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Measurement of Health Research and Development Efficiency of Countries with Data Envelopment Analysis

Veri Zarflama Analizi ile Ülkelerin Sağlıkta Araştırma ve Geliştirme Etkinliğinin Ölçülmesi

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Abstract: The aim of this study is to determine the research and development (R&D) capacity of countries by using the data envelopment analysis (DEA) technique. Variables in the DEA method consist of two inputs (health research and development expenditures and the number of full-time researchers) and three outputs (medical patents, biotechnology patents, and pharmaceutical patents). Full-time researchers in healthcare, the number of biotechnology patents, the number of pharmaceutical patents, and the number of medical technologies for 2019 within the scope of health research and development in the OECD database were determined and were considered as decision-making units in the analyses. These countries were the Czech Republic, Hungary, Latvia, Poland, Portugal, Slovakia, Slovenia, Turkey, Romania, Singapore, and the Chinese. DEA analyses were performed using BCC-CCR input and output-oriented models. As a result of the analysis, 36.3% of the CCR models were within the scope of the research and 45.5% of the BCC models were found effective. The average efficiency of the research and development capacity of all countries within the range of the study was between 78-85%. In addition to these results, our research has shown that Turkey was fully effective in health research and development capacity according to BCC-CCR input and output-oriented models. According to the analysis results, it was recommended to determine the health research and development capacity in a way that considers the current situation and the needs of the future, to be included in the strategic plan/programs and to be implemented.

Structured Abstract: The most crucial factor that plays a role in developing/developed nations is the "technology" that qualified human capital has revealed as a result of discoveries. The invention of the plow, the invention of the wheel, the use of steam power in rail systems, and the production and use of technology such as automobiles, computers, chips, and diagnosis and treatment methods for diseases have brought many changes in the historical process and R&D activities from past to present have undertaken the primary catalyst of economic growth.

R&D activities enable the production of products that facilitate human life, as well as equipment such as many drugs, vaccines, and medical devices that improve the health level of the individual. Today, the increase in global warming and changes in the ecological balance lead to new diseases that have important effects on the health of individuals. For example, the recent Covid-19 pandemic.

With the vaccines and treatment methods produced to prevent COVID-19, this disease tried to be brought under control and all these activities were related to research and development activities. This was a

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current experience that reveals the importance of health R&D expenditures and investments, for this reason, studies to evaluate the field of health R&D are gaining importance day by day.

In the literature, the number of studies evaluating the productivity of researchers and the investments in health research and developments is almost non-existent. Besides this, the number of studies in which the relationship between the number of researchers working full-time in the field of health and the number of medical patents has been limited. Besides this, patents are one of the important indicators obtained as a result of innovative processes and expressing economic value.

This study investigated the health research and development capacity by using data-enveloped analysis. So it is important to determine the health research and development capacity in a way that takes into account the current situation to the needs of the future. The aim of this study was to determine the research and development capacity of countries by using the data envelopment analysis technique. The framework of this research includes: i) determining the technical efficiency of the countries for the health R&D capacity, ii) determining the reference clusters for the health R&D capacity of the countries, iii) determining the average technical efficiency of countries' health R&D capacity.

Variables in the DEA method consist of two inputs (health research and development expenditures and the number of full-time researchers) and three outputs (medical patents, biotechnology patents, and pharmaceutical patents). Full-time researchers in healthcare, the number of biotechnology patents, the number of pharmaceutical patents, and the number of medical technologies for 2019 within the scope of health research and development in the OECD database were determined and were considered as decision-making units in the analyses. These countries were the Czech Republic, Hungary, Latvia, Poland, Portugal, Slovakia, Slovenia, Turkey, Romania, Singapore, and the Chinese. DEA analyses were performed using BCC-CCR input and output-oriented models.

According to the descriptive information of the variables in the analysis; health R&D Expenditures mean was PPP\$1078372000 \pm 1121746000 (min: 593320000, max: 2910425000); researchers mean was 5972.12 \pm 5302.43 (min:327, max:14892); medical technology patent mean was 41.95 \pm 53.89 (min: 1.7, max: 168.2); pharmaceuticals patents mean was 41.47 \pm 44.12 (min:1.1, max: 137.2); biotechnology patents was 33.77 \pm 40.51 (min: 0.00, max: 126.2). The average technical efficiency value of the countries was between 0.845-0.841 according to the BCC Output Oriented Model and the BCC Input Oriented Model. According to the CCR Input-Output-Oriented Model, the average technical efficiency value of countries was 0.789. The results obtained, 4 countries were determined to be effective according to the BCC-CCR input and output-oriented models. These countries are Latvia, Slovakia, Turkey and Singapore. Portugal was found to be effective according to BCC output and input-oriented models and was not effective according to CCR input and output-oriented models. Also, the Czech Republic, Hungary, Poland, Slovenia, Romania, and Chinese countries were found to be ineffective in all BCC-CRR models.

In this research, the effectiveness of R&D activities in 11 countries including Turkey was measured with DEA, a non-parametric performance measurement method. CCR and BCC models, which are the basic models of DEA, were used in the study. The results obtained from the analysis, 36.3% of the CCR models within the scope of the research and 45.5% of the BCC models were found effective. The average efficiency of the research and development capacity of all countries within the scope of the research was between 78-85%. In addition to these results, our research has shown that Turkey was fully effective in health research and development capacity according to BCC-CCR input and output-oriented models. In the coming years, the data of the R&D capacity can be developed at different year intervals, by applying different variables, different decision-making units and different methods. The results to be obtained as a result of these studies can help the countries that make up the decision-making units to prepare effective policies for the future.

Keywords: Health Economics, Health Management, Data Envelopment Analysis, Health Research And Development Capacity.

Öz: Bu çalışma sağlık alanındaki araştırma ve geliştirme kapasitesinin ülkeler düzeyinde veri zarflama analizi (VZA) kullanılarak incelenmesi amacıyla yapılmıştır. Veri zarflama analizinde araştırma değişkenleri iki girdi (sağlık araştırma ve geliştirme harcamaları ile tam zamanlı çalışan araştırmacı sayısı) ve üç çıktı (medical patent sayısı, bioteknoloji patent sayısı ve ilaç patent sayısı) değişkeni olmak üzere toplam 5 (beş) değişkenden oluşmaktadır. Bu çalışmada, OECD veri tabanında sağlık araştırma ve geliştirme kapsamında

2019 yılı için sağlıkta araştırma ve geliştirme harcamaları, sağlıkta tam zamanlı çalışan araştırmacı sayısı, biyoteknoloji patent sayısı, ilaç patent sayısı ve medical patent sayılarında düzenli verisi bulunan 11 (onbir) ülke değerlendirmeye alınmıştır. Bu ülkeler Çek Cumhuriyeti, Macaristan, Letonya, Polonya, Portekiz, Slovakya, Slovenya, Türkiye, Romanya, Singapur ve Çin'dir. Veri zarflama analizlerinde BCC-CCR girdi-çıkıtlı yönlü modeller kullanılarak gerçekleştirilmiştir. Yapılan analiz sonucunda araştırma kapsamındaki ülkelerin %36,3'ü CCR modellerinde, %45,5'i BCC modellerinde tam etkin bulunmuştur. Araştırma kapsamındaki tüm ülkelerin araştırma ve geliştirme kapasitesinin etkinlik ortalaması %78-85 arasındadır. Ayrıca bu sonuçların yanısıra Türkiye, sağlıkta araştırma ve geliştirme kapasitesinde BCC-CCR girdi-çıkıtlı yönlü tüm modellerde tam etkin bulunmuştur. Analiz sonuçlarına göre sağlıkta araştırma ve geliştirme kapasitesinin mevcut durumu ve gelecek ihtiyaçların da dikkate alınacak şekilde belirlenmesi, stratejik plan ve programlarda bu alana yönelik iyileştirme ve geliştirme faaliyetlerine yer verilmesi ve bu faaliyetlerin uygulanması önerilmektedir.

Anahtar Kelimeler: Sağlık Ekonomisi, Sağlık Yönetimi, Veri Zarflama Analizi, Sağlık, Araştırma ve Geliştirme Kapasitesi.

Introduction

The most crucial factor that plays a role in developing/developed nations is the "technology" that qualified human capital has revealed as a result of discoveries. The invention of the plow, the invention of the wheel, the use of steam power in rail systems, and the production and use of technology such as automobiles, computers, chips, and diagnosis and treatment methods for diseases have brought many changes in the historical process and R&D activities from past to present have undertaken the primary catalyst of economic growth.

Scientific and technological development, including creative studies and environmentally compatible product design or software activities, is carried out on a systematic basis in order to increase the knowledge of research and development (R&D), culture, people, and society and to use this to design new processes, systems, and applications. Besides this, the activities that focus on technological uncertainty and whose outputs have original, experimental, scientific, and technical content (Law No. 5746, 2008). Research and experimental development is the creative work carried out on a systematic basis to increase the knowledge of people, culture and society and to use this knowledge to design new applications (OECD, 2002).

The development of new systems and techniques encompasses three activities: basic research, applied research and experimental development. Basic research is experimental or theoretical research conducted with the aim of obtaining new knowledge. For example; measuring the physical and chemical effects of creatinine kinase enzyme.

Applied research is research conducted for a specific practical purpose or goal with the aim of acquiring new knowledge. For example; studies carried out to distinguish between chickenpox and measles antibodies are such studies.

Experimental development is the systematic study of developing new products, materials, devices, equipment, processes and methods based on the knowledge obtained as a result of research or experience. For example, establishing clinical research units and examining their impact on the economy.

A number of indicators have been determined in evaluating the R&D field. By means of these indicators, evaluations can be made about the levels of countries capacity. Indicators in the field of R&D are R&D Expenditures, human resources working in the field of R&D, number of scientific publications, number of patents, products, methods.

R&D expenditures are expenditures made for activities carried out within the scope of product development, process improvement, innovation and inventions. As it is known, the indicators of the economic growth of the countries are generally expressed by the GDP ratio of the

expenditures made in the service areas (such as Education Expenditures/GDP, R&D Expenditures/GDP) (Ekinçi, 2019).

The prerequisite for R&D activities is to have highly qualified R&D personnel. The share of the personnel operating in the R&D sector in general employment in a country is considered as an indicator of the importance and support that that country attaches to science (Adaçay, 2007). R&D personnel are calculated as full-time equivalent of R&D personnel (FTE) and R&D Personnel Number of Personnel (HC). FTE of R&D personnel is defined as the number of hours of work actually spent on R&D during a given reference period (usually a calendar year) divided by the total number. In other words, it can be thought of as a full-time equivalent person-year (OECD, 2002). For example; a person who spends 40% of his time on R&D and other activities (such as teaching, university administration, and training of resident physicians) is considered 0.4 FTE. Similarly, if a full-time R&D employee works in an R&D unit for only three months, the FTE is 0.25. FTE is considered a true measure of the volume of R&D and the main R&D personnel statistics for international comparisons. The headcount (HC) of R&D staff is defined as the total number of people who contribute to R&D, either at a statistical unit level or at the aggregate level, during a given reference period (usually a calendar year). This means that headcount data reflects the total number of people predominantly or partially employed in R&D. The use of HCs is recommended for researching R&D personnel characteristics, usually in percentages.

Patents are a tool to protect inventions developed by companies, institutions, or individuals. For this reason, patents can also be identified as indicators of invention (OECD, 1994). As a word patent comes from the Latin word “patent” meaning “to be open”. A patent can be defined as a document showing that the creative idea of the inventor is protected within the framework of legal provisions for a certain period of time (Bozkurt Yüksel, 2008, s.12). Patents are official documents that ensure the innovations that come with the advancement of invention and technology obtained by scientific methods and the ways followed, and that are arranged by specific procedures by bringing various legal rights to the creator (Ekinçi, 2019). Patents legally assure research owners that their ideas protect their economic value and profits. However, with the patent process, the researcher assumes the entire guarantee of the invention (Özcan & Özer, 2018). In scientific fields and academic findings, patents are used as an indicator of innovation instead of innovation. Patents are seen as a highly reliable measure of innovative movements. In this respect, in academic research, the number of patents is generally used instead of technological innovation and is accepted as a valuable index to measure innovative knowledge production (Akyol & Gurlaş, 2021; Prodan, 2005). While granting special rights and powers to the researchers they own, patents can also play an essential role in promoting innovation. Patents can encourage innovation and economic development if appropriate conditions are met.

Scientific publication is the publication of information that has been proven to be correct by scientific methods in the scientific community. It is the most important indicator of the performance of countries in the field of science. It is also the most important output of R&D activities.

There are many studies in the literature evaluating the efficiency of research and development activities. These researches are mostly related to general research and development activities about education, the defense industry, the number of researchers, patents, economic growth, and development. In the literature on R&D activities, efficiency-related studies were given below:

Sharma and Thomas (2008) measured R&D efficiency on 22 developed/developing countries with an R&D intensity of over 0.75%. According to the fixed return to scale method, Japan, Korea and China, and according to the variable return to scale method, Japan, Korea, China, India, Slovenia and Hungary were found effective.

Lee et al., (2009) conducted a study using Data Envelopment Analysis (DEA) method to measure and compare the effectiveness of 6 international R&D projects. According to the results of the study, more investment in well-functioning R&D programs; programs found ineffective should be terminated or funding for these programs cut unless their performance is improved.

Cullmann et al., (2009) conducted a study on the measurement of R&D efficiency with data from 28 countries. According to the results of the analysis, it has been determined that Sweden, Germany and the USA are countries that are at or close to the world technology border.

Thomas et al., (2009) measured the R&D efficiency of 22 countries using the Malmquist Productivity Index. While the results show an exemplary performance in the number of patents in Korea in recent years, it has been observed that there has been a rapid increase in the number of scientific publications in China.

Thomas et al., (2011) used the DEA method to measure the R&D efficiency of 51 American states. Their results found that only 14 of the 51 US states and territories showed modest improvements in R&D productivity.

Chen et al., (2011) evaluated the international comparison of R&D efficiency using DEA. According to the results of the analysis, it has been obtained that the countries have similar R&D efficiency in terms of patent numbers and copyrights. It has been concluded that R&D intensity, protection of intellectual property rights and knowledge stock and human capital accumulation have a positive effect on efficiency values.

Abbasi et al. (2011) used DEA to measure the effectiveness of the innovation systems of 44 countries in their study and claimed that the OLS regression technique gave better results than the Tobit regression technique in determining the important factors for the countries.

Within the scope of the study conducted by Acı (2015), it was aimed to measure the R&D activities of 33 countries with the output-oriented Charnes Cooper Rhodes (CCR) DEA model. As a result of the study, it has been determined that countries with high human development index have high R&D efficiency and in this context, the necessity of raising qualified people for Turkey as well as increasing R&D activities has been emphasized.

Baykul et al.,(2016) evaluated the R&D and Innovative efficiency of 39 Technology Development Zone (TDZs) management companies. As a result of the research, 13 TDZs were found to be effective according to the CCR model and 24 TDZs according to the BCC model.

Aybarç & Selim (2017) found that Germany, Italy, Korea, Netherlands, Spain and Sweden were fully efficient in their research, in which they examined the R&D efficiency of public expenditures of 23 OECD countries using the Stochastic Boundary Model, and stated that the country with the lowest efficiency was Turkey.

In the literature, the number of studies evaluating health research and developments has been limited. In an evaluation of health R&D capacity; it was found that health R&D activities had an important place among R&D activities in the countries covered by the research (high-income group countries) between 2005 and 2014 and Turkey also has shown a high level of performance in health R&D activities and increased its indicators over the years but in Turkey there has been a recession in health R&D indicators (health R&D indicators/total R&D indicators) over the decade and also determined that it has low capacity in this field compared to the world scale (Ekinçi et al., 2022).

In another study, the effect of Health Research and Development Expenditure on economic growth in Korea and Turkey, which are called emerging economies, was analyzed and it was determined that health R&D expenditures positively affected economic growth (Ekinçi, 2021).

Another study conducted at the level of 10 countries between 2004-2019 to determine the effect of Health Research and Development expenditures on economic growth revealed that these expenditures have a positive effect on economic growth (Ekinçi et al., 2023).

As seen in the literature the number of studies evaluating the productivity of researchers and the investments in health research and developments is almost non-existent. In addition, no studies have been found in the literature that evaluate the effectiveness of health R&D activities. This study investigated the health research and development capacity by using data-enveloped analysis.

The framework of this research includes: i) determining the technical efficiency of the countries for the health R&D capacity, ii) determining the reference clusters for the health R&D capacity of the countries, iii) determining the average technical efficiency of countries' health R&D capacity.

Methods

In this section, the method used in the analysis was evaluated under four (4) sub-titles: the statistical program, research model, limitations and ethical statements of the study. Data envelopment analysis was carried out using quantitative data.

Data Envelopment Research Model

DEA is based on the use of multiple inputs and outputs, developed by adopting the relative technical efficiency approach suggested by Farrell in efficiency measurement and weighted by linear programming method (Bakırcı, 2006). Data Envelopment Analysis is a non-parametric analysis technique that is based on linear programming principles and is used to measure the efficiency of decision-making units (DMU). The biggest advantage of the DEA method is that it benefits decision makers by converting multiple input and output values into a single efficiency value (Frehe, 2013). DEA studies that started to take place in the literature after the 1950s; it has been mainly used in the evaluation of non-profit institutions (Kılılı and Uludağ, 2020). The most important advantage of DEA is that it specifies the goals that ineffective decision-making units must achieve in order to be effective (Seiford, 1996).

Basically, two models are used in Data Envelopment Analysis: These models are Charnes-Cooper-Rhodes and Banker-Charnes-Cooper. The Charnes-Cooper-Rhodes (CCR) Model was the first to be studied in the analysis. In this model scale; with the constant return approach, the productivity frontier is considered as a straight line intersecting the starting point and the best performance values. The best performer is determined by the highest output/input ratio (Frehe, 2013).

The Banker-Charnes-Cooper (BCC) Model is based on the variable input model to scale. This model was developed by Banker, Charnes, and Cooper in 1984 because the CCR Model does not fit every analysis. The most important feature of the model is that more units are accepted as efficient and inefficient units can be compared with suitable counterparts and can give results that are closer to realistic situations (Banker et al., 1984). Input and output oriented models can be used in CCR and BCC Models.

In the Input Oriented Model, while the output rates are fixed, a unit is made efficient by proportionally reducing its inputs (Frehe, 2013).

In the Output Oriented Model, an inefficient unit is made efficient through the proportional increase of its outputs, while the input rates remain unchanged (Frehe, 2013). It is based on maximizing the output by keeping the input level constant. In Table 1, the formulas of CCR and BCC oriented models according to Input and Output oriented.

Table 1: The Formulas Of CCR-BCC Models According To Output-Input Oriented Models

Input Oriented CCR Model	Output Oriented CCR Model
$\text{Max } h_k = \frac{\sum_{r=1}^s u_r y_{rk}}{\sum_{i=1}^m v_i x_{ik}}$ $\frac{\sum_{r=1}^s u_r y_{rj}}{\sum_{i=1}^m v_i x_{ij}} \leq 1$ $v_i, u_r \geq \varepsilon \geq 0$	$\text{Min } g_k = \frac{\sum_{i=1}^m v_i x_{ik}}{\sum_{r=1}^s u_r y_{rk}}$ $\frac{\sum_{i=1}^m v_i x_{ij}}{\sum_{r=1}^s u_r y_{rj}} \geq 1$ $v_i, u_r \geq \varepsilon \geq 0$
Input Oriented BCC Model	Output Oriented BCC Model
$\text{Max } h_k = \frac{\sum_{r=1}^s u_r y_{rk} - u_0}{\sum_{i=1}^m v_i x_{ik}}$ $\frac{\sum_{r=1}^s u_r y_{rj} - u_0}{\sum_{i=1}^m v_i x_{ij}} \leq 1$ $v_i, u_r \geq \varepsilon \geq 0$	$\text{Min } g_k = \frac{\sum_{i=1}^m v_i x_{ik} - v_0}{\sum_{r=1}^s u_r y_{rk}}$ $\frac{\sum_{i=1}^m v_i x_{ij} - v_0}{\sum_{r=1}^s u_r y_{rj}} \geq 1$ $v_i, u_r \geq \varepsilon \geq 0$
<p>n: number of decision making units; m: number of inputs; s: number of outputs; vi: by the decision-making unit whose effectiveness is measured i. weight given to input; xi: decision making unit whose effectiveness is measured i. input amount; ur by the decision-making unit whose effectiveness is measured r. weight given to the output; yr: the r output amount of the decision-making unit whose effectiveness is measured; xij j. decision-making unit i. input amount; yrj j. decision-making unit r. Output amount</p>	

In data envelopment analysis, variables are evaluated at certain stages. In the first stage, the appropriate number of decision-making units related to the analysis subject are selected. Care is taken to ensure that there is no high correlation between these data and that they are homogeneous (Bakırcı, 2006; Dyson et al. 2001). As a result of these evaluations, the input and output variables that are planned to be included in the analysis are determined. The DEA model to be used in the analysis of these variables is decided. Efficiency measurement results are obtained by making analyzes within the framework of the model. Efficiency evaluation is made on the measurement results. Efficacy values were evaluated between 0 and 1. Decision-making units with an efficiency value equal to 1 are defined as effective; decision-making units with an efficiency value less than 1 are considered relatively inefficient (Bakırcı, 2006). Then, reference groups are evaluated and suggestions are made so that ineffective decision-making units can be effective.

Selection of Decision-Making Units

In this study, 11 countries with regular data on health R&D expenditures, Full-time R&D Personnel in Healthcare, number of biotechnology patents, number of pharmaceutical patents, and medical technology patent for 2019 within the scope of health R&D in the OECD database were determined and were considered as DMU in the analyzes. These countries were the Czech Republic, Hungary, Latvia, Poland, Portugal, Slovakia, Slovenia, Turkey, Romania, Singapore, and the Chinese.

There are different opinions about the number of decision making units when applying DEA in the literature. Dyson et al. (2001), on the other hand, accept that $Rv > 2(m \times s)$ and consider it appropriate to determine the number of decision-making units in accordance with the inequality $N \geq 2(m \times s)$ (m: number of inputs, s: number of outputs, N: decision-making units).

Bousofiane et al. (1991), having at least $(m+p+1)$ decision-making units (N) argued that (“m” is the number of inputs, “p” is the number of outputs).

In practice, it is recommended that the number of decision-making units should be at least twice the number of inputs and outputs (Bakırcı, 2006).

The sum of the inputs and outputs in our research was 5; decision-making units was 11 so according to formula $N \geq (m+p+1)$; $11 > 6$ the conditions mentioned for this stage of the research were met (Bousofiane et al., 1991).

Determining Input/Output Variables

Input variables, total health research and development expenditures calculated at the country level, and the number of researchers working in the medical field were formed. Output variables were defined as the number of biomedical patents, the number of pharmaceutical patents and the number of patents in the medical technology field. Explanatory information about Input (I) and Output (O) variables used in Data Envelopment Analysis were given in Table 2:

Table 2: Definition of Variables

Variables	Unit	Source	Abbreviation
Health Research and Development Expenditures	Current prices, PPP dollars, 1000	OECD	I1
Number of Researchers in the Field of Health	Total/ Full Time Equivalent	OECD	I2
Biotechnology Patents	Number	OECD	O1
Pharmaceuticals Patents	Number	OECD	O2
Medical Technology	Number	OECD	O3

Determining the DEA Model and Measuring Efficiency

In DEA; another point to be considered in the selection of Input or Output Oriented Models is the direction of the control power (Bakırcı, 2006). The aim of Input Oriented Models is to try to reduce the amount of input provided that the output value is fixed; the purpose of Output Oriented Models is to try to increase the amount of output without exceeding the available input level.

Health services do not have control over outputs due to their unique nature, so studies in the field of health mostly focus on Input Oriented Models (Bahurmoz, 1999). However, since this study aims to measure the technical and scale efficiency of health research and development capacities of countries, technical efficiency, and scale efficiency values were investigated by using CCR-BCC Input and Output Oriented Models in order to reveal the total efficiency value.

Limitations

The limitations of this research are the number of variables used in the research, the year of the research, countries and the method of the research.

Ethical Statement

Ethics committee evaluation is not required as the data used in the analyzes are obtained from the OECD, a publicly available database.

Statistical analysis

In the study, DEAP 2.1 Programs were used in DEA analysis and Eviews was used for the descriptive analysis.

Results

Under this title, the findings of the DEA Model were given. In the scope of DEA, the study was carried out using Input and Output Oriented CCR and BCC Models.

According to the descriptive information of the variables in to the analysis; Health R&D Expenditures mean was $1078372000 \pm 1121746000$ (min: 593320000, max: 2910425000); researchers mean was 5972.12 ± 5302.43 (min:327, max:14892); medical technology patent mean was 41.95 ± 53.89 (min: 1.7, max: 168.2); pharmaceuticals patents mean was 41.47 ± 44.12 (min:1.1, max: 137.2); biotechnology patents was 33.77 ± 40.51 (min: 0.00, max: 126.2). It was also determined that the variables had a homogeneous distribution ($p > 0.05$). The description analysis of DEA was given at Table 3.

Table 3: Description Analysis of Variables

	Health R&D Expenditure*	Researchers	Medical Tech.Patent	Pharmaceuticals Patents	Biotechnology Patents
Mean	1078372.	5972.120	41.95455	41.47273	33.77273
Median	548212.0	4041.000	17.20000	27.80000	11.50000
Maximum	2910425.	14892.00	168.2000	137.2000	126.2000
Minimum	59332.00	327.0000	1.700000	1.100000	0.000000
Std. Dev.	1121746.	5302.429	53.88976	44.11871	40.51997
Skewness	0.638338	0.691132	1.453694	1.061534	1.277844
Kurtosis	1.684147	1.966798	3.813796	2.981890	3.407154
Jarque-Bera	1.540629	1.364990	4.177785	2.066049	3.069601
Probability	0.462867	0.505355	0.123824	0.355929	0.215499
Sum	11862094	65693.32	461.5000	456.2000	371.5000
Sum Sq. Dev.	1.26E+13	2.81E+08	29041.07	19464.60	16418.68

*Health Expenditures x 1000

According to Table 4, the average technical efficiency value of the countries was 0.845 according to the BCC Output Oriented Model. According to the efficiency values at the country level, five (5) of the eleven (11) countries included in the analysis were active according to the BCC Output-Oriented Model. These countries were Latvia, Portugal, Slovakia, Turkey, and Singapore. Turkey, which was effective, has been referenced 5 times, Singapore and Latvia 4 times, Portugal 3 times, and Slovakia 2 times through ineffective countries. According to this result, it was recommended that ineffective countries take reference from the countries referenced to them. Namely, it was understood that Hungary was not efficient with an efficiency score value of 0.960. Hungary could become effective by updating its data according to 2.6% of Turkey's data, 27% of Portugals' data, 1.4% of Singapores' data, and 69% of Latvia's data'.

Table 4: BCC Output Oriented Model Results for Countries, 2019

Countries	Technical Efficiency	Countries in the Reference Set	Reference Frequency	Scale Efficiency*
Czech Rep.	0.911	8(0.158); 5(0.113); 3(0.729)	0	0.755 (d)
Hungary	0.960	8(0.026); 5(0.270); 10 (0.014); 3(0.690)	0	0.997 (d)
Latvia	1	3(1.000)	4	1 (-)
Poland	0.423	10(0.301); 5(0.269); 8(0.430)	0	0.792 (d)
Portugal	1	5(1.000)	3	0.994 (d)
Slovakia	1	6(1.000)	2	1 (-)
Slovenia	0.656	6(0.075); 3(0.825); 10(0.100)	0	0.998 (d)
Turkey	1	8(1.000)	5	1 (-)
Romania	0.731	8(0.042); 6(0.664); 3(0.294)	0	0.834 (i)
Singapore	1	10(1.000)	4	1 (-)
Chinese	0.617	10(0.434); 8(0.566)	0	0.722 (d)

*(i): increasing returns; (d): decreasing returns; (-): constant return

Source: Prepared by the author.

According to the BCC Input-Oriented Model, the average technical efficiency value of countries was 0.841. According to Table 5, five (5) of the eleven (11) countries included in the analysis according to the efficiency values at the country level were found effective according to the BCC Input-Oriented Model. These countries were Latvia, Portugal, Slovakia, Turkey, and Singapore. Latvia, which was effective, has been referenced 6 times, Singapore and Turkey 4 times, Slovakia 2 times through ineffective countries. According to this result, it was recommended that ineffective countries take reference from the countries referenced to them. Namely, it was

understood that Slovenia was not efficient with an efficiency score value of 0.700. Slovenia could become effective by updating its data according to 90% of Latvia's data, 6.2% of Singapore's data, and 3.7% of Slovakia's data'.

Table 5: BCC Input Oriented Model Results for Countries, 2019

Countries	Technical Efficiency	Countries in the Reference Set	Reference Frequency	Scale Efficiency*
Czech Rep.	0.901	5(0.101); 8(0.141); 3(0.759)	0	0.763(d)
Hungary	0.960	8(0.028); 5(0.239); 10(0.014); 3(0.718)	0	0.997 (d)
Latvia	1	3(1.000)	6	1 (-)
Poland	0.378	10(0.141); 5(0.679); 3(0.180)	0	0.887 (d)
Portugal	1	5(1.000)	3	0.994 (d)
Slovakia	1	6(1.000)	2	1 (-)
Slovenia	0.700	3(0.901); 10(0.062); 6(0.037)	0	0.936 (i)
Turkey	1	8(1.000)	4	1 (-)
Romania	0.779	8(0.028); 3(0.458); 6(0.514)	0	0.783 (i)
Singapore	1	10(1.000)	4	1 (-)
Chinese	0.531	8(0.192); 10(0.469); 3(0.339)	0	0.838 (d)

*(i): increasing returns; (d): decreasing returns; (-): constant return

Source: Prepared by the author.

According to the CCR Output-Oriented Model, the average technical efficiency value of countries was 0.789. According to Table 6, four (4) of the eleven (11) countries included in the analysis according to the efficiency values at the country level were found effective according to the CCR Output-Oriented Model. These countries were Latvia, Slovakia, Turkey, and Singapore. Latvia and Singapore which were effective, have been referenced 6 times, Turkey 5 times, Slovakia 2 times through ineffective countries. According to this result, it was recommended that ineffective countries take reference from the countries referenced to them. Namely, it was understood that Poland was not efficient with an efficiency score value of 0.335. Poland could become effective by updating its data according to 99.5% of Slovakia's data, 11.06 times of Latvias' data, and 58.9 % of Singapore's data'.

Table 6: CCR Output Oriented Model Results for Countries, 2019

Countries	Technical Efficiency	Countries in the Reference Set	Reference Frequency
Czech Republic	0.688	8(0.099); 10(0.007); 3(4.430)	0
Hungary	0.957	8(0.061) ; 3(1.450); 10(0.031)	0
Latvia	1	3(1.000)	6
Poland	0.335	6(0.995); 3(11.066); 10(0.589)	0
Portugal	0.994	10(0.063); 3(2.812); 8(0.127)	0
Slovakia	1	6(1.000)	2
Slovenia	0.655	3(0.840); 6(0.091); 10(0.099)	0
Turkey	1	8(1.000)	5
Romania	0.609	8(0.066)	0
Singapore	1	10(1.000)	6
Chinese	0.445	10(0.924); 8(0.126); 3(9.990)	0

Source: Prepared by the author.

According to the CCR Input-Oriented Model, the average technical efficiency value of countries was 0.789. According to Table 7, four (4) of the eleven (11) countries included in the

analysis according to the efficiency values at the country level were found effective according to the CCR Input-Oriented Model. These countries are Latvia, Slovakia, Turkey, and Singapore. Latvia and Singapore which were effective, have been referenced 6 times, Turkey 5 times, Slovakia 2 times through ineffective countries. According to this result, it was recommended that ineffective countries take reference from the countries referenced to them. Namely, it was understood that Poland was not efficient with an efficiency score value of 0.335. Poland could become effective by updating its data according to 33.3% of Slovakia's data, 3.7 times of Latvias' data, and 19.8 % of Singapore's data'.

Table 7: CCR Input Oriented Model Results for Countries, 2019

Countries	Technical Efficiency	Countries in the Reference Set	Reference Frequency
Czech Republic	0.688	8(0.068); 3(3.047); 10(0.005)	0
Hungary	0.957	8(0.058); 3(1.388); 10(0.029)	0
Latvia	1	3(1.000)	6
Poland	0.335	6(0.333); 3(3.708); 10(0.198)	0
Portugal	0.994	10(0.063); 3(2.796); 8(0.126)	0
Slovakia	1	6(1.000)	2
Slovenia	0.655	3(0.550); 6(0.0059); 10(0.065)	0
Turkey	1	8(1.000)	5
Romania	0.609	8(0.040)	0
Singapore	1	10(1.000)	6
Chinese	0.445	10(0.411) ; 8(0.056); 3(4.450)	0

Source: Prepared by the author.

The constraint $BCC > CCR$ is valid for all cases, with a randomly selected Output Oriented BCC Model efficiency value and an Output Oriented CCR Model efficiency value. This was because the convex set of production possibilities in the BCC Model is a subset of the set of production possibilities in the CCR model (Çağlar, 2003). In other words, an effective decision-making unit in a CCR output-oriented model will definitely be effective in the BCC Output-Oriented Model. For example, Portugal, which was not efficient with a value of 0.994 according to the CCR Output Oriented Model, was determined to be effective with a value of 1 in the BCC Output Oriented Model, and this situation was evaluated as an example that meets the situation we mentioned above.

When interpreting the input-output residual values obtained from the BCC and CCR Models, it is recommended to choose the effective unit with the highest weight value from the reference set instead of interpreting the target value in the CCR Model; in the BCC Model, it is recommended to determine the target values in the ratio of the weight coefficients (Tepe, 2006). For example, according to the BCC input-oriented model, if Czech Republic's health R&D expenditure is reduced by \$54073 and the number of researchers is reduced by 307,844, the number of biotechnology patents will reach 28,301, and the number of pharmaceuticals patents will reach 15,376. The number of medical technology patents will remain constant. According to the CCR input-oriented model, if Czech Republic's health R&D expenditure is reduced by \$171090.205 and the number of researchers is reduced by 974,026; the number of biotechnology patents, the number of pharmaceuticals patents, the number of medical technology patents will remain constant (see Annex 1).

Discussion and Conclusion

The number of inventions and innovations developed within the scope of research and development activities is the success indicator of the research and development system in a country. R&D activities greatly affect total factor productivity (Coe & Helpman, 1995), which makes human capital the determinant of economic growth (Poorfaraj et al., 2011; Bayraktutan &

Kethudaoğlu 2017). Commercial activities in this area contribute to economic growth by disseminating information (Luintel & Khan, 2005; Sadraoui et al., 2014; Tunalı & Erbelet, 2017). The quantitative and qualitative characteristics of the researchers of a country appear as a factor that also shapes the economy of that country. For example, it is stated that the contribution of the mRNA vaccine, which was produced in Germany during the Covid-19 pandemic process and was widely used around the world, to the German economy was pointed around 0.5 points (Gönültaş, 2021).

Although diseases caused by viruses such as Ebola and Zika remained endemic, the Covid-19 virus, which was seen in the following years, turned into a global pandemic and caused the death of 6.9 million people (Statista, 2023) With the vaccines and treatment methods produced to prevent Covid-19 disease, this disease tried to be brought under control. This is a current experience that reveals the importance of health R&D expenditures and investments in the fight against health-related uncertainties on a global scale (Chinta et al., 2023). For this reason, studies to evaluate the field of health R&D are gaining importance day by day.

In this research, the effectiveness of health R&D activities in 11 countries including Turkey was measured with DEA, a non-parametric performance measurement method. CCR and BCC models, which are the basic models of DEA, were used in the study. According to the results obtained, four (4) countries were determined to be effective according to the BCC-CCR input and output-oriented models. These countries were Latvia, Slovakia, Turkey and Singapore. Portugal was found to be effective according to BCC output and input-oriented models and was not effective according to CCR input and output-oriented models. Also The Czech Republic, Hungary, Poland, Slovenia, Romania, Chinese countries were found to be ineffective in all BCC-CRR models. With this study, in R&D activities, since control over inputs is greater than control over outputs, inefficient decision-making units can be activated by using the values of input-oriented CCR and input-oriented BCC models (see Annex 1).

In the research where the relative efficiency of the R&D sector in the EU-27 (general R&D expenditures, researchers, employment in high-technology sectors, patents, and high-technology patent applications) between 2005–2010 period was evaluated by data envelopment analysis at the regional level, Netherlands, Germany, and Austria were found to be efficient, while low knowledge production and productivity were determined in Poland Lithuania, Latvia, Romania, Bulgaria, Slovakia, Greece, Spain and Italy (Aristovnik, 2014).

In the study, which uses an output-oriented DEA model to evaluate the R&D performance of Asian countries between 2014-2017 period, it was determined that Bahrain, Armenia, Oman, Georgia, Vietnam, Singapore and Israel were operating at the productivity limit (Sinimole and Saini, 2021).

In the research where R&D activities in EU countries were examined with the DEA method, in the period 2011-2013, Austria, Bulgaria, Croatia, Cyprus, Czech Republic, Germany, Hungary, Italy, Luxembourg, Malta, Netherlands, Poland, Romania, Slovenia, Sweden, and the United Kingdom were both fixed and found to be effective under variable returns to scale assumptions. Lithuania, Estonia, Greece, Portugal and Spain are not fully effective and operate with low efficiency (Karadayı & Ekinci, 2019).

The research, which evaluated the research and development efficiency in the public and private sectors in EU countries, revealed that there was an increase in the total R&D efficiency in Spain, Slovenia and Portugal (in the public sector) and Ireland and Romania (in the private sector) in the period 2010/2013 and 2014/2017. The research also confirmed differences in R&D productivity between private and public sectors in European countries (Halaskova et al., 2020).

In the study, which examined the efficiency scores of the National Innovation System (NIS) for 22 countries, including BRICS and G7 countries from 2000 to 2008 period, using DEA, it

was found that BRICS countries differ greatly in terms of the efficiency of their NISs; China, India, and Russia are shown to rank quite high, while Brazil and South Africa rank low (Cai, 2011).

In our research, Turkey's BCC-CCR was found to be fully effective according to input and output-oriented models. In a study where Turkey's health R&D activities were also evaluated, it was stated that Turkey showed a high level of performance in health R&D activities between 2005 and 2014, despite having a low capacity compared to the world scale (Ekinçi et al., 2022). In a study where general R&D activities in Turkey were evaluated on a provincial basis, 2017-2019 were the years when the highest activity values were observed (Çelik, 2023). In a research innovation efficiency at the regional level in Turkey using the DEA method within the framework of three inputs (R&D expenditures, R&D human resources, higher education resources) and three outputs (high technology exports, patent, brand) variables in 2019, it has been determined that 10 of the 26 NUTS-2 regions were active regions in terms of regional innovation (Dağlı, 2022). In the study, it was concluded that R&D and innovation expenditures in Turkey were not sufficient and the number of patent applications and acceptances remained at very low levels over different years (Demir & Geyik, 2014).

Besides this literature, efforts to improve the research skills of health professionals, who are producers of health R&D activities, are important ways can create a strong corporate culture in terms of producing and sharing knowledge. In the literature on the subject, many studies have been conducted on health professionals. A study conducted in a hospital showed that clinical nurses had positive beliefs about the benefits of nurse-led research and its impact on the image of the institution, teamwork, and patient care (Leao et al., 2013). In an experimental study conducted among highly educated healthcare professionals for a research mentoring program in Brazil, it was found that the group receiving training performed better in research skills as critical analysis of the literature and identification of appropriate research methods (Da Silva Souza et al., 2023). In a study conducted to comprehensively analyze the difficulties in scientific research training of Master of Public Health (MPH) students in terms of health R&D, the students' overall satisfaction score for research capacity was found to be lower than that of mentors. The reasons for this difference were determined to be due to the implementation period in the application unit, funding treatment, the importance of developing research capacity, development trends, and the current status of the research (Hu et al., 2023).

According to the analysis results and literature, it is recommended that determine the health R&D capacity in a way that takes into account the current situation and the needs of the future, including them in strategic plans/programs and their implementation. In this context, the recommendations are listed as follows:

- Diversification of health R&D supports (financial, technical, etc.)
- Establishing cooperation with public, universities, private institutions, non-governmental organizations
- Ensuring diversity of human resources in the field of health
- Developing policies to increase the level of health education and the quality of health personnel
- In the face of the international mobility of the qualified healthcare R&D workforce; protection and development of this area with constructive policies
- Giving lectures on topics that will develop and encourage creative thinking in healthcare professionals
- Establishment of R&D/Clinical Research laboratories in the field of health education
- Diversifying and increasing the limits of incentives in the field of health R&D for the private sector

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- Increasing public-private sector R&D collaborations

Data envelopment analyses are frequently used to measure and improve the efficiency of healthcare (Li et al., 2020). However, since it is a non-parametric method and the results obtained from the evaluation are based on the type of models used, care should be taken in interpreting the results. It should be emphasized that the results obtained from the DEA analyses may vary depending on the data sources, years, variables, and methods. The results obtained from the study; comparisons can be made in studies to be conducted using the same variables and the same decision units and different periods. In the coming years, the data of the R&D capacity can be developed at different year intervals, by applying different variables, different decision-making units, and different methods. Besides this, the health R&D indicators discussed in this research are important in terms of providing an up-to-date contribution to the literature with the year 2019 considered in terms of selected countries and time. The results of this study also can help the countries that make up the decision-making units to prepare effective policies for the future.

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Annex 1: Projection Summary of DEA

Countries	Original Value	BCC Input Oriented Model			CCR Input Oriented Model		
		Radial Movement	Slack Movement	Projected Value	Radial Movement	Slack Movement	Projected Value
Czech Republic							
O1	17.200	0.000	11101.000	28.301	0.000	0.000	17.200
O2	11.500	0.000	3876.000	15.376	0.000	0.000	11.500
O3	27.800	0.000	0.000	27.800	0.000	0.000	27.800
I1	548212.000	-54073.687	0.000	494138.313	-171090.205	0.000	377121.795
I2	3121.000	-307.844	0.000	2813.156	-974.026	-149.143	1997.831
Hungary							
O1	15.500	0.000	0.000	15.500	0.000	0.000	15.500
O2	10.900	0.000	0.000	10.900	0.000	0.000	10.900
O3	19.000	0.000	0.000	19.000	0.000	0.000	19.000
I1	316880.000	-12750.426	0.000	304129.574	-13643.256	0.000	303236.744
I2	4041.000	-162.599	-1801.203	2077.198	-173.985	-2382.034	1484.981
Latvia							
O1	1.700	0.000	0.000	1.700	0.000	0.000	1.700
O2	1.700	0.000	0.000	1.700	0.000	0.000	1.700
O3	5.900	0.000	0.000	5.900	0.000	0.000	5.900
I1	59332.000	0.000	0.000	59332.000	0.000	0.000	59332.000
I2	327.000	0.000	0.000	327.000	0.000	0.000	327.000
Poland							
O1	30.000	0.000	9.158	39.158	0.000	0.000	30.000
O2	33.900	0.000	0.000	33.900	0.000	0.000	33.900
O3	41.900	0.000	0.000	41.900	0.000	0.000	41.900
I1	1990536.000	-1238182.217	0.000	752353.783	-1323493.240	0.000	667042.760
I2	14892.000	-9263.339	-756.254	4872.407	-9901.585	-1779.172	3211.243
Portugal							
O1	33.200	0.000	0.000	33.200	0.000	0.000	33.200

O2	23.200	0.000	0.000	23.200	0.000	0.000	23.200
O3	39.900	0.000	0.000	39.900	0.000	0.000	39.900
I1	647651.000	0.000	0.000	647651.000	-3279.540	0.000	643921.460
I2	5622.000	0.000	0.000	5622.000	-32.375	-2441.441	3148.184
Slovakia							
O1	2.700	0.000	0.000	2.700	0.000	0.000	2.700
O2	8.000	0.000	0.000	8.000	0.000	0.000	8.000
O3	2.400	0.000	0.000	2.400	0.000	0.000	2.400
I1	74986.000	0.000	0.000	74986.000	0.000	0.000	74986.000
I2	1812.000	0.000	0.000	1812.000	0.000	0.000	1812.000
Slovenia							
O1	6.300	0.000	2.437	8.737	0.000	2.284	8.524
O2	9.600	0.000	0.000	9.600	0.000	0.000	9.600
O3	9.700	0.000	1.697	11.397	0.000	0.000	9.700
I1	268405.000	-80610.977	0.000	187794.023	-92689.831	0.000	175715.169
I2	1139.000	-342.080	0.000	796.920	-393.337	0.000	745.663
Turkey							
O1	168.200	0.000	0.000	168.200	0.000	0.000	168.200
O2	83.500	0.000	0.000	83.500	0.000	0.000	83.500
O3	137.200	0.000	0.000	137.200	0.000	0.000	137.200
I1	2728276.000	0.000	0.000	2728276.000	0.000	0.000	2728276.000
I2	14205.000	0.000	0.000	14205.000	0.000	0.000	14205.000
Romania							
O1	6.800	0.000	0.000	6.800	0.000	0.000	6.800
O2	1.000	0.000	6.193	7.193	0.000	2.376	3.376
O3	1.100	0.000	6.616	7.716	0.000	4.447	5.547
I1	180976.000	-40085.772	0.000	140890.228	-70677.089	0.000	110298.911
I2	1892.000	-419.074	0.000	1472.926	-738.888	-578.831	574.281
Singapore							
O1	115.400	0.000	0.000	115.400	0.000	0.000	115.400
O2	126.200	0.000	0.000	126.200	0.000	0.000	126.200
O3	97.300	0.000	0.000	97.300	0.000	0.000	97.300
I1	2136415.000	0.000	0.000	2136415.000	0.000	0.000	2136415.000
I2	7060.660	0.000	0.000	7060.660	0.000	0.000	7060.660
Chinese							
O1	64.500	0.000	22.524	87.024	0.000	0.000	64.500
O2	63.000	0.000	12.784	75.784	0.000	1.180	64.180
O3	74.000	0.000	0.000	74.000	0.000	0.000	74.000
I1	2910425.000	-1364106.527	0.000	1546318.473	-1614041.504	0.000	1296383.496
I2	11581.660	-5427.976	0.000	6153.024	-6422.503	0.000	5158.497