Cross-country Efficiency of Secondary Education Provision: a Semi-parametric Analysis with Non-discretionary Inputs

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Introduction

In this paper we:

– i) **estimate output efficiency scores** for 25 countries, taking into account the resources employed;

– ii) **explain efficiency scores**, controlling for environment factors (non-discretionary inputs).

– Methodology:
  - "raw" efficiency scores: **DEA** (data envelopment analysis);
  - explaining inefficiency: **tobit regression**, **bootstrap technique**.

Motivation …

Two main motivations:

(1) Public finances

- In 2001 OECD countries expended an average of 6.2% of GDP on education institutions, of which 4.8% of GDP were from public sources.
- In primary and secondary education, on average, 92% of spending is public.

(2) Education and growth

Concern with education also comes from the belief that this is an important source of human capital formation and therefore of economic growth.

Table 1 – Public expenditure on education, 2001
(% of total expenditure in each level)

	Pre-primary education	Primary and secondary education	Tertiary education	All levels of education
Australia	68.9	84.4	51.3	75.6
Austria	79.3	96.3	94.6	94.4
Belgium	96.6	95.0	84.1	93.0
Czech Republic	91.8	92.1	85.3	90.6
Denmark	81.7	98.0	97.8	96.1
Finland	91.0	99.1	96.5	97.8
France	95.9	93.0	85.6	92.0
Germany	62.3	81.1	91.3	81.4
Greece	na	91.4	99.6	94.2
Hungary	90.6	93.1	77.6	89.0
Iceland	na	95.3	95.0	91.7
Indonesia	5.3	76.3	43.8	64.2
Ireland	33.2	95.3	84.7	92.2
Italy	97.0	98.0	77.8	90.7
Japan	50.4	91.5	43.1	75.0
Korea	48.7	76.2	15.9	57.1
Mexico	86.7	87.2	70.4	84.6
Netherlands	98.2	95.1	78.2	90.9
Norway	na	na	96.9	95.9
Portugal	na	99.9	92.3	98.5
Slovak Republic	97.4	98.5	93.3	97.1
Spain	83.4	93.3	75.5	87.8
Sweden	100.0	99.9	87.7	96.8
Switzerland	na	84.8	na	na
Thailand	97.8	na	82.5	95.6
Tunisia	na	100.0	100.0	100.0
Turkey	na	na	95.8	na
United Kingdom	95.7	87.2	71.0	84.7
United States	68.1	93.0	34.0	69.2
Uruguay	81.3	93.5	99.5	93.4
Mean	78.3	92.2	79.3	88.2
Median	86.7	93.3	85.3	91.9
Minimum	5.3	76.2	15.9	57.1
Maximum	100.0	100.0	100.0	100.0
Standard deviation	24.3	6.8	21.8	10.8
Observations	23	27	29	28

… and literature on education efficiency

- Previous research on the performance of the public sector in general and of education systems in particular suggest the existence of inefficiencies:
- Afonso, Schuknecht and Tanzi (2005), public expenditure in the OECD; St. Aubyn (2003), education spending in the OECD; Gupta and Verhoeven (2001), education and health in Africa; Afonso and St. Aubyn (2005) health and education in OECD.

- Methodologies used in the literature
  - FDH or DEA, or both;
  - Non-discretionary inputs are seldom considered.
  - Separate research strand: study of the determinants of schooling quality across countries using cross-country regressions, Barro and Lee (2001), Hanushek and Luque (2003).

DEA - Data Envelopment Analysis

$$
\begin{aligned}
& Max_{\lambda,\delta_i}\ \delta_i \\
& \text{s. to}\quad \delta_i y_i \leq Y\lambda \\
& \qquad\quad x_i \geq X\lambda \qquad\qquad (1) \\
& \qquad\quad n1'\lambda = 1 \\
& \qquad\quad \lambda \geq 0
\end{aligned}
$$

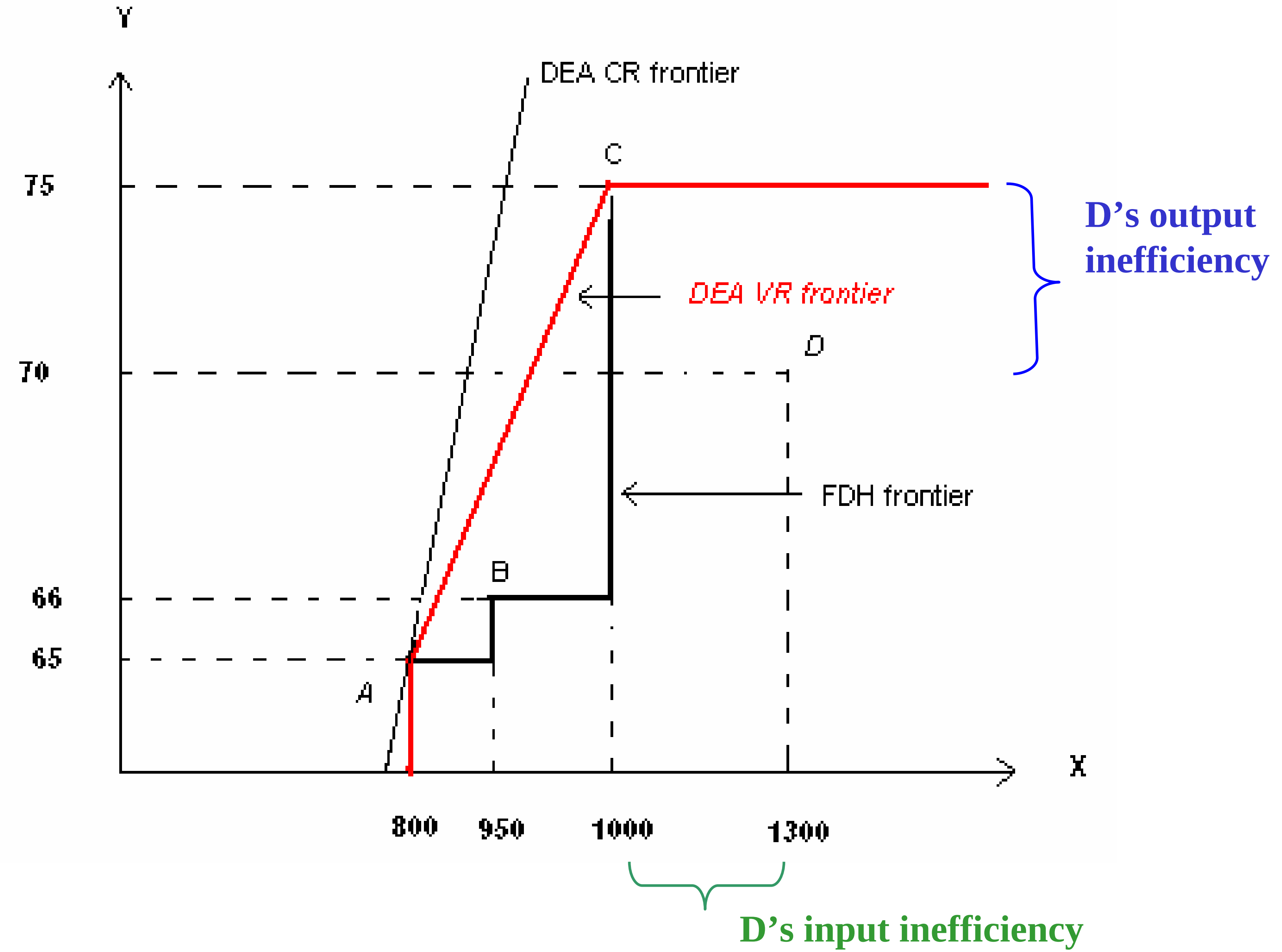
y - column vector of outputs,
x - column vector of inputs,
X - input matrix,

Y - output matrix.

δ - efficiency score (δ>=1).

δ > 1, inefficiency
δ = 1, efficiency

DEA and FDH illustration



Non-discretionary inputs and tobit two-steps procedure

Non-discretionary inputs:

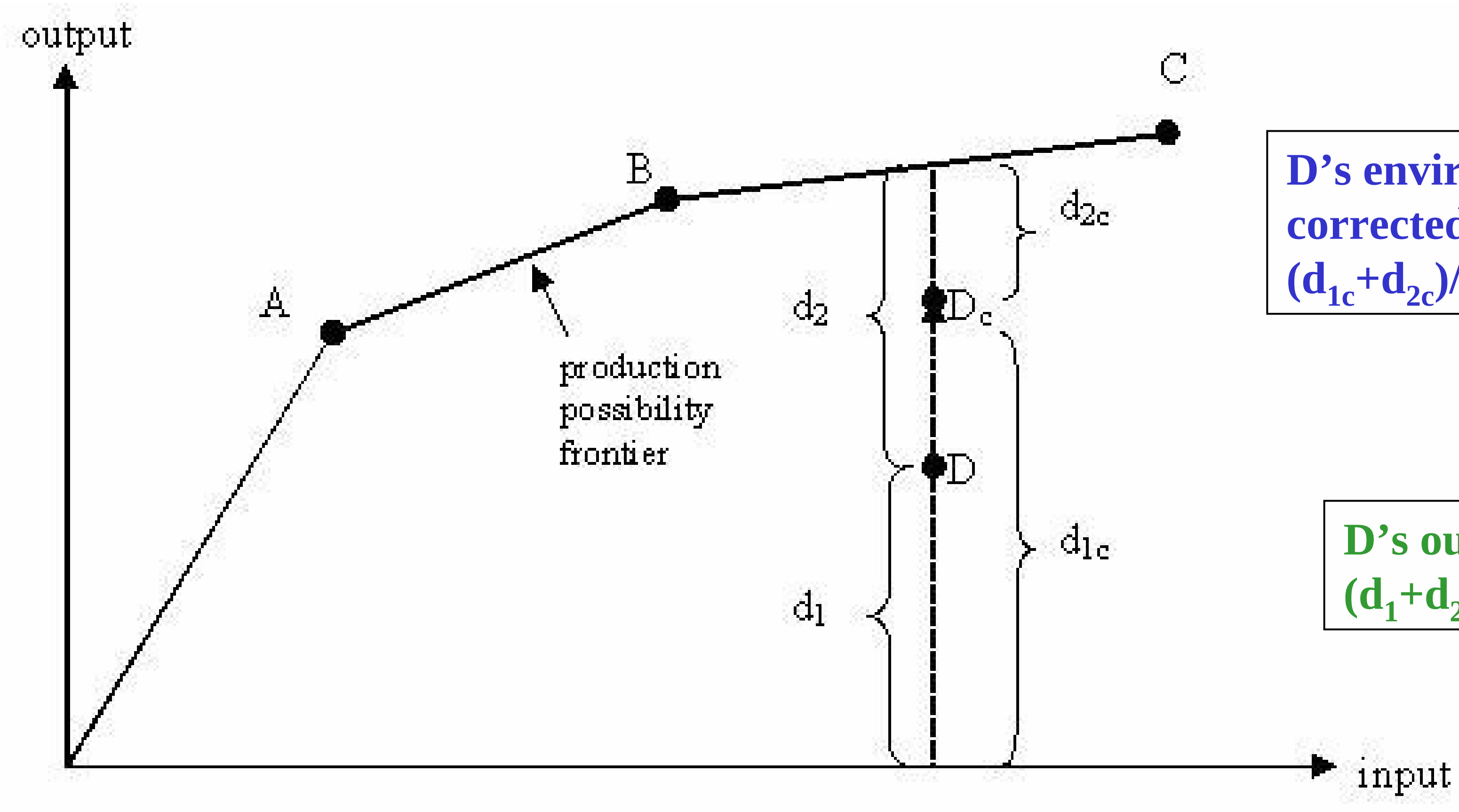
Socio-economic differences may play a relevant role in determining heterogeneity across DMUs – either secondary schools, universities or countries' achievements in an international comparison – and influence educational outcomes.

Typical two stage approach:
The output efficiency score is regressed on non-discretionary outputs (*z*):

$$\hat{\delta}_i = z_i \beta + \varepsilon_i \qquad (2)$$

The output score is not smaller than 1. This has led researchers to use a tobit regression approach.

Non-discretionary inputs and tobit two-steps procedure



D's environment corrected output score= $(d_{1c}+d_{2c})/d_{1c}$

D's output score= $(d_1+d_2)/d_1$

$1 < (d_{1c}+d_{2c})/d_{1c} < (d_1+d_2)/d_1$, the environment corrected score is closer to the frontier.

Non-discretionary inputs and tobit two-steps procedure

Problems with tobit traditional procedure: $\hat{\delta}_i = z_i \beta + \varepsilon_i$

- Each efficiency score estimate depends on all observed inputs and outputs: ε_i is serially correlated.
- The environmental variables are correlated with both inputs and outputs: ε_i is not independent from z_i.

Simar and Wilson (2007) propose alternative estimation and inference procedures based on bootstrap methods. They assume:

$$\delta_i = \psi(z_i, \beta) + \varepsilon_i \geq 1,$$

where ε_i is a left truncated normal random variable.

Data set

Country	PISA (2003) 1/	Hours per year in school, 2000-2002 2/	Teachers per 100 students, 2000-2002 3/	GDP per capita, 2003 (USD) 4/	Parental education attainment, 2001-2002 5/	Public-to-total expenditure ratio 2001-2002 6/
Australia	526.15	1023.7	8.0	29143. 4	61.1	84.6
Austria	498.35	1072.5	10.0	29972. 5	81.9	96.0
Belgium	517.59	1005.0	10.5	28396. 1	64.6	94.4
Brazil	379.84	800.0	5.5	7767. 2	57.3	
Czech Republic	511.16	867.0	7.5	16448. 2	90.5	91.9
Denmark	499.65	860.0	7.8	31630. 2	80.5	97.9
Finland	545.90	807.0	7.3	27252. 2	84.7	99.3
France	509.34	1037.0	8.1	27327. 2	67.9	93.0
Germany	502.53	886.0	6.6	27608. 8	85.6	80.8
Greece	461.67	1064.0	10.1	19973. 2	59.4	91.6
Hungary	494.06	925.0	8.7	14572. 3	78.6	92.9
Iceland	501.57	821.9	na	30657. 3	61.0	95.2
Indonesia	374.55	1274.0	5.5	3364. 5	22.7	76.4
Ireland	505.54	896.3	7.0	36774. 8	63.7	95.7
Italy	474.31	1020.0	9.8	27049. 9	49.4	97.9
Japan	531.79	875.0	6.7	28162. 2	94.0	91.6
Korea	541.29	867.0	5.1	17908. 4	77.8	78.5
Mexico	393.56	1166.9	3.3	9136. 2	15.6	86.7
Netherlands	523.87	1066.9	6.1	29411. 8	69.9	94.8
New Zealand	524.68	952.6	6.1	21176. 9	79.6	na
Norway	492.23	826.8	9.6	37063. 4	90.8	99.2
Poland	492.81	na	6.8	11622. 9	47.9	na
Portugal	470.29	881.7	11.5	18443. 5	20.0	99.9
Russian Federation	469.61	989.0	8.9	9195. 2	na	na
Slovak Republic	488.49	886.3	7.4	13468. 7	90.3	98.1
Spain	483.75	907.2	8.6	22264.	45.3	93.1
Sweden	509.50	740.9	7.3	26655. 5	86.8	99.9
Switzerland	514.99	887.0	na	30186. 1	87.3	86.9
Thailand	422.73	1167.0	5.6	7580. 3	19.0	97.8
Tunisia	365.70	890.0	4.6	7082. 9	na	100.0
Turkey	426.54	841.3	5.7	6749. 3	24.7	na
United States	486.67	na	6.5	37352. 1	88.5	91.5
Uruguay	426.35	913.0	6.9	8279. 9	35.1	93.5
Mean	480.82	942.5	7.4	21202.3	63.9	92.8
Minimum	365.70	740.9	3.3	3364.5	15.6	76.4
Maximum	545.90	1274.0	11.5	37352.1	94.0	100.0
Standard deviation	48.87	122.0	1.9	10168.7	24.6	6.5
Observations	33	31	31	33	31	28

Table 3 – Results for education efficiency (n=25)

2 inputs (teachers-students ratio, hours in school) and 1 output (PISA 2003 indicator)

Country	DEA Output oriented		Peers
	VRS TE	Rank	
Australia	1.038	7	Finland
Austria	1.095	14	Finland
Belgium	1.055	8	Finland
Czech Republic	1.068	9	Finland
Denmark	1.093	13	Finland
Finland	1.000	1	Finland
France	1.072	10	Finland
Germany	1.083	12	Finland, Korea
Greece	1.182	21	Finland
Hungary	1.105	15	Finland
Indonesia	1.447	25	Finland, Korea
Ireland	1.079	11	Finland, Korea
Italy	1.151	19	Finland
Japan	1.024	4	Finland, Korea
Korea	1.000	1	Korea
Netherlands	1.037	6	Finland, Korea
New Zealand	1.036	5	Finland, Korea
Norway	1.109	16	Finland
Portugal	1.161	20	Finland
Slovak Republic	1.118	17	Finland
Spain	1.129	18	Finland
Sweden	1.000	1	Sweden
Thailand	1.283	24	Finland, Korea
Turkey	1.260	22	Finland, Korea, Sweden
Uruguay	1.278	23	Finland, Korea
Average	1.116		

DEA results

With the same inputs, it would be possible to increase the output.

Results from tobit regression: $\hat{\delta}_i = \beta_0 + \beta_1 Y_i + \beta_2 E_i + \varepsilon_i$

Table 4 – Censored normal Tobit results
(25 countries)

	Model 1	Model 2	Model 3	Model 1a	Model 3a
Constant	1.295024 (0.000)	1.342502 (0.000)	1.374361 (0.000)	2.614888 (0.000)	2.237114 (0.000)
Y	-0.825e-5 (0.000)		-0.427e-5 (0.012)		
Log(Y)				-0.152062 (0.000)	-0.101269 (0.000)
E		-0.003566 (0.000)	-0.002574 (0.000)		-0.001903 (0.001)
$\hat{\sigma}_\varepsilon$	0.081428 (0.000)	0.071752 (0.000)	0.062480 (0.000)	0.063324 (0.000)	0.051811 (0.000)

Notes: *Y* – GDP per capita; *E* – Parental educational attainment. $\hat{\sigma}_\varepsilon$ – Estimated standard deviation of ε. P- values in brackets.

$$\Delta Y, \Delta E \Rightarrow \nabla \delta \Rightarrow \Delta \text{ efficiency}$$

Table 5 – Bootstrap results
(25 countries)

	Algorithm 1				
	Model 1	Model 2	Model 3	Model 1a	Model 3a
Constant	1.367000	1.395726	1.455587	2.907919	2.347747
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Y	-0.150344e-4		-0.710790e-5		
	(0.000)		(0.001)		
Log(Y)				-0.184488	-0.112575
				(0.000)	(0.000)
E		-0.00523442	-0.00269907		-0.00209274
		(0.000)	(0.000)		(0.001)
$\hat{\sigma}_{\varepsilon}$	0.102022	0.0876502	0.0677879	0.0710499	0.0544861
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
	Algorithm 2				
	Model 1	Model 2	Model 3	Model 1a	Model 3a
Constant	1.435993	1.412244	1.455827	3.028311	2.596005
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Y	-0.151096e-4		-0.712013e-5		
	(0.000)		(0.001)		
Log(Y)				-0.191403	-0.135911
				(0.000)	(0.000)
E		-0.00482225	-0.00270063		-0.00178054
		(0.000)	(0.001)		(0.0005)
$\hat{\sigma}_{\varepsilon}$	0.0985940	0.0875667	0.0678872	0.0588680	0.0471327
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Notes: *Y* – GDP per capita; *E* – Parental educational attainment. $\hat{\sigma}_{\varepsilon}$ – Estimated standard deviation of ε; P- values in brackets.

Table 6 – Corrected output efficiency scores (for Model 3a)

	Bias corrected scores (1)	GDP correction (2)	Education attainment correction (3)	Fully corrected scores (4)=(1)+(2)+(3)	Rank
Australia	1.047	0.037	-0.007	1.077	3
Austria	1.104	0.040	0.030	1.174	22
Belgium	1.063	0.033	-0.001	1.095	7
Czech Republic	1.083	-0.041	0.046	1.087	6
Denmark	1.108	0.048	0.028	1.184	23
Finland	1.037	0.027	0.035	1.100	8
France	1.082	0.028	0.005	1.115	14
Germany	1.104	0.029	0.037	1.170	21
Greece	1.191	-0.015	-0.010	1.167	20
Hungary	1.115	-0.058	0.024	1.082	4
Indonesia	1.528	-0.257	-0.075	1.196	24
Ireland	1.094	0.068	-0.002	1.159	19
Italy	1.160	0.026	-0.028	1.159	18
Japan	1.044	0.032	0.052	1.127	17
Korea	1.075	-0.030	0.023	1.068	2
Netherlands	1.066	0.038	0.009	1.112	13
New Zealand	1.068	-0.007	0.026	1.087	5
Norway	1.131	0.069	0.046	1.246	25
Portugal	1.172	-0.026	-0.080	1.067	1
Slovak Republic	1.131	-0.068	0.045	1.108	10
Spain	1.140	0.000	-0.035	1.105	9
Sweden	1.052	0.024	0.039	1.116	15
Thailand	1.348	-0.146	-0.082	1.120	16
Turkey	1.343	-0.162	-0.072	1.109	12
Uruguay	1.296	-0.134	-0.053	1.109	11
Average	1.143	-0.018	0.000	1.126	

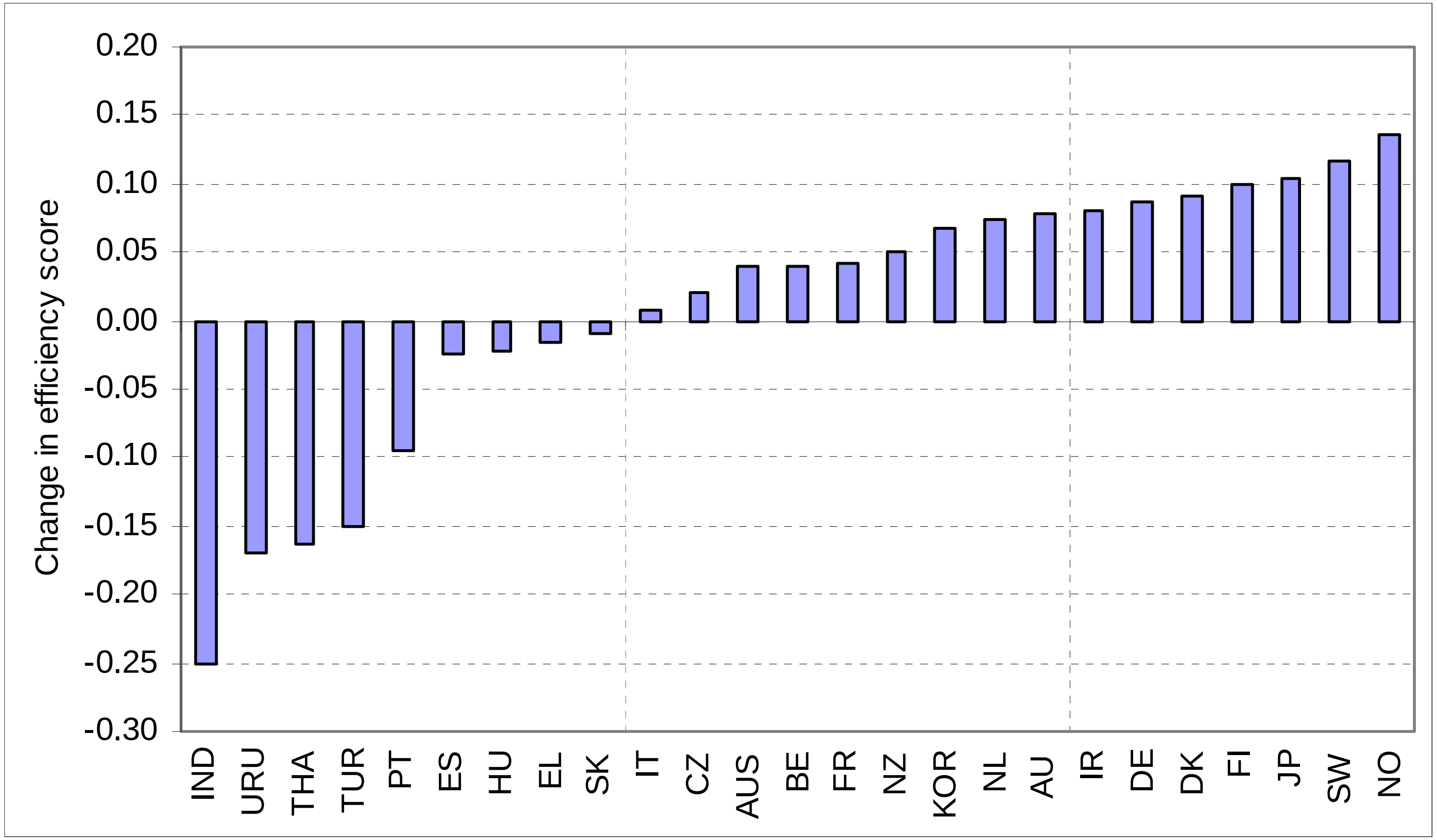
richer countries with lower levels of adult education

high educational attainment and poorer than average

Bootstrap results

Figure 3 – Change in efficiency scores after correction

-/+: DMU moves closer (further away) to (from) the production frontier



Conclusions

- Results from the first-stage imply that inefficiencies may be quite high.
- The fact that a country is seen as far from the efficiency frontier is not necessarily a result of inefficiencies engendered within the education system. GDP per head and parents' educational attainment are highly and significantly correlated to output scores.
- We have applied both the usual DEA/Tobit procedure and two very recently proposed bootstrap algorithms. Results were strikingly similar with these three different estimation processes, which brings increased confidence to obtained conclusions.

SW (2004) bootstrap methods: Algorithm 1

The first algorithm involves the following steps:

[1] The computation of $\hat{\delta}_i$ for all n decision units by solving problem (1);

[2] The estimation of equation (2) by maximum likelihood, considering it is a *truncated* regression (and not a censored or Tobit regression). Denote by $\hat{\beta}$ and $\hat{\sigma}_\varepsilon$ the maximum likelihood estimates of β and σ_ε.

[3] The computation of L bootstrap estimates for β and σ_ε, in the following way:

For $i = 1, \ldots, n$ draw ε_i from a normal distribution with variance $\hat{\sigma}_\varepsilon^2$ and left truncation at $1 - z_i\hat{\beta}$ and compute $\delta_i^* = z_i\hat{\beta} + \varepsilon_i$.

Estimate the truncated regression of δ_i^* on z_i by maximum likelihood, yielding a bootstrap estimate $(\hat{\beta}^*, \hat{\sigma}_\varepsilon^*)$.

The estimate of the scores is biased towards 1 in small samples. SW (2004) use a second bootstrap procedure, “Algorithm 2”, which includes a parametric bootstrap in the first stage problem, to produce bias-corrected efficiency scores.

SW (2004) bootstrap methods: Algorithm 2

[1] Compute $\hat{\delta}_i$ for all n decision units by solving problem (1);

[2] Estimate equation (2) by maximum likelihood, considering it is a truncated regression. Let $\hat{\beta}$ and $\hat{\sigma}_\varepsilon$ be the maximum likelihood estimates of β and σ_ε.

[3] Obtain L_1 bootstrap estimates for each δ_i, the following way:

For $i = 1, ..., n$ draw ε_i from a normal distribution with variance $\hat{\sigma}_\varepsilon^2$ and left truncation at $1 - z_i\hat{\beta}$ and compute $\delta_i^* = z_i\hat{\beta} + \varepsilon_i$.

Let $y_i^* = \dfrac{\hat{\delta}_i}{\delta_i^*} y_i$, be a modified output measure.

Compute $\hat{\delta}_i^*$ by solving problem (1), where Y is replaced by $Y^* = [y_1^* \quad ... \quad y_n^*]$. (But note that y_i is not replaced by y_i^* in the left-hand side of the first restriction of the problem.)

[4] Compute the bias-corrected output inefficiency estimator as $\hat{\hat{\delta}}_i = 2.\hat{\delta}_i - \bar{\hat{\delta}}_i^*$, where $\bar{\hat{\delta}}_i^*$ is the bootstrap average of $\hat{\delta}_i^*$.

Bootstrap results

Figure 2 – Relative change in efficiency rankings