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DEA MODEL AND EFFICIENCY OF UNIVERSITIES – CASE STUDY IN SLOVAK REPUBLIC*

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Abstract. Measuring the efficiency of organizations relates not only to economic parameters but also to non-economic ones at present, for example in organizations providing education. However, in the case of educational institutions in the form of public universities, we cannot consider profit as the main goal, but the quality of education. We do not find a lot of work on this issue in domestic and foreign literature from the point of view of universities. Universities report only data that are set by current legislation, and for this reason, measuring efficiency is a relatively challenging matter with ambiguous quantification. Measuring the efficiency of an educational institution cannot be carried out as unambiguously as in the case of companies whose mission is to produce products and services for the purpose of selling them. The aim of the presented study is to clarify the optimal way of evaluating and measuring the efficiency of higher education institutions through DEA analysis. To achieve this goal, we used the methods of descriptive statistics, mathematical-statistical calculations, DEA analysis of indicators and the method of comparison, induction, deduction and synthesis. The result is a model that will allow the comparison and evaluation of universities.

Keywords: education; efficiency of universities; performance of universities; DEA model

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1. Introduction

According to Jablonský and Dlouhy (2004), economic theory defines efficiency as a state where it is not possible to produce one unit more for a given resource without the need to limit the production of another good. Tumpach (2008) considers efficiency to be one of the key criteria for evaluating the company's results, it expresses the extent to which the set goals are being met and the conditions are being created for their fulfillment in the future.

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According to Lisý (2007), an economy, company or production unit is efficient if it operates at the limit of production possibilities. Heyne (1991) understands efficiency as the virtue that is most valued among economists. He and other authors understand the term efficiency as the ratio of specific inputs and outputs of the observed transformation process. What we can identify with in the case of evaluating the non-economic efficiency of the educational institution, in this case the added value is the achieved education of the individual.

The authors focused mainly on measuring financial indicators in measuring and evaluating efficiency in the previous period. In accordance with the development of modern methods of efficiency evaluation, methods such as Balance score card, Corporate Performance management, DEA models, or others are beginning to be used. In our study, we focused on evaluation through the DEA model, which was originally developed to measure the efficiency of non-profit organizations such as schools, hospitals, government and public administration. Later, its use was extended to various enterprises, services, the banking sector, as well as to measuring the performance of national economies. As stated by Malega and Bialková (2011), the level of efficiency expresses the quantitative and qualitative degree of compliance of the objectives (determined on the basis of knowledge and use of objective socio-economic laws) and the means needed to meet them.

2. Theoretical background

Figure 1 shows the conversion of inputs to outputs. If we want to measure efficiency, it is necessary to correctly identify and quantify inputs and outputs. Inputs are considered to be factors of production that were invested or consumed in the enterprise. In our case, we considered pedagogical, researchers and students to be inputs.

Outputs represent performances created over a period of time, in the first place it should be successful graduates whose institution has educated, but we also considered the outputs to be the number of implemented scientific projects, the number of publications. Another factor in terms of outputs is the success of graduates in the labour market.

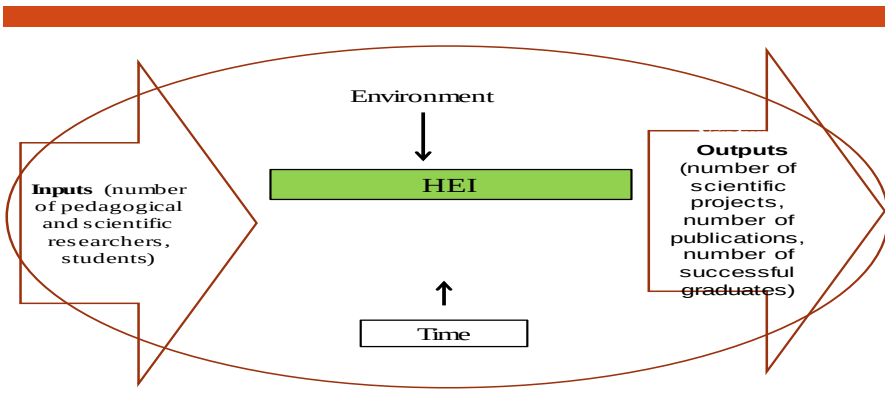

Figure 1. Transformation process of inputs to outputs in educational institutions
Source: Own processing

It is necessary to distinguish the concept of performance from the concept of efficiency. According to Wagner (2009, p.12), performance is defined as "a characteristic that describes the manner or course in which an object performs an activity, based on similarity to the reference method of performing that activity. Interpretation of this characteristic presupposes the ability to compare the investigated and the reference phenomenon in terms of a set range of criteria." According to Fibírová and Šoljaková (2005), the term performance is used in connection with the definition of the very essence of the company's existence in the market environment, its success and ability to survive in the future. Sedláček, Suchánek and Špalek (2012) add that this concept is associated with performance,

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ie with the realized output of the company and performance can be relatively easily quantified and then further analyzed. Šulák, Vacík (2003) define performance as the ability of a company to make the best use of the funds invested in business activities. And it may not be the case that a high-performing company must have good economic results. It is necessary to realize that the performance of an organization is evaluated by different entities from different perspectives. These entities can be internal or external.

One of the methods of measuring efficiency are DEA models, which belong to the non-parametric methods of efficiency evaluation. Their application is possible in different areas, because they also make it possible to compare the efficiency of non-profit-oriented entities, such as the efficiency of primary schools, the efficiency of hospital facilities and the like. The DEA method has been used to evaluate the relative efficiency of higher education published in a number of scientific studies. The first mention of this issue was in an article from 1992 by Johnes. Some articles focused on the teaching and production of students (Archibald, Feldman, 2008; Agasisti, Dal Bianco, 2009), others on publishing activities (Abramo, D'Angelo, 2009), or for research the output of which is patents (Thursby, Kemp, 2002). Other authors have focused on faculties or universities (McMillan, Datta 1998; Abbott, Doucouliagos 2003; Kao, Pao 2009). The validity of the use of DEA as an assessment tool has been addressed by Bougnol and Dula (2006) (Jeck, T., Sudzina, F., 2009).

3. Research objective and methodology

The aim of study was to clarify the optimal methods of evaluating and measuring the efficiency of higher education institutions through DEA analysis.Measuring the efficiency of education is a very complicated problem, as the output of education is taken away by the individual as his social competence, for this reason it is relatively difficult to measure. For the needs of our study, we decided to use the DEA model, which we used to assess the level of efficiency of education in the period under review, taking as inputs the total number of pedagogical, research staff and the number of students enrolled in a given year. We chose the number of successful graduates, the number of solved scientific projects, the total number of publications, the number of publications in peer-reviewed journals, based on valid quality standards for universities in the Slovak Republic. Models can be input or output oriented. In input-oriented models, DMUs (HEIs) have an efficiency rate of less than or equal to one. The degree of efficiency of an inefficient DMU in an input-oriented model expresses how much inputs need to be reduced in order for a DMU to become effective. The lower the DMU value from 1, the further away the DMU is from the data envelopment.

We determined the basic statistical characteristics of the data set before analyzing the data. Quantitative methods of descriptive statistics include procedures for determining the parameters of a set. The basic characteristics of the position are the arithmetic mean and the median. The methods of descriptive statistics will be applied to selected indicators characterizing the inputs and outputs of public universities. We analyzed 20 public universities based on available data. The analysis was focused on individual indicators that are necessary in the transformation process of the university environment.

4. Results and discussion

The first monitored indicator is the number of all pedagogical and research employees in the Slovak Republic. This indicator includes the numbers of professors, associate professors, assistant professors, assistants, lecturers and researchers. The number in each year is given in Table 1.

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Table 1. The total number of pedagogical and research employees in the Slovak Republic in the years 2011-2019

	2011	2012	2013	2014	2015	2016	2017	2018	2019
UK Bratislava	2 379,9	2 364,4	2 398,0	2 437,0	2 442,2	2 413,0	2 439,6	2 474,0	2 511,1
UPJŠ Košice	707,1	711,7	729,4	766,9	775,1	776,9	783,3	796,5	810,3
PU Prešov	562,9	586,0	550,3	547,7	554,9	553,6	559,1	561,2	569,0
UCM Trnava	290,3	327,3	317,0	342,3	330,9	308,9	307,5	295,9	308,3
UVLF Košice	201,0	208,1	222,8	234,6	243,0	251,0	253,5	253,0	256,4
UKF Nitra	566,5	552,0	559,0	575,5	557,8	541,3	539,8	519,4	519,2
UMB Banská Bystrica	630,8	622,3	623,9	608,7	576,9	551,1	530,9	517,7	497,4
TvU Trnava	325,4	324,5	322,0	325,6	317,1	309,4	300,3	296,6	283,3
STU Bratislava	1 457,3	1 459,0	1 470,6	1 457,8	1 409,5	1 368,4	1 328,2	1 323,9	1 302,0
TU Košice	969,9	979,0	973,0	960,7	951,1	902,9	885,6	880,4	885,3
ŽU Žilina	809,5	808,0	802,9	825,4	816,9	768,3	746,5	740,6	728,5
TUAD Trenčín	195,0	184,0	183,5	186,9	173,2	149,1	139,2	138,9	141,6
EU Bratislava	655,0	653,3	659,6	620,1	596,1	557,8	523,9	510,1	495,3
SPU Nitra	550,3	537,4	514,1	514,5	523,9	527,1	526,3	518,1	516,8
TU Zvolen	325,4	321,4	321,2	306,7	299,0	302,6	290,2	280,6	273,5
VŠMU Bratislava	195,8	197,9	198,5	202,2	197,0	189,6	191,8	198,2	202,3
VŠVU Bratislava	122,9	122,6	123,8	126,2	127,6	129,6	120,4	120,4	123,3
AU Banská Bystrica	103,2	104,6	105,7	112,1	114,0	112,3	116,7	117,3	120,7
KU Ružomberok	386,4	390,8	384,2	393,4	387,5	355,6	334,6	312,4	298,6
UJS Komárno	85,7	92,6	96,7	97,7	103,5	107,2	113,8	115,6	120,1
SPOLU SR	**13 531,3**	**13 558,9**	**13 569,2**	**13 656,0**	**13 512,2**	**13 191,7**	**13 048,2**	**12 988,8**	**12 982,0**

Source: The Ministry of Education, Science, Research and Sport of the Slovak Republic

Based on Table 1, it is possible to observe a slight decrease in the total number of employees since 2015. In absolute terms, this decrease represents 549.3 employees, while the percentage decrease in 2019 is 4.05% compared to 2011. We consider it necessary to note that in absolute terms In some numbers, some employees are counted multiple times because they could work part-time at several universities in the Slovak Republic. In Slovakia, was recorded in 2019 compared to 2011 in the category professors decrease of 0.55%, while associate professors when we recorded an increase of 14.92%. The increase in the number of associate professors was caused by the professional growth of the assistant professor category. It is clear from the above table that despite a slight decrease in professors as well as the total number of teaching and research staff, the qualification structure of employees at public universities did not change significantly in the period under review, on the contrary, there was an improvement in the number of associate professors. To confirm this conclusion, we recalculated the number of employees through the index as a share of the weighted sum in the total number of teaching staff, and the weights were assigned as follows: professor - 3, associate professor - 2, assistant professor and researcher - 1, lecturer and assistant 0. By determining these weights we tried to approximate the IKA coefficient, which was used in evaluating the quality of universities in the system of comprehensive accreditation. In determining, we proceeded from the assumption that lecturers and assistants have not completed the third level of higher education. The development of this indicator is shown in Figure 2.

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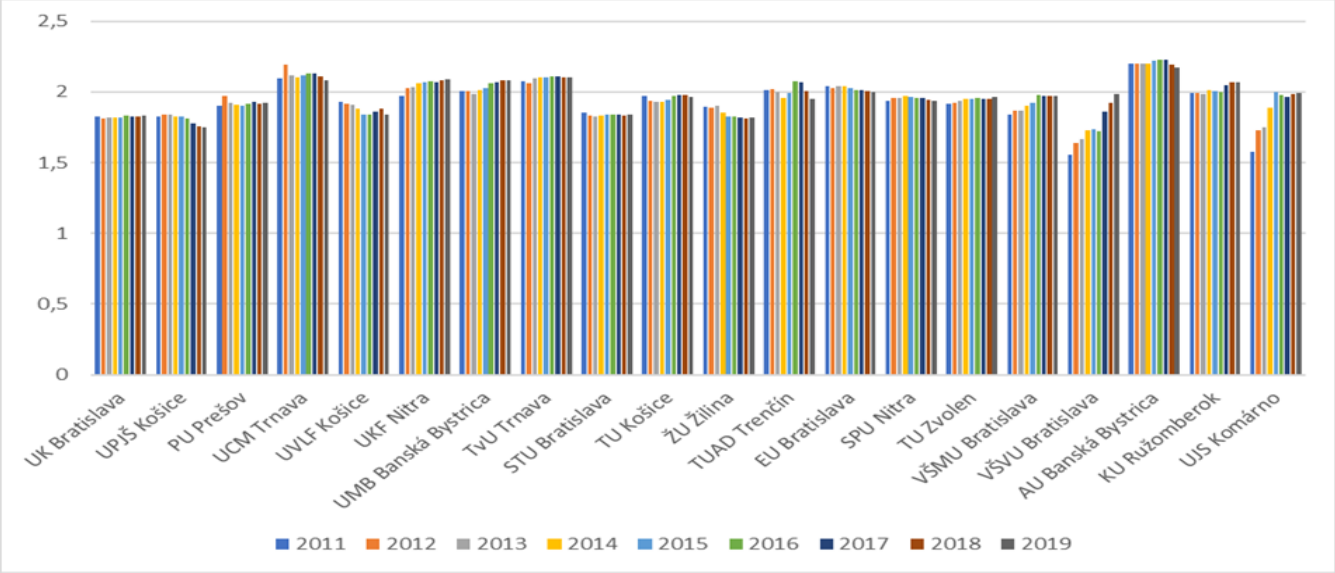

Figure 2. Development of the quality of the qualification structure of employees (IKA index)
Source: The Ministry of Education, Science, Research and Sport of the Slovak Republic, own calculations

In the case of 11 public universities, the growing trend in the quality of the structure of pedagogical and scientific researchers was confirmed to us.

Another monitored indicator on the input side, which we will use to evaluate the efficiency of the university is the number of students. We monitor the total number of university students in all levels and forms of higher education. This indicator recorded the most significant change compared to the beginning and end of the period under review. The demographic development of weak population grades, the possibility of studying abroad, caused a significant drop in the number of students at all public universities. The decrease in the number of students at all public schools in 2019 compared to 2011 was by 33.31%. In 2011, a total of 172,993 students studied, in 2019 it was 115,366 students. The development of the number of students and graduates of public universities is shown in Figure 3.

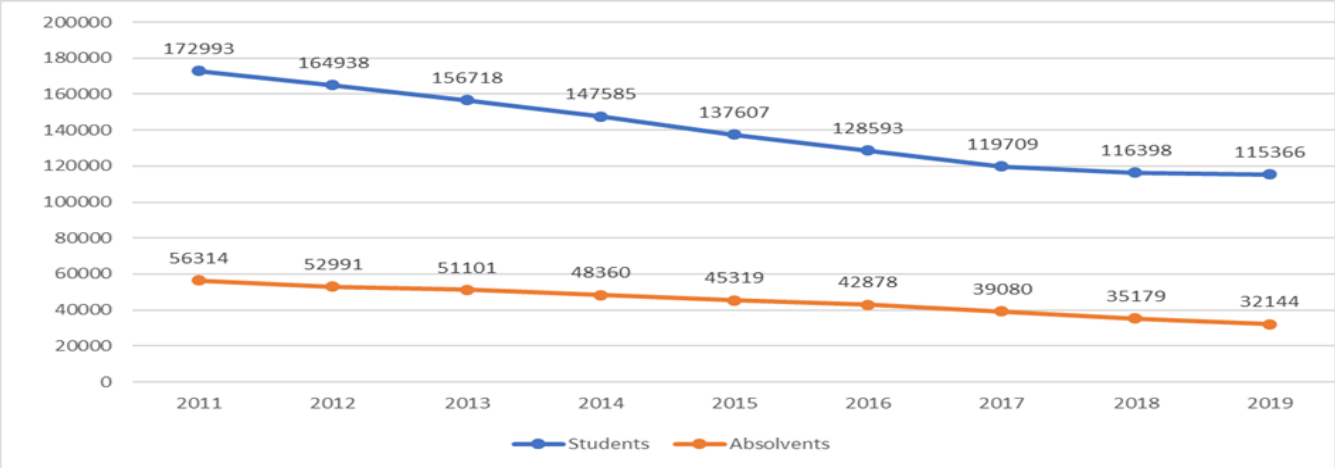

Figure 3. The development of the number of students and graduates of public universities in Slovak republic (2011-2019)
Source: The Ministry of Education, Science, Research and Sport of the Slovak Republic

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An important indicator of quality in education is the number of students per teaching staff. The above findings show that if the number of students decreased, while the decrease in the number of teaching staff was not so significant, then this indicator records a positive development trend at public universities in the Slovak Republic. The average number of students at a public university per one pedagogical employee is shown in Figure 4. We can observe the decline during the entire researched period. In 2019, we record a slight increase to 12.2 students per employee. This increase is due to an increase in the number of students in 2019 compared to 2018. Based on demographic developments, it can be expected that this growth will continue in the future.

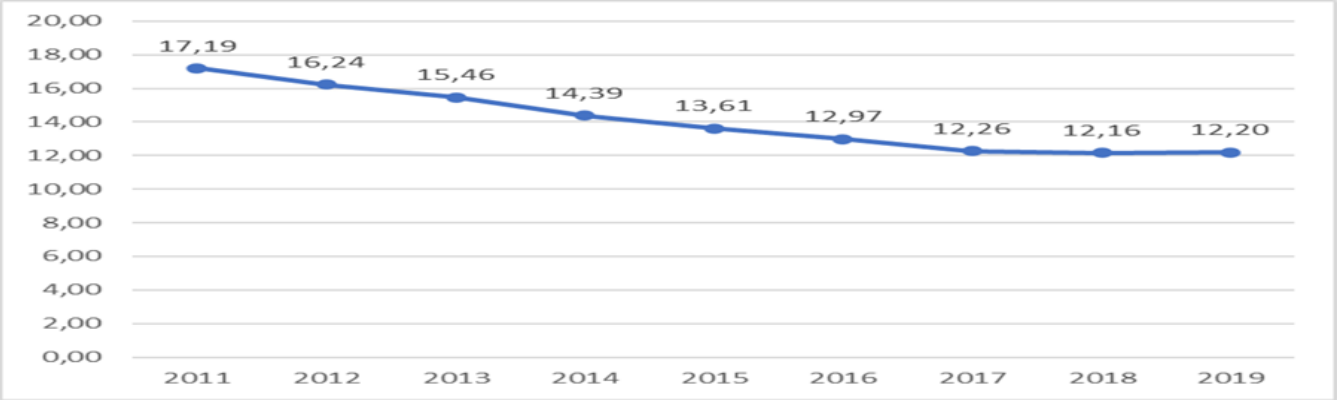

Figure 4. The average number of students at a public university per one pedagogical employee in Slovak republic (2011 – 2019).
Source: The Ministry of Education, Science, Research and Sport of the Slovak Republic

Based on the development of the number of students and graduates of public universities, we compiled a graph in which a polynomial development trend is added, which confirms the declining trend in the following period of five. The reliability of this statement is given by the value of R2, which in the case of students and graduates reaches almost 100 percent reliability, in the case of the development of the number of students it is at the level of 0.990 and in the number of graduates it is 0.998.

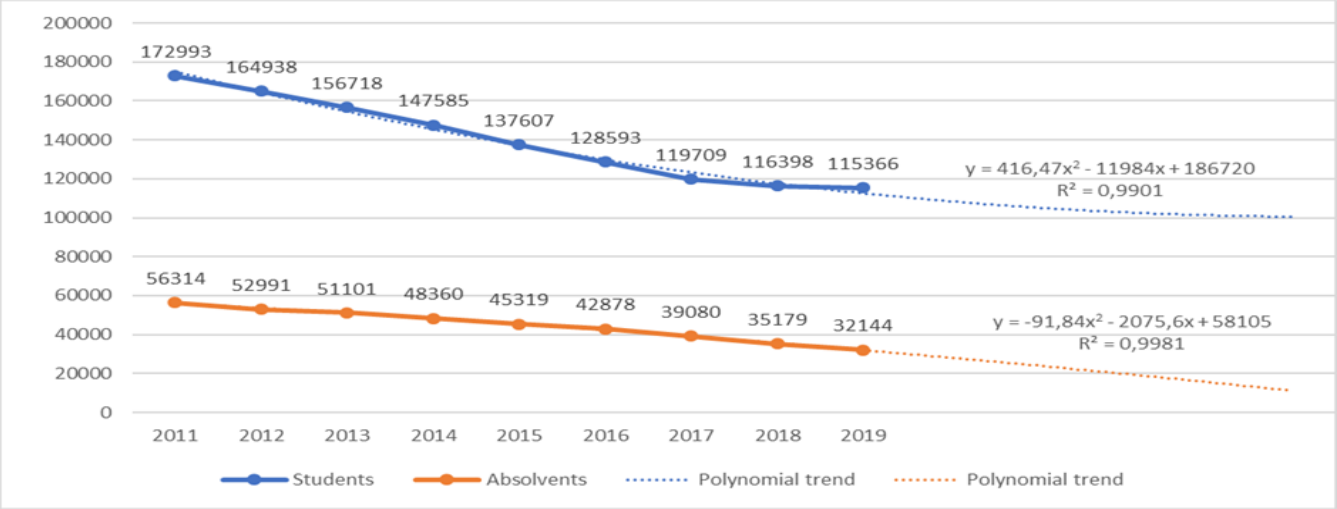

Figure 5. Polynomial trend in the number of students and graduates of public universities and its prediction for the next 5 years.
Source: The Ministry of Education, Science, Research and Sport of the Slovak Republic, own calculations

Scientific research projects are one of the main activities for any university, which is one of the important sources of funding for the operation of the university. Within the Slovak Republic, universities have the opportunity to participate mainly in research projects VEGA, KEGA and APPV. Universities are solvers of scientific research

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projects at the international level within the framework of operational programs announced in the European Union, projects resulting from bilateral agreements between states, resp. their groupings such projects Visegrad Fund. We focused on projects of a scientific nature, which are provided within the Slovak Republic through the agencies of the Ministry of Education. Project activity is one of the main indicators of the efficiency of the university on the output side for the needs of our study. The following table shows the share of employees in solved projects in individual years at public universities in the Slovak Republic.

Table 2. Share of projects per pedagogical and scientific researchers (2011-2019)

	2011	2012	2013	2014	2015	2016	2017	2018	2019
UK Bratislava	0,21	0,18	0,23	0,22	0,20	0,21	0,23	0,22	0,22
UPJŠ Košice	0,20	0,20	0,22	0,19	0,16	0,19	0,23	0,23	0,23
PU Prešov	0,18	0,15	0,21	0,21	0,18	0,20	0,23	0,23	0,24
UCM Trnava	0,04	0,03	0,07	0,06	0,07	0,07	0,08	0,13	0,14
UVLF Košice	0,37	0,35	0,39	0,29	0,25	0,25	0,27	0,22	0,21
UKF Nitra	0,15	0,14	0,18	0,15	0,15	0,16	0,17	0,19	0,20
UMB Banská Bystrica	0,14	0,12	0,14	0,13	0,13	0,18	0,21	0,24	0,25
TvU Trnava	0,19	0,15	0,18	0,18	0,20	0,20	0,21	0,24	0,26
STU Bratislava	0,22	0,18	0,23	0,21	0,20	0,20	0,23	0,23	0,25
TU Košice	0,21	0,16	0,21	0,20	0,20	0,23	0,24	0,25	0,27
ŽU Žilina	0,24	0,17	0,20	0,19	0,18	0,19	0,20	0,23	0,23
TUAD Trenčín	0,08	0,05	0,04	0,06	0,06	0,09	0,09	0,14	0,13
EU Bratislava	0,13	0,11	0,14	0,15	0,16	0,18	0,17	0,16	0,17
SPU Nitra	0,23	0,16	0,22	0,23	0,21	0,20	0,21	0,24	0,27
TU Zvolen	0,25	0,20	0,26	0,24	0,21	0,24	0,30	0,32	0,35
VŠMU Bratislava	0,05	0,03	0,04	0,03	0,03	0,05	0,07	0,07	0,06
VŠVU Bratislava	0,04	0,07	0,06	0,06	0,04	0,08	0,07	0,09	0,08
AU Banská Bystrica	0,07	0,02	0,04	0,03	0,04	0,03	0,02	0,01	0,00
KU Ružomberok	0,07	0,06	0,08	0,07	0,07	0,06	0,07	0,07	0,11
UJS Komárno	0,08	0,06	0,07	0,08	0,07	0,06	0,03	0,03	0,07
Priemer SR	**0,16**	**0,13**	**0,16**	**0,15**	**0,14**	**0,15**	**0,17**	**0,18**	**0,19**

Source: The Ministry of Education, Science, Research and Sport of the Slovak Republic, own calculations

The development of the number of projects per employee shows that the field of scientific research is stable at most universities. The trend is set by public universities, which have been operating on the Slovak education market for many years. The progress in the number of projects per employee is obvious in the case of UCM Trnava and TUAD Trenčín. Universities are marked in green, which in a given year reached a higher number than the average in the Slovak Republic. We stated amount of funds per employee in Table 3. These conversions do not take into account funds raised in international EU projects and so on.

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Table 3. Funds received from VEGA, KEGA, APVV projects per employee in the years 2011-2019

	2011	2012	2013	2014	2015	2016	2017	2018	2019
UK Bratislava	1758,67	2333,75	2659,57	2741,98	2741,86	2898,35	3567,30	3668,00	4093,91
UPJŠ Košice	2090,20	2534,02	2499,17	2554,01	2565,56	2599,72	3444,00	3987,16	4099,14
PU Prešov	941,99	1287,89	1587,91	1608,17	1696,11	1465,71	1911,74	2107,13	2621,75
UCM Trnava	250,01	361,25	675,68	832,69	660,93	673,65	1071,19	1591,74	2166,98
UVLF Košice	4380,35	5591,22	5643,07	3745,21	3460,28	3387,91	4066,21	3797,92	3546,40
UKF Nitra	811,96	921,79	946,72	956,24	934,69	1256,99	1643,74	1612,01	2038,24
UMB Banská Bystrica	610,90	769,19	859,09	922,45	1006,36	1232,28	1330,63	1544,72	2018,89
TvU Trnava	1052,64	1030,72	1220,23	1588,02	1962,18	2096,39	2506,73	3054,29	3132,52
STU Bratislava	2673,41	3102,51	3591,03	3667,65	3592,14	3735,78	4373,86	4925,43	5641,10
TU Košice	1937,96	2376,01	2556,67	2488,85	2790,31	3239,48	4155,74	4544,27	4780,95
ŽU Žilina	2632,86	2391,34	2375,56	2301,41	2614,12	2974,32	3420,08	3632,15	4025,64
TUAD Trenčín	503,17	475,91	588,09	625,64	781,51	600,91	921,96	1244,23	1513,90
EU Bratislava	555,71	781,49	743,59	843,72	885,74	1291,85	1687,10	1693,16	1584,88
SPU Nitra	1729,65	1453,96	1741,52	2211,05	2381,71	2353,98	3015,92	3538,88	3775,89
TU Zvolen	2330,94	2343,03	2447,13	2961,72	3314,74	3699,33	5119,74	5540,77	6569,81
VŠMU Bratislava	224,36	204,61	179,76	187,16	103,30	269,80	377,89	392,43	318,26
VŠVU Bratislava	219,99	866,84	472,30	607,82	534,19	613,95	652,67	938,07	821,44
AU Banská Bystrica	266,44	78,57	242,40	124,60	244,80	583,01	105,96	41,36	0,00
KU Ružomberok	226,29	267,38	307,73	295,26	277,39	75,23	236,68	294,80	458,10
UJS Komárno	287,18	433,30	216,48	212,85	203,18	156,80	139,26	139,10	302,56
Priemer SR	**1274,23**	**1480,24**	**1577,69**	**1573,83**	**1637,55**	**1760,27**	**2187,42**	**2414,38**	**2675,52**

Source: The Ministry of Education, Science, Research and Sport of the Slovak Republic, own calculations

The share of funds received per employee has a growing trend in the monitored period at all public universities in the Slovak Republic. The growing trend in the average value in Slovakia is caused mainly by the growth of funds from projects for faculties that have highly demanding material security (technology, healthcare), which is also confirmed by the values of this indicator. Low values at VŠMU Bratislava, VŠVU Bratislava and AU Banská Bystrica are given by their specific focus, although in the case of VŠVU it is possible to observe a growing trend. The next monitored output is an index expressing the ratio of the number of solved projects and the number of submitted projects. The development of this indicator is shown in Table 4.

Table 4. The ratio of the number of solved projects and the number of submitted projects

	2011	2012	2013	2014	2015	2016	2017	2018	2019
UK Bratislava	1,50	1,46	1,95	1,98	1,83	2,04	1,87	2,15	2,18
UPJŠ Košice	1,38	1,47	2,12	2,19	1,40	1,60	1,74	2,28	2,72
PU Prešov	0,99	0,90	1,10	1,16	1,00	1,01	1,07	1,39	1,58
UCM Trnava	0,57	0,61	0,78	0,47	0,81	0,79	0,72	1,23	1,40
UVLF Košice	1,36	1,41	2,53	2,09	1,09	1,62	1,73	1,51	1,35
UKF Nitra	0,87	0,89	1,09	1,14	0,90	0,92	0,92	1,04	1,59
UMB Banská Bystrica	0,98	1,09	0,99	0,88	0,85	1,02	1,29	1,32	1,35
TvU Trnava	1,03	1,07	1,20	1,46	1,35	1,48	1,51	1,85	2,34
STU Bratislava	1,60	1,19	1,82	2,10	1,76	1,77	2,00	2,25	2,79
TU Košice	1,13	1,07	1,47	1,38	1,18	1,45	1,52	1,51	2,07
ŽU Žilina	1,08	0,96	1,44	1,32	1,34	1,65	1,14	1,33	1,62
TUAD Trenčín	0,56	0,77	0,47	0,44	0,79	0,87	0,62	1,46	1,73
EU Bratislava	1,23	1,07	1,15	1,00	0,91	1,32	1,01	1,05	1,28
SPU Nitra	1,43	1,02	1,16	1,20	1,38	1,11	1,01	1,33	1,53
TU Zvolen	1,67	1,07	2,00	1,52	1,28	1,47	1,62	2,65	2,50
VŠMU Bratislava	1,13	0,38	1,75	2,33	0,63	0,71	2,00	2,80	1,50
VŠVU Bratislava	0,56	0,67	1,00	1,14	1,25	1,22	3,00	2,20	1,00
AU Banská Bystrica	1,75	1,00	0,44	0,75	2,00	0,21	0,67	0,25	0,00
KU Ružomberok	0,45	0,50	0,65	0,55	0,90	0,66	0,53	0,63	0,74
UJS Komárno	0,54	0,67	0,47	0,47	0,78	3,00	0,38	0,40	0,53
Priemer SR	**1,09**	**0,96**	**1,28**	**1,28**	**1,17**	**1,30**	**1,32**	**1,53**	**1,59**

Source: The Ministry of Education, Science, Research and Sport of the Slovak Republic, own calculations

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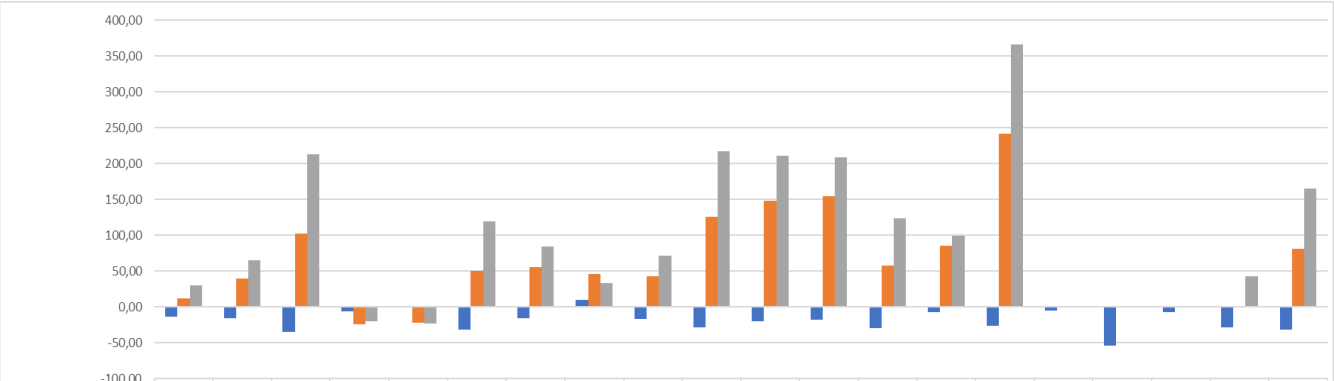
Even in this indicator, universities maintain a stable development trend in individual years, while the highest increase compared to the beginning of the observed period was recorded by TUAD Trenčín. Based on the above-mentioned developments of indicators in project activity, we can state that public universities are constantly improving results in this area. Younger and smaller universities in the observed period have a higher year-on-year growth rate, especially in the last two monitored years.

The last monitored indicator on the output side is publishing activity. For our needs, we used an indicator of the number of publications per employee as well as the number of outputs per employee in scientific journals. Data on publishing activities were available only from 2013, so we will examine this part in a shorter period 2013-2019. Figure 6 shows the percentage change in 2019 compared to 2013. There was a decrease in the number of publications per employee at all public universities, except UVLF Košice and TVU Trnava. This decrease was accompanied by an increase in the share of outputs in current journals per employee. We also see an increase in the share of outputs in current journals in the total number of university outputs.



	UK Bratislava	UPJŠ Košice	PU Prešov	UCM Trnava	UVLF Košice	UKF Nitra	UMB Banská Bystrica	TvU Trnava	STU Bratislava	TU Košice	ŽU Žilina	TUAD Trenčín	EU Bratislava	SPU Nitra	TU Zvolen	VŠMU Bratislava	VŠVU Bratislava	AU Banská Bystrica	KU Ružomberok	UJS Komárno
Publ./empl.	-14,07	-15,44	-35,20	-5,78	0,72	-31,42	-15,25	9,95	-16,70	-28,80	-20,03	-17,74	-29,38	-7,03	-26,62	-4,62	-54,42	-7,30	-28,94	-31,49
Carent/empl.	11,58	39,39	102,82	-24,34	-22,26	50,41	56,00	46,23	42,92	125,90	148,21	154,41	57,78	85,12	242,14	0,00	0,00	0,00	1,16	81,45
Share of carents	29,85	64,85	212,99	-19,70	-22,82	119,30	84,07	32,99	71,56	217,30	210,38	209,30	123,41	99,12	366,27	0,00	0,00	0,00	42,36	164,84

Figure 6. Percentage change in the publishing activities of universities in 2019 compared to 2013
Source: The Ministry of Education, Science, Research and Sport of the Slovak Republic

To verify our assumption of specified inputs and outputs, we performed a correlation analysis of the following indicators: number of employees, number of implemented projects and the total number of publication results. The results of the correlation analysis are as follows (Table 5):

Table 5. Correlation analysis

	Employees	*Projects*	*Publications*
Employees	1		
Projects	0,98394415	1	
Publications	0,971183146	0,950358645	1

Source: own calculations

As we expected, our strong dependence of the number of projects (0.98) as well as the number of publications (0.97) on the number of employees was confirmed. The assumption that projects are a prerequisite for publishing activities was also confirmed, while the dependence is at the level of 0.95. The 140 values for each correlation indicator were used, with the following statistical values within the data set. In the case of the number of employees, the median level was 444.35, the maximum value was 2511 employees (UK Bratislava year 2019) and the minimum value was 96.7 employees (UJS Komárno year 2013). Modus stood at 523.9, standard deviation

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535.19. In the case of the number of solved projects, the median was 85.5, modus was 7 and the standard deviation was 124.56. The maximum number of solved projects in the monitored period was 561 (UK Bratislava in 2019). In the case of the number of publications, the median was 1962 publications, with a minimum number of publications of 82 and a maximum of 10450.

We used DEA analysis to evaluate the efficiency of public universities, using a model for constant returns to scale. In the case of inputs in the form of the number of employees and in monitoring outputs as the number of publications, projects, it is not possible to consider increasing revenues from scale. First, we evaluated public universities according to the number of employees and the total number of publications. The results of the DEA analysis are shown in Table 6.

Table 6. Efficiency of universities according to the CCR DEA model (staff and publications)

	2019		2013	
TvU Trnava	1,00	1,00	0,68	0,40
PU Prešov	0,87	1,75	1,00	1,00
EU Bratislava	0,79	1,37	0,83	0,99
UCM Trnava	0,75	0,81	0,59	0,34
UMB Banská Bystrica	0,73	1,29	0,64	0,73
TUAD Trenčín	0,73	0,36	0,66	0,22
SPU Nitra	0,72	1,31	0,57	0,54
UJS Komárno	0,67	0,29	0,73	0,13
TU Košice	0,67	2,08	0,70	1,23
UKF Nitra	0,65	1,20	0,71	0,72
UVLF Košice	0,65	0,59	0,48	0,20
UK Bratislava	0,65	5,75	0,56	2,44
UPJŠ Košice	0,59	1,68	0,52	0,69
ŽU Žilina	0,58	1,50	0,54	0,79
KU Ružomberok	0,58	0,61	0,61	0,42
TU Zvolen	0,56	0,54	0,57	0,33
STU Bratislava	0,55	2,54	0,49	1,32
AU Banská Bystrica	0,24	0,10	0,19	0,04
VŠMU Bratislava	0,14	0,10	0,11	0,04
VŠVU Bratislava	0,12	0,05	0,19	0,04

Source: own calculations

Based on this analysis, TvU Trnava appears to be the most effective in this area in 2019, which was in 6th place at the beginning of the monitored period. Overall, it can be stated that the differences in the efficiency of individual universities in 2019 were to a lesser extent than in 2013. Universities that significantly exceeded other universities in the absolute number of published outputs in this comparison reached a median level of 0.65. Even in the case of DEA analysis, the lowest efficiency was achieved by AU Banská Bystrica, VŠMU Bratislava and VŠVU Bratislava.

In the case of the analysis of the number of employees per the number of solved projects, the results of the efficiency of public universities are shown in Table 7. Evaluation according to outputs in the form of solved projects in a given year, TU Zvolen is the most effective. The least effective in this area are UJS Komárno, VŠMU Bratislava and AU Banská Bystrica. The median in 2019 increased to 0.624 compared to 2011, when it reached the level of 0.439. The average value of efficiency increased from 0.421 in 2011 to 0.539 in 2019. Based on these facts, we can state that the efficiency of public universities in this category is increasing and the differences between individual universities are decreasing.

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Table 7. Efficiency of universities according to the CCR DEA model (employees and number of solved projects)

P. č.		2019		2011	
2019	DMU Name	Efektívnosť	Lambda	Efektívnosť	Lambda
1.	TU Zvolen	1	1	0,675353411	1,093333
2.	TU Košice	0,773963034	2,505263158	0,555397464	2,68
3.	SPU Nitra	0,768759166	1,452631579	0,628239142	1,72
4.	TvU Trnava	0,76216397	0,789473684	0,518869084	0,84
5.	UMB Banská Bystrica	0,729287029	1,326315789	0,378123018	1,186667
6.	STU Bratislava	0,723053602	3,442105263	0,577451451	4,186667
7.	PU Prešov	0,703292942	1,463157895	0,485627998	1,36
8.	UPJŠ Košice	0,65729392	1,947368421	0,538198275	1,893333
9.	ŽU Žilina	0,652060832	1,736842105	0,632340951	2,546667
10.	UK Bratislava	0,64318007	5,905263158	0,549535695	6,506667
11.	UVLF Košice	0,606330569	0,568421053	1	1
12.	UKF Nitra	0,582221637	1,105263158	0,392656664	1,106667
13.	EU Bratislava	0,499877799	0,905263158	0,355969466	1,16
14.	UCM Trnava	0,392201717	0,442105263	0,120013779	0,173333
15.	TUAD Trenčín	0,386299435	0,2	0,206153846	0,2
16.	KU Ružomberok	0,308527514	0,336842105	0,187267081	0,36
17.	VŠVU Bratislava	0,233491271	0,105263158	0,109031733	0,066667
18.	UJS Komárno	0,191770016	0,084210526	0,218903151	0,093333
19.	VŠMU Bratislava	0,170772953	0,126315789	0,123186925	0,12
20.	AU Banská Bystrica	0	0	0,181782946	0,093333

Source: own calculations

In the following table we present the efficiency of public universities according to the obtained funds for solved scientific research projects. Even in this case, the growing trend of efficiency in the given numbers of pedagogical and scientific researchers was confirmed in most public universities. The average value of efficiency increased from 0.29 in 2011 to 0.41 in 2019. The median value reached 0.36 in 2019 compared to 0.20 in 2011. The results and ranking of public universities for this output are shown in Table 8.

Table 8. Efficiency of universities according to the CCR DEA model (employees and volume of obtained funds)

P. č.		2019		2011	
2019	DMU Name	Efektívnosť	Lambda	Efektívnosť	Lambda
1.	TU Zvolen	1	1	0,532135157	0,861477
2.	STU Bratislava	0,858639308	4,087563	0,610319305	4,424967
3.	TU Košice	0,727715432	2,355563	0,442421348	2,134848
4.	UPJŠ Košice	0,623936411	1,84854	0,477175567	1,678661
5.	UK Bratislava	0,623140499	5,721273	0,401490934	4,753773
6.	ŽU Žilina	0,612748157	1,632128	0,601062596	2,420697
7.	SPU Nitra	0,574733906	1,086005	0,394866945	1,081071
8.	UVLF Košice	0,53980332	0,506053	1	1
9.	TvU Trnava	0,476806121	0,493891	0,240308919	0,389037
10.	PU Prešov	0,399060716	0,830221	0,215049042	0,602244
11.	UCM Trnava	0,329839008	0,371808	0,057075447	0,082433
12.	UKF Nitra	0,310244001	0,588953	0,185365329	0,522435
13.	UMB Banská Bystrica	0,307298393	0,558867	0,139463898	0,437681
14.	EU Bratislava	0,241236256	0,436871	0,126863976	0,413412
15.	TUAD Trenčín	0,230432663	0,119303	0,114870857	0,111442
16.	VŠVU Bratislava	0,125031896	0,056367	0,05022246	0,030708
17.	KU Ružomberok	0,069727731	0,076127	0,051660007	0,099311
18.	VŠMU Bratislava	0,048443571	0,035832	0,05121887	0,049894
19.	UJS Komárno	0,04605252	0,020223	0,065560129	0,027953
20.	AU Banská Bystrica	0	0	0,060827081	0,031231

Source: own calculations

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Also in this case, TU Zvolen took first place in 2019, while in 2011 it reached only the level of 0.532 efficiency compared to the first UVLF Košice in that year. UVLF reached an efficiency level of 0.539 in 2019 and ranked 8th in the efficiency ranking. As AU Banská Bystrica did not implement any scientific research project in 2019, it shows an efficiency of 0 in this case. The least effective include KU Ružomberok, VŠMU Bratislava and UJS Komárno.

When comparing the efficiency of public universities in the field of project activities, despite the fact that some universities show high performance in the number of solved projects, when comparing with the efficiency of the obtained funds, they are on lower serial numbers. SPU Nitra in the number of solved projects is on the 3rd place in efficiency, but in the monetary expression of the projects it fell to the 7th place. TVU Trnava from 4th place to 9th place and UMB Banská Bystrica from 5th place to 13th place. Other changes in the order are not significant.
The last DEA model, which we used to evaluate the efficiency of public universities, was based on measuring the efficiency of the university based on the input, which represented the number of teaching and research staff, and on the output side we used the following indicators: number of projects implemented in a given year, funds obtained for projects, the number of publications published in a given year, the number of publications in peer-reviewed journals and the number of graduates. The results of the multiplied DEA model at constant range returns are shown in Table 9.

Table 9. Evaluating the efficiency of public universities with a multiplied DEA model

2013			2019		
P.č.	**VŠ**	**Efektívnosť**	**P.č.**	**VŠ**	**Efektívnosť**
1.-7.	PU Prešov	1	1.-5.	UPJŠ Košice	1
1.-7.	UPJŠ Košice	1	1.-5.	TvU Trnava	1
1.-7.	UKF Nitra	1	1.-5.	TUAD Trenčín	1
1.-7.	TUAD Trenčín	1	1.-5.	UCM Trnava	1
1.-7.	UVLF Košice	1	1.-5.	TU Zvolen	1
1.-7.	SPU Nitra	1	6.	SPU Nitra	0,986875449
1.-7.	UJS Komárno	1	7.	EU Bratislava	0,981924187
8.	UK Bratislava	0,997092043	8.	UMB Banská Bystrica	0,978128748
9.	TvU Trnava	0,984686514	9.	PU Prešov	0,957976136
10.	TU Košice	0,976885224	10.	TU Košice	0,952890494
11.	TU Zvolen	0,934106777	11.	UK Bratislava	0,929819534
12.	EU Bratislava	0,933289457	12.	STU Bratislava	0,908246052
13.	STU Bratislava	0,901153487	13.	UKF Nitra	0,888865317
14.	UMB Banská Bystrica	0,885594657	14.	UJS Komárno	0,88219065
15.	KU Ružomberok	0,880376708	15.	ŽU Žilina	0,854388868
16.	UCM Trnava	0,852784169	16.	UVLF Košice	0,797327499
17.	ŽU Žilina	0,844542852	17.	KU Ružomberok	0,696552678
18.	VŠMU Bratislava	0,267631527	18.	VŠMU Bratislava	0,35920141
19.	VŠVU Bratislava	0,258727891	19.	AU Banská Bystrica	0,317763984
20.	AU Banská Bystrica	0,252725917	20.	VŠVU Bratislava	0,311891528

Source: own calculations

7 universities were effective in 2013, while in 2019 this number dropped to 5 universities. Two universities, TUAD Trenčín and UPJŠ Košice, maintained the highest level of efficiency in both years. As part of changes in the basic indicators of descriptive statistics, we observe a decrease in medians from 0.955 in 2013 to 0.941 in 2019. At the same time, in the case of specific universities AU Banská Bystrica, VŠVU Bratislava and VŠMU Bratislava we can observe a slight increase in efficiency despite previous evaluations of partial indicators. The average efficiency value in 2013 was 0.848, which means that there was a slight decrease to 0.840 in 2019.

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Conclusions

Universities have a specific position in terms of evaluating efficiency as well as performance. The evaluation of efficiency using the DEA model that we proposed eliminates inaccuracies in the case of evaluations based on absolute values. It is necessary to realize that individual universities differ in size, number of students, number of employees as well as different length of existence. The efficiency evaluation proposed by us is based on the evaluation of the efficiency of higher education institutions on the basis of share indicators. The evaluation compiled in this way can be used to evaluate not only universities. Universities can use this assessment to compare their individual faculties. This method of evaluation is the basis for evaluation for the purposes of accreditation. The results can also be used in the field of university promotion in the higher education market at the international level. Each school can choose other indicators for its needs, which will enter the model. One of the important outputs could be data on the employability of graduates in the labour market. We did not use this indicator as data is not currently available to the extent necessary. The total number of university graduates was 35,017 in 2019. 46% found employment, the unemployed accounted for 4% and 37% continued their studies. In case of using these data for a longer monitored period at individual universities, we will include them in the models of efficiency evaluation. However, even without the use of this indicator, it has been confirmed that most universities achieve high efficiency and differences in evaluation using DEA models are minimal. The trend of maintaining quality and performance is positive. Young universities achieve the same and in some cases better results than schools with a long tradition. The issue of university evaluation requires further research, which we will address in further research activities.

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