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Efficiency analysis of OECD countries during COVID-19 pandemic using multi-stage DEA

COVİD-19 pandemisinde çok aşamalı VZA ile OECD ülkelerinin etkinlik analizi

Şeyma Meltem KIDAK[1], *Rifat Aykut ARAPOĞLU*[2], *Ezgi AKTAR DEMİRTAŞ*[2*]

[1]TEI TUSAŞ Engine Industry, Eskisehir, Turkey.
meltemkidak89@gmail.com

[2]Department of Industrial Engineering, Faculty of Engineering and Architecture, Eskisehir Osmangazi University, Eskisehir, Turkey.
arapoglu@ogu.edu.tr, eaktar@ogu.edu.tr

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Abstract

The aim of this study is to compare the efficiencies of 36 OECD countries in the fight against the COVID 19 pandemic. A three-stage Data Envelopment Analysis (DEA) is proposed. While the first stage analyzes the pre-covid situation, the contagion control and medical treatment stages evaluate the current COVID status of the countries. In the three-stage model, 8 input, 3 intermediate and 3 output variables are used. Efficiency analysis was carried out using output-oriented and constant return to scale CCR model and variable return to scale BCC models. First of all, efficiency analysis was performed for all countries at each stage. Target values have been calculated for countries that are not on the efficient frontier. Considering the target values and percentage changes, suggestions were made for countries to reach the efficient frontier. It has been observed that Turkey is efficient in the pre-Covid and medical treatment stages, but inefficient in the contagion control. Suggestions have been made by comparing the countries that are in the reference position for Turkey in the contagion control stage. Afterwards, with a study that can be described as a sensitivity analysis, overall efficiency scores were calculated for each country by giving different weights to the stages. No multi-stage DEA study has been found that calculates overall efficiency scores and deals with the pre-Covid and Covid pandemic period together.

Keywords: Multi-Stage DEA, COVID-19 pandemic, OECD countries, Efficiency measurement.

Öz

Bu çalışmanın amacı, 36 OECD ülkesinin Covid 19 pandemisi ile mücadeledeki etkinliklerini karşılaştırmaktır. Üç aşamalı Veri Zarflama Analizi (VZA) önerilmiştir. İlk aşama, covid öncesi durumu analiz ederken, bulaş kontrolü ve tıbbi tedavi aşamaları ise ülkelerin mevcut COVID durumunu değerlendirmektedir. Üç aşamalı modelde 8 adet girdi değişkeni, 3 adet ara değişken ve 3 adet çıktı değişkeni kullanılmıştır. Etkinlik analizi, çıktı yönelimli ve ölçeğe göre sabit getirili CCR ve ölçeğe göre değişken getirili BCC modelleri kullanılarak gerçekleştirilmiştir. Öncelikle herbir aşama için tüm ülkelerin etkinlik analizi yapılmıştır. Etkin sınırda olmayan ülkeler için hedef değerler hesaplanmıştır. Hedef değerler ve yüzde değişimler dikkate alınarak ülkelerin etkin sınıra ulaşabilmesi için önerilerde bulunulmuştur. Türkiye'nin Covid-öncesi ve tıbbi tedavi aşamalarında etkin olduğu, bulaş kontrolünde ise etkin olmadığı görülmüştür. Bulaş kontrolünde Türkiye'ye referans olan ülkelerle kıyaslama yapılarak önerilerde bulunulmuştur. Sonrasında duyarlılık analizi olarak nitelendirilebilecek bir çalışma ile aşamalara farklı ağırlıklar verilerek her ülke için bütünsel etkinlik puanları hesaplanmıştır. Covid öncesi ve Covid pandemi sürecini birlikte ele alan ve bütünsel etkinlik puanlarını hesaplayan çok aşamalı bir VZA çalışmasına rastlanmamıştır.

Anahtar kelimeler: Çok aşamalı VZA, COVID-19 pandemisi, OECD ülkeleri, Etkinlik ölçümü.

1 Introduction

The latest emerging New Coronavirus Disease (COVID-19) was first identified on January 13, 2020, as a result of research conducted in a group of patients who developed respiratory symptoms in late December 2019 in Wuhan Province, China [1]. The new virus has been named 2019-nCoV by the World Health Organization (WHO) the coronavirus disease COVID 19. As of 13 February 2021, more than 2.3 million deaths and 107 million cases of COVID-19 have been confirmed worldwide by WHO [2]. COVID 19 affected more lives, compared to SARS and MERS, infecting a much larger population worldwide, a coronavirus variant.

DEA has become widely used in the efficiency analysis of organizations operating in the production and service sectors or in the comparison of resource usage activities of countries and regions [3]-[4].

In the literature, there are many studies on the measurement of efficiency in the health sector using DEA. The concept and objectives, input and output variables, and the type of DEA models used in these studies are summarized:

Shirouyehzad et al. [5] aimed to evaluate the performance of countries using a two-stage DEA model in Covid-19 pandemic. In the first stage, while the efficiency of contagion control was analyzed according to the population density, average of 13 IHRCCS (International Health Regulations Capacity Core Scores), and the number of confirmed cases of several countries was used as output variable. In the medical treatment stage, confirmed cases were used as input variable of the second stage and the efficiency scores were calculated by considering recovered cases and death cases as output variables. In the

*Corresponding author/Yazışılan Yazar

study of Shirouyehzad et al. [5], they did not consider health expenditure statistics and how countries are prepared for a possible pandemic situation. In addition, the results of the two stages were interpreted independently, and overall efficiency scores were not calculated.

Hadad et al. [6] used output oriented BCC model to compare healthcare systems' efficiency of countries. Physician Density, Inpatient Bed Density, Health Expenditure Per Capita, GDP Per Capita, Consumption of Vegetables and Fruits per Capita were used as input variables. Life expectancy at birth and Infant survival rate were used as output variables.

Yasar and Khushalani [7] used Dynamic Network DEA model and Malmquist Index to examine the change in efficiency of health care systems of 34 OECD countries between 2000 and 2012. Smoking and alcohol consumption, body weight, expenses on public health, number of employees in healthcare, hospital beds and medical technology were the input variables. Life expectancy at birth, Hospital discharges and consultations were considered as outputs.

Retzlaff-Roberts et al. [8] used input and output oriented BCC models to analyze technical efficiency in the production of aggregate health outcomes of reduced infant mortality and increased life expectancy, using OECD health data. Their input variables were infant death rate and life expectancy at birth.

Chen et al. [9] used a three-stage Input-Oriented DEA to offer a comprehensive assessment of the efficiency of public hospitals operating in China's 31 regions. The number of licensed doctors, registered nurses, other technical staff and number of beds were inputs. Number of infectious patients, outpatient and inpatients were the outputs.

Gavurova and Kocisova [10] used a two-stage dynamic DEA to explore whether there exists a compromise between the production and the quality of services in the process of providing health care at the level of hospitals in Slovakia. Number of doctors per patient, number of nurses per patient, number of beds per patient were inputs and average length of hospital stay, surgical procedure rate, surgical planning health care, staff access to patients, patient information and hotel services were used as output variables.

Ilgun and Sahin [11] used a two-stage DEA to reflect the efficiencies of all institutions providing primary healthcare in Turkey between the years of 2012 and 2014 at the level of provinces. Primary healthcare budget allowance per capita, number of physicians per 100,000 population, number of nurses and midwives per 100,000 population, other health personnel per 100,000 population were inputs. Average number of follow-ups per pregnant and infant, number of visits to primary healthcare per capita and infant mortality rate were the outputs of the study.

Alfiero et al. [12] used two-stage CCR and BCC models to investigate the intellectual capital impact on healthcare organizations' performance in the Italian healthcare system.

Structural capital, human capital (doctors and nurses, knowledge and skills of workers), relational capital were the inputs whereas performance was the output of the study.

Ortega-Diaz et al. [13] evaluated Spanish Health System Hospitals by using an Input-Oriented DEA Model. Number of Installed beds, faculty personnel, other healthcare personnel, non-healthcare personnel, purchases and external services were the inputs. Total discharges adjusted case, outpatient consultations, non-admitted emergencies and major surgical procedures were the outputs.

Top et al. [14] measured the healthcare system efficiency of 36 African countries and compared their efficiency levels. The ratio of total health expenditures to GDP, number of doctors, number of nurses, hospital beds per 1,000 people, the unemployment rate and Gini Coefficient were the inputs and the life expectancy and mortality rate of children were the outputs. Two-stage DEA and Input oriented CCR models were used.

Alsabah et al. [15] used a two-stage DEA to estimate technical and scale efficiency scores for fifteen public hospitals in Kuwait from 2010 to 2014. Their model type was Input-Oriented CCR. Number of beds, number of doctors, number of nurses, number of non-medical workers were the inputs and total outpatient visits, the number of discharges were the outputs.

Kamel and Mousa [16] measured and evaluated the operational efficiency of 26 isolation hospitals in Egypt during the COVID-19 pandemic, as well as identifying the most important inputs affecting their efficiency. Input-Oriented CCR and BCC Models were used. Number of physicians, number of nurses, number of beds were chosen as input variables. Number of infections, number of deaths and number of recoveries were the outputs.

An Input-oriented BCC model was proposed with a two-step methodology for hospital beds vacancy and reallocation during the COVID-19 pandemic by Nepomuceno et al. [17]. Assistants and technicians, nurses, hospital beds, and costs were inputs. The number of hospital internments was the output of the study.

The main purpose of this study is to conduct an efficiency analysis of OECD countries affected by the COVID 19 pandemic by using a three-stage DEA model. In this proposed method, stages were called pre-covid, contagion control and medical treatment.

When DEA studies on the COVID 19 pandemic are examined, to the best of our knowledge, there is no study that measure the efficiency of OECD countries with multi-stage DEA regarding the Covid-19. In addition, no study has been found that takes into account the pre-covid health infrastructure. The studies in the literature about Covid-19 and multi-stage DEA do not evaluate countries or healthcare providers by using overall efficiency scores using different weight sets for the stages.

In this study, major performance indicators before and after the Covid-19 were evaluated collectively and a DEA analysis was provided. The structure of the multi-stage DEA model is given in Figure 1.

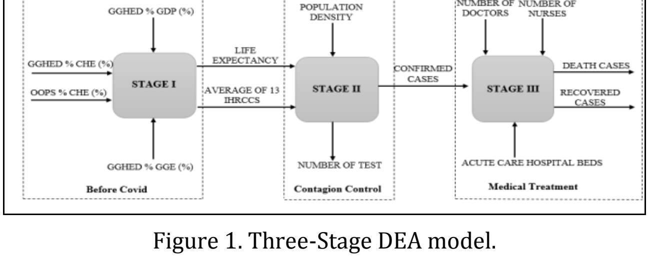

Figure 1. Three-Stage DEA model.

The definitions of input/output/intermediate variables used in pre-covid, contagion control and medical treatment stages are given in Table 1. The mentioned variables are the ones that are widely used in healthcare systems and related data are available through regular official notifications. Some input variables related to health expenditures were used to evaluate the pre-covid status of the countries and to see how effective their health infrastructures were. These are listed in the first four variables in Table 1.

Table 1. Input, intermediate and output variables.

Inputs	Definition
GGHED % GDP (%)	Domestic Public Health Expenditures in Gross Domestic Product
GGHED % CHE (%)	Domestic Public Health Expenditures in Current Health Expenditures
OOPS % CHE (%)	Share of Out of Pocket Payments in Current Health Expenditures
GGHED % GGE (%)	Domestic Public Health Expenditures in Total Government Expenditures
PD	Population Density (Persons per square km)
ND	Number of Doctors (Per thousand people)
NN	Number of Nurses (Per thousand people)
ACHB	Acute Care Hospital Beds (include not only beds in intensive care units, but also beds in acute care units-per thousand people)
Intermediates	**Definition**
LE	Life Expectancy (expected life years after birth)
Av_IHRCCS	Average of 13 IHRCCS (International Health Regulations Core Capacity Scores)
CC	Confirmed Cases (Per million people)
Outputs	**Definition**
NT	Number of Tests (Per million people)
DC	Death Cases (Per million people)
RC	Recovered Cases (Per million people)

Among the important performance indicators for countries in the management of pandemic are confirmed cases (CC), death cases (DC) and recovered cases (RC), which will be determined by the number of test (NT).

One of the most important factors affecting parameters such as CC, DC and RC in the event of pandemic in a country, is the public health infrastructure of the country and its capacity to meet the demand. In the event of pandemic, it can be controlled as long as the number of infected people remains below the total health care capacity. Otherwise, the number of deaths will increase significantly, due to both infection and the deprivation of service for other emergency patients. Therefore, it is crucial to analyze the effects of parameters affecting the total number of infected people.

At the Pre-covid stage, country efficiencies were analyzed by taking into account the health expenditure of OECD countries, life expectancy (LE) and the average of 13 International Health Regulations Capacity Core Scores (Av_IHRCCS). This is an average score indicating public health performance of the country [5],[18]. At this stage, the health system efficiencies of the countries were determined before the pandemic and how prepared they were for the pandemic was interpreted. At the contagion control stage, the efficiency of OECD countries in contagion control was determined by taking into account three inputs: population density (PD), LE and Av_IHRCCS. At the last stage medical treatment, efficiency scores were computed for each country by considering the confirmed cases (CC) per million people, the number of doctors (ND) and nurses (NN) per thousand people and acute care hospital beds (ACHB) in OECD countries.

After performing the efficiency analysis at each stage, target values of outputs for inefficient countries have been determined. Overall efficiency values were computed by combining all three stages, weighting by 12 different weight sets.

The methods, results, and discussion sections are organized as follows:

In the methodology part, brief preliminary information was given about DEA. Then, a three-stage DEA model and its input/intermediate/output variables are presented. Desirable and undesirable input/output variables were also determined. The model selection process was run. Preparation of data sets was also mentioned. In the result part, efficiency scores were computed separately for each stage. Output target values were determined for each country. Overall efficiency scores of countries were computed by using different weight sets for each stage. In discussion and conclusion part, after computing overall efficiency scores and relative ranking of countries, customized recommendations were made for inefficient ones. The limitations of the study and further studies were mentioned.

2 Methods

DEA is a non-parametric method that can measure the relative efficiency of decision-making units (DMUs) in the presence of multiple inputs and outputs with different measurement units. The original version of the DEA model is called CCR originating from the initials of the developers [19]. It works under the assumption of constant returns to scale. In 1984, BCC model based on variable returns to scale has also been developed by Banker et al. [20].

DEA classifies homogeneous DMUs into two groups as relatively efficient and inefficient by comparing them among themselves. Relatively efficient DMUs form the efficiency frontier. Relatively inefficient DMUs are made efficient similar to efficient DMUs. Target values are determined with the help of reference sets for relatively inefficient DMUs. In this way, policies can be developed for ineffective DMUs [21].

The objective function and the constraints of the linearized output-oriented CCR model is shown in Equations (1-4). In a process having n DMUs, n models are set up and the relative efficiency of each DMU is measured. A total of n optimization models are solved within this process [22].

$\mathrm{E_k}$	:	The efficiency score of DMU k	
n	:	The number of DMU	$j = 1, \dots, k, \dots, n$
m	:	the number of inputs	$i = 1, \dots, m$
s	:	the number of outputs	$r = 1, \dots, s$
$\mathrm{v_i}$	:	the weight of input *i*,	
u_r	:	the weight of output *r*,	
Y_{rj}	:	the amount of output *r* produced by DMU *j*	
X_{ij}		the amount of input *i* used by DMU *j*	
ε	:	Non-Archimedean element smaller than any positive real number	

$$\mathrm{E_k} = \min\left(\sum_{\mathrm{i}=1}^{m} \mathrm{v_i}\mathrm{X}_{\mathrm{i}k}\right) \tag{1}$$

$$\left(\sum_{\mathrm{r}=1}^{s} \mathrm{u}_r\mathrm{Y}_{rk}\right) = 1 \tag{2}$$

$$\left(\sum_{r=1}^{s} u_r Y_{rj}\right) - \left(\sum_{i=1}^{m} v_i X_{ij}\right) \geq 0 \quad \forall j,\ j = 1, \dots k, ., . n \tag{3}$$

$$u_r, v_i \geq \mathcal{E} \geq 0 \qquad \forall i,\ i = 1, \dots, m \qquad \forall r,\ r = 1, \dots, s \tag{4}$$

2.1 Model selection for three-stage DEA

In the three-stage DEA application, output-oriented CCR and BCC models were preferred in order for countries to develop policies that increase their output rather than their inputs. Today, 36 countries are members of the OECD. Therefore, only OECD countries have been evaluated as DMUs in the models. Three-letter country codes were used for standardization and abbreviation in all tables [23]-[24].

In the pre-covid stage, the efficiencies of OECD countries were analyzed by taking into account the health expenditure, LE and Av_IHRCCS. The aim of the first stage is to reach the highest LE and Av_IHRCCS while health expenditure is kept at a certain level.

In the contagion control stage, the efficiency of OECD countries was determined by taking into account the PD, NT and intermediate variables (LE, Av_IHRCCS) from the previous stage. CC is the undesirable output and the aim is to reduce CC and control the contagion by reaching as high NT as possible while PD, LE and Av_IHRCCS are kept at a certain level.

The first input in the medical treatment stage is CC coming from the second stage and used as an intermediate variable. ND, NN and ACHB were also used as inputs. The outputs are RC and DC.

A pairwise correlation check was performed so as to use the uncorrelated variables in the DEA analysis [25]. In this study, when considering the correlation between variables, no result above 0.80 was found. Thus, a total of 14 variables including 8 inputs, 3 intermediate variables and 3 outputs were used in the efficiency analysis.

At a stage, some inputs and/or outputs may be undesirable. Dyckhoff and Allen (2001) mention three basic approaches to model these variables. In this study, the undesirable output/input is modeled as f(y) = 1/y [26]. At the second stage, LE and the Av_ IHRCCS are undesirable inputs and CC is an undesirable output. At the third stage, DC is an undesirable output.

2.2 Data set

The data used in the study were taken from official websites of WHO, United Nations and OECD.

Four items related to health expenditure are taken from the "Health Expenditure Database" link on the WHO official website, and the Av_IHRCCS from the "Global Health Observatory Data Repository-Compliance with the International Health Regulations" link [27-28]. LE is taken from OECD official website "OECD Health Data" link, ND per thousand people, NN is taken from the "Health at a Glance 2019" report published by OECD periodically [29]-[30]. ACHB per thousand people is taken from the "Tackling Coronavirus Contributing to A Global Effort-Beyond Containment: Health systems responses to COVID-19 in the OECD" report, also published by the OECD [31].

PD is taken from the report by the "Department of Economic and Social Affairs Population Dynamics World Population Prospects 2019" from the United Nations official website [32]. NT, CC, DC and RC per million people were obtained from the Worldometer website on January 9, 2021 [33]. Data for all variables used in the model are included in Appendices A-C.

3 Results

For all stages, the efficiency of countries was examined using the EMS-Efficiency Measurement System 1.3 software [34]. Target values and policies for inefficient countries have been determined. The overall efficiency values were also calculated by combining all three stages using the weighted average method.

For the accuracy of the analysis, it is necessary to work with a sufficient number of DMUs. There are various opinions in the literature regarding the number of DMUs. One of these views is that the number of DMUs should be at least 2 or 3 times the sum of number of inputs and outputs. According to another view, n ≥ max [m*s, 3*(m + s)] where n is the number of DMUs, m is the number of inputs, s is the number of outputs [26]. All conditions mentioned above are met at each stage of this study. The results of each stage are summarized in the following sections.

3.1 Results for Pre-Covid stage

According to Appendix D, a total of 8 countries including France, Greece, Luxembourg, Mexico, the Netherlands, Switzerland, Turkey and the United States seem to be efficient.

When GGHED% GDP is analyzed, the average expenditure share of 36 OECD countries is 6.2%. According to the data in Appendix A, Mexico ranks last with 2.8%, while Turkey appears to be the penultimate place with 3.3%. Countries such as Latvia, Switzerland, Lithuania, South Korea, Chile, Poland, Hungary, Israel, Luxembourg, Estonia and Greece follow this order. The reason for Turkey and Mexico's emergence as a relatively efficient country is that these output levels are obtained with low input levels of LE and Av_ IHRCCS score. Looking at the GGHED% CHE values, it is seen that the average of 36 OECD countries is 70.4%. Countries such as Greece, Mexico, the Netherlands and Switzerland have proved to be relatively efficient for this expenditure item, although they are below the average with respect to the output they produce.

Looking at OOPS% CHE values, it is seen that the average of 36 OECD countries is 20.2%. France is in the last place with 9.2% and Luxembourg is the penultimate with 10.5%. This is followed by countries such as the Netherlands, the USA etc. However, France, Luxembourg, the Netherlands and the USA are relatively efficient. When GGHED% DDH values are examined, it is seen that the average of 36 OECD countries is 15%. Greece ranks last with 8.5%, while Turkey is the penultimate with 9.3%. It is possible to say that the percentage share of expenditure remains below the average in Greece, Turkey, Mexico, Luxembourg and Switzerland.

When considering LE, Japan ranks first with 84.2 years. Switzerland follows Japan with 83.8 years. While Switzerland is efficient with both CCR and BCC models, Japan is efficient with BCC model. Efficient countries such as Mexico, Turkey, and the United States cannot be considered as successful as Switzerland in producing output. Turkey is below the average with 78.3 years of LE. Achieving this LE level with low input values has brought Turkey to the efficient position. The status of Mexico and Greece is the same. These countries have become references to very few countries. Because, they reach these output levels with relatively low input rather than producing the highest health output.

Considering Av_IHRCCS scores, Canada has the highest value with 99. It is followed by South Korea, Luxembourg, Japan, Switzerland, Sweden and the USA. While South Korea and Japan are efficient with BCC model, Switzerland and Luxembourg are efficient with both models. Turkey is below the average with 83.8.

Switzerland has been reference country for 26 other countries and thus deemed to have a successful performance. LE and Av_IHRCCS score of Switzerland is above the average values. Achieving this level of output with relatively low inputs has made Switzerland efficient in using and managing inputs. Similarly, Luxembourg has become reference for 24 other countries.

Although the health shares in four different expenditure items are similar, Switzerland is more successful in generating output when compared to Turkey. Therefore, developing policies towards improving LE and Av_IHRCCS scores without increasing existing levels of input, will also increase the number of reference countries.

When calculating output targets for inefficient countries, λ (density) values (in Appendix D the column of reference set) and the output quantities of reference countries (in Appendix A) are used as in equation 5. For example, target value-TV of LE for Australia is computed as 95.4.

$$TVof\ LE\ =\ 82.4 \times 0.22\ +\ 81.9 \times 0.63\ +\ 83.8 \times 0.31 = 95.4 \qquad (5)$$

$$Per.Change\ for\ LE\ =\ (\ 95.4\ -\ 82.8\ )\ /\ 82.8\ \times\ 10 =\ 15\% \qquad (6)$$

Australia's LE value is 82.8 years. It is possible for Australia to become efficient as a result of a 15% increase in its LE value (Eq. 6).

The analyses were repeated with BCC model. In Appendix D, countries efficient with BCC model although not efficient with CCR are marked in gray.

3.2 Results for "Contagion Control" stage

At this stage, Australia, Iceland, Luxembourg and New Zeland are efficient as shown in Appendix E.

When we look at the input and output values of Australia, it is seen that LE and Av_IHRCCS are above the average values, and the PD is well below the average. The fact that CC is well below the average puts Australia in an effective position. Iceland is efficient for similar reasons. In addition, it is seen that the number of tests in Iceland is quite high. Despite numerous tests, the low rate of CC compared to other countries made Iceland efficient in contagion control stage. Another country that is efficient in this stage is Luxembourg. When the input and output variables given in Appendix B for Luxembourg are examined, it is efficient even PD and CC are above the average. The fact that CC is above average, is due to the high number of tests performed. In addition, Luxembourg has a successful performance as it is a reference to 30 countries.

LE and the Av_IHRCCS values of New Zeland as an efficient country, are above the average. Whereas PD and CC values are below the average.

Japan and South Korea are known to be successful in contagion control worldwide. However, they turned out to be inefficient in this study due to low number of test because of low number of CC. Even if Japan and South Korea do not appear to be efficient, they are good at contagion control thanks to the strict precautions taken. USA is efficient in contagion control as an interesting result of this stage. The high NT of the USA and the usage of an output oriented model, made it efficient.

Comparing Australia and Iceland, which have the same PDs, the high Av_ IHRCCS and NT in Iceland made it more successful than Australia. While Australia cannot be reference to any country, Iceland has been reference to 24 countries.

As for Turkey; Av_ IHRCCS is below average and PD is higher than other countries. NT is also below the average caused it to move away from the efficient frontier. Another country with a relatively low efficiency at this stage is Mexico. When Mexico, which has a population of approximately 129 million, is compared with other OECD countries, it is seen that the PD is quite high. Despite high PD, the total number of tests is approximately 4 million. Testing a very small portion of the total population also results in the number of CC not being accurately determined. It also appears that the number of tests per million is very low.

Target values of CC and NT and required percent changes are given in Appendix E for inefficient countries. The efficiency score for Denmark is 1.06 and very close to the efficient frontier. In order to reach the target, Denmark should reduce CC by approximately 7% and increase NT by approximately 7%.

In Appendix F, countries such as Canada, Denmark, Japan, South Korea, Norway, Spain and Switzerland with gray markings are efficient according to the BCC model.

3.3 Results for "Medical Treatment" stage

The aim is to increase RC and decrease DC for a certain number of CC, ND, NN and ACHB. In Appendix C the RC data of the Netherlands, Spain and Sweden are not available. Therefore, these countries are excluded from the analysis. The results of this stage are presented in Appendix F.

Chile, Iceland, Israel, Luxembourg, New Zeland, and Turkey are efficient countries. Turkey has a good performance as being reference to the inefficient countries 19 times. The reason is high rate of recovered patients. Approximately 94% of CC is recovered. Turkey ranks lowest according to NN and ND scores (1.9 and 2.1). Reaching certain amount of RC with relatively less input makes Turkey efficient. Referring to other countries 20 times, Iceland has a very successful performance. DC is very low compared to the RC. Reaching these output values with average ND, NN and ACHB is another factor that makes it successful.

When the input and output values of Luxembourg are examined, it is seen that CC is higher compared to other OECD countries. Although Luxembourg's CC is 75632, its RC is 70464 and its DC is 835. 93% of CC has been recovered. Luxembourg is an efficient country for such reasons and has been reference to 7 countries. In New Zeland, the number of CC is 437, RC is 420 and DC is 5. It has been efficient by recovering 96% of CC and has been reference for 11 countries. It is possible to make similar comments for Chile and Israel.

The countries that are far from the efficient frontier are Belgium, France and Greece. Looking at the input and output values of Belgium RC is quite less compared to CC. So, Belgium is located very far from the efficient frontier. The same is true for France and Greece.

Appendix F shows the target values for DC and RC. The farther away a country is from efficient frontier, the greater the percent change required.

According to the output oriented BCC model; The Czech Republic, South Korea and Mexico (colored in gray) are also efficient. Figure 2 is formed after the efficiency scores are calculated for each stage. Figure 2 is the cluster representation of efficient OECD countries with respect to stages. For instance, AUS is efficient at the Contagion Control stage only whereas LUX is efficient at all stages.

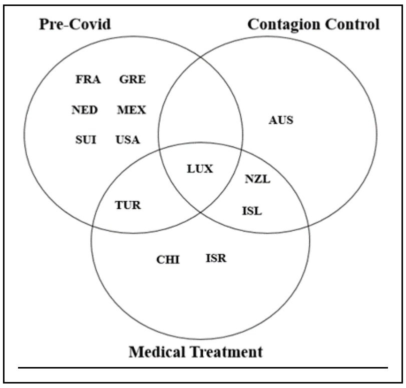

Figure 2. Cluster representation of efficient OECD countries.

in addition to Venn diagram, the chart presented in Figure 3 has been added so that the status of the countries can be seen more clearly for all stages. Figure 3 actually shows the inefficiency status of the countries for an output oriented model. The higher the column height, the more inefficient the countries are in Figure 3. For example, Mexico, which is one of the efficient countries at Pre-Covid stage, quickly deteriorates and becomes the most inefficient country in the contagion control stage mainly due to lack of number of tests and recovers back at the medical treatment stage. A similar behavior is seen in Poland and Slovakia. On the other hand, countries like Belgium, France and Greece are among the most inefficient countries at medical treatment stage (due to low number of recovered cases) although they are relatively efficient in previous stages.

3.4 Overall efficiency scores

In order to calculate the overall efficiency scores, the analyses were repeated after removing three countries (Netherlands, Spain and Sweden) having missing RC data from all stages. Efficiency scores for the remaining 33 countries are given in Appendix G. By assigning different weights to stages, the overall efficiency scores were calculated with the weighted average method. The weight sets, in Table 2, were derived with the help of the Design Expert software in accordance with the logic of Mixture Design [35].

Since it is worked with an output-oriented model, the overall efficiency scores are listed in ascending order starting from the best one (Appendix H).

The overall efficiency score of Luxembourg is 1 for all weight sets. It is the most successful country. This is followed by New Zeland. Iceland comes after New Zeland for nearly all data sets. Australia and Denmark follow these countries.

Table 2. The Weights of Stages.

No	W_1	W_2	W_3
1	0.10	0.80	0.10
2	0.30	0.25	0.45
3	0.10	0.10	0.80
4	0.10	0.45	0.45
5	0.25	0.65	0.10
6	0.40	0.10	0.50
7	0.40	0.30	0.30
8	0.20	0.40	0.40
9	0.15	0.25	0.60
10	0.40	0.50	0.10
11	0.25	0.25	0.50
12	0.25	0.50	0.25

The common factor in the success of these countries is that LE and Av_ IHRCCS are above average and PD is below average. Having relatively high NT and RC values is another factor. Low PD and high NT ensure fast and accurate detection of CCs. From the medical treatment perspective, the key to success is that the majority of CC has been recovered rather than having less CC.

Countries that are far from the efficient frontier are Mexico, Greece, Belgium and Poland. The reasons for failure of these countries vary according to the stages. For example, Mexico is efficient in the pre-covid stage, while it is far from the efficient frontier in the contagion control and medical treatment stages. Belgium is far from the efficient frontier in all three stages.

In France, Belgium and Greece, RC is very low compared to CC. Turkey, despite being efficient in the pre-covid and medical treatment stages, has stayed away from the efficient frontier in contagion control. For this reason, it is in the middle of the overall efficiency ranking.

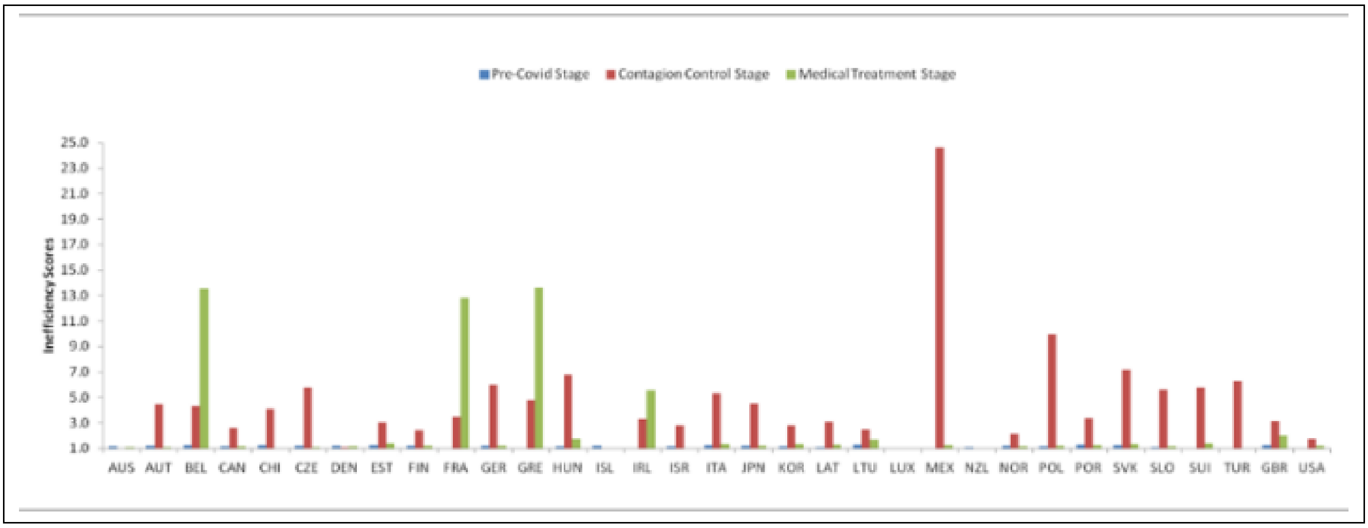

Figure 3. Inefficiency scores of countries at stages.

4 Discussion and conclusions

From the moment the coronavirus pandemic emerged, it has adversely affected social and economic life worldwide. In this study, efficiency analysis of OECD countries affected by the COVID 19 pandemic was carried out with three-stage DEA. For all three stages, efficiency measurements were made using both output-oriented CCR and BCC models. The EMS 1.3 software was used in the solution of the DEA models.

According to the output oriented CCR model in the pre-covid stage; France, Greece, Luxembourg, Mexico, the Netherlands, Switzerland, Turkey, and the United States are technically efficient countries. On the other hand, a total of 12 countries are technically efficient according to output-oriented BCC model. Compared with CCR, in the solution of BCC model; Canada, Japan, South Korea and Latvia are also technically efficient. Target values have been calculated for inefficient countries to become efficient. Efficient countries such as Turkey which has relatively low input-output values are able to manage health care resources in an efficient manner.

According to the output-oriented CCR model at the contagion control stage, the common feature of efficient countries such as Australia, Iceland, Luxembourg and New Zeland is that the NT made is relatively high. Since the health infrastructure of these countries is also strong, they are efficient at this stage. In the output-oriented BCC model, Canada, Denmark, Japan, South Korea, Norway, Spain and Switzerland are also technically efficient. In the next step, target values of CC and NT are calculated for inefficient countries. At this stage, Turkey with an efficiency score of 6.3 is far from the efficient frontier. Relatively low number of tests led to the failure of Turkey at this stage. In addition, the fact that LE and Av_IHRCCS are below average and the PD is relatively high, caused Turkey to move away from the efficient frontier.

According to the output-oriented CCR model at the medical treatment stage, Chile, Iceland, Israel, Luxembourg, New Zeland and Turkey are found to be technically efficient. In the output-oriented BCC model, the Czech Republic, South Korea and Mexico are also efficient. In this stage, Turkey took part among efficient countries being a reference for many countries. Remarkable treatment of the vast majority of patients has brought success. Turkey has managed to effectively use its health care resources at this stage. The same is true for other efficient countries. As for the medical treatment stage, target values and percent changes in DC and RC values of inefficient countries were calculated. It can be said that the farther a country moves away from the efficient frontier, the greater the amount of change is.

When calculating the overall efficiency scores; since RC data for the Netherlands, Spain and Sweden are not available, these countries were excluded from the DMU set and analyses were repeated for all three stages. According to the renewed results, Ireland has become efficient instead of the Netherlands at the pre-covid stage. Removing the Netherlands, which is in an efficient position in the first stage, from the analysis could change the efficiency scores of the other countries. In the contagion control stage, efficiency scores of the countries have not changed regarding to the renewed results. Overall efficiencies were calculated by weighing the efficiency scores of the countries at each stage. Luxembourg emerged as the most successful country by being efficient in all stages. This is followed by countries such as New zeland, Iceland, Australia and Denmark.

The keys to success of these countries are the strong health infrastructure, the relatively high number of tests made during the contagion control stage, and the recovering of the vast majority of patients during the medical treatment stage. Low PD values also positively affect the efficiency scores. In countries that are far from the efficient frontier, health infrastructure is insufficient, CC is relatively high and RC numbers are relatively low.

The results of this study are important for countries willing to locate their place among the others. Thus, OECD countries will be able to determine the reasons for being inefficient and to produce strategies. Vaccine development and distribution activities had just started at the time of the study. The lack of sufficient data on this subject restricts the analyses. In further studies, vaccine-related indicators could also be added into the multi-stage DEA model. Thus, new models can be constructed by using different input and output variables and analyses can be updated with new data.

Since sufficient data will be accumulated in the following periods, the study can be made dynamic for the contagion control and medical treatment stages in periods of 3-6 months. Dynamic DEA analysis will allow us to see lucidly the effects of the following peaks triggered by the future mutant viruses. For a dynamic analysis, techniques such as Malmquist Index and Time Windows could be used in further research. Additionally, several multi-criteria decision making techniques can be used to determine the weights of stages. By using Network DEA, different multi-objective models and solution techniques can be used in the computation of the overall efficiency scores instead of simple weighting method.

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6 Author contribution statements

This study is a part of the graduate thesis of Şeyma Meltem KIDAK. Şeyma Meltem KIDAK contributed to the literature review, modelling, analysis and paper drafting stages. Rıfat Aykut ARAPOĞLU and Ezgi AKTAR DEMİRTAŞ are the advisors of the graduate thesis. They contributed to the form of the multi-stage DEA, model selection, methodology and the preparation of the publication.

7 Ethics committee approval and conflict of interest statement

There is no need to obtain permission from the ethics committee for the article prepared. There is no conflict of interest with any person/institution in the article prepared.

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Appendix A. Dataset for pre-covid stage

Countries	Codes	GGHED % GDP (%)	GGHED % CHE (%)	OOPS % CHE (%)	GGHED % GGE (%)	LE	Av_IHRCCS
Australia	AUS	6.3	69.1	17.7	17.9	82.8	92
Austria	AUT	7.5	73.1	18.4	15.5	81.8	69
Belgium	BEL	8	75.8	19.1	15	81.7	84
Canada	CAN	7.8	73.5	14.7	19.5	82	99
Chile	CHI	4.5	50.8	33.2	18.3	80.4	76
Czech Republic	CZE	5.9	82.7	14.2	15.5	79.1	68
Denmark	DEN	8.5	83.9	13.8	16.6	81	95
Estonia	EST	4.8	73.6	24.7	12.5	78.4	74
Finland	FIN	7.1	78.6	18.4	13.3	81.8	94
France	FRA	8.7	73.4	9.2	14.8	82.8	82
Germany	GER	8.7	77.7	12.6	20	81	88
Greece	GRE	4.8	51.9	36.4	8.5	81.9	57
Hungary	HUN	4.7	69.1	26.9	9.9	76.2	68
Iceland	ISL	6.8	82.4	15.9	16.6	82.9	83
Ireland	IRL	5.3	73.9	12.1	20.2	82.3	64
Israel	ISR	4.7	64.7	21.1	12.1	82.9	87
Italy	ITA	6.5	73.9	23.5	13.2	83.4	85
Japan	JPN	9.2	84.1	12.7	23.6	84.2	95
Korea	KOR	4.4	58.5	32.5	14	82.7	97
Latvia	LAT	3.4	59.7	39.3	9.6	74.9	77
Lithuania	LTU	4.2	65.9	31.6	12.7	75.8	83
Luxembourg	LUX	4.7	84.9	10.5	10.7	82.4	97
Mexico	MEX	2.8	50.1	42.1	10.5	75	83
Netherlands	NED	6.5	64.9	10.8	15.4	81.9	90
New zeland	NZL	6.9	74.8	12.9	19.3	81.8	90
Norway	NOR	8.9	85.3	14.3	17.4	82.8	93
Poland	POL	4.5	71.1	20.8	10.8	77.7	70
Portugal	POR	5.9	61.5	29.5	13.4	81.4	82
Slovak Republic	SVK	5.3	79.2	18.9	12.7	77.4	73
Slovenia	SLO	5.9	72.4	12	13.8	81.5	86
Spain	ESP	6.3	70.4	22.2	15.2	83.5	85
Sweden	SWE	9.2	85.1	13.8	18.6	82.6	92
Switzerland	SUI	3.8	31.2	28	11	83.8	95
Turkey	TUR	3.3	77.4	17.5	9.3	78.3	77
United Kingdom	GBR	7.6	78.6	16.7	19.2	81.3	93
United States Of America	USA	8.6	50.4	10.8	22.5	78.7	92
	Mean	6.2	70.4	20.2	15	80.8	83.8

Appendix B. Dataset for contagion control stage.

Country Codes	LE	Av_IHRCCS	PD	NT	CC
AUS	82.8	92	3.3	464908	1114
AUT	81.8	69	109.3	428584	41712
BEL	81.7	84	382.7	620733	56878
CAN	82	99	4.2	406719	16995
CHI	80.4	76	25.7	352209	32985
CZE	79.1	68	138.6	373321	76750
DEN	81	95	136.5	1929462	30760
EST	78.4	74	31.3	503225	24519
FIN	81.8	94	18.2	461298	6865
FRA	82.8	82	119.2	569849	42038
GER	81	88	240.4	418455	22581
GRE	81.9	57	80.9	340523	13803
HUN	76.2	68	106.7	290122	35009
ISL	82.9	83	3.4	1308266	17135
IRL	82.3	64	71.7	513232	27360
ISR	82.9	87	400	950535	51900
ITA	83.4	85	205.6	456501	37042
JPN	84.2	95	346.9	41882	2101
KOR	82.7	97	527.3	91429	1326
LAT	74.9	77	30.3	505311	25481
LTU	75.8	83	43.4	634790	57931
LUX	82.4	97	241.7	2735667	75632

Appendix B: Continued.

Country Codes	LE	Av_IHRCCS	PD	NT	CC
MEX	75	83	66.3	29455	11632
NED	81.9	90	508.2	370314	50069
NZL	81.8	90	18.3	285238	437
NOR	82.8	93	14.8	546680	10008
POL	77.7	70	123.6	199354	36104
POR	81.4	82	111.3	579160	45841
SVK	77.4	73	113.5	275950	36836
SLO	81.5	86	103.2	340924	65716
ESP	83.5	85	93.7	595311	43845
SWE	82.6	92	24.6	445773	48308
SUI	83.8	95	219	439970	55018
TUR	78.3	77	109.6	304972	27208
GBR	81.3	93	280.6	864674	43446
USA	78.7	92	36.2	805717	67637
Mean	80.8	83.8	141.4	568903.1	34445.1

Appendix C. Dataset for medical treatment stage.

Countries	CC	ND	NN	NHB	DC	RC
AUS	1114	3.7	11.7	3.8	35	1007
AUT	41712	5.2	6.9	5.5	735	38659
BEL	56878	3.1	11	5	1721	3938
CAN	16995	2.7	10	2	441	14400
CHI	32985	2.5	2.7	2	884	31028
CZE	76750	3.7	8.1	4.1	1211	61012
DEN	30760	4	10	2.5	261	25736
EST	24519	3.5	6.2	3.5	203	16672
FIN	6865	3.2	14.3	2.8	106	5590
FRA	42038	3.2	10.5	3.1	1032	3080
GER	22581	4.3	12.9	6	481	18014
GRE	13803	6.1	3.3	3.6	500	961
HUN	35009	3.3	6.5	4.3	1082	19326
ISL	17135	3.9	14.5	2.5	85	16659
IRL	27360	3.1	12.2	2.8	469	4704
ISR	51900	3.1	5.1	2.2	391	44441
ITA	37042	4	5.8	2.6	1290	26311
JPN	2101	2.4	11.3	7.8	31	1693
KOR	1326	2.3	6.9	7.1	21	962
LAT	25481	3.2	4.6	3.3	427	18275
LTU	57931	4.6	7.7	5.5	784	32553
LUX	75632	3	11.7	3.8	835	70464
MEX	11632	2.4	2.9	1.4	1019	8754
NED	50069	3.6	10.9	2.9	709	N/A
NZL	437	3.3	10.2	2.7	5	420
NOR	10008	4.7	17.7	3.2	87	8563
POL	36104	2.4	5.1	4.9	808	29203
POR	45841	5	6.7	3.3	746	35378
SVK	36836	3.4	5.7	4.9	511	25909
SLO	65716	3.1	9.9	4.2	1417	53353
ESP	43845	3.9	5.7	2.4	1109	N/A
SWE	48308	4.1	10.9	2	931	N/A
SUI	55018	4.3	17.2	3.6	947	36557
TUR	27208	1.9	2.1	2.8	265	25729
GBR	43446	2.8	7.8	2.5	1173	20049
USA	67637	2.6	11.7	2.4	1139	39937
Mean	34445.1	3.5	8.8	3.6	663.6	22404.2

Appendix D. Results for pre-covid stage.

Countries	Efficiency	Reference Set	LE Target Value	Change (%)	Av_IHRCCS Target Value	Change (%)
AUS	115.26%	LUX (0.22) NED (0.63) SUI (0.31)	95.43	15	107.17	16
AUT	120.92%	FRA (0.50) LUX (0.20) NED (0.12) SUI (0.37)	98.92	21	106.53	54
BEL	122.95%	FRA (0.47) LUX (0.34) SUI (0.40)	100.45	23	109.5	30
CAN**	112.35%	LUX (0.48) SUI (0.12) USA (0.58)	95.18	16	111.22	12

Appendix D. Continued.

Countries	Efficiency	Reference Set	LE Target Value	Change (%)	Av_IHRCCS Target Value	Change (%)
CHI	126.30%	MEX (0.08) SUI (0.92) TUR (0.23)	101.54	26	112.2	48
CZE	118.53%	LUX (0.65) NED (0.37) SUI (0.12)	93.76	19	107.57	58
DEN	118.04%	LUX (0.76) SUI (0.08) USA (0.34)	95.69	18	112.14	18
EST	126.37%	GRE (0.06) LUX (0.35) SUI (0.46) TUR (0.35)	99.07	26	107.48	45
FIN	118.88%	FRA (0.06) LUX (0.68) NED (0.08) SUI (0.35)	97.24	19	111.75	19
FRA*	100.00%	8	82.8	0	82	0
GER	121.20%	FRA (0.24) LUX (0.00) NED (0.79) USA (0.17)	98.17	21	106.65	21
GRE*	100.00%	6	81.9	0	57	0
HUN	113.24%	GRE (0.53) LUX (0.28) SUI (0.04) TUR (0.22)	86.29	13	77.46	14
ISL	121.82%	LUX (0.41) NED (0.65) SUI (0.16)	100.99	22	114.1	37
IRL	100.67%	LUX (0.57) NED (0.36) SUI (0.08)	82.85	1	94.94	48
ISR	110.71%	LUX (0.56) SUI (0.54) TUR (0.00)	91.78	11	106.01	22
ITA	122.22%	GRE (0.05) LUX (0.64) SUI (0.54)	101.93	22	116.19	37
JPN**	118.52%	FRA (0.29) LUX (0.44) USA (0.50)	99.79	19	112.59	19
KOR**	113.45%	MEX (0.00) SUI (1.16)	97.08	17	110.05	13
LAT**	104.24%	GRE (0.02) SUI (0.33) TUR (0.63)	78.08	4	80.57	5
LTU	126.50%	MEX (0.12) SUI (0.76) TUR (0.29)	95.88	27	104.99	27
LUX*	100.00%	24	82.4	0	97	0
MEX*	100.00%	3	75	0	83	0
NED*	100.00%	13	81.9	0	90	0
NZL	112.94%	LUX (0.16) NED (0.92) SUI (0.05)	92.38	13	102.71	14
NOR	123.17%	LUX (0.34) NED (0.82) SUI (0.06) USA (0.02)	101.98	23	114.54	23
POL	111.97%	GRE (0.16) LUX (0.46) SUI (0.23) TUR (0.22)	87	12	92.07	32
POR	128.17%	GRE (0.11) LUX (0.37) SUI (0.77)	104.33	28	115.61	41
SVK	125.53%	FRA (0.01) LUX (0.79) SUI (0.38)	97.16	26	112.85	55
SLO	103.76%	FRA (0.02) LUX (0.37) NED (0.57) SUI (0.06)	84.56	4	95.31	11
ESP	123.36%	FRA (0.11) LUX (0.33) NED (0.28) SUI (0.53)	103.01	23	115.87	36
SWE	125.10%	LUX (0.21) NED (1.01) SUI (0.01) USA (0.03)	103.34	25	115.1	25
SUI*	100.00%	26	83.8	0	95	0
TUR*	100.00%	7	78.3	0	77	0
GBR	126.19%	LUX (0.38) NED (0.40) SUI (0.19) USA (0.29)	102.59	26	117.35	26
USA*	100.00%	7	78.7	0	92	0

*: Efficient countries regarding to CCR model. **: Efficient countries regarding to BCC model.

Appendix E. Results for contagion control stage.

Countries	Efficiency	Reference Countries	NT Target Value	Change (%)	CC Target Value	Change (%)
AUS*	100.00%	0	464908	0	1114	0
AUT	448.39%	ISL (0.54) LUX (0.44) NZL (0.03)	1918714	348	9435.57	342
BEL	433.49%	LUX (0.98) NZL (0.03)	2689511	333	12253.8	364
CAN**	260.10%	ISL (0.79) LUX (0.00) NZL (0.05)	1047792	158	6229.72	173
CHI	410.70%	ISL (0.91) LUX (0.09) NZL (0.03)	1445289	310	8133.55	306
CZE	577.43%	ISL (0.46) LUX (0.57) NZL (0.02)	2166837	480	12476.81	515
DEN**	105.99%	ISL (0.39) LUX (0.56) NZL (0.00)	2042768	6	28784.13	7
EST	301.02%	ISL (0.91) LUX (0.11) NZL (0.03)	1500003	198	8116.09	202
FIN	242.58%	ISL (0.71) LUX (0.06) NZL (0.14)	1132942	146	2757.9	149
FRA	346.82%	ISL (0.49) LUX (0.48) NZL (0.02)	1959875	244	12390.11	239
GER	599.63%	LUX (0.91) NZL (0.11)	2520833	502	3791.5	496
GRE	479.32%	ISL (0.56) LUX (0.32) NZL (0.14)	1647976	384	2798.93	393
HUN	676.07%	ISL (0.59) LUX (0.43) NZL (0.07)	1968180	578	4992.49	601
ISL*	100.00%	24	1308266	0	17135	0
IRL	328.66%	ISL (0.69) LUX (0.28) NZL (0.03)	1677247	227	8879.38	208
ISR	281.37%	LUX (0.98) NZL (0.02)	2686658	183	17028.79	205
ITA	534.86%	ISL (0.09) LUX (0.85) NZL (0.06)	2460175	439	6502.34	470
JPN**	455.47%	NZL (0.95)	270976.1	547	460	357
KOR**	281.54%	NZL (0.93)	265271.3	190	469.89	182

Appendix E. Continued.

Countries	Efficiency	Reference Countries	NT Target Value	Change (%)	CC Target Value	Change (%)
LAT	309.12%	ISL (0.96) LUX (0.11) NZL (0.03)	1565416	210	7928.33	221
LTU	248.78%	ISL (0.86) LUX (0.17)	1590172	151	19070.36	204
LUX*	100.00%	30	2735667	0	75632	0
MEX	2460.15%	LUX (0.17) NZL (0.92)	727482.4	2370	474.49	2351
NED	705.82%	LUX (0.95) NZL (0.06)	2615998	606	6672.87	650
NZL*	100.00%	30	285238	0	437	0
NOR**	214.46%	ISL (0.79) LUX (0.04) NZL (0.07)	1162923	113	4835.21	107
POL	998.46%	ISL (0.46) LUX (0.50) NZL (0.11)	2001012	904	3506.65	930
POR	337.96%	ISL (0.55) LUX (0.45) NZL (0.02)	1956301	238	11931.11	284
SVK	716.96%	ISL (0.54) LUX (0.46) NZL (0.07)	1984837	619	5056.13	629
SLO	558.04%	ISL (0.58) LUX (0.42) NZL (0.02)	1913479	461	11741.41	460
ESP**	306.13%	ISL (0.60) LUX (0.38) NZL (0.01)	1827365	207	15892.27	176
SWE	296.25%	ISL (0.82) LUX (0.09) NZL (0.01)	1321841	197	13902.69	247
SUI**	576.03%	ISL (0.04) LUX (0.90) NZL (0.04)	2525840	474	9454.72	482
TUR	629.71%	ISL (0.53) LUX (0.44) NZL (0.09)	1922746	530	4120.34	560
GBR	313.29%	LUX (0.99) NZL (0.03)	2716867	214	12233.97	255
USA	174.31%	ISL (0.78) LUX (0.14)	1403441	74	21109.55	220

*: Efficient countries regarding to CCR model. **: Efficient countries regarding to BCC model.

Appendix F. Results for medical treatment stage.

Countries	Efficiency	Reference Countries	DC Target Value	Change (%)	RC Target Value	Change (%)
AUS	107.48%	ISL (0.06) NZL (0.15)	32.56	7	1082.32	7
AUT	102.36%	ISL (0.28) TUR (1.36)	119.04	517	39571.5	2
BEL	1355.07%	LUX (0.40) NZL (0.02) TUR (0.98)	127	1255	53362.6	1255
CAN	113.20%	CHI (0.11) ISL (0.54) TUR (0.15)	141.08	213	16301	13
CHI*	100.00%	11	884.02	0	31028	0
CZE**	**103.05%**	**CHI (0.67) LUX (0.47) TUR (0.35)**	**379.89**	**219**	**62871**	**3**
DEN	113.34%	CHI (0.71) ISL (0.43)	169.15	54	29169.9	13
EST	139.96%	ISL (0.33) NZL (0.00) TUR (0.70)	145.04	40	23334.7	40
FIN	119.39%	ISL (0.40) NZL (0.03)	88.78	19	6674.14	19
FRA	1285.02%	CHI (0.90) LUX (0.03) NZL (0.05) TUR (0.38)	80.31	1185	39578.7	1185
GER	120.69%	ISL (0.85) TUR (0.29)	90.02	434	21740.5	21
GRE	1361.96%	ISL (0.08) NZL (0.12) TUR (0.46)	36.71	1262	13088.5	1262
HUN	171.99%	ISL (0.29) TUR (1.10)	131.72	721	33238.7	72
ISL*	100.00%	20	85	0	16659	0
IRL	552.88%	CHI (0.27) ISL (0.39) NZL (0.03) TUR (0.43)	84.83	453	26007.5	453
ISR*	100.00%	1	391.01	0	44441	0
ITA	132.89%	CHI (0.98) ISL (0.21) TUR (0.04)	267.63	382	34963.5	33
JPN	120.60%	ISL (0.12) NZL (0.19)	25.71	21	2041.72	21
KOR**	**133.85%**	**ISL (0.07) NZL (0.31)**	**15.69**	**34**	**1287.64**	**34**
LAT	132.35%	ISL (0.20) TUR (0.81)	184.98	131	24186.7	32
LTU	168.33%	CHI (0.43) ISL (0.19) TUR (1.49)	120.48	551	54796.1	68
LUX*	100.00%	7	835	0	70464	0
MEX**	**126.45%**	**ISL (0.15) TUR (0.33)**	**328.21**	**210**	**11069.2**	**26**
NZL*	100.00%	11	5	0	420	0
NOR	113.63%	ISL (0.58) NZL (0.03)	76.57	14	9729.83	14
POL	116.75%	LUX (0.05) TUR (1.20)	218.22	270	34093.1	17
POR	122.30%	CHI (1.14) ISL (0.23) TUR (0.17)	219.16	240	43265.6	22
SVK	134.83%	ISL (0.22) TUR (1.22)	140.16	265	34931.9	35
SLO	115.21%	CHI (0.01) LUX (0.64) TUR (0.62)	319.1	344	61466.1	15
SUI	141.74%	CHI (1.53) ISL (0.09) TUR (0.12)	311.31	204	51817.6	42
TUR*	100.00%	19	265	0	25729	0
GBR	203.23%	CHI (0.91) LUX (0.18) NZL (0.00)	577.18	103	40746.3	103
USA	116.13%	ISR (0.51) LUX (0.33)	582.92	95	46379.5	16

*: Efficient countries regarding to CCR model.**: Efficient countries regarding to BCC model.

Appendix G. Efficiency values for all stages (for the remaining 33 countries).

Countries	Pre-Covid	Contagion Control	Medical Treatment
AUS	1.13	1	1.07
AUT	1.2	4.48	1.02
BEL	1.23	4.33	13.55
CAN	1.12	2.6	1.13
CHI	1.26	4.11	1
CZE	1.17	5.77	1.03

Appendix G. Continued.

Countries	Pre-Covid	Contagion Control	Medical Treatment
DEN	1.18	1.06	1.13
EST	1.26	3.01	1.4
FIN	1.19	2.43	1.19
FRA	1	3.47	12.85
GER	1.18	6	1.21
GRE	1	4.79	13.62
HUN	1.13	6.76	1.72
ISL	1.19	1	1
IRL	1	3.29	5.53
ISR	1.11	2.81	1
ITA	1.22	5.35	1.33
JPN	1.19	4.55	1.21
KOR	1.13	2.82	1.34
LAT	1.04	3.09	1.32
LTU	1.27	2.49	1.68
LUX	1	1	1
MEX	1	24.6	1.26
NZL	1.1	1	1
NOR	1.2	2.14	1.14
POL	1.12	9.98	1.17
POR	1.28	3.38	1.22
SVK	1.26	7.17	1.35
SLO	1.01	5.58	1.15
SUI	1	5.76	1.42
TUR	1	6.3	1
GBR	1.25	3.13	2.03
USA	1	1.74	1.16

Appendix H. Overall efficiency values for all weight sets.

1		2		3		4		5		6	
LUX	1	LUX	1	LUX	1	LUX	1	LUX	1	LUX	1
NZL	1.01	NZL	1.03	NZL	1.01	NZL	1.01	NZL	1.02	NZL	1.04
ISL	1.02	ISL	1.06	ISL	1.02	ISL	1.02	AUS	1.04	ISL	1.08
AUS	1.02	AUS	1.07	AUS	1.07	AUS	1.05	ISL	1.05	AUS	1.09
DEN	1.08	DEN	1.13	DEN	1.13	DEN	1.11	DEN	1.1	DEN	1.14
USA	1.61	USA	1.26	ISR	1.19	USA	1.41	USA	1.5	USA	1.15
NOR	1.95	NOR	1.41	USA	1.2	NOR	1.6	NOR	1.81	ISR	1.22
FIN	2.18	ISR	1.49	NOR	1.24	FIN	1.75	FIN	1.99	NOR	1.26
LTU	2.29	CAN	1.5	CAN	1.28	CAN	1.79	CAN	2.08	CAN	1.28
CAN	2.31	FIN	1.5	FIN	1.32	ISR	1.83	LTU	2.1	FIN	1.31
ISR	2.46	KOR	1.65	CHI	1.34	KOR	1.98	ISR	2.21	LAT	1.39
KOR	2.5	LAT	1.68	AUT	1.39	LTU	2	KOR	2.25	KOR	1.4
EST	2.67	LTU	1.76	POR	1.44	LAT	2.09	LAT	2.4	CHI	1.42
LAT	2.71	EST	1.76	KOR	1.47	EST	2.11	EST	2.41	AUT	1.44
GBR	2.83	POR	1.78	LAT	1.47	POR	2.2	GBR	2.55	POR	1.46
POR	2.95	CHI	1.86	CZE	1.52	CHI	2.42	POR	2.64	EST	1.51
IRL	3.28	AUT	1.94	TUR	1.53	GBR	2.45	IRL	2.94	TUR	1.53
CHI	3.51	JPN	2.04	JPN	1.54	AUT	2.6	CHI	3.09	JPN	1.53
AUT	3.81	GBR	2.07	EST	1.55	JPN	2.71	AUT	3.32	SLO	1.54
JPN	3.88	SLO	2.22	SLO	1.58	ITA	3.13	JPN	3.38	CZE	1.56
FRA	4.16	CZE	2.26	GER	1.68	SLO	3.13	FRA	3.79	LTU	1.6
ITA	4.53	ITA	2.3	ITA	1.72	CZE	3.18	ITA	3.92	GER	1.67
SLO	4.68	TUR	2.32	LTU	1.72	SUI	3.33	SLO	4	SUI	1.68
CZE	4.84	SUI	2.38	SUI	1.81	GER	3.36	SUI	4.14	ITA	1.69
SUI	4.85	GER	2.4	SVK	1.92	TUR	3.38	CZE	4.15	GBR	1.83
BEL	4.95	SVK	2.78	POL	2.04	HUN	3.93	GER	4.31	SVK	1.89
GER	5.04	HUN	2.8	GBR	2.06	SVK	3.96	TUR	4.44	HUN	1.99
TUR	5.24	POL	3.36	HUN	2.17	IRL	4.07	BEL	4.48	POL	2.03
GRE	5.3	IRL	3.61	MEX	3.57	POL	5.13	GRE	4.73	MEX	3.49
HUN	5.69	FRA	6.95	IRL	4.85	FRA	7.44	HUN	4.85	IRL	3.49
SVK	6	MEX	7.02	FRA	10.73	BEL	8.17	SVK	5.11	FRA	7.17
POL	8.22	BEL	7.55	BEL	11.4	GRE	8.39	POL	6.89	GRE	7.69
MEX	19.91	GRE	7.63	GRE	11.48	MEX	11.74	MEX	16.37	BEL	7.7

Appendix H. Continued.

7		8		9		10		11		12	
LUX	1	LUX	1	LUX	1	LUX	1	LUX	1	LUX	1
NZL	1.04	NZL	1.02	NZL	1.01	NZL	1.04	NZL	1.02	NZL	1.02
AUS	1.07	ISL	1.04	ISL	1.03	AUS	1.06	ISL	1.05	ISL	1.05
ISL	1.08	AUS	1.06	AUS	1.06	ISL	1.08	AUS	1.07	AUS	1.05
DEN	1.13	DEN	1.11	DEN	1.12	DEN	1.12	DEN	1.13	DEN	1.11
USA	1.27	USA	1.36	USA	1.28	USA	1.39	USA	1.27	USA	1.41
NOR	1.47	NOR	1.55	NOR	1.4	NOR	1.67	NOR	1.41	NOR	1.66
FIN	1.56	FIN	1.69	ISR	1.47	FIN	1.81	ISR	1.48	FIN	1.81
CAN	1.57	CAN	1.72	CAN	1.5	CAN	1.86	CAN	1.5	CAN	1.86
ISR	1.59	ISR	1.75	FIN	1.5	LTU	1.92	FIN	1.5	ISR	1.93
KOR	1.7	KOR	1.89	KOR	1.68	ISR	1.95	KOR	1.66	LTU	1.98
LAT	1.74	LTU	1.92	LAT	1.72	KOR	2	LAT	1.7	KOR	2.03
LTU	1.76	LAT	1.97	POR	1.77	LAT	2.09	EST	1.77	LAT	2.14
EST	1.83	EST	2.02	EST	1.78	EST	2.15	POR	1.78	EST	2.17
POR	1.89	POR	2.1	CHI	1.82	GBR	2.27	LTU	1.78	POR	2.32
CHI	2.04	CHI	2.3	LTU	1.82	POR	2.32	CHI	1.84	GBR	2.39
GBR	2.05	GBR	2.32	AUT	1.92	IRL	2.6	AUT	1.92	CHI	2.62
AUT	2.13	AUT	2.44	JPN	2.04	CHI	2.66	JPN	2.04	AUT	2.8
JPN	2.2	JPN	2.54	GBR	2.19	AUT	2.83	GBR	2.11	JPN	2.88
SLO	2.42	SLO	2.9	CZE	2.24	JPN	2.87	SLO	2.22	IRL	3.28
ITA	2.49	ITA	2.92	SLO	2.24	ITA	3.3	CZE	2.25	ITA	3.31
CZE	2.51	CZE	2.96	ITA	2.32	SLO	3.31	ITA	2.31	SLO	3.33
SUI	2.55	SUI	3.07	TUR	2.32	FRA	3.42	TUR	2.32	CZE	3.44
TUR	2.59	GER	3.12	GER	2.4	SUI	3.42	GER	2.4	SUI	3.48
GER	2.63	TUR	3.12	SUI	2.44	CZE	3.46	SUI	2.4	GER	3.59
HUN	3	HUN	3.62	SVK	2.79	GER	3.59	SVK	2.78	TUR	3.65
IRL	3.04	SVK	3.66	HUN	2.89	TUR	3.65	HUN	2.83	HUN	4.09
SVK	3.06	IRL	3.73	POL	3.36	HUN	4.01	POL	3.36	SVK	4.24
POL	3.79	POL	4.68	IRL	4.29	BEL	4.01	IRL	3.84	FRA	5.2
FRA	5.3	FRA	6.73	MEX	7.06	GRE	4.16	MEX	7.03	POL	5.56
BEL	5.86	BEL	7.4	FRA	8.73	SVK	4.22	FRA	7.54	BEL	5.86
GRE	5.92	GRE	7.57	BEL	9.4	POL	5.56	BEL	8.17	GRE	6.05
MEX	8.16	MEX	10.55	GRE	9.52	MEX	12.83	GRE	8.26	MEX	12.87