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Determining Efficiency of 15 OECD Countries Coping with Covid-19 using Data Envelopment Analysis after 2 Years of Pandemic

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ABSTRACT

Covid-19, emerged in Wuhan, a city of China, at the date of December 2019, it spread to the entire world soon and then by the World Health Organization (WHO) accepted as a pandemic. Today, still the coping with Covid-19 is the one of the significant topics of countries. In this study, the relative efficiencies of 15 OECD countries for coping with the pandemic is analyzed with Data Envelopment Analysis (DEA). Current health expenditure (% of GDP), Nurses and midwives (per 1 thousand people), Hospital beds (per 1 thousand people), Physicians (per 1 thousand people) variables used as inputs; Number of Total Cases (per 1 million people), Number of Deaths (per 1 million people) and Number of Tests (per 1 million people) variables used as outputs. Output oriented Charnes, Cooper and Rhodes (CCR) and Banker, Charnes and Cooper (BCC) DEA models are used, scale efficiency values are determined and potential improvement suggestions are given for inefficient countries. Austria, Mexico, South Korea, Spain and Türkiye are found to be both relative technical, total and scale efficient. It is also concluded that inefficient countries must use their input variables efficiently and number of Covid-19 tests is important for a country's efficiency against Covid-19.

Keywords: Covid-19, Data envelopment analysis, Efficiency, OECD Countries.

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Introduction

Covid-19 epidemic emerged in China (Wuhan city) at the date of December 2019 and surrounded the world soon [1]. Since the quick spread of the Covid-19 epidemic had an impact on all countries, it created severe situations for countries that are not prepared for the pandemic. The administrators, who were afraid of the inadequacy of the health systems, chosen to lockdowns in case of the inadequacy of the distance precautions and masks. During this period, it became clear that not only the health systems, however, also the economic and social development levels of the countries are significant for the direction of the pandemic. The health variables from the World Bank database are usually used for in the evaluation of the health systems of the countries [2]. The Ministry of Health of Türkiye announced that the first case in Türkiye was seen on March 11, 2020, on this date also the WHO announced Covid-19 as a pandemic. 13 August 2022, when this study was written, the total number of cases worldwide is 594375578 and the number of deaths is 6452554 due to the pandemic that can't be brought under control totally [3].

There are national and international studies on evaluating the efficiencies of the health systems of different country groups during the Covid-19 pandemic. Some of them summarized below.

Selamzade and Ozdemir (2020) investigate OECD countries' efficiency levels when coping with the Covid-19 pandemic. Output oriented models of CCR and BCC are used to obtain total and technical efficiency values respectively, scale efficiency values are calculated and potential improvement suggestions are developed for inefficient countries. The percentage of health expenditures in the Gross Domestic Product, nurses and hospital beds, number of doctors per ten thousand people are inputs; the countries' Covid-19 pandemic data for the date of August 1, 2022 that number of cases and deaths per million population, number of tests are outputs. For CCR model, 8 countries, for BCC model, 11 countries are effective. Slovakia (CCR) and Iceland (BCC) are the leading ones in terms of super efficiency. Italy, USA, Spain, Northern Ireland, United Kingdom and France ranked at the bottom in terms of efficiency scores. It is concluded that fewer number of cases and deaths might be seen in countries with high level of development and number of healthcare workers, as well the number of tests performed is significant for increasing efficiency [1].

Shirouyehzad et al. (2020) evaluate the performances of most severely affected countries considering medical treatment and contagion control of Covid-19 with DEA. In the first step, the efficiency values are computed based on the situations of the countries and the number of approved cases for creating a basis for analysis for the contagion control. In the second step the performance evaluation is done regarding recovered cases, death cases and total number of confirmed cases for evaluating the efficiency of medical treatment in the countries. As a result of this study, it is found that Vietnam, Singapore and Belgium are the countries with the highest efficiency for

both viewpoints. Especially, Singapore, which has one of the highest population densities in the Southeast Asia, has the highest efficiency among these countries and it comes forefront. For Europe it is seen that Italy is the last one while Belgium is the leading one in terms of efficiency performance. For Middle East, although Egypt is the last efficient one in terms of contagion control, it is the leading efficient one in terms of medical treatment and Iran is the top efficient one in terms of contagion control [4].

Akbulut and Senol (2022) evaluate the efficiency performances of the countries, which are in high income class in the World Bank income classification, coping with the Covid-19 pandemic by both CCR and BCC DEA models. The analysis is conducted in DEAP package program. The share of GDP assignment to health services, mortality rate per 100000 live births, the number of patient beds, the number of nurses and midwives per thousand people, the number of physicians per thousand people and health expenditure per capita are used. The number of tests, the number of cases per 100000 people, the number of deaths and the total number of people recovering from Covid-19 are output variables. 15 of 48 countries are found to be efficient [5].

Bagriacik Ayranci (2021) analyzed the relative efficiency of 41 OECD and EU member countries for combating against the pandemic using DEA. It is found that 8 of 41 countries are have relative technical efficiency in fighting the pandemic. Chile is in the last order in terms of relative technical efficiency, although Ireland having a relatively low technical efficiency it is nearly efficient. Canada and USA, which are among the richest and developed countries, among the countries having worst performance combating against the pandemic. Türkiye is one of the countries that it is not succeeded in technical efficiency [6].

Bayram and Yurtsever (2021) evaluate and compare the efficiency performances of 27 European countries on spread and deaths due to Covid-19 pandemic by input-oriented DEA model. The model is carried on in two steps. In the first step, the contagion control efficiency is evaluated while in the second step the medical treatment efficiency is determined. Moreover, area chart is used for classifying the countries into the 4 zone. Results showed that Cyprus, Malta, Denmark, Montenegro, Estonia, Finland, Greece, Netherlands and Norway are found to be effective both in the contagion control and in the treatment of Covid-19 patients. Italy, Spain, Portugal and Iceland performed well in the treatment of Covid-19 patients, but are not effective in contagion control. It is also stated that North Macedonia, Luxembourg, Switzerland and Türkiye are not effective both in the contagion control and in the treatment of Covid-19 patients [7].

Erdem (2021) evaluates the performance of the Covid-19 pandemic management activities of OECD countries with DEA. As input; the number of doctors per 1 thousand people, the number of nurses, the number of patient beds and the percentage share of health expenditures in GDP are used. As output; the number of tests per million people, the number of cases, the number of deaths and the number of Covid-19 vaccine doses implemented per 100 people are used. The input-oriented CCR model is applied using the context dependent DEA and the model is run again to the ineffective decision-making units (DMUs) each time. As a result of the 1st level analysis, 14 of 37 DMUs are found to be efficient. Of the 23 DMUs that are inefficient at level 2, 14 are found to be efficient. At the 3rd level, 5 of the 9 DMUs are efficient. At the last level, the remaining countries such as Australia, South Korea, Japan and New Zealand are seen as the most inefficient DMUs [8].

Ergulen et al. (2021) analyzed the efficiency levels of the G7 countries in coping with the Covid-19 pandemic using DEA. Number of tests, number of vaccines are used as input variables, number of deaths is used as output variable. As a result of the study, United Kingdom, Italy and USA are totally efficient; Canada, France, Germany and Japan are not totally efficient; among the inefficient countries Germany is the leading efficient country [9].

Kaman and Yucel (2021) studied on an efficiency performance analysis of healthcare workers from 9 OECD countries which are significantly affected by the epidemic. Moreover, the other target is investigating which countries are more efficient in saving healthcare workers. The input variables are the ratio of health expenditures in the GDP, the population density of the countries and the total number of healthcare workers per 1 thousand people. The number of cases and deaths per 1 million people of healthcare workers are output variables. DEA analysis results showed that countries that have total efficiency in the safety of healthcare workers are, Poland, Portugal and Czech Republic, however, Italy is the least efficient one [10].

Sel (2021) evaluates the Covid-19 performance of the health system improvements of G-20 countries. 5 health-related variables from the World Bank database are used as inputs, Covid-19-related test numbers, healed and deaths are used as outputs. The average values of 19 years (2000-2018) for health variables are used as inputs. Scale efficiency and super efficiency values are calculated by output-oriented CCR and BCC models. For CCR model USA, Brazil, China, United Kingdom, France and Türkiye are found to be efficient. For BCC model in addition to these 6 countries also India and Indonesia are found to be efficient [2].

Mourad et al. (2021) utilize the DEA methodology to explore 7 scenarios, incorporating six variables: the count of medical practitioners (doctors and nurses), conducted COVID-19 tests, hospital beds, death cases, recovered cases, and affected cases. To illuminate the relative efficiency of factors, Tobit analysis is employed. The results from the DEA indicate that less than half of the examined countries exhibit relative efficiency. Furthermore, the Tobit regression analysis demonstrates that the primary influence on efficiency scores stemmed from the quantity of recovered and affected cases. Ultimately, the outcomes of the Spearman, Kruskal-Wallis H and Mann-Whitney U tests signify the internal validity

and robustness of the selected DEA models. The results underscore the importance of adopting best practices in achieving relative efficiency by establishing a connection between healthcare system resources and the necessary outputs [11].

Perchkolaei and HosseinzadehLotfi (2021) assess the performance of member countries of OECD utilizing the network DEA technique. To achieve this goal, efficient financial and health indicators are identified. Adverse and adaptable data are recognized across different stages, leading to the presentation of a suitable model. The outcomes derived from implementing the model offered valuable insights into the financial and health policies of the mentioned countries. To assess the two-stage network, the set of indicators for inputs, the middle stage, and the outputs (three for each) are taken into account. The input variables are population density, health costs (percentage of GDP) and population. The intermediate (middle stage) variables are hospital bed density, physician density and number of hospitals. The output variables are number of deaths, number of active patients and number of improved. The results show that Australia, Japan, Iceland and Korea are efficient in the first stage and Türkiye, Belgium, United States and Sweden are efficient in the second stage [12].

Cansever and Senol (2022) evaluate the health systems of the countries in the developed country group, taking into account the World Bank classification and their secondary aim is to compare productivity results to be obtained with the performance of the countries in the fight against Covid-19. They use input-oriented CCR and BCC models from DEA models for measuring the effectiveness of health systems. While 79 countries constitute the universe of the research; the sample constitute of 36 countries whose data can be accessed. Data on health indicators of countries; covers the years 2000-2018 and annual data are used. Data on Covid-19 is obtained for the period between 01.03.2020-01.03.2022. As a result of DEA; the health systems of 6 countries (Antigua and Barbuda, Bahamas, Barbados, Oman, Trinidad and Tobago, Uruguay) are found to be effective. The overall efficiency average of the analyzed countries is determined to be 73%, and the inefficiency factors for the ineffective countries are identified. The secondary objective of the study is measuring Covid-19 performance, involves the use of testing rates, vaccination rates, and mortality rates. By comparing the findings obtained from the analysis with the Covid-19 performances; it has been observed that there is no relationship between the efficiency level of the health systems of the countries and the Covid-19 performances [13].

Pereira et al. (2022) introduced network DEA to assess the efficiencies of 55 countries that consisted of 37 OECD member countries, 6 OECD prospective members, 4 OECD key partners, and 8 additional countries. The network DEA model is structured in a general series with 5 distinct stages: population, contagion, triage, hospitalization, and intensive care unit admission. It adopts an output maximization orientation, representing a social perspective, as well as an input minimization orientation, signifying a financial perspective. It comprises inputs associated with healthcare expenses, desirable and undesirable intermediate products linked to the utilization of personal protective equipment and the infected population, respectively. Additionally, it encompasses desirable and undesirable outputs pertaining to COVID-19 recoveries and deaths, respectively. The conclusion is New Zealand, Latvia, Netherlands, Estonia, Iceland, and Luxembourg are the countries exhibiting higher mean system efficiencies. The national COVID-19 strategies of these countries should be examined, adjusted, and adopted by nations displaying poorer performances. Furthermore, the noteworthy observation that countries with larger populations tend to exhibit lower mean efficiency scores holds statistical significance [14].

Yousfat et al. (2022) aimed to assess the efficiency of European countries using the case fatality rate (CFR) of COVID-19. A sample of 30 countries is utilized in the analysis, employing DEA. The study incorporates population density and total cases as input indicators, with CFR serving as the output indicator. Among the 30 countries examined, only six (Albania, Malta, Belgium, France, Austria, and Italy) exhibited efficiency. Inefficient countries, on average, demonstrated an efficiency score of 0.372. Among European countries, Greece attained the lowest efficiency rate when compared to others. Belgium has recorded the highest case fatality rate, while Monaco has documented the lowest case fatality rate [15].

Acar et al. (2023) aimed to assess the response of middle-income nations to the challenges posed by Covid-19, focusing on specific health indicators in accordance with the World Bank's income classification. This evaluation employed with DEA. The proportion of GDP devoted to the number of patient beds, health services, the number of nurses and midwives per thousand populations, the number of physicians per thousand populations, and lastly, the amount of health expenditure per capita are the input variables. The number of people recovering from Covid-19 disease per 100.000 people, the total number of deaths per 1 million people, the total number of cases per 1 million people and the total number of tests conducted per 1 million people are output variables of the study. The DEA input-oriented CCR model performed, and the causes of inefficiency in countries have been determined. To position these countries on the efficient frontier, the target values have been disclosed. They found that 18 countries out of 47 countries are located in the effective border. Ultimately, the causes of inefficiency among countries falling below the efficient frontier are assessed through the application of the multiple linear regression analysis method and recommendations for necessary corrections are given [16].

Kıdak et al. (2023) aimed to compare the efficiencies of 36 OECD countries in combating the COVID 19 pandemic. They used a three-stage DEA approach. The initial phase examined the pre-COVID conditions, while

the subsequent stages assessed the current COVID status of countries, focusing on medical treatment and contagion control. Within the framework of the three-stage model, a set of 8 input variables, 3 intermediate variables, and 3 output variables were employed. The efficiency analysis utilized both the output-oriented CCR model and the BCC models. Initially, efficiency analysis is conducted for all countries at each respective stage. Türkiye has demonstrated efficiency in the pre-COVID and medical treatment stages, yet inefficiency has been identified in the contagion control stage. Recommendations have been proposed by comparing countries serving as reference points for Türkiye in the contagion control stage. Subsequently, a sensitivity analysis was conducted, wherein overall efficiency scores were computed for each country by assigning varying weights to the stages. The unique of the study to be first time that a multi-stage DEA study has been conducted that computed overall efficiency scores and addressed both the pre-COVID and COVID pandemic periods together [17].

Zhu et al. (2023) aimed to quantitatively evaluate the spread of the COVID-19 pandemic. They constructed an output-oriented multi-stage super DEA model for assessing COVID-19 transmission efficiency across 117 countries. Additionally, the model was used to analyze transmission characteristics and trends in various periods in Europe, Africa, the Americas and Asia. Significant variations were identified in the spread of the pandemic across different countries that they mentioned that the United States, Brazil and the United Kingdom experiencing relatively more severe outbreaks. Nevertheless, numerous countries exhibited comparable pandemic transmission patterns, including stable or periodic transmission. Despite 14.5% of the global population being fully vaccinated as of August 1, 2021, there has been no direct observation of a vaccine effect on pandemic transmission [18].

In this study, the efficiency levels of OECD countries are analyzed in terms of their performances fighting against the pandemic. For this purpose, the Covid-19 performances of the 15 OECD countries, whose data can be accessed, are evaluated according to the literature by using the averages of health indicators between the years 2000-2018. Output-oriented Charnes, Cooper, Rhodes (CCR) and variable-scale Banker, Charnes, Cooper (BCC) models are used for Data Envelopment Analysis (DEA) efficiency analysis. Efficiency scale values are calculated with the obtained CCR and BCC values.

Data Envelopment Analysis

DEA is one of the most popular and effective methods for performance analysis. DEA is based on two main models for input and output, CCR and BCC. The CCR model based on the assumption of constant returns to scale and the BCC model based on the assumption of variable returns to scale. The CCR input-oriented model explores how the most effective input combination needed to produce a given output combination most effectively. The BCC output-oriented model, on the other hand, investigates how much output combination can be obtained with a certain input combination. The CCR model investigates the increment in output generated by increments in inputs. The BCC model examines the more or less increment in output that might occur as a result of an increment in inputs. Moreover, according to the variety of orientation, both models have subsections named as non-oriented, output and input [2, 5, 19].

DEA is non-parametric technique used for the evaluation of the efficiency of DMUs. Farrell (1957) suggested an efficiency measurement technique with one input and one output [20]. Then Charnes et al. (1978) widened Farrell's proposition and improved a model that can measure the efficiency of DMUs with various mutual inputs and outputs [19]. These comparable existences are mentioned as DMUs which are used to transform inputs into outputs. In this technique, no assumptions for specification of the production function is made, and it is solved via optimization models. A frontier function that encompasses the internal and external factors is built using the information on the real inputs and outputs of DMUs. This boundary involves linear parts that not only discover the most efficient units but produce a basis for analysis of inefficient units. The advantage of DEA is that the "efficiency frontier" can be inferred and used as a model for organizations that are similar [4].

DEA model is one of the linear programming methods that allows measuring efficiency. When constructing the CCR model, it is assumed that if there are n DMUs, it produces s outputs $\vec{Y}_j = \left(Y_{1j}, Y_{2j}, \ldots, Y_{sj}\right)^T > 0$ with m inputs $\vec{X}_j = \left(X_{1j}, X_{2j}, \ldots, X_{mj}\right)^T > 0$ for each DMU_j (j=1,…,n). The CCR model provides the non-negative best $U_{rk}\left(r = 1, \ldots, s\right)$ and $V_{ik}\left(i = 1, \ldots, m\right)$ output and input weights, respectively, to maximize the proportion of weighted outputs obtained as a result of weighted inputs for each DMU [2, 19]: $\theta = \dfrac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}}$.

The models are formulated in two different ways; input and output oriented. Input-oriented analysis models maintain the given output levels and aim to minimize the amount of input used in this way. Output-oriented analyzes, on the other hand, are carried out to investigate the maximization of outputs without changing the amount of inputs available. When DEA is done with the output-oriented CCR method, the numerator value is also equal to 1 ($\sum_{r=1}^{s} u_r y_{rj} = 1$). In this study, Covid-19 performances of 15 OECD countries are determined with 4 input variables (health indicator averages) and 3 outputs of death, case and test numbers. In application, since the

input values are an evaluation of the past periods, the output-oriented CCR model is used that the current situation is examined. The linear programming model for efficiency analysis with the output-oriented CCR model is as in follows [2, 17, 21]:

Max θ_{CCR}

Constraints:

$$\sum_{j=1}^{n}\lambda_j x_{ij} - x_{i0} \le 0; \quad \sum_{j=1}^{n}\lambda_j y_{rj} - \varphi y_{r0} \ge 0; \quad \lambda_j \ge 0$$

In these primal and dual problems:

x_{ij} : i_{th} input value for j_{th} DMU

y_{rj} : r_{th} output value for j_{th} DMU

x_{i0} : i_{th} input value for 0_{th} DMU

y_{r0} : r_{th} output value for 0_{th} DMU

λ_j : the weight for j_{th} DMU

While obtaining the output-oriented efficiency value as it is " $1/\sum_{i=1}^{m} v_i x_{ij}$ ", the efficiency comments are as follows, depending on the obtained Θ value:

If $\theta = 1$ and the residuals are zero then DMU is efficient.

If $\theta > 1$ then DMU is inefficient.

The BCC model developed by Banker, Charnes and Cooper, the convexity constraint $\left(\sum_{j=1}^{n}\lambda_j = 1\right)$ is added to the CCR model. The formula for calculating efficiency using the output-oriented BCC model is as in follows [2, 22]:

Max θ_{BCC}

Constraints:

$$\sum_{j=1}^{n}\lambda_j x_{ij} - x_{i0} \le 0; \quad \sum_{j=1}^{n}\lambda_j y_{rj} - \varphi y_{r0} \ge 0; \quad \sum_{J=1}^{n}\lambda_j = 1; \quad \lambda_j \ge 0$$

After calculating CCR and BCC efficiencies for DMU, scale efficiencies are calculated: Scale Efficiency (SE)= $\theta_{CCR}/\theta_{BCC}$. Scale efficiency values are found in the form of CCR/BCC, and the scale efficiency of DMU equals 1 in case for both scales it has an efficiency value of 1. If a technically efficient DMU is inefficient due to scale, the relevant DMU can't be efficient in total.

Application

The scope of this study is to do a country specific efficiency evaluation of the coping with Covid-19 for 15 OECD countries, listed in Table 1, using DEA. As input variables, 4 variables related to health are considered. The input variables are obtained from World Bank database and the average values of these variables for the years between 2000 and 2018 are used according to the literature. Since for some of the countries the values are missing only the OECD countries with available data set is included in the study. Output variables data set of related to Covid-19 is obtained from the statistics given in Worldometer website (https://www.worldometers.info/coronavirus/) on August 1, 2022. Since increasing cases and deaths has negative effects, these variables inverses (1/O-1) and (1/O-2) are included in the analyses. The input and output variables are given in Table 2.

Table 1. 15 OECD Countries

Austria	Israel	Mexico	Switzerland
France	Italy	Slovakia	Türkiye
Greece	South Korea	Slovenia	United Kingdom
Ireland	Lithuania	Spain	

Table 2. The Input and Output Variables

Inputs	I-1: Current health expenditure (% of GDP)
	I-2: Hospital beds (per 1 thousand people)
	I-3: Nurses and midwives (per 1 thousand people)
	I-4: Physicians (per 1 thousand people)
Outputs	O-1: Number of Total Cases (per 1 million people)
	O-2: Number of Deaths (per 1 million people)
	O-3: Number of Tests (per 1 million people)

In performance evaluation by applying DEA method, under the R programming language the "deaR" library is used. First of all, using the "install" command, the library downloaded install.packages("deaR") and then imported by command library("deaR") [23].

Table 3. CCR Model Efficiency Values, Reference Countries and Reference Values

Countries	Efficiency Value	Austria (6)	South Korea (2)	Mexico (3)	Spain (7)	Türkiye (8)
Austria	1	1	-	-	-	-
France	3.01976	0.4527	-	-	0.0579	1.222
Greece	1.44157	0.3804	-	0.0274	0.4003	0.1361
Ireland	1.86657	-	-	-	0.2129	1.3185
Israel	1.12064	-	-	-	0.3253	0.8989
Italy	2.13237	0.0471	-	0.0538	0.6406	0.4971
South Korea	1	-	1	-	-	-
Lithuania	2.28387	-	-	-	-	-
Mexico	1	-	-	1	-	-
Slovakia	3.47319	0.4257	0.3367	0.1135	-	-
Slovenia	3.61853	0.1163	0.0041	-	-	1.2202
Spain	1	-	-	-	1	-
Switzerland	2.48901	0.0236	-	-	0.2533	1.6569
Türkiye	1	-	-	-	-	1
United Kingdom	1.26669	-	-	-	0.942	0.0858

As a result of CCR model, which measures efficiency under the assumption of constant returns to scale, efficiency values and reference countries with reference values are given in Table 3. As a result of output-oriented CCR model, 5 countries are efficient while 10 countries are inefficient.

As Table 3 is examined it is clear that Austria, South Korea, Mexico, Spain and Türkiye are efficient countries in terms fighting against Covid-19 in terms of their health systems. Türkiye is the leading one that it is taken as reference for inefficient countries 8 times, while Spain 7 times, Austria 6 times, Mexico 3 times and South Korea is taken as reference only 2 times. Slovenia is the most inefficient country and Slovakia is the second inefficient one as it is clear from their efficiency values.

In Table 4 for inefficient countries the redundant values in input variables and how much the output variables should increase is shown.

From Table 4, for example, for France nurses and midwives (per 1 thousand people) 3.1027 unit and physicians (per 1 thousand people) 2.2229 unit must be used more effective. It means for these input variables there is inactive usage. For Slovenia, which is the most in efficient country, current health expenditure 1.2533 unit, hospital beds (per 1 thousand people) 0.6593 unit, nurses and midwives (per 1 thousand people) 9.6346 unit must be used more effective. For other countries similar comments could be done. For output variables Slovakia and Slovenia must increase number of tests (per 1 million people) 4564702.8753 and 70616.7246, respectively, to be efficient.

Table 4. Potential Improvement Values of Ineffective Countries for CCR Model

Countries	I-1	I-2	I-3	I-4	O-1	O-2	O-3
Austria	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
France	0.0000	0.0000	3.1027	2.2229	0.0000	0.0000	0.0000
Greece	0.5160	0.0000	0.0000	1.9598	0.0000	0.0000	0.0000
Ireland	0.2003	0.0000	9.3756	0.4477	0.0000	0.0000	0.0000
Israel	0.1171	0.0000	2.8317	4.3886	0.0000	0.0000	0.0000
Italy	0.0000	0.0000	0.8916	4.0111	0.0000	0.0000	0.0000
South Korea	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Lithuania	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Mexico	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Slovakia	0.0000	0.3160	1.7794	0.2500	0.0000	0.0000	4564702.8753
Slovenia	1.2533	0.6593	9.6346	0.0000	0.0000	0.0000	70616.7246
Spain	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Switzerland	0.0000	0.0000	11.7000	0.3869	0.0000	0.0000	0.0000
Türkiye	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
United Kingdom	0.8559	0.0000	5.5273	1.4933	0.0000	0.0000	0.0000

As a result of BCC model, which measures efficiency under the assumption of variable returns to scale, efficiency values and reference countries with reference values are given in Table 5. As a result of output-oriented BCC model, similar to CCR model, 5 countries are efficient while 10 countries are inefficient.

As Table 5 shows that Austria, South Korea, Mexico, Spain and Türkiye are efficient countries in terms fighting against Covid-19 in terms of their health systems. Türkiye is the leading one that it is taken as reference for inefficient countries 10 times, while Austria 9 times, Mexico 8 times, South Korea 7 times and Spain is taken as reference only 4 times. Slovakia is the most inefficient country and Slovenia is the second inefficient one as it is clear from their efficiency values.

Table 5. BCC Model Efficiency Values, Reference Countries and Reference Values

Countries	Efficiency Value	Austria (9)	South Korea (7)	Mexico (8)	Spain (4)	Türkiye (10)
Austria	1	1	-	-	-	-
France	2.42686	0.4633	0.3575	0.1359	-	0.0433
Greece	1.39001	0.451	-	0.2803	0.2207	0.048
Ireland	1.52925	0.1127	0.1623	0.0091	-	0.7159
Israel	1.01637	-	0.0978	0	0.3394	0.5628
Italy	1.91651	0.238	-	0.0832	0.1466	0.5322
South Korea	1	-	1	0	-	-
Lithuania	1.96336	0.291	-	0.0268	-	0.6822
Mexico	1	-	-	1	-	-
Slovakia	3.37545	0.3239	0.2112	0.1688	-	0.2961
Slovenia	3.30786	0.186	0.2313	0.0896	-	0.4931
Spain	1	-	-	-	1	-
Switzerland	1.86896	0.1698	0.3179	0.0176	-	0.4947
Türkiye	1	-	-	-	-	1
United Kingdom	1.25042	0.0207	0.0004	-	0.8844	0.0945

Table 6. Potential Improvement Values of Ineffective Countries for BCC Model

Countries	I-1	I-2	I-3	I-4	O-1	O-2	O-3
Austria	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
France	3.2071	0.0000	3.8819	3.0843	0.0000	0.0000	0.0000
Greece	0.3241	0.0000	0.0000	1.4232	0.0000	0.0000	0.0000
Ireland	2.7525	0.0000	10.2266	1.3250	0.0000	0.0000	0.0000
Israel	1.0453	0.0000	3.0375	4.6990	0.0000	0.0000	0.0000
Italy	1.8917	0.0000	1.9386	4.7256	0.0000	0.0000	0.0000
South Korea	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Lithuania	0.0000	3.3550	4.3204	1.5140	0.0000	0.0002	0.0000
Mexico	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Slovakia	0.0000	1.3274	2.2517	0.2595	0.0000	0.0000	3060805.5181
Slovenia	2.2390	0.0000	9.4812	0.0754	0.0000	0.0000	663837.3943
Spain	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001
Switzerland	4.2902	0.0000	13.0044	1.8347	0.0000	0.0000	0.0000
Türkiye	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
United Kingdom	1.0870	0.0000	5.6558	1.5892	0.0000	0.0000	0.0000

In Table 6 Potential Improvement Values of Ineffective Countries for BCC Model is shown. From Table 6, for example, for France current health expenditure (% of GDP) 3.2071 unit, nurses and midwives (per 1 thousand people) 3.8819 unit and physicians (per 1 thousand people) 3.0843 unit must be used more effective. It means for these input variables there is inactive usage. For Slovakia, which is the most inefficient country, hospital beds (per 1 thousand people) 1.3274 unit, nurses and midwives (per 1 thousand people) 2.2517 unit, physicians (per 1 thousand people) 0.2595 unit must be used more effective. For other countries similar comments could be done. For output variables Slovakia and Slovenia must increase number of tests (per 1 million people) 3060805.5181 and 663837.3943, respectively, to be efficient.

The scale efficiency values for countries are given in Table 7. For each column the value is greater than average value is showed by bold. Table 7 shows that 6 countries efficiency values are above the average for both CCR (total efficiency), BCC (technical efficiency) models and 5 countries for scale efficiency. According to the scale efficiency values as for both of CCR and BCC models the countries Austria, Mexico, South Korea, Spain and Türkiye are efficient that means they are also efficient in terms of scale efficiency. On the other hand, according to scale efficiencies, the other countries are found to be inefficient similar to results for CCR and BCC models.

Table 7. Scale Efficiency Values

Countries	CCR	BCC	Scale Efficiency Value
Austria	1	1	1
France	3.01976	2.42686	1.244307
Greece	1.44157	1.39001	1.037093
Ireland	1.86657	1.52925	1.220579
Israel	1.12064	1.01637	1.102591
Italy	2.13237	1.91651	1.112632
South Korea	1	1	1
Lithuania	2.28387	1.96336	1.163246
Mexico	1	1	1
Slovakia	3.47319	3.37545	1.028956
Slovenia	3.61853	3.30786	1.093919
Spain	1	1	1
Switzerland	2.48901	1.86896	1.331762
Türkiye	1	1	1
United Kingdom	1.26669	1.25042	1.013012
Average	1.957347	1.753433	1.102699

Conclusion

In this study, 15 OECD countries' Covid-19 performance is evaluated using average values of 19 yearly (2000-2018) data set of 4 important health variables. Only 15 of OECD countries are considered due to data availability constraint. There are 4 input variables and 3 output variables. For efficiency analysis, output-oriented CCR and BCC DEA models are used.

The results showed that Austria, Mexico, South Korea, Spain and Türkiye (5 countries) are found to be efficient for CCR, BCC models and also in terms of scale efficiency. These countries are efficient in terms of scale, technical and total efficiency. When we consider the income levels of OECD countries included in our study it is obvious that they are high or upper-middle income countries. However, as the pandemic was a sudden unexpected crisis process that these countries also suffered from the process deeply. As a result of our study Mexico and Türkiye, two upper-middle income countries are found to be efficient with the high income countries of Austria, South Korea and Spain. France, Greece, Ireland, Israel, Italy, Lithuania, Slovakia, Slovenia, Switzerland and United Kingdom are ineffective for both of CCR and BCC models. When both of CCR and BCC models results are evaluated together it is seen that both of Slovakia and Slovenia must increase the number of tests (per 1 million people) to become efficient. Moreover, as a results of both of these models, Greece uses current health expenditure (% GDP) and physicians (per 1 thousand people) inefficiently; both of Ireland, Israel and United Kingdom use current health expenditure (% GDP), nurses and midwives (per 1 thousand people), physicians (per 1 thousand people) inefficiently; Slovenia uses current health expenditure (% GDP), nurses and midwives (per 1 thousand people) inefficiently; Slovakia uses hospital beds (per 1 thousand people), nurses and midwives (per 1 thousand people), physicians (per 1 thousand people) inefficiently; both of France and Italy use nurses and midwives (per 1 thousand people) and physicians (per 1 thousand people) inefficiently. If these inefficient countries use these input variables efficiently, they become efficient.

Recently, many studies have been conducted examining the efficiencies of countries in the Covid-19 process. In these studies, different country groups, different variables, classical DEA, network DEA, different approaches and techniques were used. In these studies, in which DEA used, one or both of the input-oriented or output-oriented BCC or CCR models were used. Hence, as a result of all these causes in terms of country efficiencies different results could be obtained for different studies. When we examined literature Türkiye, our country, found to be sometimes efficient or in efficient as a result of the causes mentioned. However, we can especially emphasize that Türkiye was found to be efficient in terms of scale, technical and total efficiency in a similar study of Sel (2021) that we especially based our study at the beginning.

The restriction of this study, because of the missing values that not all OECD member countries only 15 OECD countries could be considered in the analysis. The study could be carried out and repeated in the future when data values for other countries could be obtained completely. Moreover, when the pandemic could be completely under control all over the world the study could be updated since the output variables of deaths, cases and tests will be fixed and final results could be obtained.

Conflicts of interest

There are no conflicts of interest in this work.

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