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DEA Method in efficiency assessment of public higher education institutions

Joanicjusz Nazarko
Bialystok University of Technology, Bialystok, Poland, j.nazarko@pb.edu.pl

ABSTRACT

Public higher education sector in Poland is under a growing pressure to increase efficiency and to improve the quality of its activities. Limited financial resources as well as the detailed regulations and supervision of their spending are the important features of the public higher education sector. Another important and debated issue is the division of public money among higher education institutions (HEI). It is therefore crucial to create stimuli for the rational management of public funds by HEI and for the quality improvement of HEI services. One of the proposed ways to achieve that is the comparative efficiency assessment of the HEI activities. Such an assessment may be treated as a substitute of market competition by setting clear reference points for HEI.
This paper describes a comparative efficiency study of 19 Polish technical universities. Detailed analysis of potential input, output and environmental variables describing the HEI efficiency model has been carried out. The study uses the CCR-CRS output-oriented DEA model. It was assumed that HEI have more influence on their achieved results that on the amount of their resources. The economies of scale have also been studied in relation to the efficiency achieved. Sensitivity of the model to data errors has been tested.
Keywords: *Data Envelopment Analysis (DEA), higher education, efficiency*

INTRODUCTION

Public higher education sector is under the growing pressure to increase efficiency and to improve the quality of its activities. Expectations of the state, society, media and other stakeholders stimulate universities to manage their resources more effectively and also cause increased transparency in state funding of the higher education sector. Another factor contributing to that phenomenon is the necessity to conform to the European Union standards in the Polish higher education system.

It is more and more frequent in the public sector to apply the corporate standards and models of management. However, the specificity of the public sector often makes it impossible to copy those patterns directly. Public sector is characterized, among others, by the complexity of the sector's environment and its instability (frequent political and legal changes), by the multitude and ambiguity of goals and by the variety of stakeholders with contradicting expectations. Another factor is the limited amount of public funds which are distributed and supervised according to detailed regulations. Furthermore, activities of public sector institutions are not subjects of high competitive pressure and are not profit-oriented as is the case with their private counterparts. Additionally, there is a lack of objective criteria for the assessment of the sector. This leads us to the problem of state money distribution that has nothing to do with efficiency of its management by the public institutions.

It is therefore crucial to create stimulants for rational management of public funds and for the improvement in the quality of services offered by the public sector academic institutions. One of the well-tried ways to do that is the systematic comparative study of the efficiency of public sector units (Nazarko et al., 2008, 2009). Such an assessment defines reference points (benchmarks) for studied activities. It may be therefore treated as a substitute for competition and it may contribute to the more efficient allocation of public funds, to greater care for the efficiency of conducted processes, to the higher quality of the offered services and to the improvements in public institutions management.

Data Envelopment Analysis (DEA) method occupies an important place in the comparative efficiency studies in the public sector worldwide (Chalos and Cherian, 1995; Odeck, 2005). It is also applied in the higher education sector because outcomes of DEA analysis may provide valuable information supporting HEI management. DEA does not just enable the identification of areas requiring improvement but also describes the development possibilities in those areas. Moreover, it allows to answer questions concerning HEI strengths and weaknesses, the mode of funding allocation among HEI organizational units, or the optimal size of these units.

Examples of DEA application in the area of high education has been describes in works such as Leitner, 2007; Taylor and Harris, 2004; McMillan and Datta, 1998; Bradley et al., 2006, Nazarko et al., 2008.

In Austria (Leitner, 2007), studies with the use of DEA allowed to assess the efficiency of natural sciences and engineering departments in HEI. Models developed there consisted of two input variables (number of academic teachers and floor area of the department) and 12 output variables (extramural grants, ratio of completed projects to the total academic staff, number of projects completed by the department, number of exams, diploma students, monographs, reports, presentations and other publications, number of patents obtained, and completed PhD students). According to the researchers, it has been demonstrated that DEA method surpasses traditional approaches based on simple calculation of indicators. Application of DEA method does not only allow to determine department's efficiency but also helps specify improvement possibilities of each one.

In South Africa, 10 out of 21 public HEI were studied from the perspective of their efficiency during a period of 4 years (Taylor and Harris, 2004). Taking into account the limitations of the method, seven models were tested. In each model the output variables consisted of the number of graduates and the indicators characterizing HEI engagement in research. Input variables varied in each model and included: total costs, financial resources, number of students and employees. Demonstrated efficiency differences between HEI have allowed to specify four main factors determining HEI efficiency: increase in the number of students, quality of student recruited, quality of academic staff and the level of fixed costs.

In Canada, efficiency of 45 HEI has been studied (McMillan and Datta, 1998). Three types of Canadian HEI were specified: comprehensive with medical school, comprehensive without medical school and primarily undergraduate. 9 different models were used in the analysis. Output variables included among others: number of students sorted by the field of studies, number of sponsored research grants, etc. Input variables consisted of the number of academic staff with the division between exact science and humanities, number of employees obtaining research grants, etc. Authors stress the utility of DEA method as a benchmarking tool applied by HEI. They recommend that DEA is used to study more homogenous administrative units such as departments.

Another instance of DEA application in the higher education sector are the efficiency and productivity studies of more than 500 English in-service training institutions during the period of 5 years (Bradley et al., 2006). Five main types of studied units were specified: general/tertiary colleges, Sixth Form Colleges, Specialist Colleges, Specialist Designated Institutions and External Institutions. Variables describing the number and the quality of students and teachers were used as input variables for the DEA model. Student achievement measured as the number of students continuing their education and the number of attained qualifications were treated as output variables. An environmental variable describing the socio-economic situation of students was also taken into account.

The following paper describes the application of DEA method in the comparative efficiency study of 19 Polish technical universities.

CHARACTERISTICS OF THE SECTOR

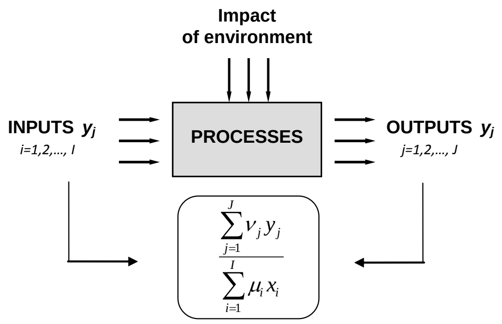
Higher education sector in Poland is divided into two sectors: public and private. There are approx. 500 HEI in total functioning in these two sectors, 130 of them are public institutions. Almost all doctoral granting HEI (approx. 100), including all of the 19 technical universities, are public.

Government budget subsidies are the primary funding source for the public HEI. Subsidies are assigned for education of full time undergraduate and masters students, education of full time PhD students, salaries of academic staff and facilities maintenance. The size of subsidy depends on: (i) number of students (including different weights given to varying fields of study); (ii) number of PhD students (with different weights assigned to various academic specialties); (iii) number of teaching and research staff (with different weights assigned to their seniority and formal qualifications); (iv) number of research grants obtained in a given year; (v) number of licenses to award PhD and higher doctorate degrees; (vi) student exchanges with foreign universities.

There are about 1,930,000 students (year 2008) in different types of HEI in Poland, 1,270,000 in public HEI and 660,000 in private HEI. About 930,000 are full time students (public: 810,000, private: 120,000) and about 1,000,000 are part-time students (public: 460,000, private: 540,000). Technical universities provide education for 320,000 students (full-time programs: about 220,000, part-time programs: about 100,000). All HEI are the primary workplace for more than 62,000 academic teachers, including 13,000 tenured professors. Technical universities employ 15,500 academic teachers, including 2,900 tenured professors.

In 2008 government budget subsidy for public HEI amounted to about US$ 3 billion, out of which US$ 730 million went to technical universities. There is a general consensus among scientists and politicians that the current level of financing is far from sufficient. However, the costs of maintaining the public higher education sector are increasingly difficult to bear even for rich countries' budgets (Johnes, 2006, Önsel et. al., 2008). Similarly to other public institutions, HEI are under the growing pressure to increase the efficiency in spending of public resources, to actively search for alternative funding sources and to compete for a good position in the educational market (*Higher Education*…, 2009).

According to DEA methodology, in order to analyze the efficiency of Polish technical universities it was assumed that each university (DMU – Decision Making Unit) may be characterized by its initial assets (system input), effects (results, system output) and transformation processes which convert assets into effects (taking into account the impact of the environment which remains out of university's control). Hence, in case of DMUs characterized by a certain amount of input and results, efficiency may be defined as the relation between the weighted sum of results to the weighted sum of inputs, taking into account the impact of the environment (Fig. 1).



Where:

x_i – *i-th* input, y_j – *j-th* output,

I – number of inputs, J – number of outputs,

μ_i – weight of the input x_i, v_j – weight of the output y_{ij}.

Fig 1. DEA method concept

Source: Derived by author, based on Thanassoulis, 2003.

DATA ANALYSIS AND SELECTION FOR THE MODEL

Comparison of teaching and scholarly achievements of universities is complex and evokes considerable amount of controversy. It is often argued that such a comparison is subjective and lacks a clear framework. DEA has its limitation too and cannot pretend to be a universal and fully objective method. However, its conscious use may prove to be a source of valuable information on the HEI performance. The possibility to measure and compare values expressed in different units is an important advantage of DEA method. Variables selection is the primary and often the most difficult aspect of DEA application in DMUs comparative analysis. This paper presents two essential stages in the variables selection process: merit-related and statistics-related stage.

15 variables concerning the financial, staff, organizational and qualitative aspects of university performance were analyzed. The merit-related analysis resulted in the selection of 5 input variables, 8 output variables and 2 environmental variables. Table 1 presents the set of analyzed variables with their description.

Table 1. Model variables

Input variables	I_1	Government budget subsidy
	I_2	Number of academic teacher
	I_3	Number of other employees
	I_4	Number of licenses to award PhD degrees
	I_5	Number of licenses to award higher doctorate degrees
Output variables	O_1	Weighted number of full-time students
	O_2	Weighted number of full-time PhD students
	O_3	Percentage of students studying abroad
	O_4	Percentage of international students
	O_5	Percentage of students with university scholarships
	O_6	Percentage of students with government ministry scholarships
	O_7	Employers' preference for hiring alumni
	O_8	Parametric assessment of scholarly achievement of faculty
Environmental variables	E_1	Population size of the city where the university is located
	E_2	Percentage of students with need-based financial aid

Source: Author's own elaboration.

In order to detect relations between the variables, a correlation analysis was carried out in each group of variables.

All input variables are strongly and significantly correlated with each other (Table 2). The strongest correlation of all input variables may be observed with the variable I_1 (government budget subsidy obtained by a university). Thus, this variable is a very good representative of all input variables analyzed initially. It is therefore accepted in the model as a variable representing input.

Table 2. Pearson correlation coefficient of input variables

	I_1	I_2	I_3	I_4	I_5
I_1	1.000	0.984	0.982	0.953	0.988
I_2	0.984	1.000	0.968	0.958	0.968
I_3	0.982	0.968	1.000	0.942	0.953
I_4	0.953	0.958	0.942	1.000	0.944
I_5	0.988	0.968	0.953	0.944	1.000

Source: Author's own calculations.

Results of a university's performance should be related to the input variable. It order to determine the strength of that relation, correlation between the input variable and the output variables was calculated (Table 3).

Table 3. Pearson correlation coefficient of input and output variables

	O_1	O_2	O_3	O_4	O_5	O_6	O_7	O_8
I_1	0.97	0.96	0.22	0.15	0.18	0.43	0.93	0.96
p	0.00	0.00	0.36	0.53	0.46	0.06	0.00	0.00

Source: Author's own calculations.

Only four out of eight output variables are strongly and significantly correlated with the input variable: O_1 – weighted number of full-time students based on their field of study; O_2 – weighted number of full-time PhD students calculated on the basis of their scholarly disciplines; O_7 – employers preferences determined through survey research and O_8 – parametric assessment of scholarly achievements of universities carried out by the Ministry of Science and Higher Education. Correlation of the remaining output variables with the input variable is insignificant. Thus, these variables were excluded from further analysis.

In order to examine the impact of the environmental variables on the achieved results the correlation between the environmental variables E_1 (population size of the city where the university is located), E_2 (percentage of students with need-based financial aid) and the output variables was calculated. It was established that the two environmental variables are characterized by a strong and significant correlation with output variables (Table 4). Variable E_2 shows negative correlation with the output variables. The obtained results indicate the need to include the environmental variables in the model.

Table 4. Pearson correlation coefficient of output and environmental variables

	O_1	O_2	O_7	O_8
E_1	0.7186	0.8391	0.8314	0.8563
E_2	-0.5496	-0.5803	-0.5079	-0.6368

Source: Author's own calculations.

Variables selected for the model should be characterized by a high level of variation, which enables clear diversification of HEI in respect to their input and achieved effects. All variables present in the model are characterized by a sufficiently high of variation (CV > 50%) (Table 5).

Table 5. Coefficient of variation of model variables

	I1	O1	O2	O7	O8	E1	E2
CV	0.59	0.65	1.10	1.19	0.82	0.78	0.86

Source: Author's own calculations.

Ultimately variables I_1, O_1, O_2, O_7, O_8 were selected for the comparative efficiency calculations with the use of DEA method (Table 6).

Table 6. Variables selected for DEA model

Input variable	I_1	Government budget subsidy
Output variables	O_1	Weighted number of full-time students
	O_2	Weighted number of full-time PhD students
	O_7	Employers hiring preferences with respect to alumni
	O_8	Parametric assessment of scholarly achievements
Environmental variables	E_1	Population size of the city where the university is located
	E_2	Percentage of students with need-based financial aid

Source: Author's own elaboration.

COMPARATIVE ANALYSIS OF THE UNIVERSITIES EFFICIENCY

Due to the character of the task a CCR-CRS output-oriented model was chosen for the calculations. That model was considered suitable because universities have no direct influence on the size of the government budget subsidy. As a result of the very strong linear correlation of output variables with the input variable and the impossibility to rapidly increase the effects, a CSR (constant returns to scale) model was selected. Calculations were carried out with the use of the Frontier Analyst v. 4.1.0, Statistica 9 and Microsoft Office Excel 2007 software.

In the first stage of calculations the efficiency of the universities was determined excluding environmental variables. On the basis of the results it was found that the O_7 variable (employers' hiring preferences) has a low share of in the DMU's efficiency assessment. As a consequence, the calculations were repeated excluding this variable. The obtained results turned out to be practically identical with the previous ones (Table 7).

Table 7. Efficiency scores for 19 universities

No	Univ.	Score	No	Univ.	Score
1	U1	100.00%	11	U9	91.10%
2	U4	100.00%	12	U15	86.50%
3	U5	100.00%	13	U16	84.10%
4	U10	100.00%	14	U14	83.30%
5	U17	100.00%	15	U13	83.10%
6	U18	100.00%	16	U8	82.80%
7	U6	97.30%	17	U7	81.20%
8	U11	96.60%	18	U3	79.80%

9	U19	95.70%	19	U12	75.00%
10	U2	93.90%			

Source: Author's own calculations.

Therefore the O_7 variable was excluded from the further calculations.

Since in several cases the DEA algorithm omitted some output variables (e.g. number of students) the author decided to impose constraints on the weighs ascribed to the output variables. It is also justified by the fact that the government budget subsidy to the Polish HEI is mainly spent on educating students and that the technical universities are required to carry out research and PhD-level education. On these premises it was assumed that the share of O_1, O_2 and O_8 variables may not be lower than 30%, 10% and 20%, respectively. Calculations conducted with these assumptions slightly changed the results of particular universities but five out of six universities considered efficient beforehand kept their status. In turn, relative efficiency of some universities fell drastically (U12, U16, U13, U2), which indicates that their research strength and PhD-level education are relatively very weak in comparison to other universities (Fig. 2).

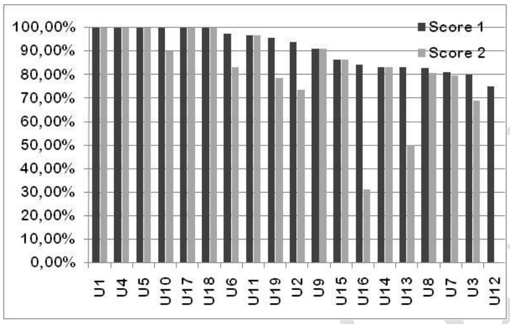


Fig 2. University efficiency scores: Score 1 – without restrictions on the output weights, Score 2 –with restrictions on the output weights

Source: Author's own calculations.

Next the E_1 and E_2 environmental variables were introduced to the model by including them in the Frontier Analyst software as uncontrolled inputs. Due to the software requirements the E_2 variable was replaced by the $1/E_2$ variable in order to obtain the positive correlation between that variable and the outputs. During the process of calculation it was observed that the introduction of E_1 and E_2 variables resulted in assigning a zero weigh to the I_1 variable by the DEA algorithm. Since the utilization of the government budget subsidy is the basis for the relative efficiency analysis of the universities the author decided to impose additional constraint on the variable weighs. It was assumed that the share of I_1 variable may not be lower than 70% and the share of E_1 and E_2 variables may not be higher than 30%. Calculations carried out with such assumptions hardly changed the results of the analysis (except single cases – U15) (Fig. 3). It is an indicator that environment in which a university functions have no significant influence on its efficiency.

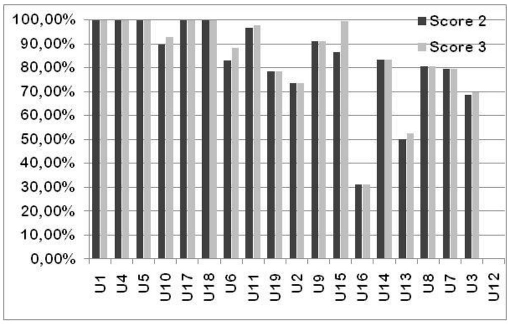


Fig 3. University efficiency scores taking into account the environmental variables: Score 1 – without restrictions on the environmental variables weights, Score 2 – with restrictions on the environmental variables weights

Source: Author's own calculations.

In order to study the sensitivity of the calculations to data error simulations were carried out where output variable were distorted with ±3%, ±5% and ±10% distortions. Input variables remained unchanged since they are determined with high accuracy. The simulation demonstrated that the calculation results remain stable with the distortion level of ±3%. Distortion of ±5% causes significant shifts but the general picture of the ranking is sustained. Distortion of ±10% causes the instability of the results. Simulation results lead to the conclusion that since the weighted number of students (including PhD students) and the number of points in the parametric assessment of research achievements carried out by the Ministry of Science and Higher Education are based on the factors and indicators which are set arbitrarily, one should exhibit far reaching caution in interpreting the results of the university efficiency calculations. These results may to a large extent be determined by some arbitrary assumptions. This problem may be a premise for further detailed studies in this area.

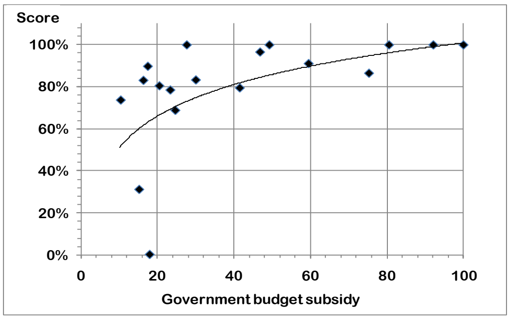


Fig 4. Efficiency score versus university size

Source: Author's own calculations.

The last analysis aimed at studying the influence of a university size on its relative efficiency. University size (measured by the size of the government budget subsidy) shows high correlation (r = 0.53) with relative efficiency. It may lead to the conclusion that larger universities on average achieve higher efficiency. This conclusion is supported by the visual analysis of the efficiency graph in the university size function (Fig. 4).

CONCLUSIONS

The paper presented an example of DEA method implementation in the efficiency assessment of the Polish technical universities. This example shows the usefulness and rationality of DEA application in the higher education sector. Systematic, and multi-criteria assessment of public sector institutions may bring many benefits not only to the authorities that operate with limited public funds but first of all to the assessed units. DEA results carry significant information on the efficiency of HEI functioning in relation to other institutions with a similar scope of activity. They point at the attainable results and at the factors which influence most the efficiency of a unit. Author is convinced that the comparative efficiency analysis may be one of the important stimuli to increase the quality of education and research, to improve the efficiency of public funds spending and their allocation as well as to perfect the HEI management.

The study presented in the paper – though limited in scope – shows that Polish technical universities are diversified in respect to the efficiency of their performance. It is demonstrated that there are considerable reserves for efficiency improvement in particular schools. At the same time one should warn against too hasty and straightforward reading of the calculation results obtained from DEA method. Proper interpretation of these results requires deep knowledge of the studied area and a high degree of caution when formulating radical conclusions.

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