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Teaching ITC in European Universities: A Non-Parametric Efficiency Approach

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Abstract

The Information Technology and Communication field of studies became popular among young people while choosing a career path in the last years due to digitalisation, artificial intelligence, automation. The purpose of this study is to measure the teaching efficiency of 40 European universities from Italy, the Czech Republic, and Croatia during the 2016-2017 academic year using the ETER database. The technical efficiency estimates of the Higher Education Institutions are computed using a Data Envelopment Analysis (DEA) estimator and a statistical inference using the Simar-Wilson Bootstrap technique is employed to correct the results. Depending on the country, the most efficient universities were identified, and an analysis of all the sample efficiency estimates allows us to compare universities based on teaching activities they employ.

Keywords: DEA, efficiency, Higher Education, ITC, Bootstrap DEA.

JEL Classification: C14, I23, N34.

1. Introduction

The higher education system includes educational institutions, academic, nonacademic, and administrative staff which work in these institutions in order to train and distribute knowledge to students depending on their educational level. This system can be classified using the ISCED levels, an international classification of educational standards used to organise study programmes based on the specialisation and year of study. ISCED levels start with ISCED 0 which represents early education and end with ISCED 8 (doctoral studies).

The activity developed in the higher education system can be quantified using multiple processes, the most important being teaching and research activities.

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The main objective of this study is to analyse the efficiency of universities which provide study programmes based on ICT (Information and Communications Technology) using a fully defined nonparametric model and a DEA estimator. Statistical inference is provided using the Simar - Wilson bootstrap technique, and corrected measures of efficiency are reported along with their confidence intervals.

Over the last decade, the number of ICT specialists increased significantly, the share of ICT employees in total employment expanded by 1.5 percentage points from 2013 to 2023 and the number of ICT specialists increased by approximately 59% during the mentioned period. The latest available data on ICT specialists concludes that the share of ICT specialists that were engaged in tertiary education increases by 10.2 percentage points according to Eurostat (2024).

2. Problem Statement

Over time, it was studied how firms from different sectors (healthcare, banking, education, agriculture, transport) use their resources or raw materials defined as inputs to obtain different outputs, such as finished products or provided services. The efficiency of different types of observations included in a selected sample is measured. Each observation is known as a decision-making unit (DMU).

The concepts of efficiency and productivity were defined as the ratio between outputs and inputs used by a decision-making unit in the production process by Sengupta (1995) and Cooper, Seiford and Tone (2000).

In order to estimate the efficiency of the DMUs, parametric methods or nonparametric methods can be used. The most used parametric methods are Stochastic Frontier Approach (SFA), Thick Frontier Approach (TFA) and Distribution Free Approach (DFA). The nonparametric methods used in the study of efficiency are Data Envelopment Analysis (DEA) and Free Disposal Hull (FDH).

The efficiency analysis can also be applied for non-profit organisations, such as Higher Education Institutions (HEIs). The next section includes several studies that focus on the analysis of efficiency of the HEIs.

A different approach used in the process of study of the efficiency of the Higher Education Institutions based on the country of origin. Some studies are focused on the efficiency analysis of HEIs from one country: UK (Johnes, 2006), Australia (Abbott & Doucouliagos, 2001), Canada (Ghimire et al.,2021), and Italy (Bonaccorsi et al.,2006). Other studies compare the performance of the educational system within countries: 12 countries from Europe (Grădinaru et al., 2019), 10 countries from Europe and SUA (Wolszczak-Derlacz, 2017), 16 countries from Europe (Herberholz & Wigger, 2021; Daraio et al., 2015).

The countries from Europe and SUA may be compared based on their predominant activity (teaching, research, or a mixt of both): German universities are less efficient in the teaching activity compared to the research activity (Daraio et al., 2015); in Belgium, Netherlands and Poland, the universities are oriented on a mixt activity between teaching and research, their main focus is on the total number of graduates ISCED 5-7, the number of publications and the number of citations (Herberholz & Wigger, 2021); the Australian tertiary educational system is homogeneous regarding the teaching and research activities, most of the Australian universities are technical efficient (Abbott & Doucouliagos, 2001); low publishing activity universities are less efficient compared to those with an intensive publishing activity, but in the same time, low publishing universities from Italy, UK, Lithuania and Ireland are also efficient in teaching activities (Grădinaru et al., 2019); universities from Poland, UK, Netherlands (Derlacz, 2017) and Italy (Bonaccorsi et al., 2006) are efficient in the teaching-research activity.

The dimension of the Italian universities quantified by the students enroled does not impact the efficiency of the teaching process, and the efficiency of the research activity is not influenced by the number of faculties, number of lectures, or number of courses reported to 100 professors (Daraio et al., 2006). The authors extended the analysis on the European tertiary system and concluded that the dimension and specialisation of the university have a significant impact on the efficiency of the teaching process. However, the specialisation of a HEI does not have a substantial effect on research focused universities (Daraio et al.,2015). Similar results were obtained by Herberholz & Wigger (2021) concluding that the number of students enrolled and the share of external financing are associated in general with a high measure of efficiency. The same conclusion was proposed by Wolszczak-Derlacz (2017), where tuition fees are positive correlated with technical efficiency.

3. Research Questions / Aims of the Research

This paper aims to analyse the technical efficiency of ICT (Information and Communication Technology) European universities from Italy, the Czech Republic, and Croatia. The teaching activity efficiency of the mentioned universities is estimated using a nonparametric approach (Data Envelopment Analysis), and the statistical inference using the Simar-Wilson Bootstrap technique is applied to correct the initial measures of efficiency obtained.

4. Research Methods

The concept of production process or production technology is defined using Debreu (1951) and Koopmans (1951) considering $x \in \mathbb{R}_{+}^{p}$ the input vector and $y \in \mathbb{R}_{+}^{q}$ the output vector.

Using Simar and Wilson (2000) the production set is defined as follows:

$$\Psi = \left\{(x, y) \in \mathbb{R}_{+}^{p+q} \mid x\ can\ produce\ y\right\} \quad (1)$$

Where an inputs vector, x is used in order to produce a desired outputs vector, y.

The efficient part of the production set Ψ is defined as the efficient frontier:

$$\Psi^{\partial} = \{(x, y) \in \Psi \mid (\gamma^{-1}x, \gamma y) \notin \Psi, \forall\, \gamma > 1\} \quad (2)$$

The measure of technical efficiency in an input-oriented model is denoted by the minimal radial contraction of the inputs in order to represent a point on the efficient frontier:

$$\theta(x, y) = \inf\{\theta \mid (\theta x, y) \in \Psi\}, \text{ where } \forall\, (x, y) \in \Psi, \theta(x, y) \leq 1. \quad (3)$$

The measure of technical efficiency in an output-oriented model is given by the maximal radial expansion for the point is projected on the efficient frontier:

$$\lambda(x, y) = \sup\{\lambda | (x, \lambda y) \in \Psi\}, \forall (x, y) \in \Psi, \lambda(x, y) \geq 1. \quad (4)$$

The value 1, no matter the orientation of the model, indicates that the decision-making unit is efficient and it is represented by one point (x,y) that is placed on the efficient frontier of the sample.

A Data Envelopment Analysis estimator was used for the first time by Farell (1957) and later by Charnes et al. (1978). The DEA estimator implies that the production set is convex.

The VRS-DEA estimator for an output-oriented model is given by the following linear program:

$$\hat{\lambda}_{VRS}(x, y) = \max_{\substack{\lambda \\ \gamma_1,\dots,\gamma_n}} \{\lambda | \lambda y \leq \sum_{i=1}^{n} \gamma_i Y_i, x \geq \sum_{i=1}^{n} \gamma_i X_i, \sum_{i=1}^{n} \gamma_i = 1, \gamma_i \geq 0, \forall\, i = \overline{1, n}\} \quad (5)$$

Simar and Wilson (2000a, 2007) created a special bootstrap technique that can be employed for a small sample in a nonparametric framework. The aim of the bootstrap algorithm is to create finite replications from sample data X_n generated from the initial data generation process (P) using a number of infinite replications (B). After this step, two subsamples are used: the first represents the original one, and the second represents the bootstrap subsample. When the technique is applied on the bootstrap subsample, the estimators from the original subsample are considered here the real estimators. The new sample X^*_n from the bootstrap subsample is created using the data generation process ($\hat{P}$) from the original subsample. In the bootstrap subsample, each point has a new estimator associated $\widehat{\theta^*}_{VRS}$(x,y). The new estimator can be considered an estimator of the estimator from the original subsample $\hat{\theta}_{VRS}$(x,y). The sample that contains a number of B replicas obtained by using the data generation process ($\hat{P}$) and by the implementation of the initial estimator to the bootstrap samples will provide a set of pseudo-estimates $\hat{\theta}_{VRS,b}$(x,y), where b=$\overline{1, \dots, B}$. Based on Simar and Wilson (2007), B=2000 replicas should be used in order to obtain a good prediction for confidence intervals.

To measure the efficiency of a production process, the FEAR package in R can be used. Created by Wilson (2008), the package is used to determine DEA and FDH estimates under different hypotheses of return to scale (variable returns to scale,, constant returns to scale or decreasing returns to scale). The representation of the efficient frontier was facilitated by using the Benchmarking package (Bogetoft et al., 2011).

5. Findings

5.1 Data Description

The data used is collected from ETER database and we extracted information regarding the first forty universities ordered by total number of graduates ISCED 5-7 from 2016/2017 academic year. The universities selected include study programmes from ICT (Information and Communication Technology) in their curriculum. Our sample includes 40 universities from three European countries: 21 Italian universities, 15 Czech Republic universities and 4 Croatian universities.

A few indicators, such as total number of academic staff and total graduates ISCED 5-7 are selected for a teaching activity model that assesses the efficiency of higher education institutions (HEIs). The total number of academic staff is used as input, while total number of graduates ISCED 5-7 is the intended output, since the result of a teaching activity is actually measured by the number of graduates in a university. We define an output-oriented model using variable returns to scale (VRS) since, in education, the production to scale varies based on the use of inputs, salary, work condition, etc. The aim of each university is to maximise the number of graduates using a constant level of teaching staff which explains the choice in an output-oriented model.

Some statistics of the sample is provided in Table 1.

Table 1. Descriptive statistics

Variable	Input / Output	Minim	Average	Maxim	Skewness	Kurtosis	Standard deviation
Total academic staff	Input	417	1793	7368	1.96	3.97	1538.33
Total graduates ISCED 5-7	Output	971	6194	21265	1.44	5.3	4813.94

Source: RStudio 2024.04.1 version.

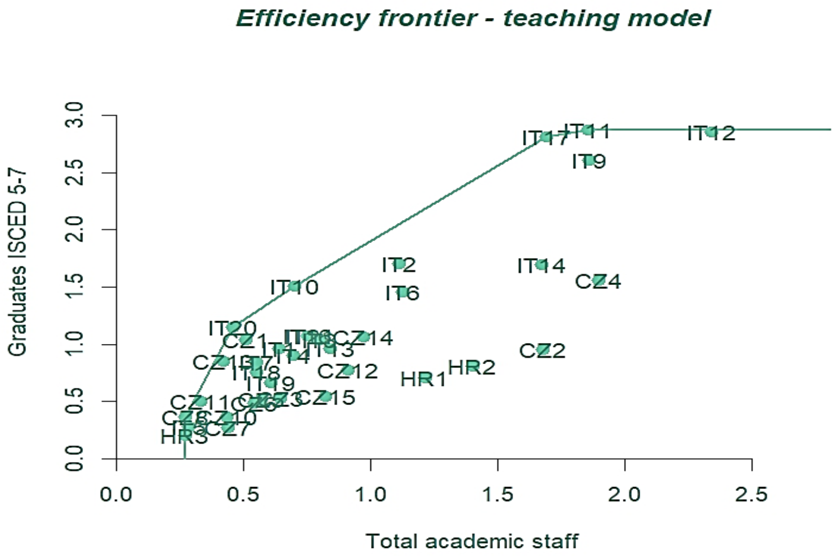
The 40 universities are characterised by reduced resources which consist of total academic personnel and total number of full professors (hypothesis sustained by the value of skewness, which is positive). In the considered universities, the personnel that is working, on average, consists of 1793 academic persons, with values ranging between 417 and 7368. The same pattern is observed for the total graduates at ISCED 5-7.

In the preliminary analysis, using the descriptive statistics and the scatter plots between the input and output, 4 outliers were identified. These DMUs are recognised as large and prestigious universities in teaching and/or research activity, and in order to not create a false efficiency frontier, we decided to remove them from the sample. Later work implies using standardised variables to their respective standard deviations. The correlation coefficient (0.68) of input to output shows a moderate to strong and direct relationship as it is expected.

5.2 Efficiency Analysis of Teaching Activities in Universities from Italy, the Czech Republic, and Croatia

The efficiency of the teaching process is quantified by how much and how well each university uses their resources, in this case, how the academic staff performs in order to maximize the number of ISCED 5-7 graduates.

Figure 1. Efficiency frontier for teaching model



Source: RStudio 2024.04.1 version.

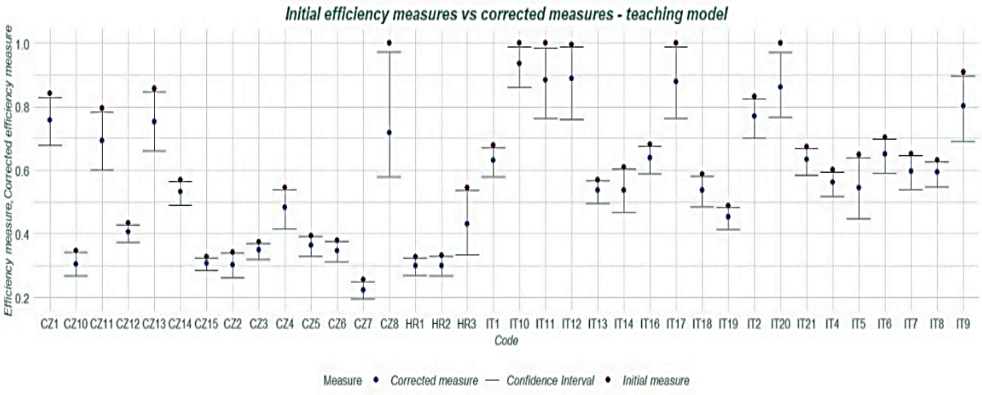
The average measure of DEA estimates is 63.63%, the measures fluctuating between 25.4% and 100%. 17 of our 36 universities are considered efficient in the teaching activity (the measure of efficiency is greater than 63.63%), which represents 47.22% of the sample and 19 of them are inefficient (the efficiency measure is less than the average value), which consists of 52.78% of the analysed observations. Ten universities have a measure of efficiency greater than 80% and 5 of them are placed on the efficient frontier, which means fulfilling a measure of efficiency equal to 100%. The 5 unitary-efficient universities are located in Italy (4 of them) and in the Czech Republic.

In the efficient universities, on average, 1419 personnel from academic staff are working in order to facilitate, on average, 6780 ISCED 5-7 graduates. On the other hand, the inefficient universities use the relatively same resources in the teaching process (1375 personnel from academic staff on average) and obtain approximately half of the output generated by the efficient ones (3754 graduates ISCED 5-7).

In order to solve the problem of the efficiency estimators, the bootstrap technique proposed by Simar and Wilson (1998) was used. This technique contributes to determine the corrected efficiency measures along with their confidence intervals., 2000 bootstrap replicas of the original sample are generated in order to obtain the corrected measures.

The average corrected DEA estimate is now equal to 56.86%, with values between 22.13% and 93.38%. In general, the average efficiency measure in teaching activity declines by 7.35%.

Figure 2. Initial efficiency measures vs corrected efficiency measures



Source: RStudio 2024.04.1 version.

In order to classify the universities based on their performance in the teaching activity, top 10 efficient universities and top 5 inefficient universities were selected.

Table 2. Initial versus corrected efficiency measures for top 10 efficient universities

DMU	**Initial measure (%)**	**Corrected measure (%)**
CZ8	100.00	72.38
IT10	100.00	93.37
IT11	100.00	88.32
IT17	100.00	87.75
IT20	100.00	86.12
IT12	99.49	88.69
IT9	90.77	80.18
CZ13	85.62	75.00
CZ1	84.21	75.46
IT2	83.11	77.03

Source: Computed in RStudio 2024.04.1 version.

Italian universities are more efficient in the teaching activity compared to the ones from the Czech Republic or Croatia. 7 of 10 efficient universities are located in Italy and the other 3 DMUs are located in the Czech Republic. IT11 (University of Naples Federico II) is one of the enormous efficient universities in teaching activity with a corrected efficiency measure of 88.32%. In this university, one person from the academic staff is working in the process of production with a load of, on average, 5 graduates ISCED 5-7. IT10 (University of Milano-Bicocca) with a corrected measure of 93.38% uses almost optimally its resources in order to maximize the total graduates ISCED 5-7, the ratio academic staff to total ISCED 5-7 graduates is equal to 1:7, which means that, in this particular HEI, one person from the academic staff category is participating in the process of graduation of 7 students.

Table 3. Initial versus corrected efficiency measures for top 5 inefficient universities

DMU	**Initial measure (%)**	**Corrected measure (%)**
CZ2	34.11	30.00
HR2	33.20	30.01
CZ15	32.66	30.66
HR1	32.60	29.97
CZ7	25.39	22.12

Source: R*S*tudio 2024.04.1 version.

Similarly, the Czech Republic universities are the most inefficient compared to those in Italy or Croatia. The 5 least inefficient universities in the teaching activities include 3 universities from the Czech Republic and 2 universities from Croatia. The most inefficient university in the teaching activity is CZ7 (Technical University of Liberec) with a corrected measure of efficiency equal to 22.12%, where each person in the academic staff category coordinates approximately two graduates. This DMU can improve its efficiency in teaching activity by increasing the total number of graduates ISCED 5-7 to each academic personnel.

6. Conclusions

We aimed to analyse the efficiency of different universities from 3 countries such as Italy, the Czech Republic, and Croatia in their teaching activity. One conclusion is, obviously, that European universities can consistently increase their performance in the teaching activity. Efficiency can be improved by increasing the number of total graduates from ISCED 5-7, which implies increasing the graduation rate for bachelor and master programmes.

Due to the size of the sample analysed, the DEA efficiency measures determined are not consistent, and the Bootstrap DEA technique was applied to obtain the corrected measures. Universities from Italy, the Czech Republic, and Croatia are more efficient in the teaching activity, the corrected average efficiency measure is greater than 55%. Universities from Italy are more efficient in the teaching activity compared to the ones from the Czech Republic or Croatia; for the first 10 best performing DMUs the corrected values vary between 77.03% and 93.37%.

To improve the quality of the teaching model, some recommendations can be taken into consideration, such as: including more inputs (administrative expenses; personal expenses; number of educational spaces which includes number of laboratories, number of libraries; government allocations) and/or outputs in the model; using an aggregated input and/or output in order to represent the efficiency frontier and reduce the dimensionality; using other types of estimators (FDH or hyperbolic); extending the database by including universities from all European countries; classify the universities based on their size using the cluster analysis, etc.

A future direction of research will include the increase of dimensions employed in the sample together with the use of a different efficiency technique that will allow us to fully rank the universities such as the hyperbolic measure of efficiency.

Bibliography

[1] Abbott, M., Doucouliagos, C. (2003). The efficiency of Australian universities: a data envelopment analysis. Economics of Education Review, 22(1), pp. 89-97.

[2] Bogetoft, P., Otto, L. (2022). Benchmarking with DEA and SFA. R package version 0.31.

[3] Bonaccorsi, A., Daraio, C., Simar, L. (2006). Advanced indicators of productivity of universities. An application of robust nonparametric methods to Italian data. Scientometrics, 66(2), pp. 389-410.

[4] Charnes, A., Cooper, W. W., Rhodes, E. (1978). Measuring the efficiency of decision making units. European Journal of Operational Research, 2(6), 429-444. doi:10.1016/ 0377-2217(78)90138-8.

[5] Coelli, T., Rao, P., Battese, G. (1998). An Introduction to Efficiency and Productivity Analysis. Springer Science + Business Media, LLC. doi:10.1007/978-1-4615-5493-6.

[6] Daraio, C., Bonaccorsi, A., Simar, L. (2015). Efficiency and economies of scale and specialization in European universities: A directional distance approach. Journal of Informetrics, pp. 430-448.

[7] Debreu, G. (1951). The coefficient of resource utilization. Econometrica, 19(3), 273-292. doi:10.2307/1906814.

[8] ETER Databse. (2022). Available at: https://www.eter-project.com/data-for-download-and-visualisations/database/.

[9] Eurostat (2024). ICT specialists in employment. Available at: https://ec.europa.eu/ eurostat/statistics-explained/index.php?title=ICT_specialists_in_employment#Number_ of_ICT_specialists.

[10] Farell, M. J. (1957). The Measurement of Productive Efficiency. Royal Statistical Society. Journal. Series A: General, 120(3), 253-281. doi:10.2307/2343100.

[11] Ghimire, S., Amin, S. H., Wardley, L. (2021). Developing new data envelopment analysis models to evaluate the efficiency in Ontario Universities. Journal of Informetrics, 15(3), p. 101172.

[12] Gradinaru, S., Aldea, A., Besir, L., Coser, A. (2019). A Non-Parametric Efficiency Perspective on the Research-Active European Universities Performance. Lumen Proceedings, Vol. 9, pp. 371-385.

[13] Herberholz, L., Wigger, B. (2021). Efficiency of European universities: A comparison of peers. Research Policy, 50(9), p. 104314.

[14] Koopmans, T.C. (1951). An analysis of production as an efficient combination of activities. Activity Analysis of Production and Allocation, 33-97.

[15] Johnes, J. (2006). Data envelopment analysis and its application to the measurement of efficiency in higher education. Economics of Education Review, pp. 273-288.

[16] Simar, L., Wilson, P.W. (2000). Statistical inference in nonparametric frontier models: The state of the art. Journal of Productivity Analysis, 13, 49-78.

[17] Simar, L., Wilson, P. (2014). Statistical Approaches for Non-parametric Frontier Models: A Guided Tour. International Statistical Review, pp. 1-34.

[18] Wilson, P. (2008). FEAR: A software package for frontier efficiency analysis with R. Socio-Economic Planning Sciences, 42(4), pp. 247-254.

[19] Wolszczak-Derlacz, J. (2017). An evaluation and explanation of (in)efficiency in higher education institutions in Europe and the U.S. with the application of two-stage. Research Policy, 46(9), pp. 1595-1605.