EVALUATION OF THE EFFICIENCY OF NATIONAL INNOVATION SYSTEM OF TOP 10 COUNTRIES IN GLOBAL INNOVATION RATING AND UZBEKISTAN THROUGH DEA MODEL

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Abstract: *this paper focuses on measuring technical efficiency of National Innovation System across a sample of Top 10 countries in GII and Uzbekistan in 2016-2018 years using DEA. It has been used an output-oriented constant returns to scale model to calculate the efficiency of the units.*
Keywords: *data envelopment analysis, National Innovation System, technical efficiency, innovation activity.*

The present paper focuses on efficiency measurement of NIS of Top 10 countries in global innovation index and Uzbekistan during 2016-2018 years by means of applying data envelopment analysis (DEA) in the form of an output-oriented constant returns to scale model (CRS). In this study, NIS is represented by the country and its variables entering the system to be transformed into outputs during the innovation process at the macroeconomic level. Innovation performance of economies is influenced by many factors, especially at the level of government which formulates and defines innovation strategy in its framework along with all other important conditions for innovation development. Our paper follows previous studies and extends this topic using the data covering the period of 3 years, from 2016 to 2018. We are measuring efficiency of the Top 10 countries which have high rates of innovation development in 3 years as well as Uzbekistan and present the inefficiency level of decision-making units (DMUs) within the sample with improvements of variables entering the national innovation systems. In the table 1 which given below, there is obvious that it is relevant to evaluate the efficiency of innovation development of these countries.

Table 1. Global innovation index ranks in 2016-2018

№	2016	2017	2018
1	Switzerland	Switzerland	Switzerland
2	Sweden	Sweden	Netherlands
3	GB	Netherlands	Sweden
4	USA	USA	GB
5	Finland	GB	Singapore
6	Singapore	Denmark	USA
7	Ireland	Singapore	Finland
8	Denmark	Finland	Denmark
9	Netherlands	Germany	Germany
10	Germany	Ireland	Ireland

Source: [1]

The main objective of the present paper was to examine the efficiency of the NIS of selected countries as well as Uzbekistan and compare the efficiency of input utilization to produce outputs of particular systems. For this measurement, data envelopment analysis was used as a specialized modeling tool for the analysis of the efficiency of homogeneous units.

This method is based on practical efficiency of the unit within the analysed group with the possibility of including environmental factors. It is used for measurement of efficiency of banks, research institutions, schools or transport services.

DEA can be adopted as an appropriate method for the examination and evaluation of the innovation efficiency of selected countries. DEA was first developed by Farrel in 1957, which later been modified by Charnes-Cooper-and Rhodes (CCR) in 1978. It is a non-parametric method that utilizes linear programming to measure the level of efficiency of comparable decision-making units (DMU) by employing multiple inputs and outputs [2, s. 66].

This technique of measuring efficiency was first introduced by Farrel in 1957 based on the basic theory of production on single input and single output such as “output per work hour” in a form of ratio [3, s. 16].

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} \qquad (1.1)$$

The CCR model, named by its developers Charnes, Cooper and Rhodes, is based on fixed or constant returns-to scale. This actually means that the proportional increase of all the inputs results in the same proportional increase of all the outputs. Accordingly, the mathematical equation to find the maximum efficiency of DMUs using weighted input-output efficiency measure can be expressed as [4, s. 437]:

$$max \frac{\sum_{j=1}^{J} v_{mj} y_{mj}}{\sum_{i=1}^{I} u_{mi} x_{mi}} \qquad (1.2)$$

Such that

$$0 \leq \frac{\sum_{j=1}^{J} v_{mj} y_{nj}}{\sum_{i=1}^{I} u_{mi} x_{ni}} \leq 1; \qquad n = 1,2, \dots \dots, N \qquad (1.3)$$

$v_{mj}, u_{mi} \geq 0; \quad i = 1,2, \dots, I; \quad J = 1,2, \dots, J$

Where:

N: Total number of DMUs

J: Weighted sum of outputs

I: Weighted sum of inputs

M: The base DMU (calculating *m*th DMU)

N: DMUs

I: Inputs

J: Outputs

vmj: Weights for output

umi: Weights for input.

When DEA is employed to measure banks efficiency for a set of DMUs, the linear programming algorithm will calculate the efficiency of each DMU given the identical inputs and outputs variables to find the maximum ratio of weighted sum of output to the weighted sum of input (most efficient DMU) and to be used as benchmark against other DMUs, causing the best-practice DMUs to lie on the efficient frontier line. It means the best-practice units are relatively efficient and identified by DEA efficiency score as 100% (efficiency = 1) [5, s. 37]. The dataset used in the present study was obtained from the websites, such as: number of patent applications of residents and number of scientific journal articles were taken from [5], [6], number of total researchers with FTE as well as gross expenditure on R&D indicators were taken from [7], [8] for the period of 2016-2018. Researchers are one of the basic factors in an innovation system and are the bearers of creativity and knowledge. Innovation is always the result of activities following ideas, so it is appropriate to focus on its effectiveness. Patents can be considered as one of the indicators of research and development activities and the highest level of intellectual property rights protection. The parameters used in the present study are key to the National Innovation System.

Table 2. Information on Input and output indicators

Inputs		
Number of researchers in all sectors of performance	counted in a full-time equivalent, which corresponds to one year of work by one person with respect to residency and non-residency of Uzbekistan in all sectors of the economy	http://data.uis.unesco.org
R&D expenditures of the country	amount of R&D expenditure invested into all sectors of a unit's economy, reported in million dollars.	http://data.uis.unesco.org
Outputs		
Number of patents	number of patents submitted to the Patent Office	https://knoema.ru
Number of scientific articles	the number of scientific articles published in journals classified by SCI and SSCI indices	https://eeca-ict.eu

Source: Done by the author.

We used DEA modeling to examine the efficiency of the NIS of selected countries and Uzbekistan. We investigated the required inputs and outputs of the units to become fully efficient, not only to be their best in innovation performance. Performance of the NIS can be measured by various indicators; however, the purpose of the present study was to compare the utilisation of resources with the relevant outputs of the system within the sample of countries.

The calculated results indicate a different position of the units in their efficiency versus their performance. The novelty of this paper comes from the application of the non-parametric method to examine the efficiency of selected countries and Uzbekistan during the period of 2016-2018. The latest completed data required for this analysis for 2019 was unavailable.

The efficiencies of the units are presented in Table 3. We calculated data using the computer program available on http://onlineoutput.com/ web page. An output-oriented constant return to scale (CRS) model was

used in the present study. We measured the efficiency, focusing on the outputs. This model offers improvements in the output variables when using the values of the inputs. We assumed that the inputs entering the NIS system are allocated and should produce proportionately more outputs to become unit efficient. Based on this, we calculated improvements of the units.

Table 3. Descriptive statistics of the DEA efficiency during the period of 2016-2018

	2016	2017	2018
Number of DMUs	10	10	10
Number of efficient DMUs	4	4	4
Number of inefficient DMUs	6	6	6
Average	0.93	0.91	0.92
Minimum	0.796	0.759	0.738
Maximum	1	1	1

Source: Authors' calculations

The average efficiency of the units is about 0.92. There is seen from the table that countries tried to keep their efficiency in innovation during these given years. This fact is supported by the "number of efficient DMUs". There wasn't so wide variance in the "minimum" and "maximum" values within the sample. The average calculated efficiency score was stable and in the terms of 0.92.

Table 4. Efficiency scores of the Top 10 countries in global innovation index and Uzbekistan

		2016	2017	2018
1	USA	1	1	1
2	Singapore	0.851	0.842	0.865
3	Denmark	0.941	0.958	0.971
4	Netherlands	1	1	0.916
5	Sweden	0.882	0.846	0.865
6	United Kingdom	1	1	1
7	Finland	0.932	0.905	0.92
8	Germany	0.796	0.759	0.738
9	Ireland	0.944	0.886	1
10	Uzbekistan	1	1	1

Source: Done by the author on online web-site: [10].

The results listed in Table 4 show the efficiencies of the units. If we follow the CRS model, most of units were scale inefficient; with the three efficient countries of USA, United Kingdom and Uzbekistan in all 3 years.

This difference is based on the principle of the DEA model and shows that the unit with the highest number of outputs, classified as the best innovative one, can be inefficient and fail to use resources sufficiently to produce effective outputs of the NIS. In 2015 Ireland entered the top 10 and Hong Kong (China) exited. After 2016 no country has entered or exited the top 10 in global innovation index. Sweden maintained 2nd place for the second time in 2017.

In 2018 the Netherlands and Sweden traded 2nd and 3rd place (GII, 2018). This innovation score doesn't explain the utilisation of the inputs compared to outputs of NIS to become effective.

Table 5. DMUs and improvements invariable in 2018 (Target inputs and outputs)

	GERD (I)	Total researchers (I)	Scientific journal articles (O)	Patent applications (O)
USA	551518 ➜ 551518	73231.4 ➜ 73231.4	422808 ➜ 422808	285095 ➜ 285095
Singapore	9890 ➜ 9890	49704 ➜ 49704	11459 ➜ 13252.054	1575 ➜ 2432.765
Denmark	9122 ➜ 9122	64591 ➜ 64591	13979 ➜ 14402.606	1262 ➜ 1300.242
Netherlands	19849 ➜ 19849	157389 ➜ 157389	30457 ➜ 33239.575	2111 ➜ 2303.863
Sweden	17061 ➜ 17061	92011 ➜ 92011	20421 ➜ 23595.222	1838 ➜ 3849.622
United Kingdom	50373 ➜ 50373	535477 ➜	97681 ➜ 97681	12865 ➜ 12865

		535477		
Finland	6914 ➜ 6914	55415 ➜ 55415	10599 ➜ 11515.124	1387 ➜ 1506.885
Germany	129647 ➜ 129647	706557 ➜ 706557	104396 ➜ 141471.76	46617 ➜ 63172.813
Ireland	3928 ➜ 3928	35817 ➜ 35817	7147 ➜ 7147	76 ➜ 76
Uzbekistan	300 ➜ 300	20477.5 ➜ 20477.5	354 ➜ 354	470 ➜ 470

Source: Done by the author on online web-site: [10].

Table 5 shows the improvements as calculated by DEA to become effective units. The improvements were calculated according to the achieved outputs of the units. There were no improvements offered for USA, United Kingdom and Uzbekistan, while Finland needs to increase the number of published scientific articles and the number of patent applications. The system should be more effective in the production of innovative outputs. Germany was more inefficient country in comparison with selected countries, with a 0.73 efficiency scale in 2018; the proposed improvements are to increase the number of "scientific articles" from 104396 to 141471.76 and "patent applications" from 46617 to 63172.813. The model proposed the same position of efficiency and possible improvements to Singapore, Denmark and other countries.

Based on the results of the DEA, we can conclude that not all the leading innovation countries in the GII are not technically effective. The efficiency scores represent the possibilities for analysis of national innovation systems of selected countries in detail to discover conditions and factors influencing innovation performance, such as a quality proinnovation environment, educated people working in R&D, support of innovation by government and funding of projects. The study is limited by the sample of DMUs and definition of NIS. This basic study needs to be extended with further relevant variables and data. The final results are dependent on the data entering the analysis, and it is necessary to compare methodologies and statistical samples to be adequate.

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