THE COMPETITIVENESS OF BELARUSIAN HEIs IN THE KNOWLEDGE-BASED INFORMATION ECONOMY

Alexander Gedranovich
gedranovich@gmail.com
Volha Hedranovich
volavada@gmail.com
Minsk Institute of Management

ABSTRACT:
The definition of competitiveness of higher educational establishment in the context of the knowledge-based information economy is given. A new set of competitiveness indices for universities, based on data envelopment analysis is proposed. The methodology allows to estimate the efficiency of universities in utilizing their recourses (human capital, physical capital and financial capital) for teaching and research activities.

KEYWORDS: Competitiveness; Higher education; Knowledge-based information economy; Data envelopment analysis.

1. INTRODUCTION

Today, it is worth remembering that the development of a modern “knowledge economy” reflects a larger transition from an economy based on land, labour and capital to one in which the main components of production are information and knowledge. Because of that, the most effective modern economies will be those that produce the most information and knowledge – and make that information and knowledge easily accessible to the greatest number of individuals and enterprises [1, P. 2]. The higher educational institutions (HEIs) are who called upon to settle this task in the first place.

The level of competition at the market of educational services is growing both in individual countries and in the world in whole. Recognizability of the higher educational institutions, the prestigiousness of their services and the reputation at the national and international market are getting the key factors of HEIs’ competitive success.

Of particular importance is the competitiveness when rendering international education services. A market of such services is at the stage of intensive growth due to the rising demands for the international mobility of students. So, as of 2001 there were an estimated 1.91 million foreign students, but in 2007, their numbers have risen to 3,100,000 [2].

It should be noted that a fundamental rethinking of HEIs’ competitiveness comes over in modern economic science. It takes place due to the transformation of the modern system of management in the knowledge-based information economy.

In order to define a HEI competitiveness in full measure it is proposed to consider it as a composite description of HEI for a certain period of time in a particular market, reflecting superiority to competitors on a number of key parameters – financial and economic, marketing, logistical, personnel and socio-political – as well as the ability of HEI to a crisis-free functioning and timely adaptation to changing ambient conditions [3, P. 71].

There are universal factors of competitiveness, which are applicable to HEIs [4]:

– staff recruitment and motivation policy;
– lifelong professional development of personnel;
– development strategy availability;
– low costs;
– high quality of service;
– diversification of product;
– current technologies possession;
– unique production;
– foreign markets entry.

Further to these, there are particular HEIs' factors of competitiveness, such as:

– number of professors per student;

– development level of a web-site;

– publication and research activity.

Unfortunately, not all of these factors can be measured in any scale. Rest of them can be used to construct indices of competitiveness. The higher education sector, however, has some features which make it difficult to measure competitiveness: it is non-profit making; HEIs produce multiply outputs from multiply inputs; it is multi-purposed.

An assortment of methodological approaches has been employed in an effort to resolve the problem of HEIs' competitiveness estimation: rankings, based on simple weighted convolution [5]; statistical methods, such as cluster analysis [6] or ordinary least squares [7]; frontier methods, such as data envelopment analysis [8], free disposal hull [9] or stochastic frontier analysis [10].

The purpose of this paper is to explore the issue of the measurement of competitiveness in the context of higher education. We suggest that competitiveness of HEIs in long-run perspective is very closely interrelated to their performance. It allows us to apply DEA analysis to measure the indices of competitiveness.

The paper is in five sections of which this is the first. Section 2 provides a brief overview of methodology of analysis and presents the nonparametric method DEA in details. The procedures for collecting the data as far as its descriptive statistics are presented in Section 3. Section 4 introduces the results of applying DEA to the data set of 50 Belarusian universities. Section 5 concludes.

2. METHODOLOGY

The theoretical basis of modern-effectiveness analysis, based on the consideration of production as a set of processes, was laid in the works of Koopmans [11] and Debreu [12]. Farrell [13] suggested the introduction of a universal index for measuring the effectiveness of an arbitrary production unit (DMU – Decision Making Unit) "from the studio to the whole economy", which makes some input factors or resources (inputs) in the output factors or products (outputs).

A set of production Ψ in terms of the Farrell-Debreu can be described as follows:

$$\Psi = \left\{(x, y) \in \mathbf{R}_{+}^{p+q} \mid x \text{ can produce } y\right\}, \tag{1}$$

where $x \in \mathbf{R}_{+}^{p}$ – is a vector of p inputs, $y \in \mathbf{R}_{+}^{q}$ – is a vector of q outputs.

Koopmans introduced the concept of input and output orientation of model. Input orientation implies that the output variables are fixed and the task is to minimize inputs, i.e. to solve the problem of search for "function of the minimum cost of production" or "minimum use of resources". Output-oriented model, by contrast, is looking for maximum production with fixed resources. In order to assess the competitiveness of Belarusian universities output orientation suits better, because resources of HEIs are fixed in the short term.

For a set of production Ψ metrics for Farrell output efficiency of a production unit $\lambda(x, y)$ are defined as follows:

$$\lambda(x, y) = \sup\{\lambda \mid (x, \lambda y) \in \Psi\}, \tag{2}$$

where $\lambda(x, y) = 1$ means belonging DMU to a production frontier, and $\lambda(x, y) > 1$ points to the possible proportional increase in production in case of elimination of inefficiencies.

In practice, production set Ψ and hence the efficiency metric $\lambda(x, y)$ is unknown, so the problem of their evaluation on a set of experimental data χ_n arises:

$$\chi_n = \left\{(x_i, y_i), i = \overline{1, n}\right\} \tag{3}$$

where n – number of investigated production units.

Existing approaches to the construction of a production frontier can be divided into parametric and nonparametric, as well as stochastic and deterministic. Parametric methods require *a priori* specification of functional relationship between resources and food production units; in non-parametric methods such limitation is absent. In the case of stochastic production frontier the presence of noise and errors in the data is allowed, the deterministic approach assumes that all the experimental points belong to the set of production $(x_i, y_i) \in \Psi, i = \overline{1,n}$, i.e. the possibility of noise presence is excluded.

In this paper we apply nonparametric deterministic methods, among the main benefits of which is possibility to identify a small number of restrictions on the set of production (usually convexity and free disposability), option to calculate the efficiency in case of multiple input and multiple output variables simultaneously, identifying the most efficient production frontier that can be achieved in practice, the calculation of simple indices of efficiency for each production unit, the presence of models with input and output orientations.

One of the most common way to estimate a deterministic production frontier and efficiency metrics is data envelopment analysis (DEA), introduced by Charnes, Cooper and Rhodes [14]. Under this method we can construct a piecewise linear production frontier on experimental data with respect to which the efficiency of DMU can be measured. In an early version of the DEA, which is also called CCR – the first letters of the names of its authors, – it was assumed constant return to scale on the final product (CRS – Constant Returns to Scale). In Banker, Charnes and Cooper [15] DEA model was modified to account for the variable return to scale (VRS – Variable Returns to Scale). This version is often referred to as the BCC model.

Estimation of feasible production set for a given observations $\hat{\Psi}_{DEA}(\chi_n)$ using DEA-model can be obtained from the following expression:

$$\hat{\Psi}_{DEA}(\chi_n) = \left\{ (x, y) \in \mathbf{R}_+^{p+q} \mid y \le \sum_{i=1}^{n} \gamma_i y_i, x \ge \sum_{i=1}^{n} \gamma_i x_i, \sum_{i=1}^{n} \gamma_i = 1, \gamma_i \ge 0, i = \overline{1,n} \right\} \tag{4}$$

where γ_i – some weighting factor for the first production unit, calculated to the experimental data. Value (4) corresponds to the model with the variable effects of scale. CCR-model differs from the BCC-model, only with the lack of equality $\sum_{i=1}^{n} \gamma_i = 1$. Comparison of the results from two models for the constant and variable return to scale allows considering if DMU is in optimal size of production, i.e. scale efficient.

For a given experimental point (x_0, y_0) which corresponds to DMU0, output efficiency metric $\hat{\lambda}(x_0, y_0)$ as defined by Farrell can be written as:

$$\hat{\lambda}(x_0, y_0) = \max_{\gamma_1, \gamma_2, \ldots \gamma_n} \left\{ \lambda \ge 1 \mid (x_0, \lambda y_0) \in \hat{\Psi}_{DEA}(\chi_n) \right\} \tag{5}$$

$\hat{\lambda}(x_0, y_0)$ is called the technical efficiency for DMU0 or efficiency metric of Farrell. In [15] is showed that DMU0 would be effective in case that its technical efficiency is equal to 1 (i.e. DMU0 is on the production possibility frontier), and limitations on resources and output in (4) take the form of equity. In the case when technical efficiency is greater than 1, DMU0 is inefficient, and removal of this inefficiency (i.e., moving to the frontier of production possibility frontier) leads to a proportional increase in product by value of $\hat{\lambda}(x_0, y_0)$.

In case of input-oriented model, the efficiency Farrell's metric $\hat{\theta}(x_0, y_0)$ takes values from 0 to 1 and indicates how DMU0 may proportionately reduce the use of their resources for a fixed amount of production. Often in practice the metric defined by Shephard [16] used instead, which is the reciprocal to the Farrell's metric.

Data envelopment analysis in recent years become a popular tool for evaluating the efficiency of various production units, including universities, for example, see [8]. However, DEA – is not the only nonparametric deterministic method of constructing the production frontier. Thus, the widely known method of free disposal hull (FDH) [17]; robust methods for assessing the production boundaries has been actively developed, for example, the model known as *order-m* [18].

One of the main drawbacks of nonparametric deterministic methods is the difficulty in constructing the statistical findings for performance evaluations, as their properties are still not fully explored [19]. Nevertheless, there is a method for identifying outliers in the experimental data [20] using the *order-m* model. Pastor [21] proposed the test to estimate the significance of variables for nested DEA-models. Using bootstrap methods adapted for the DEA-models by Simar and Wilson [19] it is possible to construct confidence intervals for the efficiency metrics for DMUs.

3. DATA DESCRIPTION

To construct the indices of competitiveness, without loss of generality, we select data from the HEIs' survey of the Republic of Belarus for the 2006/2007 academic year. After excluding universities, for which no data were available, and universities that are not functioning at present, we consider the remaining 50 HEIs.

Traditionally, the analysis of resources of universities distinguishes the following micro-indices: faculty and students (*Human capital*), logistical and information base (*Physical capital*), financial resources (*Financial capital*) [8].

Were considered following parameters in the first micro-index: full-time equivalent of faculty (*TEACHERS*), the number of administrators (*ADMIN*), adjusted number of students (*STUDENTS*), calculated as the total number of full-time students plus the half of the number of part-time students. In forming the second micro-index we took into account such indicators as: total area of teaching and laboratory facilities of HEI (*SPACE*), the number of units of literature in the university libraries (*VOLUMES*) and the total number of computers in HEI (*COMPUTERS*). To assess the financial capital of educational institutions there were involved expenditures on salaries of faculty (*EXP_SALARY*), the cost of research work (*EXP_RESEARCH*) and the cost of updating the library collection and equipment (*EXR_LIBRARY_EQUIP*).

The performance of universities can be evaluated by three micro-indices: training (*Teaching*), scientific activity (*Research*) and international activity (*International*). The adjusted number of high school graduates (*GRADUATES*) was one of the best indicators for assessing the productivity of training specialists. The impact of scientific activity was measured by quantity of publications by academic staff and postgraduate students. In our work we included into publications articles in refereed journals recommended by the Higher Attestation Commission of the Republic of Belarus (*ARTICLES*) and the number of books with the stamp of the Ministry of Education of the Republic of Belarus (*BOOKS*). International activity was evaluated as a proportion of foreign students in the total number of students (*FOREIGN_STUD*).

In order to reduce the dimension of data we used Pastor's test for nested DEA-models [20], applied to every single variable in full model. As a result of the review variables *ADMIN*, *COMPUTERS*, *VOLUMES* and *FOREIGN_STUD* were excluded as insignificant. Variables related to financing were merged into one – *EXPENDITURES*, and variables *ARTICLES* and *BOOKS* were united in *PUBLICATIONS*. We performed tests with recommended parameters $\overline{\rho} = 1.1$ and $p_0 = 0.15$. P-values for all tests after which variables were excluded were less than 0.10. Descriptive statistics for the remaining variables is shown in Table 1.

Table 1. Descriptive statistics of model variables

Variable	Average	Median	Maximum	Minimum	St. Dev
Inputs:					
TEACHERS	413	318	1 826	35	358
STUDENTS	4 686	3 608	20 955	284	4 200
SPACE	18 733	13 196	84 347	2 075	17 971
EXPENDITURES	3 380	1 897	29 659	174	5 670
Outputs:					
GRADUATES	925	778	4 182	58	894
PUBLICATIONS	372	150	4 197	3	665

TEACHERS – full-time equivalent of faculty; *STUDENTS* – full time equivalent of students; *SPACE* – total area of teaching and laboratory facilities; *EXPENDITURES* – aggregated expenditures on salaries of faculty, cost of research work and the cost of updating the library collection and equipment; *GRADUATES* – full-time equivalent of graduates; *PUBLICATIONS* – total number of refereed articles and published books.

4. RESULTS

All calculations were performed with FEAR library [22] for the statistical package R [23].

We constructed indices of competitiveness via evaluating technical efficiency (5) for HEIs data. This model was output-oriented with a constant returns to scale (CRS).

Simar and Wilson [19] described a method of constructing confidence intervals for technical efficiency using the bootstrap. We run this bootstrap-procedure for 2000 samples and constructed confidence interval with significance of 0.05. The calculation was performed for Farrell's efficiency metric, which indicates how much the university can increase its production if approached production frontier, and for the metric Shephard (inverse) – denotes the fraction of possible product from the university. Thus, if the technical efficiency by

Farrell is 1, then the entire university is using all available resources to implement its activities in two main directions. If the metric Farrell is, for example 2, it means that with available resources university can increase the efficiency in 2 times, but it needs to get rid of inefficiency – institutional and other impediments to producing graduates and publishing scientific papers. The results are presented in Table 2, the names of universities are shown as Russian abbreviations.

Table 2. Indices of competitiveness and their confidence intervals for Belarusian HEIs, 2002/2003 academic year

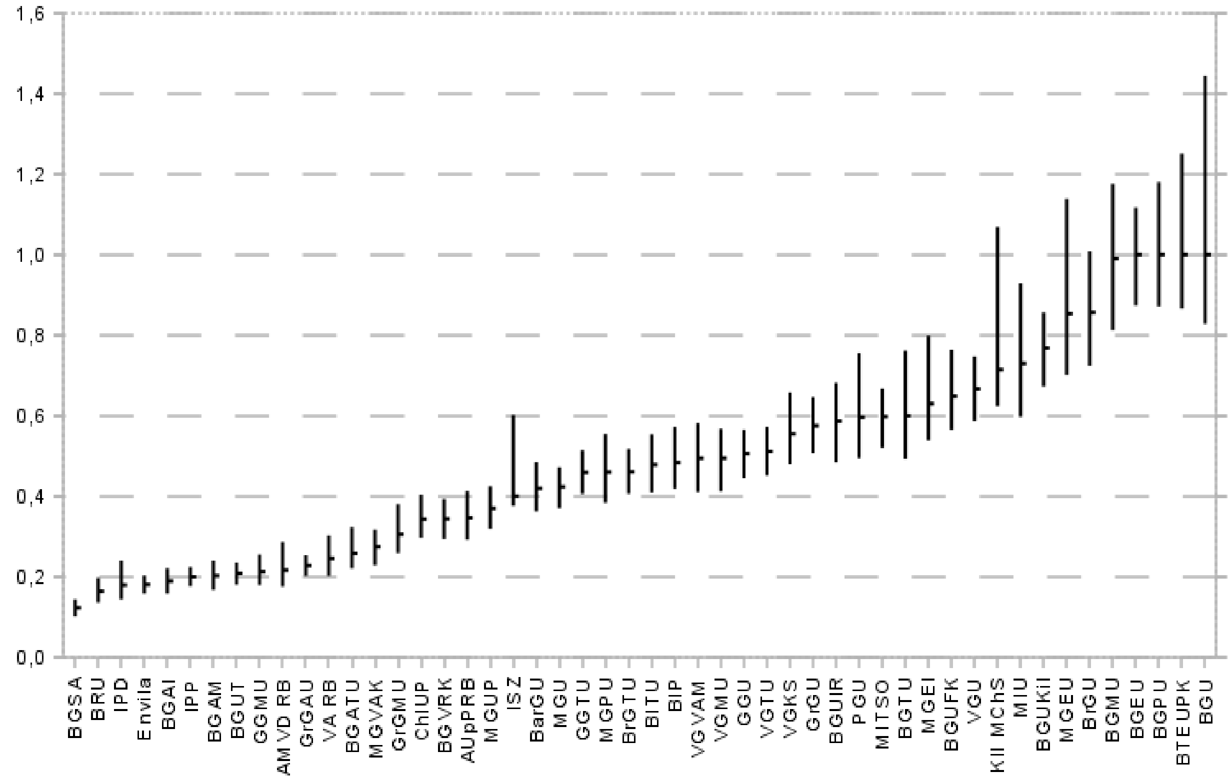
HEI	Type	Farrell's metric			Shephard's metric		
		Index	Lower limit of conf. interval	Upper limit of conf. interval	Index	Lower limit of conf. interval	Upper limit of conf. interval
AMVD RB	Public	4.6275	3.4953	5.7146	0.2161	0.1750	0.2861
AUpPRB	Public	2.8877	2.4257	3.4295	0.3463	0.2916	0.4123
BarGU	Public	2.3878	2.0653	2.7648	0.4188	0.3617	0.4842
BGAI	Public	5.2994	4.5366	6.3258	0.1887	0.1581	0.2204
BGAM	Public	4.9505	4.1733	6.0063	0.2020	0.1665	0.2396
BGATU	Public	3.8835	3.0947	4.5418	0.2575	0.2202	0.3231
BGUFK	Public	1.5432	1.3090	1.7729	0.6480	0.5641	0.7639
BGVRK	Public	2.9129	2.5466	3.4055	0.3433	0.2936	0.3927
BGMU	Public	1.0096	0.8506	1.2312	0.9905	0.8122	1.1757
BGPU	Public	1.0000	0.8473	1.1478	1.0000	0.8712	1.1803
BGSA	Public	8.1566	6.9773	9.8993	0.1226	0.1010	0.1433
BGTU	Public	1.6672	1.3130	2.0297	0.5998	0.4927	0.7616
BGU	Public	1.0000	0.6925	1.2076	1.0000	0.8281	1.4441
BGUIR	Public	1.7068	1.4678	2.0685	0.5859	0.4835	0.6813
BGUKiI	Public	1.3014	1.1681	1.4876	0.7684	0.6722	0.8561
BGUT	Public	4.7985	4.2504	5.5567	0.2084	0.1800	0.2353
BGEU	Public	1.0000	0.8955	1.1449	1.0000	0.8735	1.1167
BIP	Private	2.0691	1.7478	2.3938	0.4833	0.4177	0.5722
BITU	Public	2.0925	1.8070	2.4453	0.4779	0.4090	0.5534
BrGTU	Public	2.1716	1.9334	2.4633	0.4605	0.4060	0.5172
BrGU	Public	1.1677	0.9918	1.3820	0.8564	0.7236	1.0083
BRU	Public	6.1087	5.0817	7.4040	0.1637	0.1351	0.1968
BTEUPK	Private	1.0000	0.7994	1.1552	1.0000	0.8656	1.2509
VA RB	Public	4.0850	3.3086	4.9656	0.2448	0.2014	0.3022
VGVAM	Public	2.0243	1.7209	2.4405	0.4940	0.4098	0.5811
VGKS	Public	1.8051	1.5205	2.0854	0.5540	0.4795	0.6577
VGMU	Public	2.0239	1.7635	2.4294	0.4941	0.4116	0.5670
VGTU	Public	1.9577	1.7478	2.2160	0.5108	0.4513	0.5721
VGU	Public	1.5006	1.3387	1.7057	0.6664	0.5863	0.7470
GGMU	Public	4.7148	3.9295	5.5838	0.2121	0.1791	0.2545
GGTU	Public	2.1791	1.9447	2.4645	0.4589	0.4058	0.5142
GGU	Public	1.9782	1.7721	2.2521	0.5055	0.4440	0.5643
GrGAU	Public	4.4014	3.9567	4.9629	0.2272	0.2015	0.2527
GrGMU	Public	3.2765	2.6311	3.8699	0.3052	0.2584	0.3801
GrGU	Public	1.7403	1.5481	1.9751	0.5746	0.5063	0.6459
IPD	Private	5.5835	4.1779	6.9845	0.1791	0.1432	0.2394
IPP	Private	5.0125	4.4730	5.6745	0.1995	0.1762	0.2236
ISZ	Private	2.5000	1.6611	2.6611	0.4000	0.3758	0.6020
KII MChS	Public	1.4000	0.9355	1.6039	0.7143	0.6235	1.0689
MGVAK	Public	3.6483	3.1574	4.3914	0.2741	0.2277	0.3167
MGPU	Public	2.1749	1.8045	2.6063	0.4598	0.3837	0.5542
MGU	Public	2.3646	2.1219	2.7047	0.4229	0.3697	0.4713
MGUP	Public	2.7071	2.3567	3.1372	0.3694	0.3188	0.4243
MGEI	Private	1.5883	1.2524	1.8577	0.6296	0.5383	0.7985
MGEU	Public	1.1723	0.8785	1.4265	0.8530	0.7010	1.1383
MITSO	Private	1.6734	1.4998	1.9232	0.5976	0.5200	0.6667
MIU	Private	1.3710	1.0773	1.6745	0.7294	0.5972	0.9283
PGU	Public	1.6784	1.3240	2.0247	0.5958	0.4939	0.7553
ChIUP	Private	2.9189	2.4780	3.3729	0.3426	0.2965	0.4036
Envila	Private	5.5463	4.9312	6.3325	0.1803	0.1579	0.2028

Generally, as of 2006/2007 academic year, the productivity of Belarusian HEIs was low. Only 8 universities out of 50 exceeded the threshold of 0.75 for the Shephard's efficiency metric, and 13 universities had the value of this metric between 0.5 and 0.75.

Also we can note very slight differences between public and private universities in terms of competitiveness. Despite leaders are public universities, private schools introduced proportionally in this ranking. Thus, 2 of 10 best HEIs as far as 4 of best 20 are private. Given the total number of private universities is 10 – it is quite an unexpected result. Moreover, public universities' average score was 0.4948 (standard deviation – 0.2542) while private average – 0.4741 (standard deviation – 0.2540). So, we can't reject null hypothesis that averages are the same at significance level of 0.8197.

Figure 1 shows the confidence intervals of the Shephard's metric for the index of competitiveness. If for some universities the confident intervals intersect, then we can say that the baseline data is not sufficient to draw conclusions about the difference in the competitiveness of these institutions. You can also note that the intervals for leading universities do not intersect with the intervals for outsiders.

Figure 1. Confidence intervals of indices of competitiveness of Belarusian universities, 2006/2007 academic year.



5. CONCLUSION

Thus, the authors propose a method of competitiveness indices of universities construction, based on the DEA scores. Unlike methods based on weighted linear convolution, this approach allows to evaluate how effectively educational institutions use their resources to achieve the targets.

As the most important resources, disposable by universities, the authors propose to use the full-time equivalents of faculty and students, a total area of teaching and laboratory facilities and expenditures on faculty's salary, purchasing of equipment and maintenance of the library collection.

To assess the impact of HEIs' activity we use two indicators: the adjusted number of graduates and total number of published articles in refereed journals and academic published books with the stamp of the Ministry of Education.

Calculation of the experimental index of competitiveness for Belarusian universities for the 2006/2007 academic year has shown that this technique can be used to assess the effectiveness of resource usage by HEIs. In particular, the analysis has shown that difference between competitiveness of private and public schools in terms of resources utilization is merely non-existent.

6. REFERENCES

1. Schleicher, A. The economics of knowledge: Why education is key for Europe's success / A. Schleicher // Lisbon Council Policy Brief, 2006. – 18 p.
2. Education & Skills [Electronic source] / OECD. – Source OECD. – Access mode: http://www.sourceoecd.org/9789264024755. – Access date: 26.11.2009.
3. Lazaryev, V.A. The competitiveness of the university as an object of management / V.A. Lazaryev, S.A. Mokchnachev // Ekaterinburg: Prigorodnyje vesti, 2003. – 160 p.
4. Success factors in small and medium business [Electronic source] / IPM Research Center. – Minsk, 2007. – Access mode: http://research.by/rus/surveys/cf8d430297c09de2.html – Access date: 30.05.2010.
5. Turner, D. World university rankings / D. Turner // International Perspectives on Education and Society, 2008. – Vol. 9. – P. 27–61.
6. Rodgers, J. A Multi-Dimensional Ranking of Australian Economics Departments / J. Rodgers, A. Valadkhani // Economic Record, Blackwell Synergy, 2006, – Vol. 82. – P. 30-43.
7. Johnes, J. Performance indicators in higher education: UK universities / J. Johnes, J. Taylor // Milton Keynes: Open University Press and The Society for Research into Higher Education, 1990.
8. Bonaccorsi A., Daraio C, and Simar L. Advanced indicators of productivity of universities: An application of robust nonparametric methods to Italian data // Scientometrics, 2006. – №66(2). – P. 389-410.
9. Gedranovich, A.B. Can Belarusian Universities Benefit from Economies of Scale? / A.B. Gedranovich // Computer Data Analysis and Modeling: Complex Stochastic Data and Systems: Proceedings of the Eighth International Conference, Minsk, September 11-15, 2007. In 2 volumes. Vol 2. – Minsk: Publishing center BSU, 2007. – P. 96-99.
10. Izadi, H. Stochastic frontier estimation of a CES cost function: The case of higher education in Britain / H. Izadi, G. Johnes, R. Oskrochi and R. Crouchley // Economics of Education Review, 2002. – Vol. 21. – P. 63-71.
11. Koopmans, T. Activity Analysis of Production and Allocation / T. Koopmans // An Analysis of Production as an Efficient Combination of Activities. – John-Wiley and Sons, 1951.
12. Debreu, G. The coefficient of resource utilization / G. Debreu // Econometrica, 1951. –Vol. 19. – P. 273-292.
13. Farrell, M. The Measurement of Productive Efficiency Journal of the Royal Statistical Society / M. Farrell // Series A (General), JSTOR, 1957, – Vol. 120, – P. 253-290.
14. Charnes A., Cooper W.W., and Rhodes E. Measuring the efficiency of decision making units // European Journal of Operational Research, 1978. – №2(6). – P. 429-444.
15. Banker R.D., Charnes A., and Cooper W.W. Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis // Management Science, 1984. – №30(9). – P. 1078-1092.
16. Shephard, R.W. Theory of Cost and Production Functions / R.W. Shephard. – Princeton: Princeton University Press, 1970.
17. Deprins D., Simar L., and Tulkens H. The Performance of Public Enterprise: Concepts and measurements, chapter Measuring labour efficiency in post offices, Amsterdam, North-Holland, 1984. – P. 243-267.
18. Cazals C, Florens J.P., and Simar L. Nonparametric frontier estimation: a robust approach // Journal of Econometrics, 2002. – №106(1). – P. 1-25.
19. Simar L. and Wilson P.W. Statistical Inference in Nonparametric Frontier Models: The State of the Art // Journal of Productivity Analysis, 2000. – №13(1). – P. 49-78.
20. Simar L. Detecting Outliers in Frontier Models: A Simple Approach // Journal of Productivity Analysis, 2003. – №20(3). – P. 391-424.
21. Pastor J.A.T., Ruiz J.A.L., and Sirvent I. A Statistical Test For Nested Radial Dea Models // Operations Research, 2002. – №50(4). – P. 728-735.
22. Wilson Paul W. FEAR: Frontier Efficiency Analysis with R, 2006. R package version 1.0.
23. Team R Development Core. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria, 2006.
ISBN 3-900051-07-0.