DOI: 10.21122/2227-1031-2016-15-6-528-535

Analysis of Efficiency of Research & Development Activities among Countries with Developed and Developing Economies Including Republic of Belarus while Using Method of Stochastic Frontier Approach

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Abstract. This study evaluates efficiency of Research & Development (R&D) activities based on the stochastic frontier analysis across 69 counties with developed and developing economies. The following indicators have been used as input indices (resources) for calculation of R&D efficiency: number of researchers per one million inhabitants, number of engineers and technicians per one million inhabitants, gross domestic expenditures on R&D in purchasing power parity (in US dollars). Such indices as number of patents granted to residents by National Patent Bureau and number of scientific and technical journal articles have been considered as R&D outputs. The executed analysis has revealed that there are a number of countries including Costa Rica, Israel and Singapore which have the best indices in terms of transformation of available resources into R&D results. Meanwhile, with regard to Belarus it is necessary to note that additional investments in R&D must go together with increasing efficiency of available resources' usage.

Keywords: Research & Development, efficiency, stochastic frontier analysis

For citation: Zhukovski I. V., Gedranovich A. B. (2016) Analysis of Efficiency of Research & Development Activities among Countries with Developed and Developing Economies Including Republic of Belarus while Using Method of Stochastic Frontier Approach. *Science & Technique*. 15 (6), 528–535

УДК 338.001.36

Анализ эффективности научно-исследовательской деятельности в развитых и развивающихся странах, включая Республику Беларусь, с использованием метода стохастического анализа данных

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Реферат. В статье исследуется вопрос оценки эффективности научно-исследовательской деятельности 69 стран мира с развитой и развивающейся экономикой с помощью метода стохастического анализа данных (Stochastic Frontier Analysis, SFA). В качестве входных показателей (ресурсов) для расчета эффективности использовали следующие индикаторы: количество ученых на один миллион населения, количество инженеров и технического персонала на один миллион населения, затраты на научно-исследовательские разработки по паритету покупательской способности (в долларах США). Такие показатели, как количество патентов, выданных национальными патентными бюро резидентам, и количество опубликованных научных статей, были использованы как результаты научно-исследовательской деятельности. Проведенный анализ показал, что имеется ряд стран, таких как Коста-Рика, Израиль и Сингапур, с наилучшими показателями трансформации имеющихся ресурсов в результаты научно-исследовательской деятельности. В то же время, если говорить о Республике Беларусь, то дополнительное финансирование научно-

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исследовательской деятельности должно сопровождаться повышением эффективности использования имеющихся ресурсов.

Ключевые слова: научно-исследовательская деятельность, эффективность, метод стохастического анализа данных

Для цитирования: Жуковский, И. В. Анализ эффективности научно-исследовательской деятельности в развитых и развивающихся странах, включая Республику Беларусь, с использованием метода стохастического анализа данных / И. В. Жуковский, А. Б. Гедранович // *Наука и техника*. 2016. Т. 15, № 6. С. 528–535

Introduction

R&D is a crucial element for technological change and innovation at firm and national level as it leads to the welfare of nation via achieving productivity growth and creation of unique competitive advantage [1]. Countries which invest extensively in R&D can be considered as leaders in economic improvements. As a result, the creation of strong R&D capacities becomes an urgent issue for the least developed and developing countries, as without building strong R&D and innovation system they miss a chance to improve their technologies and can engage into market competition with developed countries [2, 3].

As national governments consider R&D as a main driving force for countries' competitive advantage, they have introduced various national R&D programs which main aim is to raise R&D investments [4, 5]. For instance it is the State Program of Innovation Development in Belarus which main aim is to provide economic growth and improve competitiveness of national economy by investing in R&D and innovation.

According to Wang and Huang [6] R&D investment is one of the most important elements for supporting scientific and technological progress, countries that are not using the funds effectively cannot succeed in the implementation of their national R&D programs [7]. In addition to this inefficient allocation and usage of limited resources leads to the situation when additional investments in R&D will not accelerate the economic growth and do not have a positive effect in the new knowledge creation. Since R&D investment is one of the most crucial elements in promoting scientific and technological progress [6, 8, 9].

In this case the evaluation of R&D programs' efficiency is extremely important in terms of better reallocation of the limited resources and improvement or closure of programs which do not give sufficient results. Most of the authors address the problem of engaging new R&D investment rather than evaluating the efficiency of usage of the resource which was allocated to the R&D [10]. This can be explained by the problem of different approaches and the aim of national R&D programs that has been set by national governments [11].

Study of the relative efficiency of R&D activities across developed and developing countries (including Belarus) can be the key to the developping policies which can better distribute limited resource and give sufficient results. According to this the purpose of this study is to measure and compare the technical efficiency of R&D activities among developed and developing countries (including Belarus) based on the stochastic frontier approach in order to evaluate the results and find possible improvements of Belarus national R&D policies.

In this study countries will be studied as decision-making unites (DMU) which perform R&D, at the same time R&D will be considered as a production process [12, 13]. The novelty of this study consist in evaluation of technical efficiency of developed and developing countries (including Belarus) implementing R&D programs by means of the stochastic frontier analysis. The sample of 69 countries is used to build a necessary framework and understand the possible efficiency of R&D activities in Belarus compared to other countries and to make recommendation for the improvement of the national R&D system in Belarus. This study is based on the works of authors who investigated the R&D and its influence on the countries' economies, as well as the efficiency of R&D among countries [10].

The impact of R&D programs on the economy and economic growth has been studied in different aspects by many authors. It is established both on firm and industry levels that investments in R&D lead to new and improved technologies of production of goods as well as productivity growth. The empirical researches have proved that all positive effects of R&D also result in better return on investment [13–16].

More efforts have been devoted to the measuring of efficiency of R&D at country, industry and company levels in recent years. There are two major approaches usually used to measure the production efficiency, i. e. data envelopment analysis (DEA) which applies linear programming to define the efficiency frontier [17–19] and stochastic frontier analysis (SFA) which is based on the econometric techniques to estimate efficiency.

The most recent study evaluated a group of 22 developed and developing counties using the data envelopment analysis. The authors have used two DEA models with constant return of scale and variable return of scale. Both models have used gross domestic expenditures on R&D and number of researchers as inputs and patents granted to residents as output. In case of the first DEA model such countries as Japan, the Republic of Korea and China got the highest level of efficiency, in case of the second model India, Slovenia and Hungary were added to the mentioned three countries. It was summarized that some developing countries which have not utilized R&D resources in efficient way have a great opportunity for economic growth and development [20].

Another paper utilizes data envelopment analysis for efficiency evaluation and Tobit regression for controlling external environment. The authors have used capital stock and manpower as inputs and patents and academic publications as outputs for their model and applied it to 30 countries. According to their findings more than two-thirds of the countries can improve their R&D performance and less than 50 % are fully efficient [6].

One of the authors of a previous study has extended it for 30 countries and has used the same inputs (capital stock and manpower) and outputs (patents and academic publications) with application of stochastic frontier analysis. Environmental factors have been included in the study as well. The mean score of efficiency in the first model excluding environmental factors is about 0.65. The mean score rose to 0.85 after adding environmental factors. One of the main findings is that it has revealed a positive correlation between efficiency and per capita income [10].

The efficiency of a country R&D performance has been examined by other researches using the data envelopment analysis. The authors treat GDP, active population and R&D expenditure as inputs, and publications and patents as outputs for 18 developed countries. They found out that 7 European countries have the highest efficiency in all tests [21].

To sum up there are a plenty of studies which examine R&D efficiency on different levels such as a company, industry and country level. Data envelopment analysis and stochastic frontier analysis are the most popular methods of efficiency evaluation. However these studies pay little attention to the problem of R&D efficiency among developing countries compared to developed countries. There is no information about the performance of the R&D national system in Belarus compared to other countries either.

Methodology

This paper is using SFA to estimate the inter-country efficiency of R&D activities. SFA is based on the econometric theory specifically on the production function. Countries are considered as DMU utilizing different resources such as R&D manpower (in terms of this study – researches and technicians) and financial investments in order to achieve tangible results such as patents and scientific articles. A trans log specification will be chosen as the Functional form of the production technology.

Aigner et al. [22] and Meeusen and van den Broeck [23] have developed and introduced a simultaneous SFA. They found out that there exists a parametric function between production inputs and outputs. There are several advantages of SFA such as measurement of technical inefficiency and acknowledgement that output results can be affected by random shocks. According to this the error term consist of two parts: the first part is a one-sided component that captures the effects of inefficiency relative to the stochastic frontier, and a symmetric component that permits random variation of the frontier across DMUs, and captures the effects of a measurement error, other statistical noise, and random shocks outside the firms control [24].

The base SFA model after the log transformation is:

$$y^k = f(x^k; \beta) + v^k - u^k;$$
$$+ (0, \sigma_u^2),\ k = 1,\ \ldots,\ K;$$
$$v^k N(0, \sigma_v^2), u^k N_+,$$

where y^k – the observed outcome (goal attainment); x^k – a vector of (transformations of the) input and output of the k-th DMU; β – a vector of unknown parameters; v^k – the stochastic part and possible measurement errors of inputs and output; u^k – the possible inefficiency of the firm.

It is supposed that the terms v and u are independent. The 100 % efficiency is achieved by the DMU $u = 0$, and, and the inefficiency exists when $u > 0$. The N_+ denotes a half-normal distribution, i. e. a truncated normal distribution where the point of truncation is 0 and the distribution is concentrated on the half-interval [0, ∞[(the support) [25].

To sum up it is possible to estimate the efficiency of individual decision making unites by means of SFA. As a result it allows to find out DMUs and to take measure to improve their performance. In addition to this it is possible to measure the influence of environmental variables on the efficiency scores.

Data and experiment description

According to the literature there are a lot of approaches to the inputs and outputs data used for estimating R&D efficiency. Gross domestic expenditures on R&D (GERD) are measured by purchasing power parity (PPP) and scientific manpower includes researchers in R&D and technicians in R&D (per millions of people) [6, 10, 20, 26]. In terms of the output variables patent application is one the most important indicator showing the result of R&D policies [27, 28] the number of publications of academic papers can be used as well [10, 20, 29].

The time lag is an integral part of the R&D process as the investments and other inputs taking place during implementation of R&D policy do not lead to immediate results [30, 31]. Two year time lag has been chosen based on the studies of [10, 16, 20, 32]. Input data were collected for the year 2011 and output data for the year 2013 respectively.

The sample of 69 developing and developed countries (including Belarus) has been used in this study. Quantitative input and output data have been collected in official sources such as the World Bank, UNESCO and WIPO IP Statistics Data Center databases. Tabl. 1 represents the full model with data, sources of the data and years of data extraction.

Due to the specific nature of the stochastic frontier analysis the output raw data have been merged in one indicator. As the patent is one of the most important results of R&D activities a weight of 0.785 has been assigned to it while the scientific and technical journal articles' acquired a weight of 0.215 [10]. This part of the paper contains a comprehensive review of the data and the analytical model subject to the examination. The data indicators for 69 countries have been extracted from existing literature and releases of the international and universally recognized organizations such as UNESCO Institute of Statistics and the World Bank.

Findings

The estimation results of the R&D efficiency framework are displayed in tabl. 2. In this model, the estimated λ parameter is 0.78, that means that the total error variance is mainly due to inefficiency, whereas random errors are less important. The percentage of the total variation due to variation inefficiency constitutes 38 %. The estimated variance due to random errors is $\sigma^2_v = 0.18$ larger than variance for the variation inefficiency $\sigma^2_u =$ $= 0.11$. All input variables are significant.

The individual efficiency scores are represented in tabl. 3. The mean score of technical efficiency is 0.713552, the maximum and minimum scores are 0.8791 and 0.5268 respectively. The efficiency score of Belarus equals to 0.7837 which is approximately 10 % more compared to the mean score.

Table 1

Input and output data variables

	Indicator	Year	Source
Inputs	Gross domestic expenditures on R&D in PPP	2011	UNESCO Institute of Statistics
	Researchers per million inhabitants	2011	UNESCO Institute of Statistics
	Technicians per million inhabitants		UNESCO Institute of Statistics
Output	Patents Granted to residents	2013	WIPO IP Statistics Data Center
	Scientific and technical journal articles	2013	The World Bank

Table 2

Estimation results of R&D efficiency

	Parameters	Std. err	*t*-value	Pr (>|*t*|)
(Intercept)	–5.1199	0.63009	–8.1256	0
xResearchers	0.1113	0.08141	1.3672	0.176
xTechnician	–0.1914	0.07642	–2.5039	0.014
xGERD	0.9019	0.02762	32.6579	0
λ	0.7854	1.23886	0.6339	0.528
σ^2 =	0.30015			
σ^2_v =	0.1856466	σ^2_u =	0.1145064	
log likelihood =	–46.74776			
Convergence	4			

Table 3

Individual R&D efficiency scores and country ranks

Country rating	Country	Individual efficiency scores	Country rating	Country	Individual efficiency scores
1	Costa Rica	0.5268	36	US	0.7791
2	Singapore	0.6248	37	Belarus	0.7837
3	Israel	0.6499	38	Moldova	0.7838
4	Tajikistan	0.6596	39	Mongolia	0.7839
5	Argentina	0.6708	40	Canada	0.7843
6	Madagascar	0.6709	41	Montenegro	0.7852
7	Azerbaijan	0.6753	42	France	0.7887
8	Mexico	0.6788	43	Russian	0.7898
9	Finland	0.6836	44	UK	0.7942
10	Iceland	0.6878	45	Bulgaria	0.7972
11	Estonia	0.6942	46	Czech	0.8030
12	Egypt	0.6951	47	Slovak	0.8040
13	Brazil	0.7051	48	Netherlands	0.8068
14	Luxembourg	0.7079	49	Chile	0.8075
15	South Africa	0.7142	50	Spain	0.8075
16	Norway	0.7246	51	Macedonia	0.8080
17	India	0.7290	52	Ukraine	0.8087
18	Pakistan	0.7367	53	Latvia	0.8159
19	Hungary	0.7381	54	New Zealand	0.8172
20	Austria	0.7388	55	Italy	0.8250
21	Switzerland	0.7407	56	Cyprus	0.8266
22	Malaysia	0.7409	57	Colombia	0.8281
23	Ireland	0.7441	58	Trinidad Tobago	0.8340
24	Denmark	0.7454	59	Poland	0.8405
25	Sweden	0.7474	60	Croatia	0.8408
26	Belgium	0.7488	61	Greece	0.8430
27	Thailand	0.7491	62	Serbia	0.8434
28	Turkey	0.7568	63	Romania	0.8456
29	Tunisia	0.7610	64	China	0.8473
30	Germany	0.7623	65	Kazakhstan	0.8484
31	Portugal	0.7633	66	Kyrgyz	0.8533
32	Australia	0.7642	67	Japan	0.8636
33	Cuba	0.7642	68	Armenia	0.8638
34	Lithuania	0.7713	69	South Korea	0.8791
35	Malta	0.7779			

The distribution of the individual efficiency scores is represented on fig. 1.

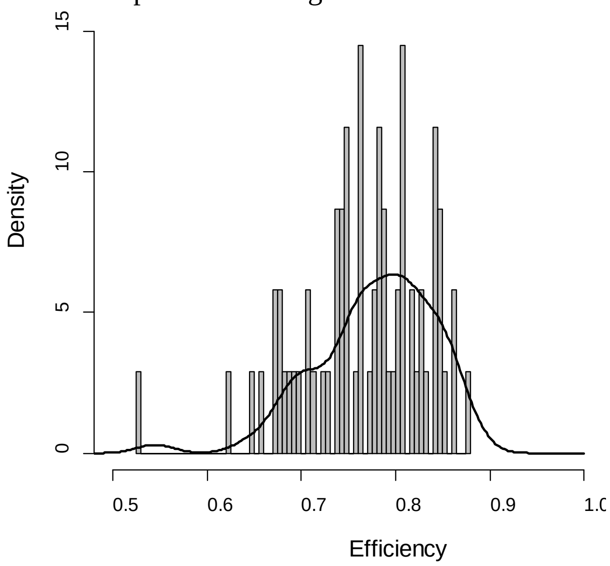

Fig. 1. Distribution of individual efficiency scores

According to the results it can be concluded that Belarus has a great potential of increasing efficiency of using R&D resources. Such countries as Costa Rica. Israel and Singapore are among the leaders. Countries with insufficient investments in R&D such as Tajikistan. Madagascar and Azerbaijan also get into the same group. as a result even small inputs give effects allowing them to get a high efficiency score compared to other countries. At the same time South Korea. Japan show low efficiency of the transformation of R&D resources of the results of R&D activities however these countries internationally recognized as R&D leaders and countries with a strong R&D policies. Such results can be explained by several factors: this countries invest in long terms investigation which bring result in a period of time longer than two years. another factor is that it is preferable to get patent protection from the United States patent and trademark office rather than for national Patent office.

CONCLUSION

The current study aims at the evaluation of the technical efficiency of using R&D resources among developed and developing countries (including Belarus) using Stochastic Frontier Analysis. The main distinction of the study compared to the previous papers is that there are countries whose R&D expenditures are below or above 0.75 % of GDP due to strengthening of globalization and competition. So efficient usage of R&D resources will give small developing countries great opportunities for economic improvements and competition with the developed countries. Belarus has R&D potential. as it possesses good and qualified R&D personnel. according to the UNESCO Institute of Statistics it is 2073 per million inhabitants. at the same time the R&D expenditures (% to GDP) during the last three years constituted around 0.7 % of GDP which is not enough for a normal functioning R&D system according to the OECD.

However Belarus individual efficiency score shows that increasing the R&D expenditures may not lead to sufficient economic outcomes. In this case it is possible to raise investments in R&D only with the improvement of efficiency performance. In this context it is extremely important for policy makers to revise R&D programs along with innovation programs to find out the unique scientific projects which can become a driver of Belarus economy. In addition to the policy revision it is necessary to study performance of the research institutions in Belarus.

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Received: 06.07.2016
Accepted: 09.09.2016
Published online: 29.11.2016

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Поступила 06.07.2016
Подписана в печать 09.09.2016
Опубликована онлайн 29.11.2016