A DEA-SFA COMPARISON OF THE IMPACT OF ICT'S UTILIZATION

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Abstract:
This article has the purpose of comparing different statistical methods of measuring efficiency, data envelopment analysis and stochastic frontier analysis. An adjacent objective is to assess the impact of the information and communication technologies on today's society. The hypotheses of the article are that there is indeed a connection between the scores obtained by applying DEA method with the ones obtained by the SFA method. Also, it is hypothesized that the level of ICTs use is higher for those countries that are more developed and it is driven by a couple of key factors, chosen as input variables in the present study.
The results show that both hypotheses are valid, as the efficiency scores obtained were statistically correlated between the different methods and as the variables chosen as inputs were significant in the SFA model.

Key Words: Efficiency, health systems, DEA, SFA

Introduction:

The end of the 20th century and the beginning of the 21st have marked the highest peak of socio-economical progress that society has ever known across history. Undoubtedly, among the factors channeled towards optimization and perpetual development of the society, scientific and technologic progress has the most consistent contribution. Furthermore, present trends of creating a virtual parallel world developed from the need of cost optimization and time saving, made information technologies an essential instrument in each citizen's life.

This article has the purpose of comparing two statistical methods of measuring efficiency, data envelopment analysis (DEA) and stochastic frontier analysis (SFA). An adjacent objective is to assess the impact of the information and communication technologies (ICT) on today's society. The hypotheses of the study are that there is indeed a connection between the scores obtained by applying DEA method with the ones obtained by the SFA method. Also, it is hypothesized that the level of ICTs use is higher for those countries that are more developed and it is driven by a couple of key factors, chosen as input variables in the present study.

Subsequent the introductory part, a literature review on the connection between ICTs and education and methods of assessing will be presented in the second part. The third part will cover the methods and data used for the study following that the forth part will be dedicated to discussing the results. The study will end with a section of general conclusions and future directions for other studies.

Literature Review:

The progress of all societies depends on the efficiency with which natural, human and financial resources are being disposed of. Therefore, when assessing public sector efficiency managers take into account that the efforts to fulfill social needs can be measured, often quantified with the value of inputs (e.g. costs of raw materials, costs of human resources, costs of information), while social effects are difficult to determine and measure. Furthermore, they are difficult to be fully forecasted. Improving public sector performance is an objective with a high importance role in the agenda of each industrialized state.

It is no wonder that governmental efficiency as a whole became the subject of an increased number of papers, received key contributions from Gupta et Verhoeven (2001), Tanzi et Schuknecht (1997, 2000) and Alfonso et al. (2006). These studies measure the efficiency of public sector by connecting government spending with socio-economical indicators. Those indicators are assumed to be in close connection with the objectives of public spending. For example, the percentage of pupils enrolled in educational units or percentage if of infant mortality are indicate substantial differences of the efficiency levels between countries, regardless the level of development.

A study from 1998 reflected that the simple allocation of the resources, even for necessary goods and services, is not enough and it is possible that the outcomes might not be the expected ones if the budgetary institutions involved in planning, management and execution do not work at their maximum efficiency. Vicious budgetary management has often been cited as one of the reasons for which the governments from the developing countries found themselves incapable of transposing public expenses into efficient services (World Bank, 2003).

The effect of income per inhabitant can be analyzed from several points of view. From the first point of view the income could reduce efficiency by increasing relative public services costs (Baumol, 1967). From the other point of view, a higher income has been many times associated with a higher level of health and education (Afonso et al., 2006). When talking about the level of efficiency, evidences show that it can be improved by increasing scale operation. This fact is shown primary in health and education sectors (Coelli et al., 2001; Curristine T, 2005; Dronkers, 2004). This is due to scale economies which are the result of the saving of additional marginal costs compared to the fixed costs of resources. Nevertheless, their impact over other fields of public sector like equity, quality or access to services has to be considered (Dooren et al., 2007).

The importance of environmental variables is also taken into account. Kasman’s (2005) paper presents an empirical analysis of banks’ efficiency in Poland and Czech Republic, taking into account the country-specific environmental factors in the second part of the analysis. The authors used Stochastic Frontier Analysis in order to measure efficiency. The results show that, without environmental variables, the cost-inefficiency scores of Czech banks are quite high compared with those of Polish banks. However, when environmental variables are included in the model, the differences between the two banking sectors decrease dramatically. Therefore, the results indicate that country-specific environmental variables are important in the definition of the common frontier (Kasman, 2005).

Researcher’s interest has also been channeled towards the connection between sectoral public spending (especially for education and health) and their outcomes (Rajkumar et al. 2008). Jayasuriya et al. (2007) use panel data for provinces from Argentina and Mexico to measure the efficiency of medical and educational services.

Nowadays ICTs are an important leverage of social and economic development, both at micro and macro level. Most of the production processes rely on human resources that are not only trained according to their positions but who can use different forms of ICTs. In other words, given the extent of today society’s speed in changing and adapting to never-ending needs, workers have to be more efficient or to improve their skills, might those skills be in their areas of expertise or in any interdisciplinary fields. ICTs have many advances and recently governments have started emphasizing those advances. Some of the attractive features of ICTs are flexibility, interactivity and their ability to move high amount of data in almost real time or to engage more people at once.

In the field of education, ICTs have been growing in importance for the last years, especially by the use of E-learning which started to be more and more chosen by students in higher education institutions. Compared to higher education enrollments in general, online enrollments have been growing significantly faster (Allen et al., 2008). In connection to this, Asandului et al (2008), conclude that students wish to have a wider range of options in connection to the e-technologies, which will definitely contribute to increasing students’ competences. Therefore, the student will benefit from the added value of e-learning after graduating university too, by making use of the technical skills he will have acquired during the study period. Moreover, Asandului et al., (2011) emphasize the connection between computers and e-learning, stating that by the use of the e-technologies the curricula is not abandoned and that abilities and capacities are more easily formed. Moreover, the use of e-technologies has been identified as a measure to increase firm’s performance and productivity growth (Clayton et al., 2003).

DEA has also been used with various occasions for assessing different aspects of the medical field, such as hospital performance (Zhu, 2002), the efficiency of public policies (Coppola et al. 2003; Miller et al, 1996; Rosko, 1990; Sherman, 1984) and the performances of cardiac surgery (Chilingerian, 1995).

Method and Data:

This study is based upon two methods of measuring efficiency: data envelopment analysis (DEA) and stochastic frontier analysis (SFA). The main difference between the two is that DEA is a nonparametric method, based on empirical observed data, whereas SFA is a parametric method who based on the observed data infers the values of the efficiency also taking into account the inefficiency factors. The two methods are shortly presented in the next paragraphs.

The economic literature that influenced directly the development of SFA is given by the total number of studies researching the efficiency of the production process from the beginning of the 1950. Thus, Koopmans (1951) suggested a definition for technical efficiency while Debreu (1951) and Shephard (1953) presented distance functions and used them to model multiple outputs on one hand and to measure radial distance of a producer from the frontier on the other hand. This was done either by extending the outputs (Debreu) or by conserving the inputs (Shephard).

The first method applied in this research, Data Envelopment Analysis (DEA), is generally accepted as one of the best in assessing the efficiency of a set of decision making units (DMU)s. First presented in 1978 and based on the paper of Farrell, the first DEA model is known in the literature as the CCR model, after its authors, Charnes, Cooper and Rhodes. In essence, DEA is a non-parametric approach, who, with the help of linear programming techniques and based on the dataset, computes an efficiency frontier on which only the most efficient DMUs are placed. The DEA model is usually input or output oriented. An output oriented DEA model is channeled towards maximizing the outputs obtained by the DMUs while keeping the inputs constant whilst the input oriented models focus on minimizing the inputs used for processing the given amount of outputs. For input-oriented models, the others DMUs not as efficient as those placed on the frontier will be given a certain efficiency score above than 0 but below 1[2].

Thus, by using linear programming and by applying nonparametric techniques of frontier estimation, it can be measured the efficiency of a DMU, by comparing it with an identified frontier of efficiency. The advantage is that DEA does not require any prerequisite hypotheses regarding the analytical shape of the production function.

In this study, two DEA models will be run: a constant returns to scale, input oriented and a variable returns to scale input oriented model.

The CRS model

For a given set of data, the efficiency DMU_j is measured, *n* times, where *n* represents the number of DMU to be evaluated *j* ranges over 1, 2,…, n. To obtain the scores for the weights of the inputs (v_i) (i= 1,2,…,m) and the weights of the output (u_r) (r=1,2,…, s), the following set of linear programming equations need to be solved:

$$\text{Max } \theta=\mu_1 y_{10}+\cdots+\mu_s y_{s0} \quad (1)$$

Subject to

$$\mu_1 y_{10}+\cdots+\mu_s y_{s0} \leq v_1 x_{10}+\cdots+v_m x_{m0} \quad (j=1,2,\ldots,n)$$

$$v_1, v_2, v_3, \ldots, v_m \geq 0$$

$$\mu_1, \mu_2, \mu_3, \ldots, \mu_s \geq 0,$$

where θ is the optimal objective value and it is at most 1.

The VRS model is not completely different to the one previously presented. Thus, by adding the restraint $v_1 x_{10}+\cdots+v_m x_{m0}=1$ to the model above, we obtain the input oriented VRS DEA model.

Stochastic Frontier Analysis

As Greene (1997) concluded, the function of production frontier can be described as an extension of the regression, based on the micro economical assumption that a production function is an ideal, the maximum level of output that can be attained with the use of a given set of inputs[3]. SFA has become a very popular, used in analyzing the production from several points of view. Similar to DEA, the development of SFA and the preceding papers is based upon Farrell's study from 1957. Among others, Aigner et. Chu (1968), Seitz (1971), Timmer (1971) or Afriat (1972) contributed to SFA's

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[2] Output oriented and super efficiency models have different restrictions regarding the efficiency scores.

[3] Greene, W. (1997). Frontier Production Functions. In Handbook of Applied Econometrics. Volume II: Microeconomics, M.H. Pesaran and Schmidt, P. (Eds.), Oxford: Blackwell, p 35

elaboration. And even though the authors' inputs differ under certain aspects, each of them contributed to identifying a production frontier, either by using linear programming or by modifying the technique of the sum of squares, having the a-priori hypothesis of nonnegative residuals.

The fundaments of SFA were set concomitantly with the release of two papers from two continents. The paper of Meesen and van den Broeck (the MB model) was released in June 1977, and the paper of Aigner, Lovell and Schmidt (the ALS model) one month after. The second one was actually a compilation of papers very similar in context, some belonging to Aigner, some to Lovell and Schimdt.

The ASL model was the first who separated the environmental effect by two components.

$$y_i = f(x_i;\beta) + \varepsilon_i, \quad i = 1, 2, ..., N. \qquad (2)$$

where $\varepsilon_i = v_i - u_i$, $i = 1, 2, ..., N$

where y_i is the maximum output attainable by using x_i, a (non-stochastic) input, and β is an unknown vector parameter which has to be estimated. Moreover, the first component of the inefficiency term (ε_i), v_i is a sum of random events and facts (e.g. hazard, climate, machines' performance). Observation and measurement errors also fall in its structure. This error is assumed to be independent and normally distributed with $N(0, \sigma_v^2)$. The second component u_i, is actually the sum of certain factors on which the firm, the producer can have an impact on like economic and technological inefficiency, availability, producer's effort, etc. The second component is considered to be independent from the first one, also complying to the restriction $u_i \geq 0$. The second error is meant to reflect that the output of any firm can be placed under or on the frontirer of production [$f(x_i,\beta)+v_i$]. If we consider that $f(x_i,\beta)$ is a log-linear Cobb Douglas[4] function, we can rewrite (2) as

$$ln y_i = \beta_0 + \sum_n \beta_n ln x_{ni} + v_i - u_i \qquad (3)$$

For the analysis, the study uses data on 75 countries, the first 75 United Nation countries by the Human Development Index which had available information in regards to the variables chosen in the DEA model. The number of variables was set to five, four input variables and one output variable, with no missing data for the 75 countries.

Inputs

Quality of the Educational System. The variable uses 2010- 2011 values from the World Economic Forum's Reports and surveys, and represents a weighted score of the efficiency of the Educational System. To be more precise, the subjects were asked to rate on a scale from 1 (very bad) to 7 (very good) how well does the educational system in their country cope with the needs of a competitive economy. Thus the variable is very interesting by itself, as it contains information about the overall way of functioning of the educational systems and about how it interacts with the economy in the given country.

The availability of latest technologies. This indicator, collected from the World Economic Forum, Executive Opinion Survey 2010 and 2011 editions, shows to what extent are the latest technologies available in each country, on a scale from 1 (not available) to 7 (widely available).

The impact of ICT on access to basic services. This indicator is a 2010-2011 weighted average data from the World Economic Forum, Executive Opinion Survey 2010 and 2011 editions showing to what extent are information and communication technologies enabling access to citizens for basic services (education, health, etc.), on a scale from 1 (do not enable at all) to 7 (enable access significantly).

ICT use and government efficiency. The indicator is a 2010-2011 weighted average data from the World Economic Forum, Executive Opinion Survey 2010 and 2011 editions showing to what extent has the use of information and communication technologies by the government improved the efficiency of government's services in the countries on a scale from 1 (no effect) to 7 (extensive).

Outputs

Households with a personal computer. The indicator, based on data collected from the International Telecommunication Union, ITU World Telecommunication/ICT Indicators Database 2011, marks the proportion of households with at least one computer (e.g. a laptop or a desktop computer).

[4] Three-dimensional production function, usually used to describe the relationship between inputs and outpus.

Data processing and analyses were run in R, a statistical software, using SFA and Benchmarking libraries.

Results:

Table 1 summarizes the descriptive statistics of the data. The use of latest technologies ranges from 3.1 (Barbados) to 6.9 (Sweden). This is a normal trend since towards the highest values the most developed countries are identified. From the 27 European Union member states, Romania is the one having the lowest score, being placed on the 72nd position. The small coefficient of variance (14.92%) indicates that the series is homogenous.

Table 1. Descriptive statistics for the chosen variables

Descriptive Statistics	**Use of Latest Technologies**	**Quality of Educational System**	**Use of Basic ICTs**	**Use of ICT by the Government**	**Percentage of PCs at home**
Minimum	3.1	2.3	3.1	2.5	15.6
1st Quintile	4.85	3.3	4.3	4.05	36.3
Median	5.5	4.1	4.9	4.5	61.4
Mean	5.503	4.108	4.909	4.625	58.23
3rd Quintile	6.25	4.8	5.6	5.3	78.75
Maximum	6.9	5.9	6.3	6.4	93
Coeff. of Variance	14.92%	22.70%	15.67%	18.08%	40.88%

From the Summary table, it can be observed that the Educational System variable ranges from a minimum score of 2.3 (Dominican Republic) to 5.9 (Switzerland, Finland and Singapore). For this variable, the last country from the EU-27 was Greece. Given that the Coefficient of variance is 22.7%, it can be concluded that the values for the variable are homogenous.

The use of basic ICTs ranges from 3.1 (Lebanon) to 6.3 (Sweden). The coefficient of variance is showing a homogeneous series (15.67%) and the mean and median are very close to each-other, pointing out the symmetry of the series.

Table 2. The frequencies of the efficiency scores for the three frontier models.

Efficiency Score	DEA				SFA	
	CRS		VRS			
	No of countries	% of countries	No of countries	% of countries	No of countries	% of countries
0-0.1	11	14.67%	0	0.00%	0	0.00%
0.1-0.2	14	18.67%	0	0.00%	0	0.00%
0.2-0.3	13	17.33%	4	5.33%	2	2.67%
0.3-0.4	6	8.00%	28	37.33%	7	9.33%
0.4-0.5	7	9.33%	9	12.00%	6	8.00%
0.5-0.6	7	9.33%	9	12.00%	8	10.67%
0.6-0.7	9	12.00%	12	16.00%	5	6.67%
0.7-0.8	2	2.67%	7	9.33%	12	16.00%
0.8-0.9	0	0.00%	0	0.00%	19	25.33%
0.9-1	2	2.67%	0	0.00%	16	21.33%
1	4	5.33%	6	8.00%	0	0.00%
Total	75	100.00%	75	100.00%	75	100.00%

The results in table 2 are controversial and deserve further discussions. Thus, the CRS DEA model has an average efficiency score of 0.38 and identifies 4 countries on the efficiency frontier: Qatar, Singapore, Sweden and Switzerland. The ranking is not surprising, as these countries are known for having high levels of development and standards of living. Also, the countries on the frontier were identified as having strong efficiency[5] (efficiency score 1 and no inputs excess). Moreover, all the Nordic countries were identified in the top ten, which reconfirms these states' reputation of high quality public services providers. Moreover, the model places the developed countries towards the first part of the ranking and the less developed countries towards the second half. From the 27 European Union countries, Bulgaria had the lowest efficiency score (0.13). This means that Bulgaria has to decrease the utilization of inputs until 13% of the current level, to become as efficient as Qatar and Singapore (Bulgaria's set of reference) for the amount of output obtained. Except for the countries on the frontier, the others were identified as having different amounts of excess for each of the four inputs. The availability of latest technologies should improve in average by 19.81% (from 5.5 points to 6.59 points) to ensure maximum efficiency, indifferent proportions ranging from 0.016 points for Iceland to 2.59 points for Armenia. The quality of Educational System should improve in average by 2.00 points (from 4.108 to 6.108), with improvements ranging from 0.056 for Iceland to 4.439 for Venezuela. Similar, the impact of ICT on access to basic services should improve by 1.468 points, from 4.909 to 6.377, ranging from 0.04 points for Iceland to 3.312 for Venezuela. The ICT use and government efficiency should improve by 1.63 points, from 4.625 to 6.255 points to ensure efficiency, ranging from 0.068 for Iceland to 3.596 for Venezuela.

The VRS DEA model is consistent with the CRS model, especially since it is known that all DMUs CRS efficient will also be VRS efficient (Cesaro et al., 2009). Thus, besides the four efficient countries already identified by the CRS model, the VRS identified Iceland and Finland as being efficient (score of 1) who, in the CRS model, had the next scores after the efficient countries. Moreover, in average, the VRS model had efficiency scores 0.13 points higher than the CRS model and consistent rankings[6]. The average efficiency increase is also aligned with the theory that the VRS frontier is more flexible and therefore envelops the data more tightly. Out of the 27 EU members, in the VRS model Greece was identified as having the lowest score (0.31), dropping 16 positions compared to the CRS model. Regarding the inputs excess, the VRS model identified, in average, 0.334 points of inputs excess compared to the CRS model, meaning approximately 21% decrease of inputs excess.

The maximum likelihood estimates of the SFA model are shown below.

Table 3. SFA estimates and significations

	Estimate	Std. Error	Z value	Sig.
(Intercept)	2.1354	0.204	10.484	***
Latest Technologies	0.8002	0.087	9.225	***
Educational System	0.5118	0.124	4.118	***
ICT impact on basic access	0.9801	0.178	5.510	***
ICT use & Gov Eff	-0.9236	0.167	-5.536	***
sigmaSq	0.2567	0.026	9.957	***
Gamma	1.0000	0.001	1205.452	***
Log - Likelihood	-7.4792			

***-significant at 1%

The SFA model identified an average efficiency of 0.71, the highest of the three tested model (0.51 the VRS DEA model and 0.38 the CRS DEA model). However, the results obtained with the SFA model differ significantly from the ones obtained by the other two models.

Thus, table 3 encompasses the estimates, standard errors, z-values and significances for the model's parameters. As shown, all coefficients are statistically significant for the 1% threshold. However, even though we would have expected positive values for all the parameters, ICT use and government efficiency was identified as having negative influence on the efficiency score. The estimation of gamma parameter, statistically significant, suggested that inefficiency was present during the production process and therefore the traditional production average would not be an

[5] See Hongliang et al., (2007) for more details regarding strong and weak disposability.
[6] Only 7% of the countries had rankings that changed more than 20 positions between the 2 models.

adequate representation of the data. As a result, technical inefficiencies have significant impact on the output and the one sided error component accounts for up to 100% of the total variance. In other words, 100% of the variation in the data between countries can be considered inefficiency, the model identifying no "noise". Sigma squared was also statistically significant suggesting that the data does not fit the conventional production function.

As it can be seen in the table above, in the CRS DEA model 50.67% of the countries have the efficiency score of less than 0.3, whilst in the SFA model 62.66% of the countries have scores higher than 0.7. The results are not surprising since DEA considers all the deviations from the frontier as being inefficiency whereas SFA takes into account the fact that random shocks which are not under the control of the DMUs can have an impact on the output amount.

Table 4. Peason correlations coefficients

	CRS	VRS	SFA
CRS	1		
VRS	.954**	1	
SFA	.587**	.408**	1

**. Correlation is significant at the 0.01 level (2-tailed).

Table 4 shows Pearson correlation coefficients between the three models. The first important fact to notice is that all three correlation coefficients are positive and highly statistically significant for the 1% threshold. The highest correlation coefficient is obtained as expected between the CRS and VRS DEA models whilst the weakest is between the VRS and SFA models.

Similar to the present study, in the literature there are a couple of studies that have been conducted to analyze the technical efficiency scores obtained by applying the methods above. Lin et al. (2005), Theodoridis et al. (2008) obtained similar efficiency scores rankings (SFA>VRS>CRS) and similar correlation coefficients ranking (CRS-VRS>CRS-SFA>VRS-SFA).

Conclusion:

Information is the resource of the future and correct communication will be the leverage necessary to fully benefit from the use of information. The beginning of the 21st century created the needed premises so as those who possess information have a considerable advantage. One of the biggest added values of ICTs is that they provide an astonishing amount of information with a very low level of requirements and they also work as catalysts in channeling information towards those who needed. Moreover the information pool is increasing exponentially in the virtual environment, supported by the new cloud computing concept.

However, when discussing the implementation of ICT, sensitive aspects need to be taken into account. The technical infrastructure is not sufficient and might not provide the expected results unless it is correlated with Educational efforts to provide minimum level of know-how.

This study analyzed the efficiency scores obtained by applying a CRS DEA model, a VRS DEA model and a SFA model. The results showed significant correlation exists between the efficiency scores of the above methods, the CRS DEA model having the lowest average efficiency score whilst the SFA model has the highest average efficiency. Also, the secondary hypothesis that developed countries make more use of ICTs that countries under developed or developing countries was validated by the models.

Future studies should focus identifying a relationship between the statistical methods applied in the research. Also, regarding the ICTs, the author believes that ICTs' use and efficiency is highly influenced by the domain in which they are applied, therefore the exact impact of ICTs on each domain should be studied.

Acknowledgements

This work was supported by the **European Social Fund in Romania**, under the responsibility of the Managing Authority for the Sectoral Operational Programme for Human Resources Development 2007-2013 [**grant POSDRU/CPP 107/DMI 1.5/S/78342]**

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