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AN EXAMPLE OF NETWORK DEA – ASSESSMENT OF OPERATING EFFICIENCY OF UNIVERSITIES

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Abstract: The purpose of the article is to present the use of network DEA for evaluating the efficiency of Polish universities. Network DEA assessment of operating efficiency of universities was compared with the single stage DEA results that focus on teaching efficiency, research efficiency and aggregate performance. The study presented in the paper – though limited in scope – shows that biggest Polish universities are diversified in regard to the efficiency of their performance.

Keywords: DEA, network DEA, efficiency, universities

INTRODUCTION

Since the initial work by Charnes et al. (1978), Data Envelopment Analysis (DEA) has been methodological developed and widely successfully applied to assess the relative efficiency of entities – Decision Making Units (DMUs) in many areas. Education is an area of application that attracted the most attention in the early days of the development of the DEA and is still very popular. According to [Liu et al. 2013] there are 184 papers that concern DEA applications in education in journals indexed by the Web of Science database from 1978 through 2010. It provides a fifth place of the most common field of study in DEA literature. Looking for the reasons it is worth noting that DEA allows multi input and output variables, it can take into account many different fields of the performance [Chodakowska 2015]. Outcomes of DEA may provide valuable information supporting the management of educational institutions. It allows identifying strengths and weaknesses, the mode of fund allocation among institutions, or the optimal size of them [Nazarko, Šaparauskas 2014]. Brief references of the newest efficiency studies in the higher educational institutions is given below.

Among others, DEA was explicitly used to asses research productivity ([Johnes, Yu 2008], [Kao, Hung 2008]), teaching quality ([Celik, Ecer 2009], [Johnes 2006]) or aggregate performance ([Johnes 2014], [Leitner et al. 2007], [Worthington, Lee 2008]) of universities or theirs departments. Such a distinction represent the two most important activities of a university: teaching and researching with transferring the new knowledge. There were also attempts to assess the allocative efficiency ([Abbasi et al. 2010], [Tauer et al. 2007]).

Network DEA models are relatively recent innovations on methodology that gain popularity in various application areas [Liu et al. 2013]. The examples of network DEA application in the area of higher education proposed [Saniee Monfared, Safi 2013].

The aim of this paper is to use a network DEA approach to perform an efficiency analysis of the Polish universities.

METHODS

The proposed methodology

Network DEA to measure the relative efficiency of a system, taking into account its internal structure, was popularized by Färe and Grosskopf ([Färe, Grosskopf 1996], [Färe, Grosskopf 2000], [Färe et al. 2007]).

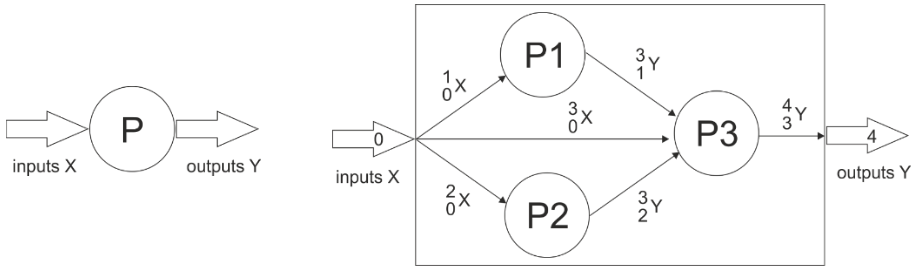
The main difference between network DEA and conventional non-network DEA is that while conventional DEA considers a single process that consumes all the inputs and produces all the outputs, network DEA considers the existence of several stages each of which consumes its owns set of inputs and produce its own set of outputs, in addition to consuming and producing intermediate products. These intermediate products are defined as inputs for some stages are outputs for others [Saniee Monfared, Safi 2013].

The differences between non-network and networks models are illustrated in Fig. 1. Inputs are denoted by $X=(X_1, \ldots, X_m)$ and outputs by $Y=(Y_1, \ldots, Y_s)$. In non-network technology inputs are transformed in the process P into outputs [Färe, Grosskopf 2000]. In network DEA model available inputs are attached to sub-technologies. Assuming that there are three production processes P1, P2 and P3 that use the same source of inputs, ${}_0^1X$ is employed by P1, ${}_0^2X$ by P2, and ${}_0^3X$ by P3. The total amounts used in three activities cannot exceed the total amount available [Färe et al. 2007]:

$$X \geq \sum_{i=1}^{3} X_0^i \tag{1}$$

P3 uses ${}_0^3X$ as exogenous input and ${}_1^3Y$, ${}_2^3Y$ as intermediate inputs. The final product from P3 is output vector ${}_3^4Y$.

Figure 1. A non-network versus network technology



Source: adopted from [Färe et al. 2007]

Since its introduction various network models have been developed and proposed to measure the efficiency [Kao 2014]. In this case, in order to evaluate the efficiency of Polish universities, two-stage process was considered where X are inputs to the first stage and outputs from the first stage at the same time are inputs to the second stage. The implemented DEA model inspired by (Saniee Monfared, Safi 2013) and can be written as follows [Chiu et al. 2011], [Zhu 2003]:

$$\min\left(\theta_{1j_0} + \theta_{2j_0}\right)/2$$

(stage 1)

$$\sum_{j=1}^{n} \lambda_j x_{ij} \le \theta_{1j_0} x_{ij_0} \quad i = 1, 2, \dots, I \qquad (2)$$

$$\sum_{j=1}^{n} \lambda_j q_{ej} \ge q_{ej_0} \quad e = 1, 2, \dots, E$$

$$\sum_{j=1}^{n} \lambda_j z_{dj} \ge \tilde{z}_{dj_0} \quad d = 1, 2, \dots, D$$

(stage 2)

$$\sum_{j=1}^{n} \mu_j p_{sj} \le \theta_{2j_0} p_{sj_0} \quad s = 1, 2, \dots, S$$

$$\sum_{j=1}^{n} \mu_j z_{dj} \le \tilde{z}_{dj_0} \quad d = 1, 2, \dots, D$$

$$\sum_{j=1}^{n} \mu_j y_{rj} \ge y_{rj_0} \quad r = 1, 2, \dots, R$$

$$\lambda_j, \mu_j \ge 0 \quad j = 1, 2, \dots, n$$

where:

$X_j = \left(x_{1j}, x_{2j}, x_{3j}, \dots, x_{Ij},\right)$ – input vector of stage 1,

$Q_j = \left(q_{1j}, q_{2j}, q_{3j}, \dots, q_{Ej},\right)$ – output vector of stage 1,

$P_j = \left(p_{1j}, p_{2j}, p_{3j}, \dots, p_{Sj},\right)$ – input vector of stage 2,

$Y_j = \left(y_{1j}, y_{2j}, y_{3j}, \dots, y_{Rj},\right)$ – output vector of stage 2,

z_{dj} – the *d*th intermediate variables of the *j*th DMU,

$\tilde{z}_{ij_0}$ – decision variables,

$j = 1, 2, \dots, n$ – number of DMUs,

θ_{j_0} – efficiency ratio taking values in the range <0.1>; 1 for fully effective entities. The larger θ_{j_0} is, the better efficiency DMU_{j0} has.

A Case Study

In Poland in the 2013/2014 academic year there were nearly 1 550 thousand students in 133 public and 312 non-public higher education institutions [Jagielski, Żebrowska 2013]. To show an example of network DEA assessment of operating efficiency of universities was considered a data set that consists of 12 Polish universities with h-index over 80. They are also the largest Polish universities taking into account number of undergraduate and graduate students (Table 1).

Table 1. Performance of selected universities – data from 2013

University	Abbrev.	h Index	Grants [PLN]	The number of students	The number of PhD students
University of Warsaw	Univ Warsaw	197	108 016 954	46 125	3 167
Jagiellonian University in Cracow	Jagiellonian Univ	163	115 497 162	42 374	3 220
Warsaw University of Technology	Warsaw Univ Technol	121	25 080 067	34 135	1 248
University of Wroclaw	Univ Wroclaw	101	33 121 948	26 239	1 554
University of Gdańsk	Univ Gdansk	98	20 554 024	27 640	1 431
Nicolaus Copernicus University in Toruń	Nicholas Copernicus Univ	95	21 058 072	28 034	881
AGH University of Science and Technology in Cracow	Agh Univ Sci Technol	93	23 629 991	33 244	987
Adam Mickiewicz University in Poznań	Adam Mickiewicz Univ Poznan	91	43 969 843	40 633	1 382
University of Łódź	Univ Lodz	88	17 360 475	36 734	3 220
Poznań University of Technology	Poznan Tech Univ	84	15 444 946	34 135	597
Wrocław University of Technology	Wroclaw Univ Technol	82	27 481 164	34 428	1 091
University of Silesia in Katowice	Silesian Univ	80	15 074 819	26 908	1 372

Source: [Jagielski, Żebrowska 2013], [Ranking 2014]

To assessment of operating efficiency of universities was done under the assumption that the most important resources are people. The number of academic staff contains Table 2. Universities differ in the number of research workers, especially in the number of employed assistants. For the purposes of this study, the following translation and grouping of academic positions was done: assistant – polish *asystent*, junior assistant professors – polish *adiunkt* and *docent*, associate professor and professor – polish *profesor nadzwyczajny* and *profesor zwyczajny*.

This division of academic staff was done due to the assumed difference in the duties usually expressed in the number of normal working hours of teaching, payments, and employers' expectations. It is noteworthy that at Polish universities the smallest group of employees are assistants. The largest group are junior assistant professors and associate professors.

Table 2. Employment at universities in 2013

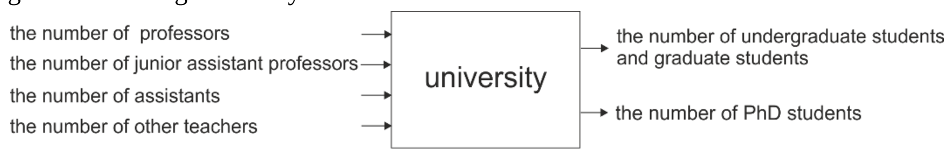
University	The number of professors	The number of junior assistant professors	The number assistants	The number of other teachers
Univ Warsaw	865	1 721	152	587
Jagiellonian Univ	671	1 708	643	617
Warsaw Univ Technol	474	1 087	221	366
Univ Wroclaw	422	1 111	43	239
Univ Gdansk	463	749	162	285
Nicholas Copernicus Univ	481	885	319	315
Agh Univ Sci Technol	441	1 152	330	225
Adam Mickiewicz Univ Poznan	733	1 481	14	646
Univ Lodz	551	1 015	200	395
Poznan Tech Univ	198	560	254	234
Wroclaw Univ Technol	358	1 063	223	261
Silesian Univ	355	1 014	146	293

Source: [Jagielski, Żebrowska 2013], [Ranking 2014], [The National Science Centre]

Using the data simple single stage DEA CCR-I models that the focus on teaching efficiency, research efficiency or aggregate performance can be applied.

The teaching efficiency model (Fig. 2) assumes that the academic staff should above all teach, so the inputs in form of numbers of professors, assistant professors, assistants and lecturers should produce the graduates: bachelors, master and PhD students. In Poland, the number of graduates is practically equal to the number of students in their last year of studies. Author is aware that such assumption exclude the quality measurement of teaching but promotes cost minimizing. But the determination of the quality of teaching is not possible without the study of labour market situation of graduates, without taking into account localisation of the university and in particular its candidates among which recruits its students.

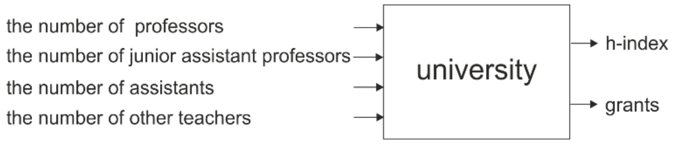
Figure 2. Teaching efficiency



Source: adopted on the basis of [Saniee Monfared, Safi 2013]

Using DEA scholarly productivity of academic staff can also be calculated (Figure 3.). Presented model takes into account the total value of grants founded by National Science Centre (NCN) and h-index.

Figure 3. Research efficiency



Source: adopted on the basis of [Saniee Monfared, Safi 2013]

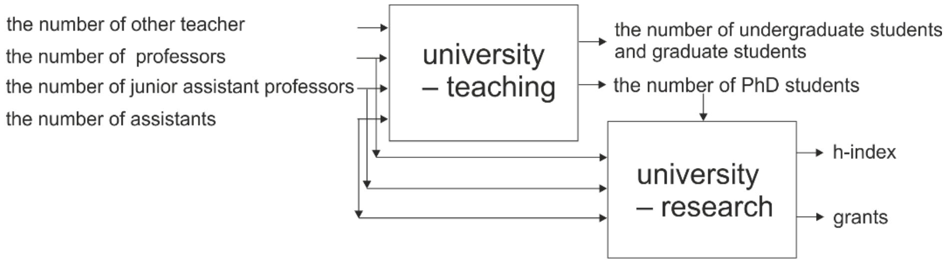
Aggregated model do not distinguishes between research and teaching activities. Inputs in form of number of academic staff produce graduates, high cited articles and win grants (Figure 4.).

Figure 4. Teaching and research efficiency model – aggregated model

Source: adopted on the basis of [Saniee Monfared, Safi 2013]

The network DEA model was built on the assessment that 1/3 working time is used for teaching by professors, assistant professors and assistant, while other teachers spend the whole time for teaching. In addition, PhD students assist with scholarly works.

Figure 5. Teaching and research efficiency model – a network DEA



Source: adopted on the basis of [Saniee Monfared, Safi 2013]

In the all models author assumed that the working time devoted to didactic and research work can be represented by the data of number of employees. Moreover, the division of 1/3 and 2/3 for teaching and scientific work, done in the network model work is simplistic and might be controversial. Author is aware that in practise, depending on university, even with the same group of workers, number of teaching hours spread unevenly.

The results of the network DEA model against three alternative single-stage models presented in Table 3.

RESULTS, DISCUSSION AND LIMITATIONS

The network DEA approach was tested and its results were compare with the single-stage DEA models.

Table 3. Results of the single-stage and network DEA models

University	Teaching efficiency	Research efficiency	Aggregated efficiency	Network DEA efficiency
Univ Warsaw	0.949	1	1	0.974
Jagiellonian Univ	0.851	1	1	0.925
Warsaw Univ Technol	0.804	0.918	0.918	0.860
Univ Wroclaw	1	1	1	1
Univ Gdansk	0.928	1	1	0.964
Nicholas Copernicus Univ	0.669	0.816	0.818	0.713
Agh Univ Sci Technol	1	0.978	1	0.814
Adam Mickiewicz Univ Poznan	1	1	1	1
Univ Lodz	1	0.683	1	0.794
Poznan Tech Univ	1	1	1	1.000
Wroclaw Univ Technol	0.984	0.833	1	0.854
Silesian Univ	0.900	0.783	0.907	0.807

Source: own calculation performed using Solver Microsoft Excel and VBA procedures

It is worth notice that the average efficiency is high, regardless the model. It is the effect of correspondence between the number of DMUs and the sum of the number of inputs and outputs. Among the compared models the network DEA has the highest discriminant power since they use more detailed data.

DEA is an effective technique for measuring the relative efficiency of a set of decision making units (DMUs) that apply multiple inputs to produce multiple outputs. However, it should be recalled that the efficiency scores do not measure the performance of Polish universities relative to their counterpart in the world. Polish universities do not occupy important places in global rankings. Academic Ranking of World Universities [http://www.shanghairanking.com] assesses two Polish high schools and in databases records three more.

Apart for that, author is of the opinion that the DEA implementation can be a complementary tool to rankings with fixed weight such as mentioned Academic Ranking of World Universities or The Ranking Web or Webometrics [http://www.webometrics.info/] or local comparisons to see for example Perspektywy education institutions ranking [http://www.perspektywy.pl/portal/].

Network DEA approach that takes the internal structure of the system into account in measuring efficiency, can supersede conventional DEA models. However, author agrees that comparison of teaching and scholarly achievements of universities is complex and evokes a considerable amount of controversy [Nazarko, Šaparauskas 2014].

In terms to further research, a key limitation of this work is arbitrary selection of variables and the model. Definitely it would be reasonable to check other variables and the relationship (transformation processes) between the assets and the outcomes of the universities. Another issue, emphasized by researchers, as the most difficult area in academic performance evaluation, is measuring teaching quality. The number of students are limited by the regulations, students' achievements recorded on the diplomas, and their subsequent situation on the labour market as the output performance are in high degree the result of the students' initial ability which they have already acquired before enrolment at the university. Analogically, typical research performance indicators included number of publications or citation, and journal impact factors are discussed and criticised. Furthermore, teaching and research although considered as the two major tasks of the universities, are not the only outputs. Universities produce also some extremely difficult to measure social outputs.

CONCLUSIONS

The paper presented an example of network DEA method in the efficiency assessment of Polish universities. The study presented in the paper – though limited in scope – shows that the biggest Polish universities are diversified in regard to the efficiency of their performance. The results of the analysis show that selection of variables and models affect unit's efficiency. On the basis of selected Polish universities, author shows that the application of network DEA could be useful and provides additional knowledge about the efficiency of educational institutions, but proper interpretation of these results requires a high degree of caution when formulating conclusions.

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