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TEACHERS' EFFICIENCY MEASURING: AN APPLICATION OF DEA

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Abstract: *The aim of this paper is to present the results of a study about the relative efficiency of teaching performances at the University of Belgrade, the Faculty of Organizational Sciences, using the Data Envelopment Analysis (DEA). DEA is a linear programming based technique for measuring the relative performance of decision-making units (DMUs) where the presence of multiple inputs and outputs makes comparisons difficult. DEA is able to use more parameters of input and output to evaluate which of teachers under examination is the most effective, and to compare other teachers with it. In this paper, teacher's efficiency measuring was analyzed in two aspects: efficiency of teaching and efficiency of research. Based on the results, relatively efficient and inefficient teachers were identified; reasons for all inefficient teachers were discovered; teacher's ranking was done. Considering growing competition in the field of education, with pointing out to the teachers on the weakness sources in their work, bigger responsibility level and commitment to the work is expected.*

Keywords: *Data envelopment analysis, university, teacher's efficiency.*

1. INTRODUCTION

Universities all around the world realize more and more that they are part of the service industry and they are facing competition pressure from different directions. On one side, students' pleasure is connected to their employment (Deahields, Kara & Kaynak, 2005; Elliott & Healy, 2001; Helgesen & Nesset, 2007), which led university authorities to direct their attention to those factors which can help them to more efficiently attract students and create simulative environment for learning (Venesaar, Ling & Voolaid, 2011). On the other side, universities are more included into different rankings, while ranking instruments unavoidably includes some of the measures of teacher's efficiency.

Each teacher efficiency measurement system should link the evaluation for improvement and the policy and research policy guidance for strengthening the system (Looney, 2011). Although lot of researches are focused on the effectiveness of teachers, and it is precisely this teacher's efficiency identified as the main component in the teaching process, but still it is not quite clear what the 'teacher's efficiency' is. Lack of clarity in literature seems to be leading to situation where researchers prioritize different aspects of teacher's efficiency (i.e. to use more student-oriented practices, teacher aligned with professional learning and development, interpersonal skills, productivity and content creation). All of this points out that 'teacher's efficiency' has multidimensional.

Productivity in higher education has an obvious multidimensional character as it relates to both production and dissemination of knowledge through its various activities of teaching, research, and outreach activities (Dundar & Lewis, 1998). Data Envelopment Analysis (DEA) is an approach to relative efficiency measurement where there are multiple incommensurate inputs and outputs. If a suitable set of measures can be defined DEA provides an efficiency measure not relying on the application of a common weighting of the inputs and outputs (Tongzon, 2001). Additionally the method identifies peer units and targets for inefficient units. Charnes, Cooper, and Rhodes (1978, 1981) introduced the method of DEA to address the problem of efficiency measurement for decision making units (DMUs) with multiple inputs and multiple outputs in the absence of market prices. They coined the phrase decision making units in order to include non-market agencies like schools, hospitals, and courts, which produce identifiable and measurable outputs from measurable inputs but generally lack market prices of outputs (and often of some inputs as well). The field of DEA is growing steadily, attracting unabated interest from the management science and economics communities, and continuing to be applied in practice to address new problems in policy making and

management (Banker & Podinovski, 2017). New models and methods developed in recent years allow the assessment of the efficiency, performance, and productivity in public institutions (especially educational).

Evaluation of teacher's efficiency measuring is challenging as the criteria for evaluation are both objective and subjective (Thanassoulis et al., 2017). The academic roles of higher education institutions comprise three major components: teaching, research, and service (Edgar & Gear, 2013). In this study, the concept of research performance is examined in a two perspective: efficiency of teaching and efficiency of research. DEA method was used to analyze efficiency of 68 teachers at the University of Belgrade, the Faculty of Organizational Sciences. For long period of time there is a dilemma about relationship between teaching and scientific-research work, especially whether teaching activates disturb scientific-research work or scientific-research work contributes to the teaching efficiency. Results of the carried out study have shown that a teacher can be completely efficient only if he is committed to the teaching ad scientific-research work, equally.

The structure of the paper is built in the following way: the second section describes the DEA basics followed by literature survey in the sector of education. The third section will contain study about the relative efficiency of teaching performances at the University of Belgrade. The main conclusions are summarized in the last section.

2. DATA ENVELOPMENT ANALYSIS

DEA is a mathematical-programming-based approach for identifying the best practice when multiple performance metrics are present. Performance metrics are commonly classified as inputs and outputs of peer DMUs. This special mathematical technique was first introduced by Charnes et al. (1978), initially to evaluate relative efficiency in the non-profit sector.

There is basically input-oriented a constant returns-to-scale (CRS) model that initially introduced by Charnes et al. (1978):

$$\begin{aligned} &(\max)\ h_k = \sum_{r=1}^{s} u_r y_{rk} \\ &st \\ &\sum_{i=1}^{m} v_i x_{ik} = 1 \\ &\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0,\ \ j = 1,\ldots,n \\ &u_r \ge \varepsilon;\ \ r = 1,2,...,s, \\ &v_i \ge \varepsilon;\ i = 1,2,...,m, \end{aligned} \tag{1}$$

where:

$u_r \ge 0,$ are weights assigned to the *r*th outputs, $r = 1,\ldots,s$, and

$v_i \ge 0,$ are weights assigned to the *i*th inputs, $i = 1,\ldots,m$ in order to assess DMU_k as efficient as possible.

This basic CCR DEA model, should be solved *n* times, once for each DMU_k. The index h_k shows relative efficiency of DMU_k, obtained as maximum possible achievement in comparison with the other DMUs under the evaluation. DEA empirically identifies the efficient frontier of a set of DMUs based on the input and output variables. Assume that there are *n* DMUs, and the *j*th DMU, produces *s* outputs ($y_{ij},..,y_{sj}$) by using *m* inputs ($x_{ij},..,x_{mj}$). The efficiency score of the observed DMU_k is given as virtual outputs (sum of weighted outputs). For a given set of inputs and outputs, DEA produces a single comprehensive measure of performance (efficiency score) for each DMU.

DEA method occupies an important place in the comparative efficiency studies in the public sector worldwide (Chalos & Cherian, 1995; Odeck, 2005). It is implemented in many aspects of higher education such as evaluation of universities, evaluation of study programs (or faculties) and evaluation of academic staff, including teaching evaluation. Thus, it is possible to determine which variables contribute to improving the performance of higher education, to assess the relative effectiveness of units in higher education institutions, and determining exactly which inputs and outputs contribute to achieving optimal performance.

Examples of DEA application in the area of higher education from around the globe are described in works by Kao and Hung (2008), Berbegal-Mirabent et al. (2013), Agasisti & Perez-Esparrells, (2010), Fuentes et al. (2016), Kuah and Wong (2011).

Kao and Hung (2008) applied DEA to assess the relative efficiency of the academic departments at National Cheng Kung University in Taiwan in utilizing the scarce resources in teaching students and producing research results in measured. The investigation is focused on the efficiency of resources utilization rather than academic performances. This type of assessment alleviates the problem of comparing departments with different characteristics. Although teaching and research have been considered by most people as the two major tasks of the university, they are difficult to measure. The overall efficiency shows whether resources are effectively utilized by each department separately, while pure technical efficiency helps identify weak areas in which more efforts should be made to improve the efficiency of the department. Fourteen (out of 41) inefficient departments with an unsatisfactory result of overall technical efficiency were identified and they are in this way able to calculate the number of inputs that need to be reduced and the number of outputs that need to be increased in order to increase efficiency. Teaching has the largest contribution with 58.2% of the average total score. Publications are the second with 23.7% of the average total score. And finally, external grants contribute with only 18.1% of the average total score. Via the DEA calculations, efficiency decompositions, and cluster analysis, the top administrators of a university are able to detect the departments that are inefficient in utilizing their resources and the department heads are able to identify the area which the greatest gains can be acquired from improvements in efficiency.

Berbegal-Mirabent et al. (2013) assesses the efficiency of universities in terms of teaching, research and knowledge transfer 44 state universities in Spain. The DEA model which is used has an exit orientation based on the assumption that in the public sector labour and budget tend to be fixed and that these organizations produce the maximum possible output forasmuch as resources they have. The results show that average inefficiency at Spanish universities is 12% indicating that they can increase their output by 12%, with the same input values. Also, 21 universities out of 44 are efficient, with a maximum value of 53.7%.

The goal of another study which uses DEA model in higher education (Agasisti & Perez-Esparrells, 2010), is to provide efficiency analysis of 74 Spanish and 76 Italian universities, as well as a perspective of comparison between countries, in order to identify the main similarities and differences. The authors use DEA allowing each of these 150 universities to assign differente weights to different dimensions of their activities in order to maximize their score. As inputs, we consider number of students, number of Ph.D. students, number of professors and financial resources available. As outputs, we use number of graduates as a proxy for teaching performance, and the amount of external resources attracted to research activities as a proxy for research performances. In the first step, a DEA analysis was run separately for Italian and Spanish universities. In general terms, it seems that Spanish HE has a higher average level of efficiency. The next step was to run a DEA analysis considering Italian and Spanish universities together. Here, the average level of efficiency is about 0.7 and, above all, there are more Italian efficient universities (12 out of 14 effective in previous analysis) than Spanish ones (only 3). It means that comparing all universities together, the efficiency barrier for Spanish universities has shifted, and the number of universities that are able to reach it is smaller.

In the work of Fuentes et al. (2016), the technical efficiency of the learning process in higher education is assessed using a three-step procedure that provides progress in relation to previous studies and improves the quality of the results. First, the authors use DEA with contextual variables (socio-economic and cultural levels of pupils' families and student education before the university). Secondly, the efficiency levels have been calculated to prioritize the efficiency units. Finally, through the sensitivity analysis, the contribution of each KPI was determined to the levels of efficiency without distorting the variables. Analytical data were collected from a survey of 633 students. The results show that the level of satisfaction with the course, the diversity of materials and satisfaction with teachers are the most important factors that influence the performance of the teaching. The methodology used in this paper allows better quality control of education, along with data obtained from students that serve to detect inefficiency in individual units and to improve results.

Kuah and Wong (2011) presented the DEA model for joint evaluation of the relative teaching and research efficiencies of universities in Malaysia. The inputs and outputs for university performance measurement were identified. They comprised of 16 measures in total. Joint DEA maximisation was used to model and evaluate these measures. The application of DEA enabled academics to identify deficient activities in their universities and take appropriate actions for improvement.

3. EMPIRICAL STUDY – TEACHER'S EFFICIENCY MEASURING

The main objective of this study was to measure the efficiency of teachers at the University of Belgrade, the Faculty of Organizational Sciences. The survey was fielded in June 2017. Altogether, 68 teachers (DMUs), who gave lectures in the third year of undergraduate study, are used in the survey. Teacher's efficiency measuring is analyzed in two aspects (Hattie & Marsh, 1996):

- efficiency of teaching (E_1) and
- efficiency of research (E_2).

Therefore, a summarized assessment of teacher's efficiency is calculated as follows:

$$Ej = w_1 * Ej_1 + w_2 * Ej_2, \; j=1,2,\ldots,n \tag{2}$$

where w_1, w_2, weight coefficients that define the importance of each of the performance estimates in each sum assessment. Weight coefficients have a value of 0.5, since it is assumed that these two aspects of efficiency estimates have the same importance ($w_1 = w_2 = 0.5$).

3.1. Study design

***Efficiency of teaching* (*E1*)**

An input-oriented DEA CRS model (1) was used to estimate the efficiency of teaching. The parameters used for the CRS model are:

Inputs:

- Teacher's workload coefficient values – *I1*
- Average number of students in the third year of study in the school year 2015/16 per teacher – *I2*

Outputs:

- Average number of students who passed the exam per teacher – *O1*
- Average grade for all students who passed the exam (per teacher) – *O2*

Teacher's workload coefficient values are calculated as the reciprocal value of the number of subjects that a teacher hands over to students in the third year of study because the more number of subjects the greater workload of the teacher. The data for the input and output values were obtained from the student service of Faculty of Organizational Sciences. Each teacher is assigned an ID.

***Efficiency of research* (*E_2*)**

The assessment of efficiency of research was measured with the following equation:

$$E_{j2} = O_j / I_j, \; j = 1,...,n \tag{3}$$

Due to the heterogeneity of the obtained results, we used normalization technique to get results in a [0-1] scale within the equation (4):

$$\bar{E}_{j2} = E_{j2} / \max E_{j2}, \; j = 1,...,n \tag{4}$$

The parameters used for this assessment are:

Input:

- The appointment of teachers -*I*
  - assistant professors got value1
  - associate professors got value 1.5
  - full professor got value 2

Output:

- Number of scientific papers published in SCI journal list in the school year 2015/16 by teacher - *O*

The data required for the assessment of the efficiency of research are the number of scientific papers published in SCI journal list by the teacher and engagement in the project Ministry of Education, Science and Technological Development. Since no exact engagement data is available, teachers are assigned value, which is equivalent to their engagement. Thus, the values in DEA are derived from the data instead of being fixed in advance. To assess the efficiency of teachers in scientific research, data were downloaded from http://www.scopus.com/. The date showed about 11% "outliers" (number of scientific papers published in the school year 2015/16 by teacher more than 5). We have chosen to keep the outliers in the data and give all of them maximum values 5.

3.2. Analysis and results

Descriptive statistics of these parameters values, which used for the CRS model, is given in Table 1.

Table 1. Descriptive Statistics

Parameters	I1	I2	O1	O2
Min	0.33333	1.71	1.22	6.93
Max	1	963	145.56	9.77
Mean	0.786765	147.1356	47.41824	8.144412
Std. Dev.	0.266369	138.2835	40.3438	0.686743
Correlation coefficients				
I1	1			
I2	-0.30158	1		
O1	-0.47439	0.362323	1	
O2	-0.15564	-0.0862	0.151575	1

Based on the results of the correlation, it is obvious that the input *I1* (teacher's workload coefficient values) negatively affects to the outputs *O1* and *O2* (average number of students who passed the exam per teacher and average grade for all students who passed the exam (per teacher)).

Table 2. Results of the teacher's efficiency measuring

ID	Efficiency of research $\overline{E}_{j2}$	Efficiency of teaching E_{j1}	***E***	**Rank**
1	0.666	1	0.833	7
2	0	0.926	0.463	49
3	0.4	0.636	0.518	35
4	0	1	0.5	38
5	0	1	0.5	38
6	**1**	**1**	**1**	**1**
7	0.2	0.798	0.499	44
8	0	0.476	0.238	66
9	0.4	0.661	0.530	30
10	0	1	0.5	38
11	0	0.636	0.318	59
12	0.4	0.653	0.526	33
13	0.133	0.498	0.315	60
14	0.4	0.532	0.466	48
15	0	0.483	0.241	64
16	0	0.476	0.238	66
17	0.133	0.675	0.404	54
18	0	1	0.5	38
19	0.4	0.423	0.411	52
20	0	1	0.5	38
21	0.2	0.854	0.527	32
22	0.1	0.414	0.257	63
23	0	0.483	0.241	64
24	0.2	0.758	0.479	47
25	**1**	**1**	**1**	**1**
26	0.666	0.393	0.530	31
27	0.5	0.975	0.737	14
28	0	0.343	0.171	68
29	1	0.540	0.770	10
30	0.3	0.540	0.420	50
31	0.1	0.423	0.261	61
32	0.4	1	0.7	17
33	0.5	0.926	0.713	16
34	1	0.540	0.770	10
35	0.3	0.975	0.637	20
36	0.5	0.975	0.737	14
37	0.2	0.625	0.412	51

38	0.533	1	0.766	12
39	1	0.926	0.963	5
40	0.5	1	0.75	13
41	0.4	1	0.7	17
42	0.6	0.975	0.787	9
43	0	0.661	0.330	58
44	0.4	1	0.7	17
45	0.5	0.758	0.629	22
46	0.2	1	0.6	26
47	0.4	0.807	0.603	25
48	0.6	0.653	0.626	23
49	1	0.975	0.987	3
50	0.4	0.718	0.559	28
51	0.3	0.393	0.346	56
52	0.6	0.653	0.626	23
53	0.6	1	0.8	8
54	0.2	0.807	0.503	36
55	0.2	0.807	0.503	36
56	1	0.975	0.987	3
57	0.1	1	0.55	29
58	0	0.515	0.257	62
59	0.2	1	0.6	26
60	0.5	0.318	0.409	53
61	0.3	0.966	0.633	21
62	0.5	0.540	0.520	34
63	0.2	0.489	0.344	57
64	0	0.975	0.487	45
65	0	0.807	0.403	55
66	0.8	1	0.9	6
67	0	0.966	0.483	46
68	0	1	0.5	38

Teacher ranking was done on the summarized assessment of teachers' efficiency (E). Rank 1 are shared only two assistant professors with ID 6 and ID 25 (Table 2). Those teachers have both excellent performance grades, i.e. he is also successful in teaching and publishing scientific papers. Rank 3 (E = 0.987) are shared an assistant professors with ID 49 and ID 56, who have excellent grades but fewer than first-ranked. Six teachers are shared rank 38. They are very efective in teaching (E_{j1} = 1), but in the same time, have a very low estimate of efficiency in research (E_{j2} = 0). More than 7.35% of teachers have an efficiency index greater than 0.9, which means that, based on this summary score, most teachers are effective.

Based on the results of the teachers' efficiency of research (E_{j2}) is distinguished by 18 teachers (26%) who did not publish any scientific papers in the school year 2015/16 (Table 2), which according to this „aspect“ is classified as clusters of ineffective teachers (E_{j2} = 0). This cluster also has the three lowest ranked teachers who have a very low average grade on the subject. One more interesting note is that the assistant professors with ID 29 and ID 34 have a excellent grade of research (E_{j2} = 1) but poor in teaching (E_{j1} = 0.54).

4. CONCLUSION

Public higher education sector is under a growing pressure worldwide to increase efficiency and improve the quality of its activities. Results of teachers' efficiency measuring are used by University and faculty representatives to improve teaching efficiency and to assess who is to be promoted, full time employed, or supported to hold a particular course. Though numerous researches show that there is no a unique measure, it seems that teachers accomplish positive results if they are monitored and adequately supported. The choice of a model, or the way to measure teachers' efficiency, is made based on the issued Regulations of a faculty.

In this paper, we used DEA method for measuring teachers' efficiency and demonstrated its advantages: the obtained results can be easily interpreted; all criteria for efficient teaching are include; clear determination of low scores and insight into their causes, based on a specific criterion.

Continuous measuring of teachers' efficiency and enabling individual and collective development allow teachers become more efficient in contribution of research to effective continuing professional development activities and teaching. It is worth noted that this way of measuring must be continuously adapted to changing market pressures to ensure students’ satisfaction is achieved.

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