ECONOMICS
& Sociology

Krajčo, K., Habánik, J., & Grenčíková, A.(2024). DEA models as a tool for evaluating and measuring the efficiency of public universities. *Economics and Sociology*, *17*(1), 166-181. doi:10.14254/2071-789X.2024/17-1/11

DEA MODELS AS A TOOL FOR EVALUATING AND MEASURING THE EFFICIENCY OF PUBLIC UNIVERSITIES

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ABSTRACT. Nowadays, the issue of measuring economic and non-economic efficiency is related not only to the enterprise itself but also to the organizations providing education. Measuring the economic efficiency of an educational institution cannot be done as clearly as in the case of enterprises whose mission is to produce products and services for the purpose of selling them. In the case of educational institutions in the form of public universities, profit cannot be considered as the main objective. Universities only report data stipulated by the current legislation, thus measuring efficiency is a rather challenging matter with ambiguous quantification. This study analyzes the efficiency of public universities through some publicly available indicators of their activities. The selection of indicators was made based on the analysis of previous scientific works that dealt with the issue. The basic selection criteria were whether the indicators were verifiable and unquestionable. The work focused on the construction of a model based on DEA analysis of efficiency at constant returns to scale. Descriptive statistics, correlation analysis, cluster analysis, deduction, induction, comparison, and synthesis were also used. Through these methods, it was possible to construct a general model for evaluating the efficiency of public universities.

Received: February, 2023
1st Revision: September, 2023
Accepted: February, 2024

DOI: 10.14254//2071-789X.2024/17-1/11

JEL Classification: D02, O17, P31

Keywords: DEA model for universities, efficiency indicators, university education

Introduction

The higher education system has undergone several reforms in recent decades to ensure the quality of the offered study programmes as well as the quality of the universities themselves. Education has a significant impact on the development of a country, whether at the local or regional level (Masárová et al., 2022; Oliinyk et al., 2021). Of course, it is also important for the population, specifically for university graduates, who have a better chance of finding a job in the labour market than unqualified candidates. Several evaluations of the quality of universities in the Slovak Republic have already been carried out in the past. All of these analyses focused on assessing the quality of public universities without evaluating and measuring the efficiency of these schools. That is why we have addressed this topic and analysed the efficiency of public universities through publicly available indicators of the results of their activities. The indicators were selected based on the analysis of previous Slovak and international scientific works that dealt with the issue. The basic criterion for the selection was whether the indicators were verifiable and unquestionable. Public universities in the Slovak Republic are governed on the basis of the academic autonomy principle. Academic autonomy means that the management of the school is based on the academic community, which consists of students and staff of the school, to the extent provided for by law. In addition to the academic community, external actors (non-academic stakeholders) have a limited influence on the management of the school; their role is to promote the public interest. Universities can be divided into faculties according to the law. Schools organised into faculties are governed at two basic levels: central and faculty. The management of Slovak public universities is characterised by a high degree of decentralisation. Schools are autonomous institutions, influenced by the state only through the legislative framework and funding. The management of the schools themselves is two-tier and also largely decentralised. Central authorities set the school management strategy through a long-term plan, make decisions and control quality at the whole-school level. The faculties decide on their strategy and budget in line with the central bodies, but above all, they decide on their own teaching and creative activities.

Each university management system makes it possible to measure the efficiency of the university itself or its institutional components. Evaluating the efficiency of public universities through DEA analysis allows for application in any country. It also allows for adjustment of input and output data if necessary. Several similar analyses have been carried out around the world using different indicators. The literature suggests two basic approaches to measuring efficiency. Using parametric methods, efficiency is measured through stochastic frontier analysis, the coarse frontier approach, and the freely distributed approach. These approaches are also referred to as econometric and are stochastic in nature; that is, at least one parameter is random. The parametric approach assumes that the production function has a specific shape and is given by a volume of inputs and also a multivariate vector of unknown parameters. These are estimated in the model using the values of the inputs and outputs in the specified model. Because parametric methods will not be used in our work, we will not discuss them in detail. DEA models use linear programming to construct nonparametric angled data envelopments. Each DMU's efficiency scores are calculated relative to this data envelopment (Grmanová, 2015). The basic difference between parametric and non-parametric approaches is due to the fact that in the case of non-parametric methods it is not necessary that the values of input and output variables are expressed in identical units of measurement, also in the case of non-parametric methods the measurement error is part of the resulting efficiency. We have selected indicators that are readily available and relevant to university management. In the nonparametric method, the measurement does not include a random component, making it impossible to eliminate distortions resulting from random measurement errors. In the case of the DEA method, multiple inputs and outputs are transformed into a single virtual input and output and into a single final value of technical efficiency. DEA defines the analysis as: "Data envelopment analysis is based on linear programming and focuses on evaluating the technical efficiency of production units" (Dlouhý, 2018). In the case of DEA analysis, we examine homogeneous units, and the most important thing is the correct determination of input and output parameters. The chosen outputs mostly represent values where the growth of the value represents higher efficiency with the unchanged amount of inputs used. In the case of DEA analysis, a necessary condition is to ensure data homogeneity. It is also to have data available for all subjects under study. Regarding returns to scale, we distinguish between a model for constant returns to scale (CCR) and for variable returns to scale (BCC). In the case of constant returns to scale, if the quantity of inputs used is increased by one unit, there is an equal increase in the value of outputs, while the same value of efficiency will be maintained even in the case of such an increase. A model was proposed through the implemented DEA analysis of the observed indicators. This model will allow evaluating and comparing public universities' efficiency in the Slovak Republic, possibly also in the international context. The individual indicators were selected based on availability as well as on the basis of already conducted researches, which are presented in the following chapter.

1. Literature review

Several authors (Polouček, 2006, Worthington,2001) divide efficiency into 4 basic components. Technical efficiency means focusing on the area of the best use of available production factors. It means that an economic entity tries to maximize the outputs from a given input or inputs. Allocative efficiency is based on the optimal allocation (distribution) of inputs with respect to their availability, technological complexity and price. In this case, the resources are used in an optimal ratio that ensures maximisation of outputs. Overall efficiency is a combination of technical and allocative efficiency. If an economic entity achieves both technical and allocative efficiency, it has achieved maximum overall efficiency, otherwise, its overall efficiency is insufficient and it must focus on identifying the causes of this fact (Quattara, 2012). Farrell (1957) refers to overall efficiency. X-efficiency was used by (Leibenstein, 1966) in his work to denote technical and allocative efficiency. In all approaches the understanding of efficiency is identical and it is an evaluation of the ratio of inputs to outputs of the production process. Whereby allocative and technical efficiency is given in the transformation process of inputs to outputs. The final result of this process is influenced by the external as well as the internal environment of the economic entity. The internal environment is influenced by the entity itself, while the external environment and its factors force the economic entity to adapt to possible changes. The factors of the external environment can include e.g. the competitive environment, economic and social developments in the economy, legislation, geographic and demographic conditions, etc.

Most authors who deal with the issue of measuring and evaluating the efficiency of an economic entity follow the work of Farrell (1957), who was the first author of a method of how allocative, technical and overall efficiency can be determined. This method allowed the evaluation of efficiency using multiple input indicators. He focused on determining the efficient determination of optimal combinations of inputs as well as outputs. In this case, Farrell assumes that a certain quantity of output y is produced when two production inputs x1 and x2 are used. Thus, the production function is given by the volume of inputs.

The application of DEA analysis is possible in various fields, as it also allows comparing the efficiency of non-profit entities, such as the efficiency of primary schools in a network of primary schools, the efficiency of hospitals in a network of hospitals, and so on. DEA has been used to assess the relative efficiency of higher education in a number of scholarly articles. Some articles have focused on the teaching process and the number of students graduating (Archibald and Feldman, 2008; Agasisti and Dal Bianco, 2009; Zuluaga-Ortiz et al., 2022), others on the area of publication outputs (Abramo and D'Angelo, 2009), or on research whose output is represented by the number of patents (Thursby and Kemp, 2002). Some articles have focused on components of universities and some on universities only (McMillan and Datta, 1998; Abbott and Doucouliagos, 2003; Kao and Pao, 2009; Ginevicus et al., 2022). The appropriateness of using DEA analysis as a means or tool for evaluating universities has been addressed by Bougnol and Dula (2006) (Jeck and Sudzina, 2009).

Several studies using DEA models have been carried out in the past. Nazarko and Šaparauskas (2014) in their study evaluated the efficiency of public technical universities in Poland (19 universities) through a DEA model. The input was the amount of government subsidy. The outputs were: the number of students, the number of PhD students, scholarships provided and the success rate of graduates. The results of the study confirmed the appropriateness of using the DEA method in the evaluation of universities.

Mikušová (2015) conducted a DEA analysis of universities in the Czech Republic. She examined a total of 71 subjects, with 26 public universities, 2 state universities and 43 private universities. Her analysis was based on the variable returns to scale (BCC) model for 2013. The inputs to the analysis were academic staff and other costs. The specified outputs were absolute student numbers, numbers of graduates of all levels of higher education. The first part of the analysis carried out a comparison of colleges against each other and then divided these colleges into three groups according to the level of cost coefficients. In the second analysis, she conducted a group-wise evaluation of these schools, showing that dividing the schools into groups changed the result of the efficiency value. For schools with lower efficiency in the first analysis, the second analysis identified these schools as efficient.

Cretan (2015), through descriptive statistics and DEA analysis, examined the relative efficiency of universities in Romania. He observed selected indicators in 2007, 2009 and 2010 compared to 2006 values. He determined the periods mentioned above in order to identify the impact of the economic crisis on public financial resources for higher education institutions. The following indicators were identified as input data: allocated funds and the share of qualitative indicators in the total allocated funds. The outputs were: absolute number of graduates, volume of funding for research projects from international bodies and volume of revenues from services and products provided. The result was a recommendation for public universities, through their management, to implement policies that will lead to a higher use, allocation and optimisation of the public funds received. The outcome of the study pointed towards more performance oriented funding of public universities.

Kulshreshtha and Nayak (2015) evaluated the efficiency of 6 Indian public universities during the academic years 2001/2002 to 2004/2005. The results of the efficiency ratio ranged from 0.8 to 1.0. The authors used the number of academic staff, the number of non-academic staff and the change in the publication stock of the university in a given year as inputs. On the output side were: number of scientific publications, number of students enrolled.

Hock-Eam et al. (2016) focused on public universities (17) in their DEA analysis, comparing them with private (1) and foreign universities (4) in Malaysia. The research was conducted with data from 2008 and 2011. The inputs were: cost of the college, number of academic and administrative staff, government grants and assets of the college. The number of graduates and the revenue of the college were on the output side. The study showed the low efficiency of public colleges in the revenue side compared to private and foreign colleges. The recommendations suggested that public colleges should have greater financial independence.

A broad analysis of 348 universities in 10 European countries and 158 universities in the US was conducted by Wolszczak-Derlac in 2017. The observation period was the years 2000-2012. They used the following indicators on the input side: number of academic staff, expenditure on administrative staff, financial and material resources. The outputs represented: number of students with a final excellent rating in the best quartile, total number of students in all levels of undergraduate studies, weighted number of indexed journals, weighted number of articles in indexed journals, number of academic staff mobility. The following countries were identified as the most effective from the perspective of universities: Poland, the Netherlands, Italy and the UK. Based on the DEA analysis, the authors are able to determine what changes need to be implemented on the output side in order for a university to become more efficient.

The efficiency of public universities in the Slovak Republic was discussed in their study by Grausová et al. (2017). The evaluated period was the years 2014 and 2015. They focused on two areas in which they used the DEA model. For the area of education, the indicators tracked were the number of students, the number of teaching staff and the value of assets directly related to education (an estimate of the value of all buildings owned by the public school). In the area of science and research, the focus was on publications for scientific and educational purposes, funds received for grants. On the basis of the analyses carried out in this way, it is possible to identify measures that could be used by the management of public higher education institutions to increase the efficiency of the public higher education institution.

The efficiency of 43 public universities in 2014-2015 in Turkey was analyzed by Türkan and Özel (2017). The number of academic and administrative staff, college costs, and expenditures above the college budget formed the inputs to the analysis. The following indicators were determined as outputs: college revenue, number of publications, number of students, and number of graduates. The study identified 22% of public colleges as efficient.

Gromov (2017) concluded through DEA analysis that college size negatively affects their efficiency. His analysis included 120 public universities in Russia between 2013 and 2015. On the input side, he used the financial resources of the college, and on the output side, he used the number of students, the number of PhD students, and the number of indexed publications.

Klumpp (2018) compared the efficiency of 70 European universities between 2011 and 2016. He also used DEA analysis for both constant returns to scale (CCR model) and variable returns to scale (BCC model) for the evaluation. As inputs he identified: the college budget and the number of academic staff. The outputs were: teaching, international impact, research, citations and income from the college's own activities. The resultant finding was a significant growth in efficiency over the period under study (efficiency grew disproportionately between schools).

Erkoc and Acar (2018) analyzed 123 Turkish universities in 2009 and 2013. For the DEA analysis, they chose the number of academic and administrative staff, number of students and number of graduates on the input side. On the output side, they used indicators of teaching, research, collaboration with the business sector. The results showed lower efficiency for public universities.

These aforementioned studies have been followed up by other authors in recent years. In measuring efficiency based on DEA analysis, the authors of the most recent studies include: Loganthan and Subrahmanya (2022), Zarrin (2022), Zhao et al. (2022), Chen and Shu (2021).

2. Methodological approach

The main objective of the present study is to compare the evaluation and efficiency of universities using different models based on the analysis of selected indicators of efficiency of public universities in the Slovak Republic. In order to fulfil this objective, it was necessary to define the scientific problem, as well as to determine the object and subject of investigation through the study of specialized domestic and foreign secondary sources. The object of the research is public universities in the Slovak Republic and the subject is the measurement and evaluation of their efficiency from several aspects. Within the framework of the study of domestic and foreign sources, we have identified various approaches to the evaluation and measurement of the efficiency of universities as well as the possibilities of increasing efficiency on the input and output side. We are aware that it is essential to approach the selection of individual indicators responsibly, as any change in any of the indicators will cause changes in the outcome period. Therefore, when comparing the results of DEA analyses, the results can only be compared over time if the same inputs and outputs are kept in all the years studied and the number of units studied must not be changed. Therefore, when selecting indicators, we have chosen those that are objective, publicly available and verifiable. The main source of the necessary data for the analyses and subsequent processing were the Annual Reports on the State of Higher Education in 2011-2020, Methodologies for the allocation of state budget subsidies to public universities in the years under review. The obtained results are presented in the present study.

DEA models do not only provide us with a measure of efficiency, but also give us clues as to how the management of the entity under study should improve its behaviour so that a point on the efficient frontier is reached. An entity that is a projection of an inefficient unit onto the efficient frontier is referred to as a virtual unit (virtual by virtue of the fact that it is usually not a real unit, i.e. one of the other units of the set). We refer to the inputs and outputs of a virtual unit as the target values for the inputs and outputs.

Other methods used in the study were descriptive statistics, correlation analysis, cluster analysis, deduction, induction, comparison and synthesis.

The main model used for the efficiency assessment was the model for constant returns to scale. The CCR model is based on the Farrell model, allowing for evaluation with multiple inputs and multiple outputs. In this case, constant returns to scale are assumed. Based on the proportion of weighted outputs and inputs, the unit at which the model maximises the efficiency rate is determined. In determining this unit, all other units must have an elasticity coefficient less than or equal to one. If the resulting value of the model is equal to 1, it indicates that the subject is on the efficient frontier and is efficient. A value less than 1 is for entities that are less efficient, it does not mean that they are not efficient.

To assess the efficiency of public universities, an analysis and compilation of available data for the 2018-2020 reporting period was required. There were 20 public universities in Slovakia during the period under review. Private universities, state universities and foreign universities could not be included in the evaluation (changes in the number of private universities, different funding system and also the unavailability of some indicators throughout the whole reporting period). In the framework of the analysis of the development of quantitative and qualitative indicators, we examined the number of students enrolled in all forms and levels of higher education, the number of graduates in each year, the number of teaching and research staff at public universities, the coefficient of the qualification structure of staff, the number of projects and the funds obtained for them, the number of publications overall and according to the quality of the output, based on the evaluation of previous evaluations carried out at home and abroad. In the economic area, we analysed the development of total revenues from core and business activities, costs of core and business activities. The use of the economic result in the case of DEA models is not possible, since these models do not allow the analysis of data with a negative value. The appropriateness of the indicators used was verified by correlation analysis.

The evaluation model is based on the analysis of the following 8 models:

1. A model constructed for the education sector and monitors the input represented by the number of students, on the output side is the number of graduates.
2. The model is also focused on the field of education, the input is represented by the number of academic staff and the output by the number of graduates.
3. The model assesses the efficiency of educational activities by analyzing the input represented by the number of academic staff and on the output side by the number of students.
4. The model for the area of publication activity is based on the analysis of the number of staff on the input side and the number of all publication outputs.
5. The model assesses efficiency in terms of the quality of publishing activity through the number of academic staff and the number of publication outputs in categories A1, A2, B, C.
6. The model focuses on the evaluation of scientific research through the number of academic staff and the number of projects.
7. The model assesses efficiency in the success rate of public universities in new projects. Inputs are represented by the number of academic staff and outputs by the number of projects approved in a given year.
8. The model assesses financial efficiency in project activity and tracks the relationship between the number of academic staff and the amount of funding allocated to research projects.

The CCR model is based on the Farrell model, allowing for evaluation with multiple inputs and multiple outputs. In this case, constant returns to scale are assumed. Based on the proportion of weighted outputs and inputs, the Uq at which the model maximises the efficiency rate is determined. In determining this unit, all other units must have an elasticity coefficient less than or equal to one. Through the weights for the inputs vj (j=1,...,m), we obtain the weighted sum of the inputs. By analogy to this, through the weights for the outputs uk (k=1,...,n) we obtain the weighted sum of the outputs, which can be expressed mathematically as:

$$x'_q = \sum_j^m v_j\, x_{qj} \tag{1}$$
$$y'_q = \sum_k^r u_k\, y_{qk} \tag{2}$$

Efficiency maximisation expressed as a proportion of weighted inputs and outputs can then be expressed mathematically as follows:

$$eff(U_q) = \frac{\sum_k^r u_k y_{qk}}{\sum_j^m v_j x_{qj}} \tag{3}$$

The following conditions must be met:

$$\frac{\sum_k^r u_k\, y_{ki}}{\sum_j^m v_j\, x_{ji}} \leq 1, i = 1,2, \ldots, n$$

$$u_k \geq \varepsilon,\ k = 1,2,..., r$$

$$v_j \geq \varepsilon,\ j = 1,2, ..., m$$

In this mathematical expression, ε represents an infinitesimal constant (infinitesimally low) that ensures that all the values of the weights for the inputs and outputs take positive values. The matrix of inputs X with range (n,m) and the matrix of outputs Y with range (n,r) have the form:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \qquad Y = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1r} \\ y_{21} & y_{22} & \cdots & y_{2r} \\ \cdots & \cdots & \cdots & \cdots \\ y_{n1} & y_{n2} & \cdots & y_{nr} \end{bmatrix}$$

3. Conducting research and results

The efficiency of education is the primary issue of any education implemented, higher education also includes scientific research activity, which is important for the preparation of specialists to enable them to acquire the latest knowledge. We verified the correctness of the indicators used in the different evaluation models by means of correlation analysis, the results of which are presented in Table 1 and all indicators indicate a significant correlation at the 0.01 level.

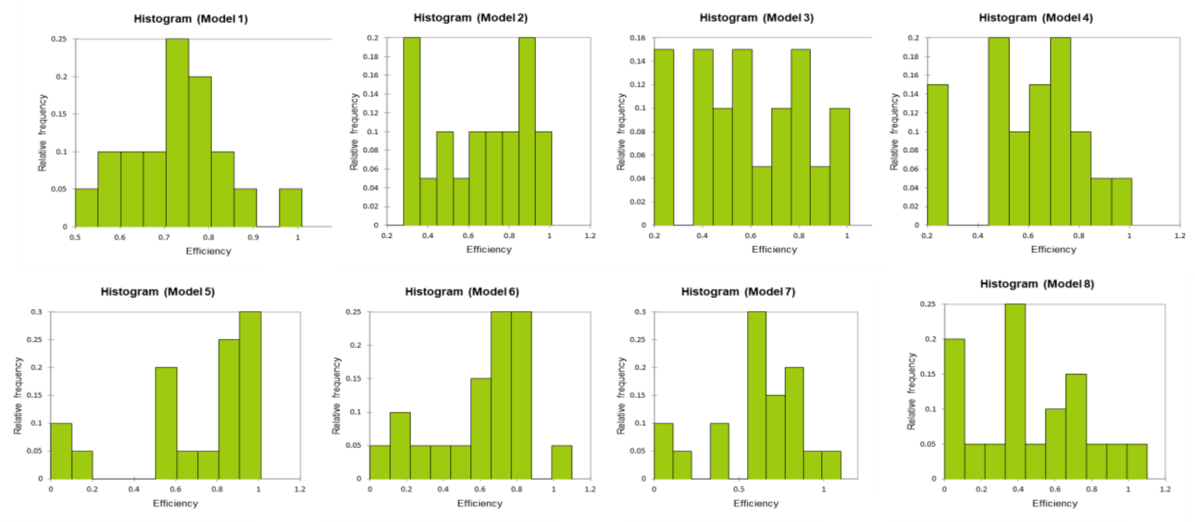
The correlation coefficient is weaker in the case of the correlation of the project allocations with the other indicators, which have no relationship with this indicator; in the case of the project indicators, the value already determines a high correlation dependence. The DEA model thus constructed determined the average efficiency of public universities at 0.86 and the median up to 0.98, with a mode of 1. The model identified 8 public universities with an efficiency value equal to 1. The results of this model confirmed that public universities do not show significant variation among themselves in such an aggregated model, and their efficiency relative to the reference units is minimal. 14 public colleges have an efficiency value above 0.9 and 3 public colleges are in the efficiency range of 0.76 to 0.89.

Table 1. Correlation coefficient of the surveyed efficiency indicators

	Staff	Students	Publications	Publications A-C	Sum of projects	New projects	Funds allocated
Staff	**1**	0.922	0.948	0.949	0.975	0.960	0.926
Students	0.922	**1**	0.983	0.923	0.899	0.917	0.786
Publications	0.948	0.983	**1**	0.957	0.919	0.933	0.806
Publications A-C	0.949	0.923	0.957	**1**	0.943	0.946	0.849
Sum of projects	0.975	0.899	0.919	0.943	**1**	0.982	0.963
New projects	0.960	0.917	0.933	0.946	0.982	**1**	0.917
Funds allocated	0.926	0.786	0.806	0.849	0.963	0.917	**1**

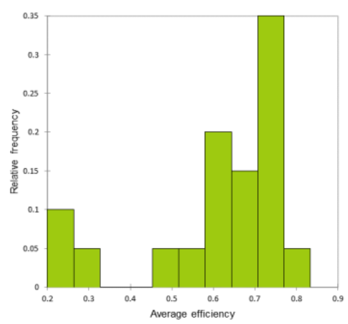
Source: Ministry of Education, own compilation

In the following Graph 1, we present a histogram of the results of each model. Models 1, 2, 3 were analysed for the education domain, the remaining models for the research domain. As we can see, the efficiency is without significant differences between the universities. A more pronounced difference is evident in the case of model 4 and model 5, in both of these cases the least efficient units were identified as public art colleges. A positive result is that in all models, the majority of public colleges analysed achieved efficiency values above the efficiency level of 0.5.



Graph 1. Histogram of the distribution of the relative frequency of the investigated units according to the achieved efficiency value
Source: *Ministry of Education, own compilation*

In the case of determining the average efficiency value of these models, as the previous results indicated, no public college reached an efficiency value of 1. The average value of efficiency thus determined was at 0.62, with a maximum value of 0.82 and a minimum value of 0.221. When the results are divided into a histogram according to the results, we can observe that the highest number (7 public colleges) was in the range of efficiency values from 0.707 to 0.77, the second largest group (4 public colleges) in the range of efficiency from 0.58 to 0.64 and 3 public colleges in the range of efficiency from 0.65 to 0.706. We report this distribution in Graph 2.



Graph 2. Histogram of the distribution of the relative frequency of the investigated units according to the average efficiency value in all models
Source: Ministry of Education, own compilation

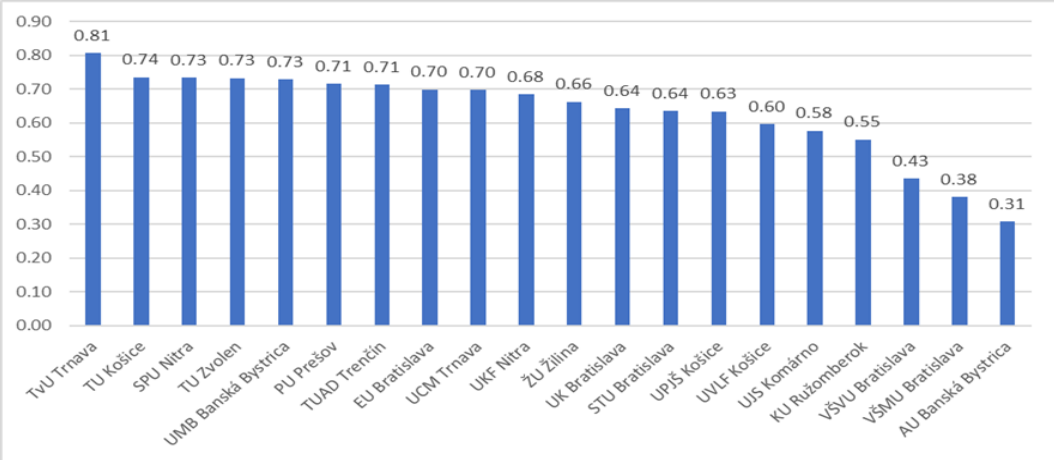
Based on the efficiency results obtained from the individual analyses of the indicators of interest through DEA analysis with constant returns to scale focusing on outcomes, our model was constructed based on the individual sub-results for the study areas. Verification and testing of the performed analyses confirmed that this procedure is sound and the results are easy to interpret. The original model, which was built on the weighted average of the efficiency results in economic, pedagogical and scientific research activities, has been modified based on the findings, and for the pedagogical and scientific research activities, the resulting efficiency values in the individual models 1 to 8, which fully cover these two areas, will be used for the evaluation of efficiency. At the same time, possible subjectivity in determining the value of weight 2 of this domain has been eliminated. The results of the individual efficiencies in the models as well as for the economic domain (efficiency of the main economic activity, efficiency of the business activity) are presented in Table 2.

Table 2. Resulting efficiency values for all areas analysed

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Main activity	Business activity
UK Bratislava	0.62	0.45	0.49	0.61	0.81	0.68	0.62	0.66	0.82	0.66
UPJŠ Košice	0.57	0.4	0.48	0.53	0.88	0.73	0.73	0.74	0.82	0.46
PU Prešov	0.76	0.9	0.81	0.84	0.85	0.68	0.66	0.40	0.79	0.45
UCM Trnava	0.61	0.9	0.99	0.79	0.79	0.52	0.62	0.43	0.81	0.51
UVLF Košice	0.5	0.29	0.39	0.52	0.59	0.77	1.00	0.63	0.79	0.48
UKF Nitra	0.8	0.86	0.73	0.72	0.89	0.62	0.58	0.35	0.81	0.48
UMB Banská Bystrica	0.75	0.84	0.76	0.69	0.84	0.79	0.92	0.39	0.8	0.51
TvU Trnava	0.67	1	1	1	0.96	0.82	0.64	0.51	0.86	0.62
STU Bratislava	0.71	0.47	0.44	0.46	0.57	0.78	0.65	0.96	0.78	0.54
TU Košice	0.72	0.62	0.58	0.64	1.00	0.85	0.84	0.81	0.82	0.47
ŽU Žilina	0.71	0.63	0.59	0.61	0.68	0.75	0.66	0.73	0.8	0.47
TUAD Trenčín	0.67	0.88	0.88	0.57	0.92	0.56	0.84	0.34	1	0.46
EU Bratislava	0.79	0.98	0.83	0.89	0.58	0.56	0.79	0.30	0.81	0.45
SPU Nitra	1	0.83	0.56	0.69	0.95	0.75	0.64	0.63	0.79	0.51
TU Zvolen	0.84	0.54	0.43	0.48	0.93	1.00	0.80	1.00	0.8	0.5
VŠMU Bratislava	0.83	0.33	0.26	0.2	0.07	0.14	0.07	0.05	0.86	1
VŠVU Bratislava	0.74	0.31	0.28	0.23	0.12	0.32	0.44	0.15	0.81	0.95
AU Banská Bystrica	0.9	0.33	0.25	0.2	0.09	0.00	0.00	0.00	0.81	0.51
KU Ružomberok	0.77	0.76	0.66	0.51	0.52	0.37	0.37	0.09	0.81	0.65
UJS Komárno	0.58	0.72	0.83	0.74	1.00	0.21	0.22	0.07	0.79	0.61

Source: Ministry of Education, own compilation

Based on the results, we find that no public college was rated as an efficient unit in all models. TvU in Trnava was identified as effective in 3 models with a value of 1, this was the case for 2 models focused on the pedagogical area and in one case for the area of total publication activity. TU in Zvolen was identified as an effective unit in 2 models and this was in the area of project activities. 5 public universities were identified in one of the models as an effective unit (UVLF in Košice, TU in Košice, TuAD in Trenčín, SPU in Nitra and VŠMU in Bratislava). This is not to conclude that the remaining 13 public universities are not efficient; these schools have lower efficiency rates than the reference units. It is by increasing the assessed indicators as mentioned in the previous section that the lower efficiency rate can be eliminated. The resulting ranking of public universities by average efficiency value is presented in Graph 3.



Graph 3. Resulting ranking of public universities according to the efficiency of the analysed areas
Source: Ministry of Education, own compilation

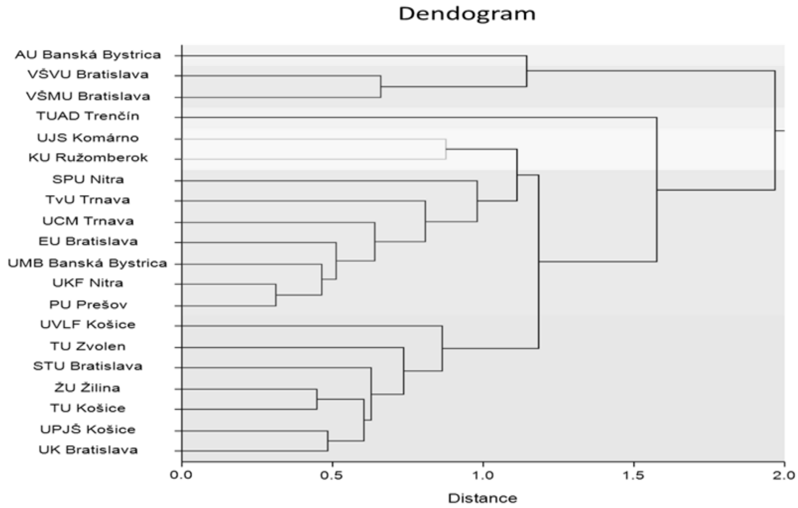
Here again, the minimal difference in efficiency values between public universities is evident, and in some cases the rankings are determined by thousandths of an efficiency value. For this reason, we consider it appropriate to recalculate the above values in such a way that TvU in Trnava represents an efficient unit and is the reference for all other public universities, therefore we will express to what percentage these schools are less efficient from the point of view of the reference unit. Also in the case of this recalculation, we find that most public universities have reached a high value of efficiency to the reference unit. We report this recalculation with the rankings in Table 3.

Table 3. Final ranking of public universities

Rank	University	Efektívnosť (%)
1	TvU Trnava	100.00
2	TU Košice	91.08
3	SPU Nitra	90.94
4	TU Zvolen	90.72
5	UMB Banská Bystrica	90.32
6	PU Prešov	88.58
7	TUAD Trenčín	88.26
8	EU Bratislava	86.58
9	UCM Trnava	86.35
10	UKF Nitra	84.86
11	ŽU Žilina	82.08
12	UK Bratislava	79.60
13	STU Bratislava	78.76
14	UPJŠ Košice	78.55
15	UVLF Košice	73.81
16	UJS Komárno	71.49
17	KU Ružomberok	68.24
18	VŠVU Bratislava	53.83
19	VŠMU Bratislava	47.16
20	AU Banská Bystrica	38.31

Source: *Ministry of Education, own compilation*

In the final evaluation, the mean efficiency against the reference unit was 78.47% and the median was 83.47%. 14 public universities scored above the average, and the same number scored above the median efficiency score. In the case of evaluation of all models and efficiency scores in them, 4 groups of public universities were identified through cluster analysis. Based on the resulting values, AU in Banská Bystrica and TUAD in Trenčín were not included in any group in the first stage. In the case of AU in Banská Bystrica, it is possible to observe its assignment to the group of the remaining two art public universities. The result of the cluster analysis is shown in Graph 4.



Graph 4. Dendogram of public universities based on efficiency in all DEA models
Source: Ministry of Education, own compilation

As we can see from the dendogram, two groups of 7 public universities are formed, which also corresponds to the results of the evaluation and the results of the previous analysis in Chapter 3. For the sake of illustration, we just point out that Group 1 is formed by the University of Bratislava, UPJŠ in Košice, UVLF in Košice, STU in Bratislava, TU in Košice, ŽU in Žilina and TU in Zvolen. The composition of this group is made up of public universities that have been established in the Slovak Republic for a long time and have above-average absolute values in the monitored indicators compared to smaller and younger schools. Also on the basis of this cluster analysis, we conclude that the model established in this way is suitable for assessing the efficiency of public universities in the conditions of the Slovak Republic as well as in other countries.

Conclusion

Based on the analyses conducted, we conclude that the use of DEA analysis in the case of public university evaluation is an appropriate method, especially in the case of a small number of units under study. It is very important to use the right indicators when evaluating efficiency. Despite the possibility of comparing different units of measurement, it is necessary to observe the interdependence of inputs and outputs. Use models with fewer inputs and outputs, as the number of identified efficient units increases with a large number of inputs. In validating our evaluation model, we found that 50 percent of public universities had an efficiency coefficient equal to 1 when evaluated by aggregating all observed indicators for education and research. With the inputs and outputs set in this way, we verified the efficiency assessment for 2020. The mean efficiency value in this DEA CCR analysis was 93.81%, the median was 97.57% and the modus was 100%. We therefore recommend an assessment based on fewer indicators. The efficiency values thus obtained should then be converted into an aggregated indicator value.

By DEA analysis, individual public universities can identify the need to minimize input indicators for input-oriented models. We did not use this model in our work, as we based our analysis on the development of the number of employees of public universities, their qualification structure and the needs of public universities to ensure quality educational and scientific research activities. In the case of such oriented models, where the number of academic staff is on the input side, the recommendations for staff reduction would be incorrect and the target values would only be of a theoretical nature. In our models, in some cases a staff reduction of more than 50% would be indicated, which would be devastating for the school. Therefore, we have focused on output-oriented analysis in our models and the recommended target values are presented in the paper.

In terms of the practical application of these models, there is an opportunity for individual universities to apply the model at the level of their faculties and to monitor mutual efficiency and identify weaknesses in their faculties in given areas. Moreover, in the case of faculty-level evaluation, public colleges can also specify other indicators such as those used in our model.

Views on measuring effectiveness vary in the professional and scientific community and it is not possible to clearly identify ways of measuring effectiveness, as well as to identify appropriate measurable indicators. A typical example is the indicator of the number of students, which is considered by some authors as an input and by some as an output. In our model, we solved this problem with model 1 and 2, where we used students as input and output, respectively. In the case of output, we consider this indicator as a qualitative one, since it gives us the efficiency in terms of the number of students per employee in the DAE analysis. But we do not consider the student as an output of the transformation process of a public university, the output is the graduate.

In the case of regular evaluation of the efficiency of public universities, it would be advisable for the Ministry of Education to establish precise definition of the models for evaluating the required areas. The indicators to be used for this evaluation should be clearly defined for the areas of education, scientific research (possibly dividing this area into project and publication activities) and, last but not least, the economic area. As the indicators chosen in the model have a significant impact on the resulting efficiency value. If other indicators were used in a given area, the result would be different and could lead to subjective adjustments of the models.

We have built a model through which the efficiency of public universities can be objectively measured and evaluated. The findings of the sub-models can be the basis for setting short-term, as well as long-term goals by the management of universities for the next period. The aim of this study was to build on the basis of existing research and currently available data to create a model that eliminates ambiguous indicators and is general in nature. It evaluates both qualitative and quantitative indicators that cannot be questioned from a professional point of view. Model also gives the possibility to modify inputs or outputs according to the needs of the institutions.

References

Abbott, M., & Doucouliagos, C. (2003). The efficiency of Australian universities: a data envelopment analysis. In: *Economics of Education Review*, 22(1), 89–97.

Abramo, G., & D'angelo, C. A. (2009). Assessing technical and cost efficiency of research activities: a case study of the Italian university system. In: *Research Evaluation*, 18(1), 61-70.

Agasisti, T., & Dal Bianco, A. (2009). Reforming the university sector: effects on teaching efficiency-evidence from Italy. In: *Higher Education*, 57(4), 477-498

Agasisti, T., & Johnes, G. (2009). Beyond frontiers: Comparing the efficiency of higher education decision-making units across more than one country. In: *Education Economics*, 17, 59–79. https://doi.org/10.1080/09645290701523291

Archibald, R. B., & Feldman, D. H. (2008). Graduation rates and accountability: Regressions versus production frontiers. In: *Research in Higher Education*, 49(1), 80-100.

Chen, X, & Shu, X. (2021). The Scientific and Technological Innovation Performance of Chinese World-Class Universities and its Influencing Factors. In *IEEE Access*, 9, 84639-84650, 2021, https://doi.org/10.1109/ACCESS.2021.3087659

Cretan, G. C. (2015). Impact of Romanian higher education funding policy on university efficiency. In: *Annals of the University of Oradea: Economic Science*, 25(1), 724-732

Dlouhý, M., Jablonský, J. & Zýková, P. (2018). *Analýza obalu dat*. Praha: Professional Publishing.

Erkoc, T.E., & Acar, M.F. (2018). Comparative research on the efficiencies of universities and the impact of ownership. In: *Journal of Economics and Economic Education Research*, 19(2), 1-14.

Farrell, M.J. (1957). The Measurement of Productive Efficiency. In: *Journal of the Royal Statistical Society, Series A*, 120(3), 253 – 290.

Ginevičius, R., Žemaitis, E., & Petraškevičius, V. (2022). Evaluation of the Impact of R&D on the Socio-Economic Development of EU Countries. *Amfiteatru Economic*, 24(16), 1001-1013. DOI: 10.24818/EA/2022/S16/1001

Grausová, M., Hužvár, M., & Rigová, Z. (2017). Efficiency Assessment of Slovakian Universities. In: *Proceedings of Conference: Applications of Mathematics and Statistics in Economics*. International Scientific Conference: Szklarska Poręba. https://doi.org/10.15611/amse.2017.20.15.

Grmanová, E. (2015). Efficiency of National Life Insurance Markets in Europe. In: European Financial Systems 2015. In: *Proceedings of the 12th International Scientific Conference*, Brno: Masaryk University, 2015, 151-157.

Gromov, A.D. (2017). The Efficiency of Russian Higher Education Institution and its Determinants. *HSE Working papers WP BRP 40/EDU/2017*, National Research University, Higher School of Economics.

Hock-eam, L., Taib, F.M., Abdullah, N.A.H., & Hwa, Y.S. (2016). How Efficient Are Malaysian Public Universities? A Comparative Analysis Using Data Envelopment Analysis. In: *Asian Academy of Management Journal*. 2016, 21(2), 75-97.

Jeck, T., & Sudzina, F. (2009). Relatívna efektívnosť producentov znalostí na Slovensku v regionálnom kontexte. In: *Trendy regionálnych disparít Slovenska*. Bratislava: Ekonomický ústav SAV. 105 - 118.

Kao, C., & Pao, H. L. (2009). An evaluation of research performance in management of 168 Taiwan universities. In: *Scientometrics*, 78(2), 261-277.

Klumpp, M. (2018). The Index Number Problem with DEA: Insights from European University Efficiency Data, In: *Education Sciences*, 2018. 8(2), 79.

Kulshreshtha, P., & Nayak, T. K. (2015). Efficiency of Higher Technical Educational Institutions in India. In: *Archives of Business Research*, 3(1), 94-122.

Leibenstein, H. (1966). Allocative Efficiency vs. "X-Efficiency." In: *The American Economic Review*, 56(3), 392–415. http://www.jstor.org/stable/1823775

Loganthan, M., Subrahmanya, MHB. (2022). Efficiency of Entrepreneurial Universities in India: A Data Envelopment Analysis. In: *Journal of the Knowledge Economy*. https://doi.org/10.1007/s13132-022-00897-z

Masárová, J., Koišová, E., & Habánik, J. (2022). Assessment of the evolution of the educational attainment in economically active population in the regions of the Slovak Republic. *Economics and Sociology, 15*(3), 172-185. https://doi.org/10.14254/2071-789X.2022/15-3/10

McMillan, M. L., & Datta, D. (1998). The relative efficiencies of Canadian universities: a DEA perspective. In: *Canadian Public Policy-Analyse De Politiques*, 24(4), 485-511

Mikušová, P. (2015). An Application of DEA Methodology in Efficiency Measurement of the Czech Public Universities. *Procedia Economics and Finance* 25, 569-578. 16th Annual Conference on Finance and Accounting, ACFA Prague

Nazarko, J., & Šaparauskas, J. (2014). Application of DEA method in efficiency evaluation of public higher education institution. In: T*echnological and Economic Development of Economy*. https://doi.org/10.3846/20294913.2014.837116

Oliinyk, O., Bilan, Y., & Mishchuk, H. (2021). Knowledge Management and Economic Growth: The Assessment of Links and Determinants of Regulation. *Central European Management Journal*, *29*(3), 20-39. https://doi.org/10.7206/cemj.2658-0845.52

Polouček, S. et al. (2006). *Bankovnictví*. 1. Praha, C. H. Beck, ISBN 80-7179-462- 7

Thursby, J. G., & Kemp, S. (2002). Growth and productive efficiency of university intellectual property licensing. In: *Research Policy*, 31(1), 109-124

Türkan, S., & Özel, G. (2017). Efficiency of State Universities in Turkey During the 2014-2015 Academic Year and Determination of Factors Affecting Efficiency. In: *Egitim ve Bilim*. 42, 191.

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 twostage semi-parametric DEA. In: *Research Policy*, 46, 1595–1605. Doi: 10.1016/j.respol.2017.07.010.

Worthington, A. (2001). An Empirical Survey of Frontier Efficiency Measurement Techniques in Education. In: *Education Economics*. 9, 245–268. doi:10.1080/09645290110086126.

Zarrin, M. (2023). A mixed-integer slacks-based measure data envelopment analysis for efficiency measuring of German university hospitals. In: *Health Care Management Science*. 26(1), 138-160. https://doi.org/10.1007/s10729-022-09620-5

Zhao, HH., Liu, Y., Li, J., Guo, XG., Gui, Hj. (2022) Chinese Provincial Difference in the Efficiency of Universities' Scientific and Technological Activities Based on DEA with Shared Input. In: *Mathematical Problems in Engineering*. 2022, https://doi.org/10.1155/2022/8319498

Zuluaga-Ortiz, R., DelaHoz-Dominguez, E., & Camelo-Guarín, A. (2022). Academic efficiency of engineering university degrees and its driving factors. A PLS-DEA approach. *Journal of International Studies, 15*(2), 107-121. https://doi.org/10.14254/2071-8330.2022/15-2/8

Internet sources

MŠVVaŠ SR (2018). Metodika rozpisu dotácií zo štátneho rozpočtu verejným vysokým školám na rok 2018. Available at: https://www.minedu.sk/data/att/12765.pdf

MŠVVaŠ SR (2019). Metodika rozpisu dotácií zo štátneho rozpočtu verejným vysokým školám na rok 2019. Available at: https://www.minedu.sk/data/att/14159.pdf

MŠVVaŠ SR (2020). Metodika rozpisu dotácií zo štátneho rozpočtu verejným vysokým školám na rok 2020. Available at: https://www.minedu.sk/data/att/15779.docx

MŠVVaŠ SR (2021). Metodika rozpisu dotácií zo štátneho rozpočtu verejným vysokým školám na rok 2021. Available at: https://www.minedu.sk/data/att/18518.docx

MŠVVaŠ SR (2018). Výročná správa o stave vysokého školstva za rok 2017. Available at: https://www.minedu.sk/data/att/13721.zip

MŠVVaŠ SR (2019). Výročná správa o stave vysokého školstva za rok 2018. Available at: https://www.minedu.sk/data/att/15381.zip

MŠVVaŠ SR (2020). Výročná správa o stave vysokého školstva za rok 2019. Available at: https://www.minedu.sk/data/att/17747.zip

MŠVVaŠ SR (2021). Výročná správa o stave vysokého školstva za rok 2020. Available at: https://www.minedu.sk/data/att/22196.zip