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Educational efficiency in a dea-bootstrap approach

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Abstract

We use the PISA 2006 results to analyse the students' proficiencies in 24 European Countries with regard to two indexes that represent the educational resources available at home and the family background of students. Many factors affect the proficiencies and therefore, using a DEA-bootstrap method, we intend to measure the efficiency of the European educational systems as capability to ensure high students' competencies despite adverse conditions about the educational resources available in students' home and the family background.

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1. Introduction

Many papers in the economic field are addressed towards the aspects of the educational process and the factors that directly or indirectly influence it (for example, Coleman, 1966; Putnam, 1993; Putnam & Helliwell, 1999; Brunello & Checchi, 2005). This is a relevant issue for the sustainable development of the modern economies and an important key to promoting development in all nations of the world (Barro, 2001; De La Fuente & Ciccone, 2002). The first major scientific contributions of Mincer (1958), Schultz (1961) and Becker (1964) on the education economics have encouraged studies about the relationship between human capital and productivity, the distribution of wealth and, more generally, the economic and social development of Countries (Romer, 1990). Briefly, more education and, then, more human capital generates economic and social well-being and ensures economic and social progress (Nelson & Phelps, 1966). So, in the human capital theory the education of the population is highly instrumental and necessary to improve the production (Schultz, 1971; Sakamota & Powers, 1995; Psacharopoulos & Woodhall, 1997). The training success of a population implies a population better educated, more skilled and competent workers, and it determines, in fact, the success of the scholastic educational system whose main purpose is human capital accumulation (Hanushek & Kimko, 2000; Krueger & Lindahl, 2001).

Among the useful tools to measure the human capital, the surveys about skills, capabilities and competencies appear relevant (Tyler et al., 2000). Specifically, it is useful to measure the human capital through the scholastic competency of the students (the future workers) even if this doesn't capture completely their attitudes and motivations; anyhow, the results could provide some important evidences about level and quality of the human capital in some Countries.

Moreover, as the innate ability cannot be measured, the student background has been shown to be the most decisive factor in explaining the student performances (Hanushek & Luque, 2003; Wößmann, 2003). In this paper, we study the students' competencies taking into account some educational resources available at students' home and some components about the students' family background. Obviously, many other factors affect the students' competencies, for example school resources or institutional context. In particular, we will say that the educational system will be more efficient if, with equal family conditions, it achieves a higher students' proficiency and, hence, the greater efficiency can be explained by the action of these factors.

PISA is the most comprehensive survey that analyses the disparities of the students' proficiencies among Countries; furthermore, it allows us to easily analyze the socio-demographic characteristics of students (OECD, 2006; Bratti et al., 2007).

With these justifications, we use the PISA 2006 data to represent, through the students' scholastic competencies in mathematics, reading and science, the human capital in the following 24 European Countries: Austria, Belgium, Bulgaria, Czech Republic, Germany, Denmark, Estonia, Finland, France, Greece, Hungary, Ireland, Italy, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden, United Kingdom (Cyprus, Latvia and Malta are missing).

Therefore, the purpose of this paper is to connect the students' competencies in mathematics, reading and science to a measure of educational resources available at home and a measure of family background as proxy of socio-economic students' conditions.

For this aim, we have constructed two specific indexes named IAR (educational resources available at home) and IFB (family background).

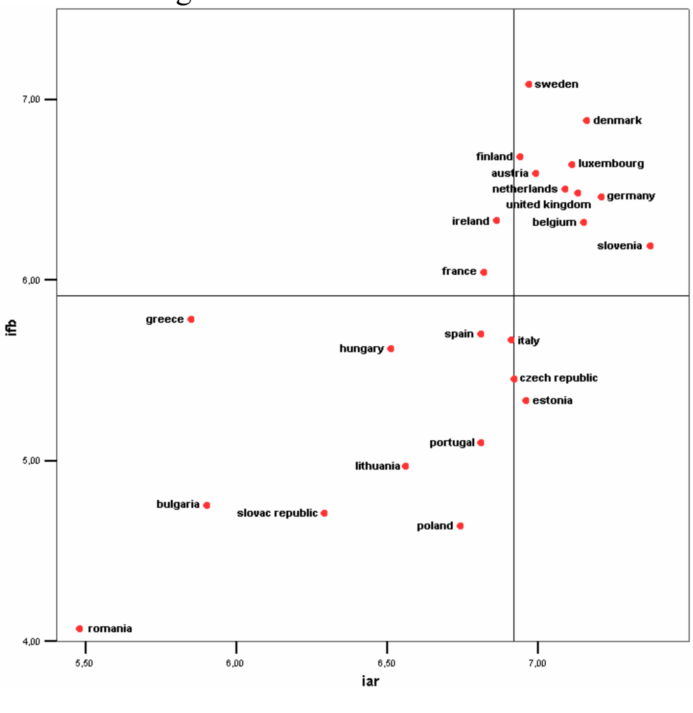
In this way, we build an efficiency rank of the educational systems giving a greater value to those systems where the competencies are high despite an unfavorable context about the educational resources available at home and the family background (Cunha et al., 2006)[1].

In literature, both non-parametric DEA methods and classical parametric frontier models are utilized to analyse the educational process and to measure its statistical efficiency (Cooper & Cohn, 1997; Afonso & Aubyn, 2005; Johnes, 2006; Soares de Mello *et al.*, 2006). But, a robust DEA nonparametric approach is here preferable. In particular, the DEA-bootstrap algorithm avoids the curse of dimensionality, it corrects the typical bias of the classical DEA estimates and it can also be applied with a few of data.

2. Socio-economic conditions and competencies of PISA students

To evaluate the efficiency of educational systems, we have considered the three students' competencies in mathematics, reading and science and two indexes representing the students' conditions. In particular, we have considered 1) the educational resources which are available for the student at home (named IAR) and 2) some features related to the family background (named IFB). The role of the students' conditions and, in particular, the dimensions represented in the two indexes have a significant relationship with the students' skills (Acemoglu & Angrist, 2000; Currie & Thomas, 2001; Feinstein, 2004; Fuchs & Wößmann, 2004; Moretti, 2004; Schulz, 2005).

Figure 1 – IAR and IFB values



Following the indicated literature, to represent the educational resources available at home that are useful for the student training, we have selected the possession (value 1) or not (value

[1] In general terms, a high students' skill with low resources at home and bad family background is translated in a high efficiency score assuming the positive presence of institutional factors, local and global school policy, school facilities, expertise of teachers, etc. In the paper, these elements are treated as explanatory factors of the efficiency scores. Moreover, it should be noted that we are interested in a comparison of Countries about the educational system. The micro level analysis allows for high detail at student level but it does not allow to generalize at Country level; then, in the paper, we shift from a micro to a macro approach.

0) about some relevant goods from the question nr.13 in the student questionnaire (OECD, 2005):

1. desk to study, 2. quiet place to study, 3. computer to use for school work, 4. educational software, 5. link to the internet, 6. own calculator, 7. books to help with school work, 8. dictionary.

The index of the educational resources available at student's home (IAR) is obtained by the sum of the possession values (1=yes or 0=no); therefore, the index varies from 0 (none availability) to 8 (whole availability). Finally, the Country value is the mean for the corresponding students.

With the second index we represent the family background of the students. So, in the student questionnaire, we consider:

the possession about the goods b) and m) from the question nr.13

1. own room, 2. dishwasher;

the possession of two or more about the goods a), b), c) and d) from question nr.14:

3. cellular phone, 4. television, 5. computer, 6. car;

from question nr.15:

7. possession of 100 books or more;

from questions nr.7 and 10:

8. a level 4 in the ISCED qualification of at least one parent;

from questions nr.5 and 8:

9. at least one parent legislator, senior official, manager, professional, technician or associate professional according to the ISCO classification.

The index of family background of the students (IFB), obtained by the sum of the possession values (1=yes or 0=no), varies from a minimum of 0 (no possession) to a maximum of 9 (whole possession); the Country value is the mean for the corresponding students.

The Figure 1 shows the IAR and IFB values for the 24 European Countries.

3. Efficiency of educational systems via DEA-bootstrap

As mentioned earlier, the student's skills are influenced by many factors including the quality of teachers and the facilities available in schools; these factors are not explicit in the paper but they affect the competencies values and, then, influence the efficiency score of the educational system: they will help us in explaining differences in performance (Bishop & Wößmann, 2004; Brunello & Checchi, 2005; Jacob, 2005; West & Peterson 2006).

The traditional view of the Farrell-efficiency concept corresponds to the relationship between inputs and outputs usually with reference to micro units; the mathematical form can be deterministic or stochastic, parametric or non-parametric. The extension to a macroeconomic context where territorial areas are the considered units doesn't represent a formal difficulty, but requires some caution on the setting of the analysis and the interpretation of the results.

In the production analysis of a micro unit, for example a firm, the production is constrained by the technical possibilities denoted, for a given a technology, by the production set

$$\Psi = \left\{ (x, y) \in \Re_{+}^{p+q} \mid x \text{ can produce } y \right\} \tag{1}$$

where $x \in \Re_{+}^{p}$ represents a matrix of inputs and $y \in \Re_{+}^{q}$ one of outputs. If

$$\forall\, y \in \Psi,\; X(y) = \left\{ x \in \Re_{+}^{p} \mid (x, y) \in \Psi \right\} \tag{2}$$

then the radial input-oriented efficient frontier is

$$\partial X(y) = \left\{ x \mid x \in X(y),\; \theta x \notin X(y) \;\; \forall\; 0 < \theta < 1 \right\} \tag{3}$$

Consequently, the Farrell input-oriented technical efficiency for a generic point (x, y) is

$$\theta(x, y) = \inf\left\{ \theta \mid \theta x \in X(y) \right\} \tag{4}$$

Therefore, a production unit is technically efficient when it minimises the input levels for a given level of output. It is easy to transpose this analysis to the output-oriented case: then, a unit will be technically efficient when it is able to maximise output for a given level of input.

In this paper, the units are the selected Countries, but the production process is virtual because we consider the two indexes IAR and IFB as inputs and the PISA proficiencies values for mathematics, reading and science as outputs. No specific consideration is made about the adopted technology (considered as space-invariant) and about returns to scale, assumed here in general term as variable. The implicit hypothesis is that the students' proficiencies are related to the educational resources available at home and to the family background. As a rule, poor conditions determine poor proficiency and good conditions determine good proficiency, but it is interesting to verify if bad context is related to good proficiency.

The production possibilities set Ψ is unknown and only the combinations (x, y) of the effectively observed units are know. Therefore, it will be necessary to estimate in some way Ψ, $X(y)$, $\partial X(y)$ and $\theta(x, y)$ for the input orientation, or with a similar reasoning, $Y(x)$, $\partial Y(x)$ and $\phi(x, y)$ for the output orientation. Among all the alternatives, the estimates obtained using DEA (Data Envelopment Analysis) are the most common (Førsund e Sarafoglou, 2005).

For an input-oriented DEA, we have the following estimator

$$\hat{\theta}_{dea}(x_0, y_0) = \inf\left\{ \theta \mid (\theta x_0, y_0) \in \hat{\Psi}_{dea}(\aleph_n) \right\} \tag{5}$$

and

$$\hat{\Psi}_{dea}(\aleph_n) = \left\{ (x, y) \in \Re_{+}^{p+q} \mid y \le \sum_{i=1}^{n} \gamma_i y_i,\, x \ge \sum_{i=1}^{n} \gamma_i x_i,\, \sum_{i=1}^{n} \gamma_1 = 1, \gamma_i \ge 0 \;\forall i = 1, \ldots, n \right\} \tag{6}$$

where $\aleph_n = \left\{ (x_i, y_i), i = 1, \ldots, n \right\}$ and with

$$\hat{\Psi}_{dea} \subseteq \Psi \quad \text{and} \quad \theta(x_0, y_0) \le \hat{\theta}_{dea}(x_0, y_0) \le 1 \tag{7}$$

It is immediate to translate this in output-oriented terms, where

$$\forall x \in \Psi,\;\; Y(x) = \left\{ y \in \Re_{+}^{q} \mid (x, y) \in \Psi \right\}, \tag{8}$$

$\partial Y(x) = \{ y \mid y \in Y(x), \phi y \notin Y(x) \ \ \forall \ \phi > 1 \}$, and
$\phi(x, y) = \sup \{ \phi \mid \phi y \in Y(x) \}$

Here, the DEA is applied under the generic assumption of variable returns to scale with a space-invariant technology, so the frontier is unique for all the 24 Countries; different options or other restrictions have a higher level of arbitrariness. Moreover, we have chosen the output orientation because it is more suitable than input orientation; it implies the goal of achieving greater output, i.e. higher students' proficiency for given inputs (that is, educational resources available at home and family background), under the realistic assumption that the units, to say the Countries, seen as the ensemble of private and public efforts and policies, will be able to exercise a sufficient impact on inputs and outputs, so the inputs are not conceived as environmental factors but *de facto* as explanatory variables. Therefore, a Country has a higher efficiency score of the educational system (or performance score) if, for given inputs (educational resources available at home and family background), its students have a higher value for the proficiencies in mathematics, reading and science. Besides, since the Farrell output-oriented efficiency score varies from 1 to infinite, we use the reciprocal $1/\phi$ that varies from 0 to 1 as in the Shephard representation.

The classic DEA approach has considerable advantages and it doesn't demand a specific, often unjustifiable, mathematical form between inputs and outputs, but it has also some drawbacks not at all negligible at times. In particular, the DEA scores show a bias (see formula 7) yet a correction is possible. The absence of theoretical information about the DEA estimates suggests a bootstrap procedure to simulate the Data Generating Process (DGP) (Simar & Wilson, 1998, 2000a and 2000b). Following these Authors, it is possible to obtain bootstrap samples so that from each sample we have one efficiency score for each specific Country and consequently to study the statistical characteristics of the efficiency values and, then, to correct the bias.

If the data $\aleph_n$ are from the process $P(\Psi, f(x, y))$, where Ψ is the unknown set and f is a suitable probability density function, from the same $\aleph_n$ it is possible to derive an estimator of P, Ψ and score θ (or ϕ). Let $\hat{P}(\aleph_n)$ be a consistent estimator of the DGP P, then $\hat{P}(\aleph_n) = P(\hat{\Psi}, \hat{f}(x, y))$. In a bootstrap way, a new dataset or pseudo-sample $\aleph_n^* = \{ (x_i^*, y_i^*), i = 1, ..., n \}$ is drawn from $\hat{P}$. An estimator of $\hat{\Psi}$ is now $\hat{\Psi}^*(\aleph_n^*)$, and so for a fixed point (x_0, y_0) we have $\hat{\theta}_{dea}^*(x_0, y_0)$ as estimator of $\hat{\theta}_{dea}(x_0, y_0)$. If the bootstrap is consistent, then approximately

$$\left(\hat{\theta}_{dea}^*(x_0, y_0) - \hat{\theta}_{dea}(x_0, y_0) \right) \mid \hat{P}(\aleph_n) \sim \left(\hat{\theta}_{dea}(x_0, y_0) - \theta(x_0, y_0) \right) \mid P \qquad (9)$$

In theory, the sampling distribution of $\hat{\theta}_{dea}^*(x_0, y_0)$ is known but, in practice, for impossibility of computation it is indispensable to use Monte Carlo simulations. Then, we use $\hat{P}(\aleph_n)$ to generate B samples, so we have $\aleph_{n,b}^*$ of size n with $b = 1, ..., B$; consequently, we obtain B pseudo-estimates $\hat{\theta}_{dea,b}^*(x_0, y_0)$ and their empirical distribution provides an approximation of the sampling distribution of $\hat{\theta}_{dea}^*(x_0, y_0)$. Evidently, the quality of the bootstrap procedure is greater if B and n are big.

Furthermore, if some circumstances are verified, the bootstrap procedure allows to correct the bias of the DEA estimators. It is

$$bias\left(\hat{\theta}_{dea}(x_0, y_0)\right) = E\left(\hat{\theta}_{dea}(x_0, y_0)\right) - \theta(x_0, y_0) \qquad (10)$$

and, then,

$$\widehat{bias}_B\left(\hat{\theta}_{dea}(x_0, y_0)\right) = (1/B)\sum_{b=1}^{B} \hat{\theta}^{*}_{dea,b}(x_0, y_0) - \hat{\theta}_{dea}(x_0, y_0) \qquad (11)$$

But all this is valid if the bootstrap is consistent. In fact, in some cases the bootstrap estimates could be inconsistent (Beran & Ducharme, 1991; Efron & Tibshirani, 1993), and this is a typical situation for the naïve bootstrap (Ferrier & Hirschberg, 1997; see the criticism of Simar & Wilson, 1999). Therefore, Simar & Wilson (1998 and 2000b) suggest a homogeneous and a heterogeneous procedure. The first approach is based on a homogeneity assumption for the structure of inefficiency, whereas the second approach allows for possible heterogeneity in the structure of inefficiency. In this paper, we follow the homogeneous case of the Simar-Wilson method with $B = 2,000$ Monte Carlo resampling since the homogeneity conjecture is here credible and the computations don't meet the typical problems of the heterogeneous bootstrap case; for this matter, we defer to the cited literature.

4. Efficiency of the educational systems

The mathematical, reading and scientific literacy of students may vary a lot among Countries. The reasons may be numerous: different family characteristics, high or low social and economic conditions, presence or absence of specific educational policies, and so on.

Therefore, our interest is to analyze the students' proficiencies in the 24 Countries taking into account the educational resources available at home (IAR) and the family background (IFB). With a high level of educational resources available at home and a good family background we expect a high students' proficiency. So, the success of an educational system in a Country is as much evident as higher is the proficiency score with given educational resources available at home and family background, where the positive effect of factors about schools, institutions, etc., explains the higher performances.

Table 1 presents the estimates of the efficiency scores (or the performance of the educational system), the bias of the classical DEA values and the confidence interval at 95 *per cent*. A smaller score indicates a greater incapacity of the educational system to obtain higher levels of the students' proficiencies for given educational resources available at home and family background; obviously, the reasons could derive from lower investment and lower quality in school facilities, teacher training, etc..

It is interesting to note that Italy is in the last position (0.8755), following Luxembourg (0.8807), Portugal (0.8987) and Spain (0.9035). At the top, we have Czech Republic (0.9742), Estonia (0.9736), Netherlands (0.9649) and Finland (0.9640).

The ordered scores and the confidence intervals suggest some interpretative cautions since sometimes they are wide and overlapping (that is in Romania, Poland and Greece); but, Italy remains undoubtedly in the last position.

Italy and Luxembourg are in the last positions since they have good inputs but bad outputs. On the contrary, Czech Republic is at the top of the performance rank since it has bad inputs but good outputs. In particular, Italy is 13th in the IAR ranking and 15th in the IFB ranking, but 21st, 19th and 20th for the proficiencies in mathematics, reading and science respectively. Luxembourg has the 6th and the 4th position for the inputs but it is 16th in mathematics and reading and 19th in science. Czech Republic has the 12th and the 17th position for inputs but it is 6th for mathematics and 7th for science even if it is 14th for reading. Bulgaria and Romania are respectively at the 10th and 15th position since these Countries present low levels of inputs but also low levels of outputs. Other Countries, for example Greece and Slovak Republic, show very bad inputs but intermediate outputs and so the performance score has high positions (8th and 5th respectively). Finland has the 4th position in the efficiency rank because it is always in the first position for the three proficiencies but it has also good positions for the IAR and IFB indexes.

Table 1 – Efficiency scores, bias and confidence intervals

Rank	Countries	Efficiency scores	Bias	Inf.bound	Sup.bound
1	Czech Republic	0.9742	0.0114	0.9583	0.9838
2	Estonia	0.9736	0.0264	0.9517	0.9983
3	Netherlands	0.9649	0.0108	0.9468	0.9749
4	Finland	0.9640	0.0360	0.9399	0.9987
5	Slovak Republic	0.9604	0.0396	0.9269	0.9982
6	Belgium	0.9562	0.0085	0.9421	0.9636
7	Hungary	0.9532	0.0207	0.9346	0.9726
8	Greece	0.9531	0.0469	0.9129	0.9984
9	Poland	0.9520	0.0480	0.9041	0.9987
10	Romania	0.9497	0.0503	0.9002	0.9984
11	Lithuania	0.9475	0.0222	0.9214	0.9683
12	Ireland	0.9427	0.0207	0.9203	0.9619
13	Slovenia	0.9254	0.0155	0.9064	0.9397
14	Denmark	0.9229	0.0126	0.9035	0.9348
15	Bulgaria	0.9186	0.0243	0.8894	0.9414
16	France	0.9154	0.0176	0.8988	0.9315
17	Germany	0.9128	0.0152	0.8908	0.9268
18	Austria	0.9070	0.0186	0.8866	0.9246
19	Sweden	0.9067	0.0209	0.8819	0.9269
20	Spain	0.9035	0.0150	0.8903	0.9171
21	United Kingdom	0.9035	0.0180	0.8812	0.9202
22	Portugal	0.8987	0.0229	0.8686	0.9202
23	Luxembourg	0.8807	0.0145	0.8630	0.8944
24	Italy	0.8755	0.0173	0.8561	0.8918
	Median	0.9341	---	---	---
	Mean	0.9318	---	---	---

5. Conclusion

In this paper emerges an interesting differentiation among the 24 European Countries about the efficiency scores of the educational systems. In particular, we have run a DEA-bootstrap analysis where the educational resources available at home and the family background of students are inputs in a virtual process with proficiencies values in mathematics, reading and science as outputs. The analysis is carried out in a macroeconomic context because the results could be useful for national policy: in fact, it is appropriate to compare the students' abilities contextualizing the PISA values under the students' conditions about the educational resources at home and the family background. Thus, the greater ability of this process to transform inputs to outputs, i.e. greater efficiency, shows a better educational system, that is the bechmark for those nations where efficiency is lower.

Therefore, the DEA score varies from 0 to 1 in relation to the capability of the educational system to obtain a higher level in the students' proficiency for given resources at home and family background. Italy has the minimum score with 0.8755 while the best performance is in Czech Republic with 0.9742. It is interesting to note the bad positioning of Spain (20th), United Kingdom (21st), Portugal (22nd) and Luxembourg (23rd), while Estonia, Netherlands and Finland are at the top of ranking (2nd, 3rd and 4th respectively). In general, the Euro-Mediterranean Countries show worse positions than the Northern ones.

We note that Italy is in the last position for the efficiency ranking of the educational systems. The reasons could derive from the critical state of the national economic and social system, for example lower investment and lower quality in school facilities, teacher trainings or, in general, an unfavourable economic and social context. In general, the more industrialized and developed Countries should have better educational resources available at home and better family background and also higher students' proficiencies in mathematics, reading and science. Nevertheless, this doesn't always happen: it is not prominent the total costs allocated for the educational system but if money is spent in an optimal way or not. For example, in Italy the middle and high schools often have poor facilities, especially in the Southern areas, and it is well-known that they give scarce attention to foreign languages and scientific subjects, with low investment outlays while enormous economic resources are absorbed by unproductive consumer expenditures.

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