THE IMPACT OF COMPETITIVE ALLOCATION OF SUBSIDIES ON PRODUCTIVITY CHANGE OF UNIVERSITIES IN SLOVAKIA

MÁRIA GRAUSOVÁ, MIROSLAV HUŽVÁR, ZUZANA RIGOVÁ

Matej Bel University, Faculty of Economics,
Department of Quantitative Methods and Information Systems,
Tajovského 10, Banská Bystrica, Slovakia
e-mails: maria.grausova@umb.sk, miroslav.huzvar@umb.sk, zuzana.rigova@umb.sk

Abstract

The implementation of the Higher Education Act of 2002 in Slovakia has significantly changed the economic conditions for universities that were transformed to public higher education institutions. Subsidies from the state budget are allocated to individual universities based on their share on the total performance of all public higher education institutions in education and research. The competition for financial resources has greatly influenced the behaviour of universities. Although some effects of this system of financing are considered questionable, it is naturally expected that the increasing competition may have a positive impact on the productivity of universities in the transformation of input resources into desirable outputs. We study the productivity change of Slovakian universities over the period when the new legislation is applied. Malmquist index is used for the assessment of total productivity change, and data envelopment analysis for calculating efficiency scores to construct the index.

Keywords*: data envelopment analysis, Malmquist index, productivity change, Slovakian public higher education institutions*

JEL Codes*: C44, I23*

1. Introduction

The aim of this empirical study is to evaluate the productivity change in performance of public higher education institutions (HEIs) in Slovakia. We aim to assess and compare the productivity of Slovakian public HEIs in using their labour and financial resources as the key inputs to produce expected outputs in the main areas of their mission, i.e. in education and in research. The motivation for the study naturally arises from several reasons. Undoubtedly, a higher productivity brings a comparative advantage to individual HEIs, and efficient and effective use of budgetary resources allocated to public HEIs is expected by all stakeholders. Another question is whether the competitive system of allocating the main portion of subsidies form the state budget to individual public HEIs has resulted in the increase of their productivity. Thus, the results of the analysis may be valuable for university managements as well as for the authorities involved in setting the rules for financing public HEIs.

The general principles of financing public HEIs from the state budget are specified by the Higher Education Act introduced in 2002. The financial support is provided to public HEIs on the base of contracts in the form of subsidies for education and for research and development (R&D). The Higher Education Act sets out the basic criteria for the allocation of subsidies to individual public HEIs. The allocation criteria are annually updated by the Ministry of Education, Science, Research and Sport of the Slovak Republic. The annual evaluation of the performance of public HEIs for budgetary purposes gives an opportunity for a regular

comparison of the HEIs based on numerous indicators. We apply some of the indicators used in the calculation of subsidies and their settings in our paper.

The most important subsidies to cover the operation costs of a public HEI are the subsidy for running of accredited study programs and the subsidy for research, development or artistic activities. The two subsidies are allocated in a competitive way, i.e. the amount of subsidies depends on the share of the university on the total performance of all Slovakian public higher education institutions measured by given criteria. While defining the amount of subsidy for running of accredited study programs, the number of students, number of graduates, economic demand of the study programs, quality and other criteria related to provision of teaching, are decisive. While defining the amount of subsidy for research and development activities, the research and development capacity of the university, the achieved results in the field of science, technology or art, and the evaluation of research, development and other creative activity of the university by the Accreditation Commission within the framework of complex accreditation, are taken into account.

The competitive allocation of subsidies is expected to force the public HEIs to increase their productivity in education and R&D and efficiently use their human, financial and material resources to produce the desired outputs in both areas. The competition among universities for subsidies emphasizes the importance of reliable assessment of their relative productivity that can help university managers to reveal possibilities for improvement their position on the higher education market.

We study the changes in productivity of selected Slovakian public HEIs within the period of 2009-2016. The productivity is considered in a standard way as a relation between the outputs and the inputs of analysed processes. For the evaluation of productivity, we apply simple ratio indicators (relating one output to one input) as well as more complex efficiency scores (taking into account multiple inputs and/or multiple outputs at the same time). The efficiency scores are calculated using data envelopment analysis (DEA). We use the efficiency scores to build the Malmquist index that is capable to provide information on the changes of productivity in time.

DEA has been applied for the assessment of relative efficiency of universities in several countries, e.g. in Australia (Abbott and Doucouliagosa, 2003), England (Johnes, 2006) and Mexico (Sagarra *et al*., 2017). Andersson *et al*. (2016) studied the technical efficiency and productivity of universities in Sweden. They applied DEA and Malmquist index for evaluating the efficiency of 30 HEIs in years 2005 – 2008.

Most of the studies designed a set of DEA models with various combinations of inputs and outputs, input or output orientation, and assuming variable returns to scale. As inputs the studies usually considered teaching, research and other staff, and some approximation for capital, e.g. the value of non-current assets, expenditures on energy and other services, depreciation and interest payable. The most frequently used outputs include the number of students, graduates, scientific publications and research income. Some studies used the number of enrolled students as an input while the number of graduates being an output. Research grants are considered as inputs or outputs. As explanatory variables, Andersson *et al*. (2017) used the share of distance students, university beginners, and the number of education fields.

The paper is organized as follows. In Section 2, we introduce the observed public HEIs, the inputs and outputs that we consider crucial for the efficiency and productivity assessment of Slovakian public HEIs in education and R&D, and we display the changes in productivity by selected ratio indicators and by the shares of individual HEIs on the total performance of public HEIs in Slovakia. In Section 3 we explain the methodology for efficiency and productivity change assessment and characterize applied DEA models. Sections 4 is devoted

to present and discuss the empirical results. In Conclusion we summarize our findings and outline topics for further research.

2. Data

We do the analysis for 16 out of 20 Slovakian public HEIs. We exclude from the analysis three academies of arts that much differ from other public HEIs in their creative activities, and University of Veterinary Medicine and Pharmacy in Košice which has a unique and narrow specialization in both education and research. The list of public HEIs in consideration is given in Table 1. We introduce their shortened names by which we refer to the HEIs in our paper.

Table 1: List of compared public HEIs

Public HEI	Shortened name
Comenius University in Bratislava	UK
Slovak University of Technology in Bratislava	STU
Technical University of Košice	TUKE
University of Žilina	ŽU
Pavol Jozef Šafárik University in Košice	UPJŠ
University of Economics in Bratislava	EU
Matej Bel University in Banská Bystrica	UMB
Constantine the Philosopher University in Nitra	UKF
University of Prešov in Prešov	PU
Slovak University of Agriculture in Nitra	SPU
The Catholic University in Ružomberok	KU
Trnava University in Trnava	TVU
University of Ss. Cyril and Methodius in Trnava	UCM
Technical University in Zvolen	TUZVO
Alexander Dubček University of Trenčín	TUAD
J. Selye University in Komárno	UJS

Source: The authors.

All public HEIs in Slovakia have the official status of universities. UK and UPJŠ represent universities of traditional type, i.e. their fields of education and research cover natural sciences, social sciences, humanities, and applied sciences including medicine, with a significant share of each branch of science on their educational and R&D activities. On the contrary, only one or two branches of science dominate in each of the other public HEIs. STU, TUKE, and ŽU are mostly technical universities. SPU and TUZVO specialize in agriculture and forestry, respectively. The other universities are mostly specialized in social sciences and humanities.

We study the performance of public HEIs from two viewpoints corresponding to the main areas of their mission. We focus on their productivity change in education as well as in R&D activities. Although the education and R&D are naturally considered joint processes at universities, we do the analysis separately for each of these areas. The main reason for a separate assessment is to distinguish the productivity change in both areas that may develop in different ways. Moreover, this approach allows us to specify more precisely the human resources that are crucial input for each area.

The productivity change is studied for the period 2009-2016. The selection of period was determined by three factors. First, the key changes resulting from the Higher Education Act of 2002 had been implemented by the beginning of this period (e.g., the first students of newly

conceived bachelor study programs graduated from majority of Slovakian universities in 2008). Second, public HEIs worked in a relatively stable environment since only partial changes in legislation or financing were adopted and gradually implemented during this period. Third, data on relevant inputs and outputs in education and R&D are available for each year of this period.

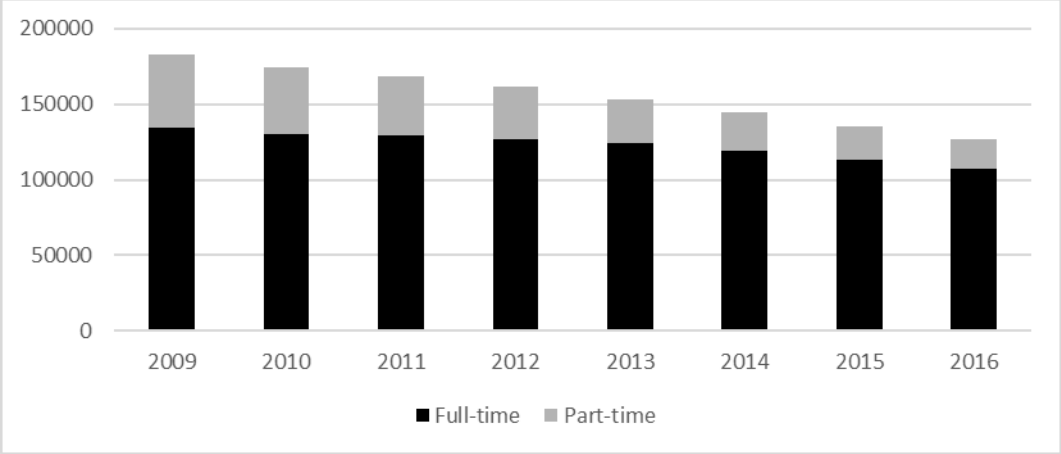
In order to evaluate the productivity changes in performance of public HEIs, we consider the indicators that characterize the main inputs and outputs of providing education and doing research at universities. The selection of indicators depends on the assessment objectives, examined production technology, and available data sources.

2.1. Performance in Education

The objective of performance assessment in education is to reveal the changes in productivity of teachers as the main human resource involved in teaching students and preparing them for their future professional career. That is why we take into account the teaching staff as a unique input, the total performance in education (derived from the number of students, as explained later in this section) and the employment of graduates as the key outputs of education process at universities. By the teaching staff we mean the total number of teachers[1], calculated with respect to part time contracts.

The development of the number of students during the period 2009-2016 in both forms of study is demonstrated in Figure 1. We see that the total number of students at public HEIs in Slovakia gradually decreased during the whole analysed period. But the total decline was much sharper in part time study (by 59 %) than in full time study (21 %). Over the same time, the total number of teachers at selected universities came down by 7 %.

Figure 1: Total number of full-time and part-time students at considered public HEIs

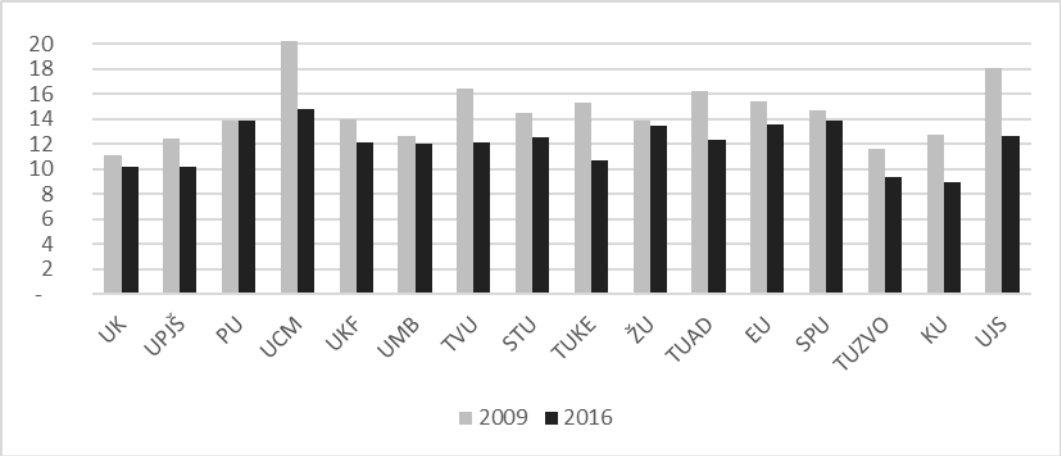


Source: The authors based on data published by the Ministry of Education, Science, Research and Sport of the Slovak Republic[1].

In the following two figures the changes in number of students per teacher for both forms of study and all universities are given. The numbers of students decreased in all cases, but the range of changes is different. The greatest fall can be observed at UJS, TUAD and TUKE (in both forms), UCM, TVU and KU (in full time students), and STU (in part time students).

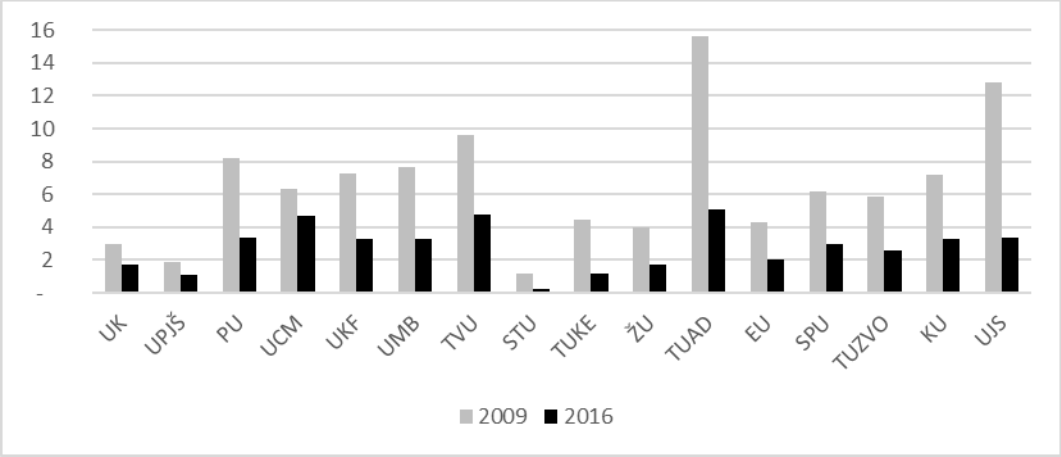
[1] Data from the Ministry of Education, Science, Research and Sport of the Slovak Republic available at http://www.minedu.sk /677-sk/financovanie/ (accessed April, 2018).

Figure 2: Number of full-time students per teacher



Source: The authors based on data published by the Ministry of Education, Science, Research and Sport of the Slovak Republic[1].

Figure 3: Number of part-time students per teacher



Source: The authors based on data published by the Ministry of Education, Science, Research and Sport of the Slovak Republic[1].

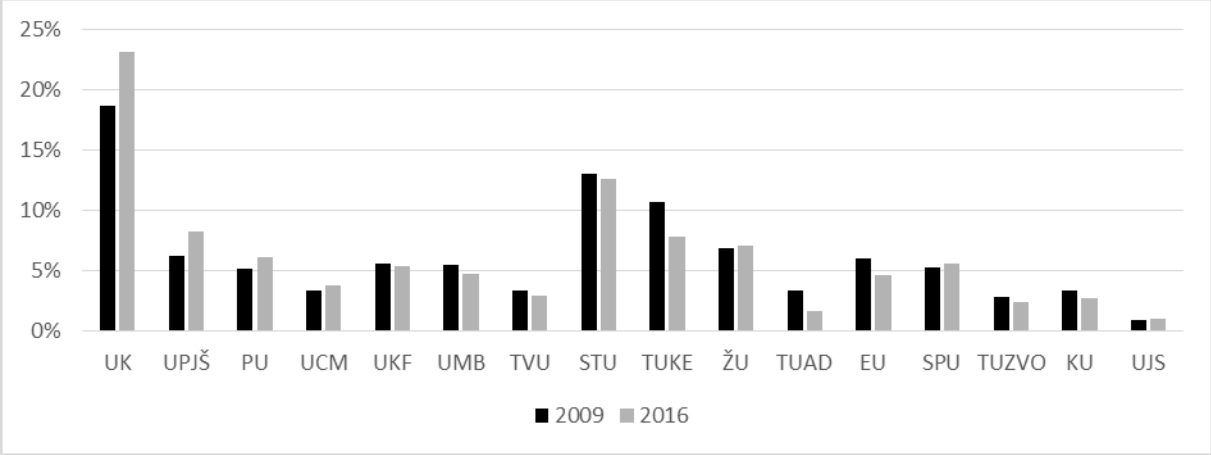
Besides the teaching staff, another important input are tangible and intangible assets used for educational purposes that may be estimated by the value of buildings owned by universities (Grausová *et al*., 2017). However, we do not consider this indicator in our analysis. The reason is that a considerable increase in the value of assets at some public HEIs during the analysed period was not financed by budgetary resources. The assets were mostly built or reconstructed within the infrastructure development projects supported with EU funds that were primarily targeted to less developed regions of Slovakia. Thus, the public HEIs had no equal access to these additional financial resources and the inclusion of assets to the analysis, even in the form of their depreciation, may significantly influence the comparison of productivity changes.

The total performance of a public HEI in education is considered as the number of students[1] for all bachelor, master and doctoral study programs, adjusted by given coefficients that represent the relative weights of the form of study and economic demands of the study programs. The weight of a full time student and a part time student is 1 and 0.3, respectively, which reflects the fact the part time study is less relied on a direct interaction between students and teachers. The economic demands of study programs are expressed with special coefficients[1] assigned to respective study fields that are used by the ministry for the

calculation of subsidies for running of accredited study programs at public HEIs. In our analysis we apply the values of the coefficients currently used for the allocation of subsidies. The coefficients express the relative personal needs of providing education for one student in the specific study program and form of study. Thus, the adjusted number of students estimates the total performance in education provided by the university.

Figure 4 reveals that the shares of individual universities on the total performance of public HEIs in education between 2009 and 2016 really changed. While the two universities of the traditional type UK and UPJŠ exhibit a significant increase in their shares, TUKE, TUAD and EU show a considerable decrease, e.g. the share of TUAD is lower in 2016 by 59.2 % in full time study and by 82.6 % in part time study, compared with the beginning of the period. The changes in the shares of other public HEIs on the total performance in education were less significant.

Figure 4: Shares of universities on the total performance of public HEIs in education



Source: The authors based on data published by the Ministry of Education, Science, Research and Sport of the Slovak Republic[1].

To capture the quality of graduates, we take into account their employment on the labour market. In order to distinguish the most successful universities from the rest, the number of unemployed graduates[1,2] at the end of the year is considered as an undesired output in our productivity analysis. The unemployment of graduates is detected as the number of graduates from the public HEI in all three levels who had not succeeded to get their first job during two years after their graduation.

2.2. Performance in R&D

The objective of productivity assessment in R&D is to show how efficient the observed public HEIs are in producing publications of the most influential categories, compared to their human and financial resources available for R&D. For this purpose, we consider the academic staff[3] and the received financial grants[1] as inputs, and high-level scientific and educational publications as a unique output.

[2] Central Office of Labour, Social Affairs and Family (accessed April, 2018) available at http://www.upsvar.sk/statistiky/nezamestnanost-absolventi-statistiky.html?page_id=1252

[3] Data from the Ministry of Education, Science, Research and Sport of the Slovak Republic available at http://www.minedu.sk/vyrocne-spravy-o-stave-vysokeho-skolstva/ (accessed April, 2018).

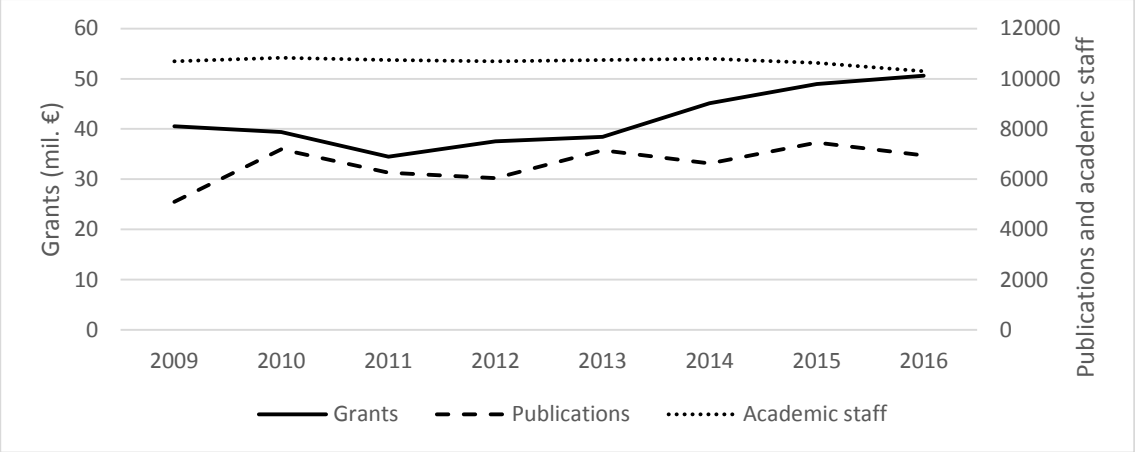
The academic staff is expressed as the total number of teachers (without lectors) and researchers, adjusted with respect to their part time contracts. These two groups of university employees represent the key labour resources involved in preparing the publications.

The grants[1] include all money received from home and foreign research agencies as well as from other organizational and private sources (with the exception of EU operational programs that were primarily used for building and innovation of the university infrastructure). In contrast with subsidies from the state budget, the grants represent the main sources of financial support for research and educational activities that are usually not used for salaries of academic staff in Slovakia. Thus, the total amount of received grants estimates the financial inputs for academic research. When dealing with grants expressed in € we do not take into account the inflation rate since it was close to zero during the whole considered period.

Scientific publications[4] of wide potential impact such as monographs, chapters in scholarly books, articles in scholarly refereed journals, and registered patents are considered the most significant outputs of R&D. The most important publications for educational purposes include textbooks, professional books, expert translations of publications, bibliographies, catalogues, encyclopaedias, dictionaries, anthologies, atlases, etc. In our analysis of productivity in R&D, we use the total number of most influential scientific and educational publications as a unique output.

While the academic staff remains stable during the whole analysed period (with a small decrease in the last two years), the number of high-level publications increases (in spite of minor falls in some years). The highest jumps are observed in years 2010, 2013 and 2015. The total amount of research and educational grants received by public HEIs exhibits a similar trend as the number of publications. After a fall in year 2011, it gradually increases (Figure 5).

Figure 5: Development of the amount of grants, the number of publications and the number of academic staff of public HEIs



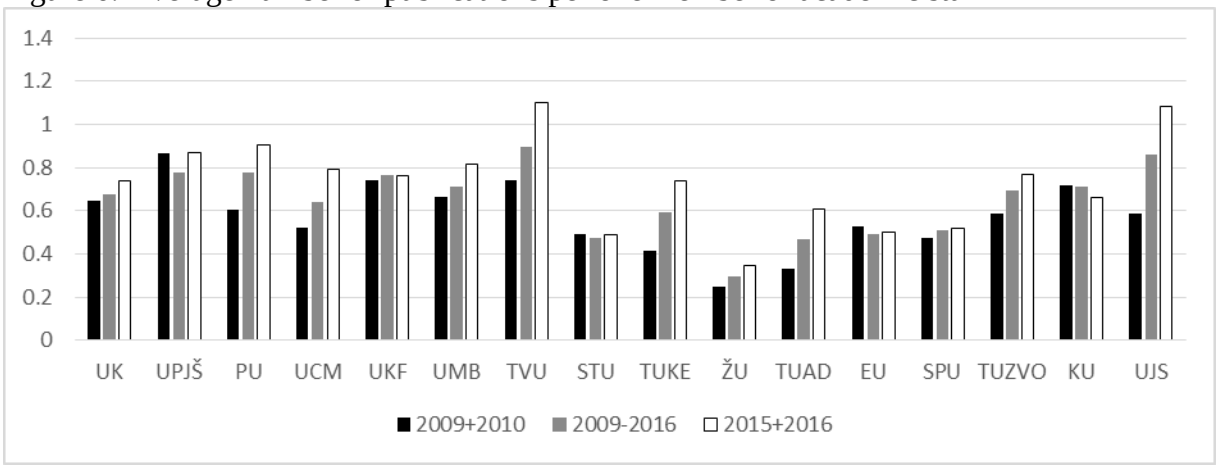
Source: The authors based on data published by the Ministry of Education, Science, Research and Sport of the Slovak Republic[3] and the Central register of the publication activities[4].

Figure 6 shows the average annual level of publishing performance per one member of academic staff during the period 2009-2016 and the averages of the first two and the last two years of the period.

[4] Data from the Central register of the publication activities available at http://cms.crepc.sk/statistiky.aspx (accessed April, 2018).

The highest average performance during the whole period was reached by TVU, UJS, UPJŠ, PU and UKF. Moreover, UJS and TVU belong to the universities with the highest increase in publishing activities per one member of academic staff, comparing the beginning and the end of the observed period, along with TUKE, TUAD and UCM. On the contrary, the lowest average performance during the whole period was reached by ŽU followed by TUAD, STU, EU and SPU. In case of KU we even see a moderate decrease in this ratio.

Figure 6: Average number of publications per one member of academic staff



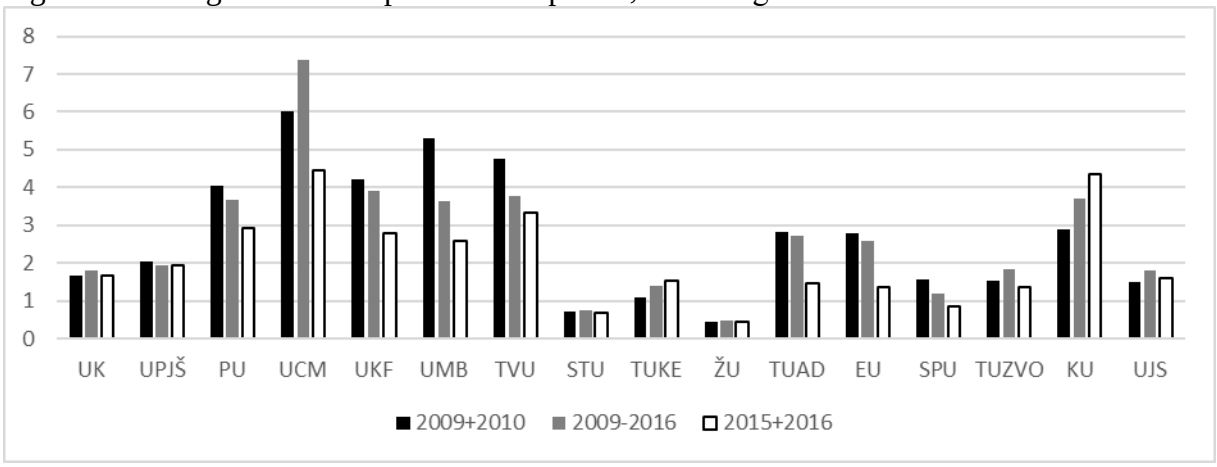
Source: The authors based on data published by the Ministry of Education, Science, Research and Sport of the Slovak Republic[3] and the Central register of the publication activities[4].

Figure 7 shows the intensity of publishing activity regarding to the amount of received grants. It is expressed by an average number of publications per 10,000 € of grants in the period 2009-2016 and the averages of the first two and the last two years of the period.

The highest average performance during the whole period was reached by UCM, followed by UKF, TVU, KU, PU and UMB.

KU along with TUKE are the universities with the highest progress in publishing activities per amount 10,000 € of grants. On the contrary, the lowest average performance in this indicator during the whole period was reached by ŽU, STU, SPU and TUKE, but these universities obtained a large amount of grants. The biggest fall is observed in the case of UMB.

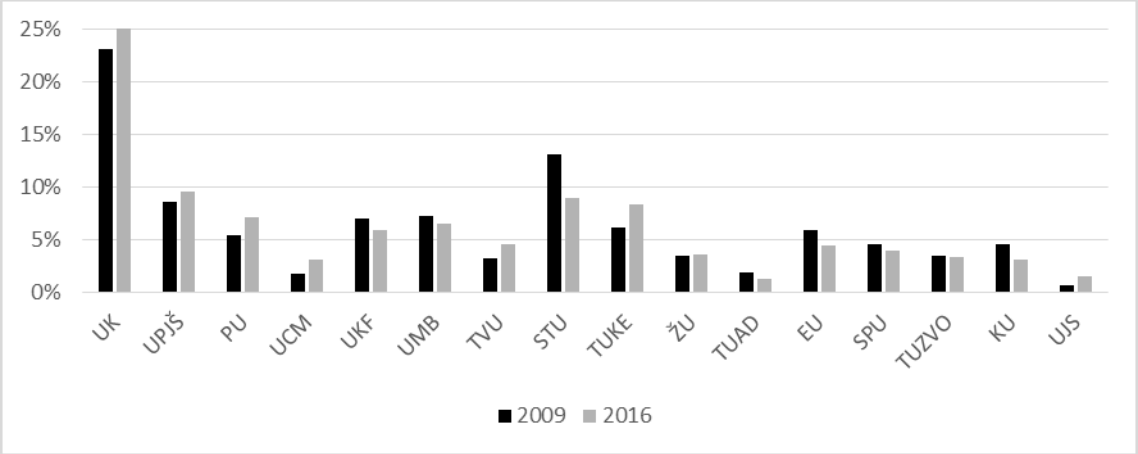
Figure 7: Average number of publications per 10,000 € of grants



Source: The authors based on data published by the Ministry of Education, Science, Research and Sport of the Slovak Republic[3] and the Central register of the publication activities[4].

Finally, we compare the shares of individual public HEIs on the total publishing activity in years 2009 and 2016 (Figure 8). We see a significant positive shift in case of UJS, UCM, UK, TUKE, TVU, UPJŠ, and PU. On the other hand, TUAD, KU, STU and EU show a marked decline in their positions.

Figure 8: Shares of universities on the total publishing activity of public HEIs



Source: The authors based on data published by the Central register of the publication activities[4].

3. Methodology for Evaluation of Efficiency and Productivity Change

To achieve our goal to identify changes in the productivity of Slovak universities over the period of 2009-2016, we use the Malmquist index (MI). We compute MI by means of DEA technology using DEA-Solver software (www.saitech-inc.com). Moreover, we will compare the technical efficiency of public HEIs in years 2009 and 2016.

MI evaluates the productivity change of a decision making unit (DMU) between two time periods. It is an index representing Total Factor Productivity (TFP) of the DMU that reflects progress or regress in productivity of the DMU along with progress or regress of the frontier technology determined by the most efficient DMUs. MI is defined as the product of "Catch-up" and "Frontier-shift" terms.

We denote the activities of DMU_o at the time period 1 and 2 by $(x_o, y_o)^1$ and $(x_o, y_o)^2$, respectively. Then we develop the numerical measures for which we employ the notation $\delta^s((x_o, y_o)^t)$ (t = 1, 2 and s = 1, 2), for the efficiency score of DMU_o at the time period t measured by the frontier technology s. Using this notation, MI can be expressed by the following formula:

$$\mathrm{MI} = \frac{\delta^2((x_o, y_o)^2)}{\delta^1((x_o, y_o)^1)} \times \left[\frac{\delta^1((x_o, y_o)^1)}{\delta^2((x_o, y_o)^1)} \times \frac{\delta^1((x_o, y_o)^2)}{\delta^2((x_o, y_o)^2)} \right]^{1/2} = Catch-up \times Frontier\ shift \qquad (1)$$

For MI and each of its components, a value greater than one indicates an improvement of the DMU_o from period 1 to 2, while a value equal to one or less than one indicates the status quo or a decrease, respectively.

The "Catch-up" term (CU) is related to the degree of efforts that the DMU attained for improving its technical efficiency, while the "Frontier-shift" term (FS) reflects the change in the efficient frontier surrounding the DMU between the two time periods 1 and 2.

There are a number of ways to compute MI. In a non-parametric framework MI can be constructed by means of DEA technologies. DEA is a mathematical programming – based technique for measuring the efficiency of a DMU relative to all other compared units, and thus estimating the best ones within the group of units. For each DMU, the DEA provides an

efficiency score in the range $(0,1\rangle$, where the value 1 indicates an efficient unit. For each inefficient unit, DEA identifies the extent and the sources of its inefficiency in terms of input excesses and/or output shortfalls (see Cooper *et al*., 2007).

We apply for DEA the oriented Slacks-Based Measure (SBM) which reflects all nonzero slacks in inputs or outputs when they are present. We assume variable returns to scale due to rather different sizes of the assessed universities.

The input oriented model (SBM-I-V) will be applied for educational efficiency assessment since the HEIs may intend to optimize their teaching staff with respect to the number of students since this output can hardly be significantly increased in current demographic situation. Following the approach of Korhonen and Luptáčik (2004), the number of unemployed graduates as an undesirable output is treated as an additional input in our DEA.

On the other hand, the output oriented model (SBM-O-V) will be applied for efficiency assessment in R&D because the public HEIs may be interested in increasing the publishing outputs produced by existing academic staff and using the received volume of grants. In order to reduce the influence of natural annual volatility in grants received by individual HEIs, we take into account the total volume of grants obtained by a public HEI for a two-year period ending at the year for which the efficiency scores are calculated.

Applied DEA models are summarized in Table 2. Note that the same DEA technology is used for the computing of non-radial Malmquist index and its components. The names of DEA models are in accordance with Cooper *et al*. (2007) where the details on the models can be consulted.

Table 2: Characteristics of applied models

	Education	R&D
Inputs	Teachers	Academic staff Grants (in €)
Outputs	Total performance in education Unemployed graduates (undesirable output)	High-level publications
Orientation	Input	Output
Returns to scale	Variable	Variable
DEA model	SBM-I-V / Malmquist-I-V	SBM-O-V / Malmquist-O-V

Source: The authors.

4. Results and Discussion

In this section we introduce the results of MI analysis for both education and R&D. First, we present the productivity changes of all considered universities as a group in consecutive years. Second, we demonstrate efficiency scores for individual universities in years 2009 and 2016 and their productivity changes between these two years.

Table 3 Decomposition of Malmquist index in education performance

Average values	2009→2010	2010→2011	2011→2012	2012→2013	2013→2014	2014→2015	2015→2016
CU	0.98	0.97	0.97	1.09	1.01	0.96	1.04
FS	1.06	0.98	1.29	0.68	0.95	1.10	1.00

MI	1.04	0.95	1.25	0.74	0.96	1.05	1.04

Source: The authors.

Table 3 shows the average annual productivity changes of all public HEIs in education. As we can see, the total productivity measured by MI is substantially influenced by its FS component that was improved in years 2010, 2012 and 2015 caused by the decrease in number of unemployed graduates. The CU component had a positive impact on the total productivity growth in the last year.

MI and both its components of the R&D model exhibit relatively large fluctuation between consecutive years. It is not surprising because in this case we consider two relatively volatile indicators (the amount of grants and the number of publications). The highest increase of average MI can be observed in years 2010, 2013 and 2015 when the number of publications significantly increased. The productivity significantly decreased in 2014 where the number of publications decreased while the amount of grants increased (Table 4).

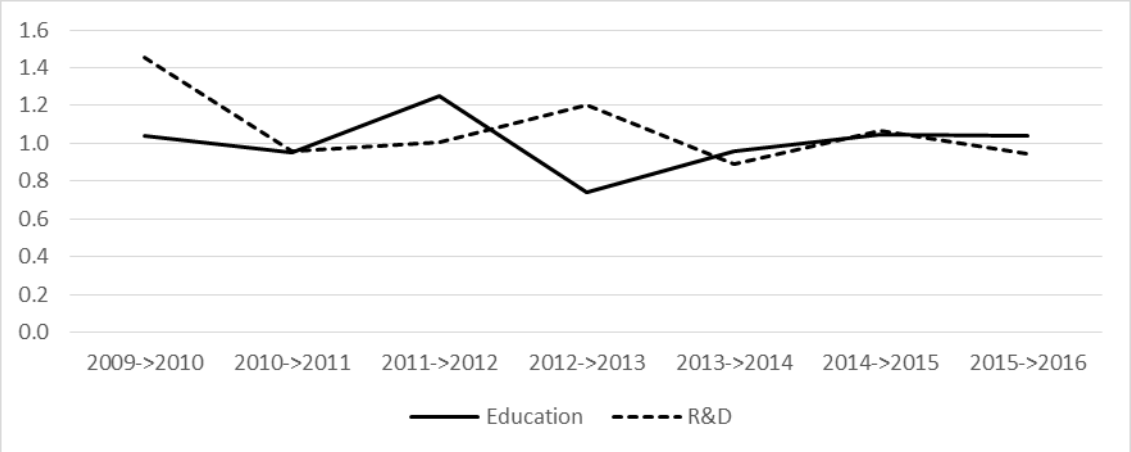
Table 4 Decomposition of Malmquist index in R&D performance

Average values	2009→2010	2010→2011	2011→2012	2012→2013	2013→2014	2014→2015	2015→2016
CU	0.93	1.24	1.03	0.98	0.99	0.98	1.05
FS	1.58	0.79	0.98	1.25	0.90	1.08	0.91
MI	1.46	0.96	1.00	1.20	0.89	1.07	0.94

Source: The authors.

Figure 9 compares total productivity change in education and R&D. It may be interesting that the productivity in both areas changed in the same direction, with the only exception in year 2013.

Figure 9: Comparison of total productivity change in education and R&D



Source: The authors.

Chyba! Chybný odkaz na záložku. shows the total productivity changes of individual public HEIs in education and R&D between the years 2009 and 2016 and reveals the reasons for the changes determined by Malmquist index and its two components.

The average productivity in education decreased by 8 %, mainly as a result of FS component decrease. It indicates the decline of the performance of referential universities while the average technical efficiency only slightly came down. SPU and UPJŠ reached the most significant improvement of technical efficiency (CU component), but their total

productivity (MI) is close to 1, due to the regress of referential universities. EU is the only one that succeeded to improve its technical efficiency although the respective frontier was improved, too. TUKE, UJS and UCM exhibit the worst regress in both technical efficiency and total productivity.

On the other hand, the average productivity in R&D increased by 30%, mostly as a result of the frontier shift, i.e. the improvement of productivity of referential HEIs. The most significant improvement in the total productivity can be observed for TUKE, UK, TUZVO, ŽU, PU and UJS. STU and EU significantly decreased their technical efficiency, and along with KU are the only three HEIs that decreased their total productivity in R&D.

Table 5: Change of productivity of individual public HEIs between 2009 and 2016

HEI	Education			R&D		
	Catch-up	Frontier	Malmquist	Catch-up	Frontier	Malmquist
UK	1.00	1.13	1.13	1.50	1.21	1.81
UPJŠ	1.22	0.84	1.03	0.94	1.42	1.34
PU	1.06	0.94	0.99	1.25	1.15	1.44
UCM	0.83	0.90	0.74	1.11	1.03	1.14
UKF	0.97	1.00	0.97	0.84	1.23	1.03
UMB	0.97	1.02	0.99	0.88	1.26	1.10
TVU	1.01	0.86	0.87	1.08	1.26	1.36
STU	1.00	1.09	1.08	0.68	1.42	0.96
TUKE	0.56	0.97	0.55	1.40	1.40	1.95
ŽU	1.08	0.85	0.91	1.03	1.39	1.44
TUAD	1.05	0.80	0.84	1.52	0.84	1.28
EU	1.12	1.04	1.16	0.74	1.23	0.91
SPU	1.49	0.67	1.00	0.85	1.47	1.25
TUZVO	0.94	0.85	0.80	0.89	1.68	1.50
KU	0.99	0.98	0.97	0.90	1.06	0.95
UJS	0.56	1.32	0.74	1.00	1.42	1.42
Average	0.99	0.95	0.92	1.04	1.28	1.30

Source: The authors.

Only two universities (UK and UPJŠ) succeeded to improve their total productivity in both areas and at a same time increase their shares on the total performance of all selected public HEIs in education (Figure 4) as well as in R&D (Figure 8). PU increased its shares in both areas and the total productivity in R&D, but slightly decreased the productivity in education. One university (KU) exhibits a slight decrease of total productivity in both areas. Other public HEIs show an increase of total productivity in one area and a decline in the other area, e.g. TUKE compensated the fall in education with a remarkable rise of the total productivity in R&D.

Finally, we illustrate the changes in technical efficiency of individual public HEIs over the studied period by comparing their efficiency scores reached at the beginning and at the end of the period. The efficiency scores are calculated by SBM DEA models described in Table 2.

Figure 10 shows the efficiency scores in education performance for public HEIs in the years 2009 and 2016. In both years, 6 out of 16 compared HEIs were efficient, and the average efficiency scores were nearly the same (0.786 and 0.787, respectively). Since we assumed variable returns to scale, UK and UJS were efficient by default, due to highest value

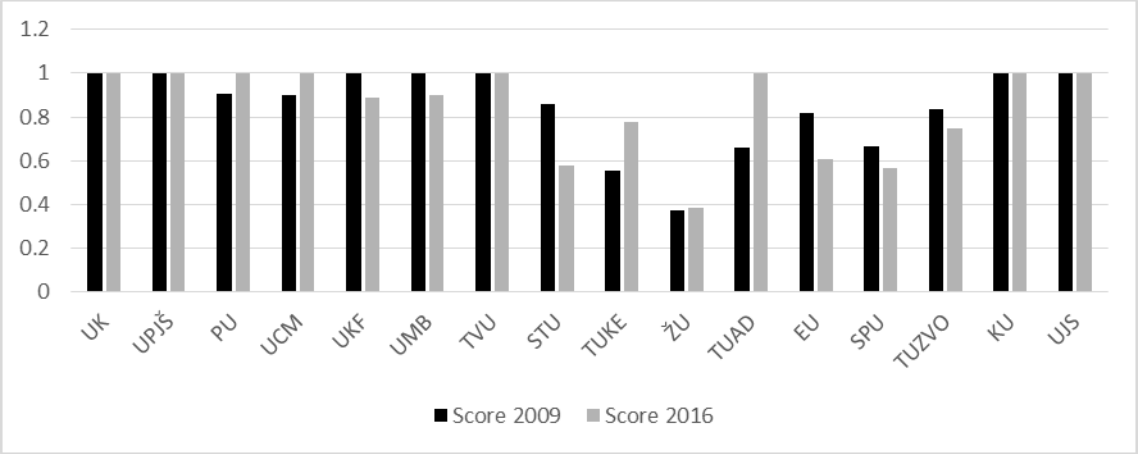
of output and lowest values of inputs, respectively. The other two efficient HEIs in both years were TUAD and STU. While SPU and UPJŠ improved their technical efficiency during the period to maximum value in 2016, UCM and TUKE became inefficient in 2016. All the other HEIs were inefficient in both years, with relatively small changes in their efficiency scores.

Figure 10: Efficiency in education (by SBM-I-V DEA model)

Source: The authors.

The average R&D efficiency scores in 2009 and 2016 were also very similar, but higher than in education (0.848 and 0.840, respectively). The number of efficient HEIs was greater in 2016 (8) than in 2009 (7). UK, UPJŠ, TVU, KU and UJS were technically efficient in both considered years. While TUAD, PU and UCM became efficient, UKF and UMB lost their full efficiency over the period. The lowest efficiency at about the same level in both years was reached by ŽU (Figure 11).

Figure 11: Efficiency in R&D (by SBM-O-V DEA model)



Source: The authors.

The advantages of DEA for efficiency assessment in public sector, compared to alternative techniques, are generally known and widely discussed in literature. The possibility of simultaneous treatment of multiple inputs and outputs to provide a complex efficiency measure and valuable managerial recommendations for efficiency improvement belongs to highly appreciated DEA features. However, the discrimination power of DEA models, i.e. their ability to distinguish the best performances from the rest, decreases with the increasing number of input and output indicators included to the analysis.

Hence, the small number of comparable public HEIs in Slovakia critically restricts the application of DEA for their efficiency assessment by a single DEA model. For this reason, we assess the efficiency by separate DEA models, each of them focusing on one of the key mission areas of HEIs. This approach allows us to more carefully identify and express the key inputs for individual areas, e.g. consider the teaching staff as the crucial input for education and the total academic staff contributing to R&D in the study of publications.

Nevertheless, providing education and doing R&D represent joint production processes at universities and it is practically impossible to completely separate them in terms of inputs and outputs. In fact, their joint character is still partially present in our DEA models as well. For instance, doctoral students are included to the adjusted number of students as an output of educational DEA model although they are primarily expected to do the research during their study. On the other hand, financial funds received from educational grants and publications intended to support education are involved in the DEA model assessing the efficiency of HEIs in R&D.

5. Conclusion

In the paper we summarized the results of empirical research on the productivity of Slovakian public HEIs in providing education and doing R&D. We focused on their productivity change over the period of 2009-2016. We intended to find out whether the introduction of competitive principle to the allocation of subsidies from the state budget and other changes of the whole economic conditions for public HEIs in Slovakia, implemented before and during the period, actually led to the increase of their productivity. Although the impact of economic conditions on the productivity can be hardly separated from that of other influential factors, e.g. demographic trends and accreditation rules, the analysis reveals significant differences in productivity change between the two core areas of performance as well as among individual universities.

In order to assess the productivity changes, we applied measures of different types. Simple ratio indicators relating a key output to a key input of education or R&D were used to visualise and compare the productivity of individual universities. Their shares on the total performance of all considered public HEIs gave us an information on the development of their position in the higher education market in Slovakia over the period. Data envelopment analysis helped us to evaluate the relative efficiency of individual universities within the whole group of selected public HEIs, with multiple inputs and outputs considered at a same time. DEA efficiency scores were also used to calculate Malmquist index and its components in order to capture the total productivity changes over the period and determine their reasons.

For the study of productivity in education, we contrasted the real number of students or the total educational performance estimated by the number of students adjusted regarding to the form of study and economic demands of their study programs, with the teaching staff. When calculating efficiency scores and Malmquist index, we also incorporated to DEA models the employment of graduates as an important external indicator of the quality of education.

The productivity of public HEIs in R&D was estimated by their ability to produce highly influential publications for both educational and scientific purposes that was contrasted with their significant personnel and financial resources devoted to R&D. i.e. the whole academic staff and the funds received in the form of grants from domestic and foreign research agencies and cooperating organizations.

The main contribution of the paper consists in the assessment of productivity changes with different methods that provide a complementary information on the current state and development trends in productivity with regard to specific national context. The empirical

results may serve the university managements in searching the measures for improvement their performance productivity and efficiency.

A low number of public HEIs in Slovakia along with their heterogeneity as for the specialization in different areas of science represent the main restrictions for the analysis. However, the research may be extended in several directions. In order to evaluate the effectiveness of the funding system implemented in Slovakia on the productivity of public HEIs, the comparison with foreign universities in countries with similar environment is worth studying. Useful results for managerial purposes may also arise from productivity analysis of the performance of faculties specialized in the same branch of science. The identification of steady trends and their explanation require a longer period for studying the behaviour of public HEIs and is another challenge for further research.

Acknowledgements

The paper was prepared with the support of the grant VEGA No. 1/0843/18 Methodological aspects of DEA application on efficiency assessment of production units.

References

[1] Abbott, M., Doucouliagos, C. 2003. The efficiency of Australian universities: a data envelopment analysis. Economics of Education Review, vol. 22, issue 1, pp. 89-97.

[2] Andersson, C., *et al*. 2016. Technical efficiency and productivity for higher education institutions in Sweden. Scandinavian journal of educational research, vol. 61, issue 2, pp. 205-223.

[3] Cooper W. W., Seiford L. M., Tone K. 2007. Data Envelopment Analysis: A Comprehensive Text with Models, Applications, References and DEA-Solver Software. Springer, Heidelberg.

[4] Grausová, M., Hužvár, M., Rigová. Z. 2017. Efficiency assessment of Slovakian universities. Wrocław : Wrocław university of economics. ISBN 978-83-7695-693-0. pp. 195-206.

[5] Johnes, J. 2006. Data envelopment analysis and its application to the measurement of efficiency in higher education. Economics of Education Review, vol. 25, issue 3, pp. 273-288

[6] Korhonen P. J., Luptáčik, M. 2004. Eco-Efficiency Analysis of Power Plants: An Extension of Data Envelopment Analysis. European Journal of Operational Research, vol. 154, issue 2, pp. 437-446.

[7] Sagarra, M., Mar-Molinero, C., Agasisti, T. 2017. Exploring the efficiency of Mexican universities: Integrating Data Envelopment Analysis and Multidimensional Scaling. Omega, vol. 67, pp. 123-133.