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Assessment of the impact of public higher education institutions on innovative activity in St. Petersburg

Evaluación del impacto de las instituciones públicas de educación superior en la actividad innovadora en San Petersburgo

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ABSTRACT:
This study tests the hypothesis that there is a relationship between the performance indicators of higher education institutions and the regional innovative activity using Data Envelopment Analysis. The study substantiates the need to divide the total innovative activity of a region, with the participation of universities, into two stages: the creation of knowledge by universities and the commercialization of knowledge. The results of the study expand the possibilities of identifying the most effective mechanisms of interaction between the participants to the regional innovation system in implementing an innovative development strategy.
Keywords: higher education institution, innovations, innovation activity, region

RESUMEN:
Este estudio prueba la hipótesis de que existe una relación entre los indicadores de desempeño de las instituciones de educación superior y la actividad innovadora regional utilizando el Análisis de Envoltura de Datos. El estudio confirma la necesidad de dividir la actividad innovadora total de una región, con la participación de las universidades, en dos etapas: la creación de conocimiento por parte de las universidades y la comercialización del conocimiento. Los resultados del estudio amplían las posibilidades de identificar los mecanismos más efectivos de interacción entre los participantes con el sistema regional de innovación para implementar una estrategia de desarrollo innovadora.
Palabras clave: institución de educación superior, innovaciones, actividad de innovación, región

1. Introduction

Today, the transition to an innovative way of development is Russia's main strategic objective. Innovations are the key tool, which will allow to ensure and implement the competitive advantages of the country and its certain territories in the long run. The basis for innovation is new knowledge generated and then commercialized by various institutions (Kudryavtseva et al., 2017; Yuryevna et al., 2016).

The activities of the higher education institutions can be considered as an important channel for the transfer of knowledge, manifested in the process of training students, developing the potential of innovators, improving the qualitative characteristics of the workforce. Application-oriented studies are carried out in universities, and for their industrial implementation as intermediate structures business incubators and technoparks are created. Opportunities for collaboration between higher

education institutions and businesses based on the concept of public-private partnerships are considered (Sharafanova et al., 2017). Departments are established on the basis of the enterprise-participants of innovative territorial clusters. In addition, it should be noted that studies carried out by universities have the spillover effect: the information collected and used for the implementation of a specific project (or activity) creates new opportunities for applying this knowledge in other areas. Scientific activities of employees of higher education institutions, their publications, participation in conferences, forums and symposiums promote access to knowledge, which can be effectively used by commercial organizations (Guzikova and Plotnikova, 2017; Goncharova et al., 2017).

To assess the performance of higher education institutions, a lot of methods and ratings are used. The analysis of such approaches, highlighting their strengths and weaknesses is given in the works of Russian researchers, including Velichenkova, Rodionov and Skhvediani (2017). Despite numerous ratings and indicators available today, the issue of developing a methodology for assessing the contribution of the higher education system to regional innovation development remains rather significant both from scientific and practical standpoints.

The purpose of this study is to assess the impact of the operating performance of public higher education institutions on the rates of innovative activity of regions through the use of methods of mathematical modeling.

To achieve this purpose the following tasks have been completed:

- On the basis of the analysis of Russian and foreign scholarly writings on the assessment of the impact of universities on regional development, to reveal and justify both factors and outputs (result indicators);

- On the basis of the two-stage model of Data Envelopment Analysis, to identify the factors that have the greatest correlation with the results of innovation activity in the region;

- To formulate recommendations for the development of the most effective mechanisms and tools for cooperation between the participants of the innovation system of the region in the context of the implementation of the strategy of innovation-driven development of the regions.

The study consists of an introduction, justifying the relevance of the chosen theme, the literary review, in which the views of different scholars on the issue of assessing the impact of universities on regional development are represented, and hypotheses' outlining. Further, the paper describes the data used and the method of the study, as well as the results obtained.

1.1. Assessment of the impact of higher education institutions on innovative activity of the region. Main theoretical aspects

Numerous academic papers are devoted to the connection of innovation with the higher education sector. Let us review and summarize the most important of them.

When analyzing the papers on the experience of assessing the impact of universities on regional development, the first study to be considered is the study conducted by B. Clark (1983), who defined the so-called triangle of coordination – Science, Business and the State. According to the researcher, the interaction of these parties has an impact on the modern university and defines a vector of its institutional dynamics. As key characteristics of the entrepreneurial university, the author emphasizes "reliance on innovation, university's own capabilities, personnel competence, delegating of rights and responsibilities to executors, flexible network building, consumer orientation, ability to operate in high-risk environments and dynamic demand, cost efficiency" (Clark, 1983). Thus, only the proactive position of the university in relation to business and the state (including at the regional level) can provide an opportunity for successful functioning under current conditions.

The academic paper by H. Etzkowitz and L. Leydesdorff (1995) is dedicated to the interaction and interconnection of the university, private business and the government. This study is related to the development of the theory of Triple Helix, describing a model of balanced interaction of major institutions, which are key elements of the innovation system. As part of the model, the emphasis is placed on the network nature of the interaction between participants of the innovation process as universities create ideas, the business provides resources and the state forms a legal environment. Thus, three spectra of intersectional relations – intra-firm, intra-state and intra-university, as well as hybrid institutional forms, which make it possible to reduce uncertainty, are created.

There is need to highlight the methodology for analyzing the processes of interaction between higher education institutions and the regions, which was developed in the framework of the project "Review of the role of higher education institutions in regional development" implemented by the

program "Institutional management in higher education" (Higher Education and Regions. Globally Competitive, Locally Engaged) of the Organization for Economic Cooperation and Development. Originally, the methodology of this project was based on a closed model of interaction between the higher education institution and the region. The study involved 14 regions in 12 countries participating in the project. In this regard, the study subjected three universally recognized functions of higher education institutions: implementation of the education, research activities and actions concerning addressing socio-economic challenges of the society in combination with basic regional development indices: innovation, skills and competencies, cultural identity, social cohesion and stability in the region. Later, J. B. Goddard and P. Chatterton (2000) supplemented this model with national and global contexts that influence the process of cooperation of higher education institutions and regions (the concept of "educational region"). This methodology helps to develop effective recommendations on the formulation and implementation of strategies aimed at enhancing the contribution of higher education institutions to the social, economic and cultural development of regions for national and regional education authorities.

American scientists Anselin, Varga and Acs (1997) investigated the impact of universities on regional development as the interaction between small- and medium-sized businesses and research laboratories. The study was conducted in 125 agglomerations of 43 US states. Scientists found a strong positive correlation between studies carried out by universities, their innovative activities and the R&D activities of companies.

The study by Belderbos, Carree and Lokshin (2004) is based on the investigation of the impact of cooperation of the four types of R&D partners in innovation on the business performance of the firm. The study revealed that the cooperation of universities, as well as cooperation with competitors, plays an important role in the creation of innovations, generating sales of innovative products that improve the growth rates of firms. In addition, clients and universities are important sources of knowledge for firms pursuing radical innovations that promote the growth of innovative sales in the absence of official R&D cooperation.

The influence of academic knowledge and technology transfer on the performance indicators of private companies was also considered by Swiss scientists, Arvanitis, Sydow and Wörter (2005). The researchers determined that the knowledge and experience gained by the firm are not replaced but rather supplemented. This has a positive effect both on the intensity of the research activity of the firm and the sales of innovative products. The fact that cooperation with universities has a positive effect on the probability of using patents in commercial production by firms has been proven by Miotti and Sachwald (2003), as well as Lööf and Broström (2008).

Cowan and Zinovyeva (2008) undertook a short analysis of the impact of universities on regional innovations. The resulting econometric model made it possible to prove the hypothesis that the establishment of new departments actually influences the innovative activities of the region.

Ponds, Oort and Frenken (2009) studied the spillover effect in the context of geographical constraints. As a result of the study, the differences in the potential of innovative development of regions were explained by agglomeration economies, giving benefits to firms that are located in areas with a large number of identical firms and universities.

In the study of the German scientists M. Schwartz et al. (2012), the existence of a positive impact of scientific research in universities on regional innovation processes was empirically proved. According to the authors, this is because higher education institutions can provide access to certain equipment and infrastructure unavailable for private business, as well as provide entrepreneurs with advanced scientific knowledge and experience in particular technological areas.

1.2. Hypothesis setting

Based on the analysis of academic papers on the issue under study, we came to the conclusion, that there is a research gap in the application of non-parametric approach – the two-stage model of Data Envelopment Analysis aimed to examine the impact of higher education institutions on innovation development in St. Petersburg. Being a city of federal significance, St. Petersburg is one of the largest centers of academic, industrial and university science, where scientific and technological achievements in various fields are generated. Hence, the following hypotheses have been formulated:

1. In St. Petersburg, innovation activity is determined by the performance indicators of higher education institutions located in the area.

2. For the assessment, it is necessary to carry out two successive stages, dividing the factors under study into resource-factors (basic at the stage of knowledge creation) and resource-result factors (in the stage of creating knowledge and basic at the stage of innovation commercialization), as well as

the factors, which are the results of the stage of commercialization of innovations at the regional level.

2. Data and method

Before proceeding to the description of the method used in this study, it is necessary to assess the context, in which the methodology of Data Envelopment Analysis is generally used. Today, the challenge faced in the performance assessment of socio-economic systems is particularly relevant. Different methods are used for performance assessment. An especially popular method is the method of building an efficient frontier, which can also be defined as the production function frontier.

For the definition of the efficient frontier, the method of Data Envelopment Analysis based on linear programming can be used. When using this method, a piecewise linear efficient frontier is formed. Efficiency in the Data Envelopment Analysis system is understood as the optimal ratio of "results" to "resources" for each research object. A study object is considered technically effective when the value of this ratio is equal to 1. The main advantage of this method is the ability to detect provisions to improve the performance of an enterprise and determine the allocative efficiency understood as the allocative efficiency of the use of human resources if their cost is known.

For the study, the Data Envelopment Analysis modified model, which implies two-stage solving of the problem was used (Chen and Guan, 2012). It is based on the fact that the results of the first stage are inputs for the subsequent stage and act as sub-aggregates in the model. An effective model minimizes inputs of the intermediate stage, and in turn, in an effective model, the results of the intermediate stage are achieved with a minimum investment of inputs at the initial stage. The economic unit is effective at both stages, achieving optimal economic clouts at each stage.

In this study, the first stage involves determining production knowledge effectiveness – innovative products by universities. The second stage is the assessment of the effectiveness of commercialization of knowledge gained by a university and their contribution to the structure of innovation activity in St. Petersburg.

Consequently, the outputs of the first stage become the input data – input for the second stage. As input and output indicators at the first and second stages, the indicators presented in Table 1 are used.

Table 1
Input and output data for the study.

Input data for stage 1 (2012)	**Output data of stage 1** **Input data of stage 2** **Results – Inputs (2014)**	**Output data for stage 2** **Results (2016)**
1. The number of employees with academic degrees of Candidate or Doctor of Sciences per 100 students of the faculty (aligned to share of rate); 2. Contribution of a higher education institution to regional R&D expenditures; 3. Domestic R&D expenditures of higher education institutions in thous. rub.	1. Scope of license agreements; 2. Total scope of R&D works; 3. The share of income from R&D in the total income of an educational organization; 4. Amount of grants received for the reporting year per 100 positions of academic staff; 5. Number of industrial parks (involving higher education institutions); 6. Quantity of business incubators.	• Quantity of the patents used; • Quantity of the advanced manufacturing techniques used; • The contribution of higher education institutions to regional R&D-related income; • Quantum of output for innovative products of the region.

Source: compiled by the authors

As data, statistical information on the state higher education institutions located in St. Petersburg was used. The sample included 20 higher education institutions included in the Top 200 rating based on the results of the "National Rating of Universities 2017" in innovations. The data were collected by year: 2012, 2014 and 2016 accordingly. This is conditioned by the necessity to take into account the time lag between the formation of resources and the results of innovation. Data Envelopment

Analysis Frontier Solver package based on Microsoft Excel was used to conduct calculations (Zhu, 2016).

3. Results

The calculations show that 10 of the 20 analyzed higher education institutions included in the Top-200 are totally effective in terms of effects on innovative activity of the region. One can say that these 10 higher education institutions are effective both at the production stage and at the stage of the contribution to the formation and improvement of innovative activity of the region.

Table 2 shows high-performance higher education institutions assessed with the use of the two-stage model with Data Envelopment Analysis. For better and deeper analysis, results of the ranking of these higher education institutions according to the data of "National Rating of Universities 2017" in innovations (Interfax, 2017) were to the Table.

Table 2
High-performance higher education institutions based on the Data Envelopment Analysis methodology and their rank within the region's innovative activity system.

No.	Higher education institution	Performance	Rank	Place in the National Rating
1	ITMO University (St. Petersburg National Research University of Information Technologies, Mechanics and Optics)	1.00000	1	13
2	St. Petersburg Mining University	1.00000	1	20
3	Peter the Great St. Petersburg Polytechnic University	0.91409	2	21
4	St. Petersburg State University	1.00000	1	24
5	St. Petersburg State Electrotechnical University "LETI" named after V.I. Ulyanov	0.85369	4	39
6	Emperor Alexander I St. Petersburg State Transport University	0.42756	7	62
7	St. Petersburg State Marine Technical University	1.00000	1	68
8	St. Petersburg Academic University of the Russian Academy of Sciences	1.00000	1	71
9	St. Petersburg State University of Aerospace Instrumentation (SUAI)	1.00000	1	88
10	St. Petersburg State Chemical Pharmaceutical Academy	0.55703	5	107
11	Bonch-Bruevich St. Petersburg State University of Telecommunications	1.00000	1	110
12	Pavlov First St. Petersburg State Medical University	0.26782	9	118
13	St. Petersburg State University of Industrial Technologies and Design (SUTD)	1.00000	1	136
14	St. Petersburg State Institute of Technology (Technical University)	0.52454	6	142
15	Herzen State Pedagogical University of Russia in St.	1.00000	1	144

	Petersburg			
16	St. Petersburg State Agrarian University	0.09988	11	161
17	Baltic State Technical University "Voenmekh" named after D.F. Ustinov	0.27354	8	172
18	State University of the Marine and River Fleet named after Admiral S.O. Makarov	0.16010	10	193
19	Russian State Hydrometeorological University	0.85654	3	195
20	St. Petersburg State University of Economics	1.00000	1	199

Source: compiled by the authors

Simulation results show that over a long period of time (taking into account the two-stage process of higher education institutions' performance assessment within the frameworks of the region's innovation activity system), high-performance higher education institutions are those that took leading positions in the National Rating. The exception among the poor-performance higher education institutions under study is the Peter the Great St. Petersburg Polytechnic University and the St. Petersburg State Electrotechnical University (LETI), despite the fact that these higher education institutions occupy leading positions among Russian higher education institutions, both according to Russian and international ratings. In order to identify the cause for the failure of these higher education institutions to be high-performance, it is necessary to undertake an in-depth (fundamental) analysis of the results of the two-stage study of the performance, namely, to identify troubling indicators and analyze their recommended values, which has been accomplished by us.

As for the main troubled lines with the greatest deviation from the recommended, we can name the "Quantity of the patents used", "Scope of licensing agreements", as well as "Total scope of R&D works". Thus, one can conclude that these two higher education institutions have good provisions to improve performance without increasing investment in innovation. Calculations also indicate that, in order to achieve maximum performance, it is necessary to reduce the scope of R&D and the number of patents that are developed at the higher education institution and used in the region and increase the scope of licensing agreements.

Next, the analysis of the remaining poor-performance higher education institutions has been undertaken and the most significant indicators for achieving their maximum impact on the level of innovative activity of the region have been revealed. All remaining higher education institutions, which are among the poor-performance higher education institutions, have the problem in the optimal ratio of the "Quantity of the patents used" and "Total scope of R&D works" indicators. It was found that, in contrast to the Polytechnic University and the LETI, for these higher education institutions, a serious increase of the R&D scope, provided that the scope of the patents used should be reduced, is needed.

Another interesting conclusion can be drawn on the amount of the grants received during the reporting period per 100 positions of academic staff. Upon analyzing the initial data of absolutely high-performance higher education institutions, it becomes obvious that all of them have the largest amount of grants received during the reporting period. For example, this indicator for St. Petersburg Academic University of the Russian Academy of Sciences is 70, St. Petersburg Mining University – 21, St. Petersburg State University of Industrial Technologies and Design – 15. For poor-performance higher education institutions, it does not exceed 5. Moreover, according to the results of the study, it becomes obvious that all poor-performance higher education institutions have problems with the formation of the innovative infrastructure. This can be judged on the basis of the obtained recommended values. All poor-performance higher education institutions should increase the number of technology parks and business incubators.

4. Discussion

From the conducted analysis and case study, it follows that the hypothesis put forward has been proven. The study presents evidence that the high performance of higher education institutions, from the view of innovation, affects the innovative activity of the region, in which they are located. The existence of high-performance innovative higher education institutions can provide a powerful benefit to the region, regardless of external factors.

Although there is no universal solution to assess the impact of higher education institutions on the level of innovative activity of the region, in the present study, an attempt was made to identify some of the factors that give the opportunity to adequately assess this contribution. The study includes concrete recommendations on improving the performance of higher education institutions and, therefore, enhancing their influence on innovation activity of the region. As it turned out, most higher education institutions have a chance to achieve the desired level of performance, increasing the scope of R&D and reducing sales of patents. However, the situation with patents also may indicate that extensive work with legislative instruments in this regard not only at the level of higher education institutions but also at the state level is needed. This argumentative issue requires further study.

5. Conclusions

To summarize, we can say that the purpose of the study has been achieved.

Due to the obtained results, it is now possible to formulate the following recommendations for the development of the most effective mechanisms and tools for cooperation between the participants of the innovation system in the region in the context of the implementation of the strategy of innovation-driven development of the regions:

- For the most active impact on the innovation system of the region, higher education institutions must actively create an integrated innovative infrastructure of an educational institution (science parks, business incubators, centers of excellence, etc.);

- To optimize the scope of R&D carried out in an educational institution in accordance with the market needs and demand for innovative products;

- To develop mechanisms for stimulating grant activity of research teams within a higher education institution (in-house) (the system of motivation and awards);

- There is a need for extensive work in the regulatory and legal aspects of regulating the patent and intellectual property protection system since at the moment, taking into account the current legislation requirements, patenting and selling of intellectual property is not profitable for higher education institutions;

- As a consequence of the previous paragraph, it is recommended to establish an effective system of registering and recording the results of intellectual activities of higher education institutions.

For further development of the approach, first, regression analysis is required to identify the significance of each factor in relation to the level of innovative activity of the region. For this purpose, it is necessary to expand the sampling of the study objects. Second, there is a need to extend the periodization of the study and analyze the performance indicators obtained in dynamics. However, the approach has proven its applicability to broaden understanding about higher education institutions as drivers of innovation activity in the regions of Russia.

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