between school inputs or expenditures and student performance or even significant coefficient estimates with a different sign to that expected (Coleman *et al*, 1966; Summers and Wolfe 1977; Hanushek 1986, 1996, 1997, 2003; Pritchett and Filmer, 1999).

Many different reasons have been put forward in the literature to explain why empirical research does not find systematic relationships between school inputs and outputs. Some of these are summarized as follows. First, education is a highly complex process where measuring some variables such as student motivation or teacher quality can be difficult (Vandenberghe 1999). Second, education is not an instantaneous process but generates its effects in the medium or long term. Third, the educational output is multi-dimensional and difficult to measure. Fourth, educational production can be characterized by two-way causal relationships between inputs and outputs (Orme and Smith, 1996). Fifth, most production function studies in the economics of education do not consider the theoretically potential role of the efficiency component (Farrell 1957; Leibenstein 1966). All these factors make it extraordinarily difficult to define a general educational production function that accurately includes all relevant aspects of the school production process and, consequently, makes it possible to measure efficiency though a simple comparison between real results and those which could potentially be achieved (Hanushek, 1986).

Another relevant aspect that causes concern for the estimation of educational production is the inconsistency of the use of Cobb–Douglas specifications. It is questionable to assume that the marginal effects of school inputs on student performance can be the same regardless of the scale of production, and the restrictive Cobb-Douglas equation fails to capture potentially nonlinear effects of those school resources (Eide and Showalter 1998; Baker 2001). In this sense, the use of more flexible functional forms as the *translog* functional form introduced by Christensen, Jorgenson and Lau (1971) has been suggested for those who use parametric methods to estimate efficiency in education (Callan and Santerre, 1990; Gyimah-Brempong and Gyapong, 1992; Figlio 1999; Perelman and Santin, 2008).

Thus, a simulation study that pretends to test the adequacy of a method to measure efficiency in a real world educational context should take into account all factors mentioned above. The studies we review in this paper (Bifulco and Bretschneider, 2001, 2003) tried to originally emulate the characteristics of this framework but unfortunately they failed in both using a flexible functional form and considering a multi output framework.

In their experimental design those authors used a log linear Cobb-Douglas function with two outputs and three inputs defined by $y_1^{0.5} y_2^{0.5} = x_1^{0.4} x_2^{0.4} x_3^{0.2}$. Thus, they assumed that both outputs have the same relative value ($\alpha = \beta = 0.5$) and constant return to scale, since the sum of inputs coefficients is one. Likewise, they test the presence (or not) of measurement error, the presence of endogeneity, that is, correlation (or not) between inputs and inefficiency and three different sample sizes (20, 100 and 500), so they generate 12 different scenarios where they can test the performance of alternative methods (DEA and COLS).

However, according to Ruggiero (2003) the generating process used in that simulation exercise presents two main drawbacks. The first one is the selection of a Cobb-Douglas production function for the output aggregate, since it means that violates the convexity of the production set. The second is that, although the authors state that they use a constant return to scale technology with three inputs and two outputs, they actually generate an increasing return to scale technology with one output and four inputs in all scenarios considered. Essentially, the problem arises because the second output (y_2) can actually be interpreted as the inverse of a fourth input, since inefficiency is modeled as an output reduction of the other output (y_1). Thus, the efficient level of the only output (y_1) is defined by: $y_1 = x_1^{0.8} x_2^{0.8} x_3^{0.4}, x_4$; where $x_4 = (y_2)^{-1}$. This production function exhibits increasing returns to scale, so the application of a CCR DEA model leads to estimates of efficiency that are biased downward.

Using a corrected data generation process, Ruggiero (2003) concludes that, in the absence of measurement error, DEA provides decent measures of efficiency even in the presence of endogeneity. In turn, Bifulco and Bretschneider (2003) conclude that when datasets are characterized by significant amounts of measurement error, the use of DEA can lead to misleading results. However, once they assumed the correction proposed by Ruggiero (2003) their results are limited to a one output framework, leaving apart Bifulco and Bretschneiders' (2001) original idea of analyzing the performance of DEA in a two output setting.

In order to test the robustness of those conclusions, in this paper we replicate those experiments (considering also noise and endogeneity) with the aim of returning to Bifulco and Bretschneiders (2001) question. Our aim is basically the same, testing the accuracy of DEA in an experimental context that reproduces the educational framework in a more appropriate way. For this purpose, we use a new data generation process predicated on a more flexible educational production function with two outputs.

3. METHODOLOGY AND EXPERIMENTAL DESING

3.1. The *translog* output distance function

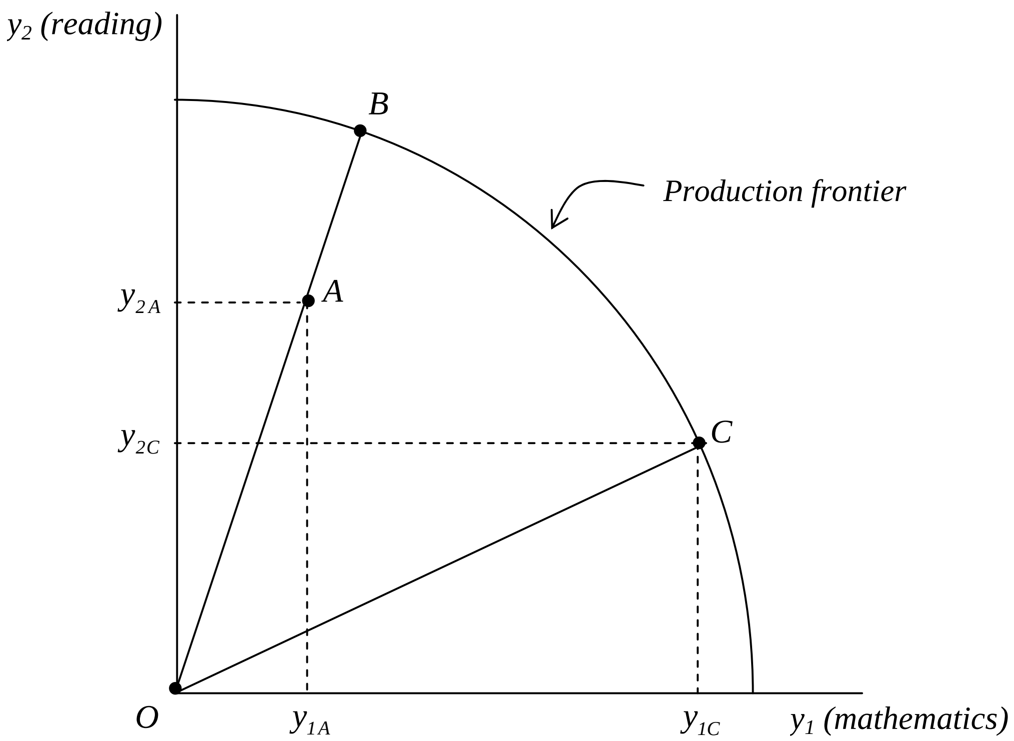
The parametric distance function is an appropriate framework to model the educational production function because it simultaneously allows dealing with multiple inputs and outputs. To the best of our knowledge this tool has only been applied in an economics of education context with data from PISA 2003 in Perelman and Santín (2008). The parametric output distance function can be defined using the output production possibility set *P(x)*. Let us define a vector of educational inputs $x = (x_1, \ldots, x_K) \in \Re^{K+}$ and a vector of educational outputs $y = (y_1, \ldots, y_M) \in \Re^{M+}$, the feasible multi-input multi-output production technology is $P(x) = \{y: x$ can produce $y)$, which is assumed to satisfy the set of axioms enumerated in Färe and Primont (1995)[4]. Rearranging terms, this technology can also be defined as the output distance function proposed by Shephard (1970):

$$D_O(x,y) = inf\{\theta : \theta > 0, (x, y/\theta) \in P(x)\}. \qquad (1)$$

[4] Regularity conditions assume that *P*(*x*) is non-decreasing, linearly homogeneity of degree +1 and convex in outputs, and non-decreasing and quasi-convex in inputs.

If $D_O(x,y) \le 1$ then (x,y) belongs to the production set *P*(*x*). In addition, $D_O(x,y) = 1$ if *y* is located on the outer boundary of the output possibility set. Figure 1 illustrates these concepts in a simple two-output one input setting. Following Perelman and Santín (2008) let us assume that two pupils *A* and *C*, dispose of equal input endowments to achieve outputs y_1 (mathematics) and y_2 (reading). Then *C* is efficient, $D_O(x, y_C) \equiv \theta_C = 1$, because it lies on the boundary of the output possibility set, whereas *A* is inefficient at a rate given by the radial distance function $D_O(x, y_A) \equiv \theta_A = OA/OB$ where $D_O(x, y) \equiv \theta \in [0;1]$.

Figure 1. Output possibility set *P(x)*



In order to estimate the distance function in a parametric setting it is usual to assume a *translog* functional form. According to Coelli and Perelman (1999), this specification fulfills a set of desirable characteristics: flexible, easy to derive and allowing the imposition of homogeneity. In education as the relationship between educational resources and achievements is not well-known, this technology allows one to seek possible second order effects between input and output variables. The *translog* distance function specification for the case of *K* inputs and *M* outputs is:

$$\ln D_{Oi}(x,y) = \alpha_0 + \sum_{m=1}^{M} \alpha_m \ln y_{mi} + \frac{1}{2}\sum_{m=1}^{M}\sum_{n=1}^{M} \alpha_{mn} \ln y_{mi} \ln y_{ni} + \sum_{k=1}^{K} \beta_k \ln x_{ki}$$

$$+ \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K} \beta_{kl}\, ln\, x_{ki}\, ln\, x_{li} + \sum_{k=1}^{K}\sum_{m=1}^{M} \delta_{km}\, ln\, x_{ki}\, ln\, y_{mi}\ , \quad i = 1,2,\ldots, N, \qquad (2)$$

where *i* denotes the *i*th unit (DMU) in the sample. In order to obtain the production frontier surface, we set $D_O(x,y)=1$, which implies $ln\, D_O(x,y)=0$. The parameters of the above output distance function must satisfy a number of restrictions. Symmetry requires:

$\alpha_{mn} = \alpha_{nm}$, *m, n* = 1, 2,…, *M*, and

$\beta_{kl} = \beta_{lk}$, *k, l* = 1, 2,…, *K*,

and linear homogeneity of degree + 1 in outputs can be imposed in the following way:

$$\sum_{m=1}^{M} \alpha_m = 1,$$

$\sum_{n=1}^{M} \alpha_{mn} = 0$, *m* = 1, 2,…, *M*, and

$\sum_{m=1}^{M} \delta_{km} = 0$, *k* = 1, 2,…, *K.*

This latter restriction indicates that distances with respect to the boundary of the production set are measured by radial expansions of the outputs. Following Shephard (1970), homogeneity in outputs implies:

$$D_O(x,\omega y) = \omega D_O(x,y) \quad \text{for any } \omega > 0$$

Furthermore, according to Lovell *et al*. (1994), normalizing the output distance function by one of the outputs is equivalent to setting $\omega = 1/y_M$ imposing homogeneity of degree +1, as follows:

$$D_O(x, y/y_M) = D_O(x,y)/y_M$$

For unit *i*, we can rewrite the above expression as:

$$ln\left(D_{Oi}(x,y)/y_{Mi}\right) = TL(x_i, y_i/y_{Mi}, \alpha, \beta, \delta), \qquad i = 1, 2, \ldots, N,$$

where

$$TL(x_i, y_i/y_{Mi}, \alpha, \beta, \delta) = \alpha_0 + \sum_{m=1}^{M-1} \alpha_m \ln\left(y_{mi}/y_{Mi}\right) + \frac{1}{2}\sum_{m=1}^{M-1}\sum_{n=1}^{M-1} \alpha_{mn} \ln\left(y_{mi}/y_{Mi}\right)\ln\left(y_{ni}/y_{Mi}\right)$$

$$+ \sum_{k=1}^{K} \beta_k \ln x_{ki} + \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K} \beta_{kl} \ln x_{ki} \ln x_{li} + \frac{1}{2}\sum_{k=1}^{K}\sum_{m=1}^{M-1} \delta_{km} \ln x_{ki} \ln\left(y_{mi}/y_{Mi}\right). \qquad (3)$$

And rearranging terms:

$$-\ln\left(y_{Mi}\right) = TL(x_i, y_i/y_{Mi}, \alpha, \beta, \delta) - \ln D_{Oi}(x,y), \quad i = 1, 2, \ldots, N, \qquad (4)$$

where $-ln\,D_{Oi}(x,y)$ corresponds to the radial distance function from the boundary. Hence we can set $u = -ln\,D_{Oi}(x,y)$ and add up a term v_i capturing for noise to obtain the Battese and Coelli (1988) version of the traditional stochastic frontier model proposed by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977):

$$-ln\left(y_{Mi}\right) = TL(x_i, y_i/y_{Mi}, \alpha, \beta, \delta) + \varepsilon_i, \qquad \varepsilon_i = v_i - u_i,$$

where *u* = $-ln\,D_{Oi}(x,y)$, the distance to the boundary set, is a negative random term assumed to be independently distributed as $N\left(0,\sigma_u^2\right)$, and the term v_i is assumed to be a two-sided random (stochastic) disturbance designated to account for statistical noise and distributed iid $N\left(0,\sigma_v^2\right)$. Both terms are independently distributed $\sigma_{uv} = 0$.

As we noted above, Färe and Primont (1995) provide the general regularity properties for output distance functions. These technological constraints rely on economic theory but also apply to education. For example, in education a production function that violates microeconomic regularity conditions, mainly monotonicity, turns unreliable. The violation of monotonicity on outputs (inputs) in education means that an efficient school could reduce (increase) its vector of outputs (inputs) holding fixed the vector of inputs (outputs) while it still belongs on the frontier. In order to assure a well-behaved production technology we follow Perelman and Santín (2009) which derives the microeconomic restrictions that the distance function must fulfill in the data generation process[5].

3.2. Experimental design for generating regular data in a multi output multi input framework

For the sake of simplicity we re-write Equation (4) for three inputs and two outputs as in the experiment we conduct later in section 4. To do this we choose as numeraire $\ln y_1$ so we can calculate a value for $-\ln y_1$ in the production frontier using Equation 4:

$$-\ln\left(y_1\right) = \alpha_0 + \alpha_1 \ln\left(\frac{y_2}{y_1}\right) + \frac{1}{2}\alpha_{11}\left[\ln\left(\frac{y_2}{y_1}\right)\right]^2 + \beta_1 \ln x_1 + \beta_2 \ln x_2 + \beta_3 \ln x_3 + \frac{1}{2}\beta_{11}\left[\ln x_1\right]^2$$
$$+ \frac{1}{2}\beta_{22}\left[\ln x_2\right]^2 + \frac{1}{2}\beta_{33}\left[\ln x_3\right]^2 + \beta_{12}\ln x_1 \ln x_2 + \beta_{13}\ln x_1 \ln x_3 + \beta_{23}\ln x_2 \ln x_3$$
$$+ \gamma_{11}\ln x_1 \ln\left(\frac{y_2}{y_1}\right) + \gamma_{12}\ln x_2 \ln\left(\frac{y_2}{y_1}\right) + \gamma_{13}\ln x_3 \ln\left(\frac{y_2}{y_1}\right) \quad (5)$$

[5] Our data generation process is mainly based on Perelman and Santín (2009) but adapted to the presence of the endogeneity issues addressed by Bifulco and Bretschneiders' (2001, 2003) papers.

Where the value of α_0 must be imposed with the restriction that $-\ln y_1 - \alpha_0 < 0$ for all DMUs, in order to avoid negative production values. In order to carry out the experimental design, the first step is the selection of the parameters as well as the definition of a meaningful distribution ratio of outputs and inputs, and its logarithm. These parameters will impose the maximum and minimum values for the exogenous inputs and outputs in logarithms as well as the range of scale elasticity and scale inefficiency to fulfill all regularity conditions. Secondly, we can calculate $\ln y_1$ and $\ln y_2$, and y_1^* and y_2^* where the values with an asterisks represent the output values on the production frontier. Thirdly, the distribution of technical inefficiency values has to be defined within the interval $[1; \infty]$. A recommended possibility is to generate $\ln D = u \sim \left|N(0; \sigma_u^2)\right|$ where a number of efficient units will automatically receive $D = 1 \ (\ln D = 0)$. The fourth step consists of generating a normal distribution for the random noise *v*, $v \sim N(0; \sigma_v^2)$ by definition distributed independently of the inefficiency term *D*. Here it is possible to relax the hypothesis of a radial random disturbance, affecting the two outputs in the same way, and to generate two independent random noise terms $v_1 \sim N(0; \sigma_{v_1}^2)$, $v_2 \sim N(0; \sigma_{v_2}^2)$ for each output[6].

The fifth step is to generate the observed outputs capturing technical inefficiency. In order to do this, we multiply the output values in the frontier y_1^* and y_2^* by $\frac{1}{\exp(\ln D)}$ in order to generate outputs taking into account potential inefficiency:

$$y_1^{**} = y_1^* \frac{1}{\exp(\ln D)} \quad \text{and} \quad y_2^{**} = y_2^* \frac{1}{\exp(\ln D)} .$$

[6] This assumption allows us to explore DEA properties when random shocks affect differently each output. In any case, in the data generating process, the researcher may decide whether to make this assumption or to include only a single random term affecting both outputs identically.

The sixth and last step is to introduce random noise, independently for each output, in order to obtain the final output values that we will employ in the Monte Carlo experiment:

$$y_1 = y_1^{**}\frac{1}{\exp(v_1)} \quad \text{and} \quad y_2 = y_2^{**}\frac{1}{\exp(v_2)}.$$

From this *well-behaved* production function, we can extract the required number of samples in order to perform Monte Carlo experimentation in a multi-input multi-output setting. This methodology can be generalized to include more dimensions. For example, in the case of three outputs it would be necessary to generate exogenously two ratios of output, say $\ln(y_2/y_1)$ and $\ln(y_3/y_1)$, analogously to the three-input two-output case discussed here, which would impose the range of output parameter values, and so on[7].

4. DATA GENERATION AND EXPERIMENT RESULTS

In order to illustrate the ideas developed above we performed a Monte Carlo experiment. Our first purpose is to evaluate the performance of DEA technical efficiency measurement replicating and adapting Bifulco and Bretschneiders' (2001) experiment for a *translog* multi output production function. In order to conduct the Monte Carlo experiment, we first need to define the production function. We use the *translog* output distance function described in equation (5) defining:

$$\alpha_0 = -1; \alpha_1 = 0.5; \alpha_{11} = 0.5; \beta_1 = -0.4; \beta_2 = -0.4; \beta_3 = -0.2;$$

$$\beta_{11} = 0.1.; \beta_{22} = 0.1; \beta_{33} = 0.05; \beta_{12} = -0.01.; \beta_{13} = -0.01; \beta_{23} = -0.01;$$

[7] As remarked in Perelman and Santin (2009) increasing the number of inputs and/or outputs also increases the number of regularity conditions the generated data has to fulfill. The procedure described here can be extended in a straightforward way for being used in higher multi-input multi-output dimensions, although the generation of regular data in these cases could become cumbersome.

$\gamma_{11} = \gamma_{22} = \gamma_{32} = -0.05; \gamma_{12} = \gamma_{21} = \gamma_{31} = 0.05$.

The second step was to define the exogenous ratio between the two outputs and the statistical distribution of the three inputs. We defined $\left|\ln y_2 - \ln y_1\right| \leq 1$, and the endowments of inputs x_2 and x_3 were generated randomly and independently using a uniform distribution over the interval [5, 15]. Input x_1 was generated with endogeneity as in Bifulco and Bretschneider (2001) incorporating a high negative correlation between this input and the efficiency term. However our equation to generate endogeneity: $x_{1i}=55-(40/u_i)+e_i$, where *e* is a normally distributed variable with a mean of 0 and variance of 4, is slightly different from that in Bifulco and Bretschneider (2001), because under their specification it is possible to have less than one or even negative values damaging the Monte Carlo experimentation[8].

Once the parameters and the ratio of outputs and input logarithms have been generated, we calculate the output values in the frontier y_1^* and y_2^* taking the exponential function. The parameters selection and the distribution of inputs and outputs chosen for this simulation assure decreasing returns to scale in the translog production function[9]. Following Balk (2001) the scale elasticity value for any data point of the output distance function described for equation (2) is

$$\phi_{Oi}\left(x_i, y_i\right) = -\sum_{k=1}^{K} \frac{\partial \ln D_{Oi}\left(x_i, y_i\right)}{\partial \ln x_k}, \qquad (6)$$

[8] For instance, if we simultaneously have an efficient value (45-40=5) and a high positive *e* value the input result could turns negative which is inconsistent from the point of view of economics.

[9] In a recent paper, Trostel (2004) points out that despite evidence of increasing returns for initial investments in education, this is followed by significant decreasing returns for investments at high levels of educational attainment. We do think that if we consider tests scores as output, doubling all school inputs does not guarantee doubling test scores. Moreover, most of DEA empirical applications on schools run the variable returns to scale program.

where $\phi_{Oi}(x_i, y_i)$ denotes the (output distance function based) scale elasticity value of DMU *i* at point (x_i, y_i). Its value will be greater than, equal to or lower than 1 for increasing, constant or decreasing returns to scale, respectively. In our case generated data presents scale elasticity values between 0.48 and 0.73. Compared with the simple Cobb-Douglas constant elasticity technology, the *translog* function allows for decreasing returns to scale technology.

Balk (2001) shows that the corresponding scale efficiency value can be obtained through the following expression:

$$ln\, SE_{Oi}(x_i, y_i) = -\frac{(\phi_{Oi}(x_i, y_i) - 1)^2}{2\beta}, \qquad (7)$$

where $SE_{Oi}(x_i, y_i)$ denotes the output scale efficiency, and $\beta = \sum_{k=1}^{K}\sum_{l=1}^{K}\beta_{kl}$. Its value will be one for local constant returns to scale and lower than one otherwise.

Third, in order to generate inefficiency, we use a half-normal distribution, where $\ln D = u \sim |N(0;0.16)|$, so that the true distance or technical inefficiency could be easily calculated as $\frac{1}{\exp(\ln D)}$. We allow 20% of the decision making units to be on the true frontier[10]. We think that this scenario with some schools in the educational production frontier is more adequate for assessing the performance of DEA since this tool measures relative efficiency instead of absolute efficiency, which implicitly assumes that a number of schools are really efficient. Regarding the random statistical perturbation in the production function, we independently generated two random terms one for each output. As in Bifulco

[10] We follow here an intermediate percentage of efficient units according to the literature. This assumption can be relaxed or made more restrictive depending on the research objectives; e.g. 30% in Holland and Lee (2002), 25% in Perelman and Santín (2009) and Bardhan, Cooper and Kumbhakar (1998), 20% in Cordero, Pedraja and Santin (2009), 12.5% in Ruggiero (1998), 10% in Muñiz, Paradi, Ruggiero and Yang (2006) or 0% DMU on the production frontier in Pedraja, Salinas and Smith (1997, 1999) and Bifulco and Bretschneider (2001, 2003).

and Bretschneider (2001, 2003) we consider three possible scenarios allowing random shocks to affect output in different quantity and direction:

- Large measurement error: $v_1 \sim N(0;0.16)$, $v_2 \sim N(0;0.16)$,
- Medium measurement error: $v_1 \sim N(0;0.04)$, $v_2 \sim N(0;0.04)$,
- Small measurement error: $v_1 \sim N(0;0.01)$, $v_2 \sim N(0;0.01)$,

Using this information we generated observed outputs y_1 and y_2, as described in Section 3.2. Table 1 provides a rough comparison of the differences between the experimental design provided by Bifulco and Bretschneider´s (2001, 2003) and ours. As mentioned in the introduction, we think that our data generation process is closer to the context of school production than the one proposed by those authors.

Table 1. A rough comparison between two alternative experimental designs for simulating the educational production function.

	Bifulco and Bretschneider (2001, 2003)	**Cordero and Santín**
Framework	One output Multi input	Multi output multi input
Production Function	Cobb Douglas	Translog
Endogeneity issues	YES	YES
Schools in the frontier	None	YES (20%)
Returns to scale	Constant	Decreasing
Scale Efficiency	NO	YES
Simulation	Single	Monte Carlo
Methods Compared	DEA, COLS	DEA

Each experiment was replicated 100 times for three different sample sizes ranging from 20 to 400 DMUs. In each experiment we measure the efficiency of the data by running output oriented DEA models with constant and variable returns to scale (CRS and VRS hereafter) proposed by Charnes, Cooper y Rhodes (1978) and Banker, Charnes and Cooper (1984) respectively. The average Kendall and Spearman correlation coefficients between the 100 generated and estimated efficiency scores pairs were calculated and averaged. These coefficients reflect the ability of the method to correctly rank observations. A high rank correlation suggests that the measure performs well in the identification of the level of efficiency. The results obtained are shown in Table 2.

Table 2. Kendall and Spearman correlation coefficients for different scenarios.

Sample size (DMUs)	Kendall's τ correlation			Spearman's correlation		
	CRS	VRS	SE	CRS	VRS	SE
Large noise						
20	0.3077 (0.1324)	0.2364 (0.1377)	0.0827 (0.1646)	0.4278 (0.1744)	0.3275 (0.1875)	0.1172 (0.2293)
100	0.3483 (0.0613)	0.3150 (0.0483)	0.1053 (0.0994)	0.4919 (0.0801)	0.4474 (0.0652)	0.1524 (0.1464)
400	0.3626 (0.0254)	0.3386 (0.0278)	0.1086 (0.0470)	0.5111 (0.0329)	0.4762 (0.0397)	0.1556 (0.1387)
Medium noise						
20	0.3860 (0.1315)	0.3345 (0.1336)	0.1347 (0.1470)	0.5243 (0.1726)	0.4520 (0.1844)	0.1873 (0.2088)
100	0.4717 (0.0513)	0.5590 (0.0347)	0.1455 (0.0851)	0.6460 (0.0615)	0.7285 (0.0414)	0.2122 (0.1214)
400	0.4578 (0.0256)	0.6308 (0.0221)	0.1225 (0.0473)	0.6344 (0.0296)	0.8046 (0.0161)	0.1816 (0.0695)
Small noise						
20	0.4101 (0.1501)	0.3511 (0.1647)	0.1429 (0.1583)	0.5501 (0.1831)	0.4685 (0.2044)	0.2008 (0.2212)
100	0.4741 (0.0555)	0.6378 (0.0622)	0.1339 (0.0481)	0.6491 (0.0640)	0.7940 (0.0663)	0.1976 (0.0658)
400	0.5026 (0.0432)	0.7461 (0.0157)	0.1571 (0.0143)	0.6891 (0.0513)	0.8857 (0.0185)	0.2322 (0.0189)

(*) Standard deviation are shown in brackets.

The first conclusion that can be derived from these values is that, despite the distortion introduced by the presence of endogeneity, DEA performs reasonably well when the measurement error is not high and the sample size is large enough. Thus, Kendall and Spearman coefficients for the VRS model are higher than 0.55 and 0.72, respectively, when the noise is not large and the sample size consists of at least 100 units. In contrast, for a larger measurement error generated with the same standard deviation that school efficiency (large noise), DEA does not perform so well. In fact, in that case DEA-CCR obtains better results than DEA-VRS since the accuracy of the latter for detecting decreasing returns to scale is only evident when the noise is smaller.

Second, we can observe that the correlation coefficients between estimated scores and true efficiency become higher as the sample size increases. Likewise, these improvements are larger when the noise is smaller. These results contrast with those obtained by Bifulco and Bretschneider (2003), where the correlation coefficients were higher for small sample sizes independently of the measurement error considered.

Third, it can be noticed that the performance of DEA improves to a larger extent when sample size is increased from 20 to 100 than when it is augmented from 100 to 400. For instance, for a medium measurement error, the average Spearman's correlation coefficient for the VRS model increases from 0.4520 for 20 units to 0.7285 for 100 units, while it only increases to 0.8046 for 400 units. Those improvements are even greater if a small noise is considered (from 0.4685 to 0.7940 and 0.8857, respectively). This fact is a very important finding because in most of cases in which DEA can be used as a management tool to analyze efficiency in the educational context the available dataset comprises far fewer than 400 units.

Fourth, average rank correlation coefficients between real and estimated scale efficiency (SE) scores are remarkably small independently of sample size. Perelman and Santín (2009) obtain that scale efficiency estimations significantly improve when sample size grows in presence of small noise. In our case, we suspect that endogeneity can be damaging scale efficiency estimations even with small noise. In principle, school size cannot be considered as a controllable variable in the short-run, thus we think that scale efficiency is not crucial for introducing incentives based on school performance. Nevertheless, the use of a performance monitoring system based on DEA results can be very helpful in order to inform policy makers about the possibilities of dividing or merge schools districts based on scale efficiency arguments.

We now check for the reliability of DEA to detect full efficient DMUs in the generated data. Table 3 reports the proportion of truly technically efficient (TE=1) and inefficient (TE<1) DMUs qualified as technically efficient under DEA-CRS and DEA-VRS.

From these results we can conclude, as expected, that DEA-VRS is more successful than DEA-CRS to detect efficient DMUs, although the percentage of success in predictions decreases as the sample size grows. We also can observe that the rate of success decreases less when random noise is smaller. For example, the identification of true efficient units with DEA-VRS under the presence of large noise to efficiency varies from 79.50% for a sample size of 20 schools up to 23.75% when sample size increases to 400 schools. However, when the error term is small the range goes from 100% with a sample size of 20 schools to 91.75% for a sample size of 400 schools.

Table 3. Identification and misidentification of true technical efficient DMUs.

Sample size (DMUs)	True TE=1 DEA TE=1 (%)		True TE<1 DEA TE=1 (%)	
	CRS	VRS	CRS	VRS
Large noise				
20	64.50	79.50	38.81	57.13
100	32.33	41.17	12.71	23.46
400	15.75	23.75	3.25	8.87
Medium noise				
20	84.75	99.75	44.31	64.94
100	51.17	88.17	17.54	32.67
400	24.25	54.50	5.56	14.62
Small noise				
20	84.50	100	45.00	66.75
100	51.50	99.50	17.56	34.75
400	29.50	91.75	6.56	17.13

This evidence might have to do with the fact that the proportion of DMUs identified as efficient by the technique decreases as sample size increases. However, we decided to maintain the same percentage for every sample size in the experimental design in order to facilitate the comparisons in different contexts.

Finally, it can be noticed that the misidentification of efficient units, that is, to label a school as efficient when in fact is inefficient, follows the opposite direction. Thus, as long as the sample size increases it is less likely to have an incorrect identification.

Following the same criteria used in Bifulco and Bretschneider (2001, 2003), the next step in our analysis is to divide the observations into quintiles based on their actual efficiency score so that we can examine the ability of DEA to place observations in the appropriate quintile. For this purpose, we perform the analysis only for the DEA-VRS case, given that this option seems to provide better results in the context of our simulation study. In order to test the sensitivity of our results we also consider error terms with different variances and different sample sizes. The results of this analysis are presented in Table 4.

The values showed in Table 4 confirm that efficiency scores assigned by DEA for school performance in the presence of endogeneity do not deviate substantially from the actual values. The percentage of units placed two or more quintiles from the real value is less than 34 % in all the cases and we cannot find units assigned to the top (bottom) quintile that are actually ranked in the two last (first) quintiles. According to these criteria, we can also observe that DEA results improve notably when the noise is smaller and the sample size is higher. Again, the improvement in results is more significant when it increases from 20 to 100 than from 100 to 400. Thus, it is worth noting that when the measurement error is not large and we have a sample of at least 100 units, around half of units are placed in the correct quintile and less than 15 percent of units are two or more quintiles away from the actual value.

Table 4

Measures of how well DEA-VRS assign observations to quintiles (mean values after 100 replications)

Sample size	% Assigned to correct quintile	% assigned two or more quintiles from actual	% assigned to top quintile actually in top quintile	% assigned to bottom quintile actually in bottom quintile	% assigned to top quintile actually ranked in the two last quintiles	% assigned to bottom quintile actually ranked in the two first quintiles
Endogeneity and large noise[a]						
20	30.05%	33.25%	27.25%	48.00%	0%	0%
100	32.55%	29.12%	33.75%	49.85%	0%	0%
400	33.38%	27.71%	36.38%	51.52%	0%	0%
Endogeneity and medium noise[b]						
20	32.70%	33.05%	27.00%	59.75%	0%	0%
100	45.69%	14.16%	40.30%	73.85%	0%	0%
400	51.25%	9.50%	48.25%	78.75%	0%	0%
Endogeneity and small noise[c]						
20	33.40%	29.75%	24.00%	63.50%	0%	0%
100	50.32%	10.60%	43.25%	78.35%	0%	0%
400	66.50%	2.05%	62.25%	88.75%	0%	0%

[a] Both measurement error generated to have std. dev. equal to the std. dev. of school inefficiency.
[b] Both measurement errors generated to have std. dev. equal to one-half the std. dev. of school inefficiency.
[c] Both measurement error generated to have std. dev. equal to one-quarter the std. dev. of school inefficiency.

These results clearly outperform those obtained by Bifulco and Bretschneider (2001, 2003), although they only examined a DEA-CRS model in their simulation study. Actually, we suspect that their choice of using constant returns to scale can explain why they obtain similar results for different sample sizes while our results improve when the sample size is larger. On the basis of their results, those authors concluded that DEA is not adequate for the purpose of school based accountability, although they maintained that in cases with endogeneity and small measurement error the use of this method was a matter of judgment (Bifulco and Bretschneider, 2003, p. 638).

Our results allow us to step forward and conclude that DEA can provide adequate measures of school performance even in the presence of moderate noise and endogeneity. However, it requires the sample size to be large enough (at least 100 units) and the assumption of variable returns to scale in the evaluation in order to assure accurate results.

5. CONCLUSIONS

In this paper we have conducted a simulation study to test the accuracy of DEA as a tool for measuring efficiency in educational contexts. For this purpose, we followed an approach similar to Bifulco and Bretschneider (2001, 2003), considering endogeneity, different levels of measurement error in data and several sample sizes. Nevertheless, we use a data generation process that is closer to the educational settings than the one proposed by those authors, since it represents a multi-output framework and a flexible production technology. The methodology used to generate data in this scenario is based on a parametric *translog* function (Perelman and Santin, 2009).

The results obtained in our Monte Carlo analysis show that DEA provides an adequate measure of efficiency in this context even though endogeneity and noise can exist in available data. However, the reliability of the measures depends on how much error there is in the administrative datasets used for school accountability results. Thus, we concur with Bretschneider and Bifulco (2003) that significant efforts are needed to reduce or minimize random errors in available data from educational contexts, since noisy data can damage significantly the accuracy of estimated measures obtained with this technique.

In addition, one of the main findings in this research is that the use of enlarged sample sizes clearly enhances the validity of estimations. Specifically, the results of our experiment show that the performance of DEA improves to a larger extent when sample size is increased from 20 to 100 units than when it is increased from 100 to 400 units. This is a conclusion of great importance since it identifies the sample size required for reliable use of DEA as well as the point where returns to sample size begin to become exhausted. According to this result we recommend to policy makers in small villages or towns to collaborate with other local authorities by combining data on school units in order to obtain reliable evaluations of their schools.

Another important conclusion that can be drawn from our results is that, independently of the sample size and the level of noise in available data, DEA-VRS outperforms DEA-CRS model. This issue was not discussed in Bifulco and Bretschneider (2001, 2003) since they generate data using a constant returns to scale technology and thus only evaluate the performance of DEA-CRS. In contrast, we assume decreasing returns to scale in our experimental design, since we believe it represents more properly the technology of production in education. In this context, the use of the DEA-VRS model enhances both the detection of efficient DMUs and the estimation of accurate measures of actual inefficiencies for DMUs that are no placed in the boundary. Furthermore, this is the appropriate option for the DEA model in cases where ratios are used in inputs or in outputs as it is usual in educational frameworks (Hollingsworth and Smith, 2003).

In summary, the results of this paper provide some guidance about the conditions under which DEA can be considered a useful management tool for policy and management decisions. First, it requires having a sufficient sample size, with 100 production units being an adequate threshold to be confident about the precision of estimates. Fortunately, this first requirement is not difficult to fulfill since most of administrative datasets in educational contexts have at least one hundred units, whether they are school districts or schools in the same urban district. Second, DEA-VRS should be used in order to take into account potential divergences in the scale of production among units. Finally, the use of DEA can lead to misleading results in the presence of substantial measurement errors in available data. Despite the fact that those errors are less frequent in aggregated data (Ruggiero, 2006), the potential use of DEA as an instrument to analyze the efficiency in performance-based accountability systems requires great enhancements in the quality of data in order to minimize errors.

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