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The efficiency of nations in the struggle against the COVID-19 pandemic

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The efficiency of nations in the struggle against the COVID-19 pandemic

Abstract

The COVID-19 crisis has caused unprecedented suffering across the world. Millions have become infected, and hundreds of thousands have lost their lives. Nations mobilised their health workers and infrastructure to curb the spread of the disease and cure the infected. This paper aims to investigate the efficiency of nations in their struggle against the COVID-19 and how their efficiency changed over time analysing data from June and December 2020 with a novel three-stage methodology. In the first stage, we clustered 107 nations into highly competitive, competitive, and non-competitive countries using their Global Competitiveness Index scores published by the World Economic Forum evaluate a country in a group of comparable countries. In the second stage, we used Data Envelopment Analysis to assess the efficiency of each nation. In the third stage, we investigated the relationship between countries' efficiency and performance in 66 variables published in the United Nations Human Development Report along with the long-debated aspect of a nation's political governance regime using Tobit regression. Based on the data in June and December, the USA and the UK were the worst performers in the highly competitive nations cluster, Chile and Peru were the worst performers in the competitive nations cluster, and Brazil and Mozambique were the worst performers in the non-competitive nations cluster, respectively. Air pollution, international inbound tourists, urban population significantly reduced while domestic credit and gross national income per capita significantly increased efficiency, but the political regime did not affect efficiency.

Keywords: Competitiveness Index, COVID-19, Human Development, Cluster Analysis, Data Envelopment Analysis, Tobit Regression

INTRODUCTION

The COVID-19 crisis has caused unprecedented suffering across the world. Millions have become infected, and hundreds of thousands have lost their lives. Nations mobilised their health workers and infrastructure to curb the spread of the disease and cure the infected. A global pandemic has severe worldwide impacts influencing economic and living conditions of nations. It reduces the Gross National Product (GNP), restricts the life expectancies, and even prevents the students from getting an adequate education. On the last day of 2019, Chinese officials warned the World Health Organization (WHO) of pneumonia cases with an unknown cause in Wuhan City, Hubei, China. The International Committee on Taxonomy of Viruses announced the name of the new virus as the Severe Acute Respiratory Syndrome CoronaVirus 2 (SARS-CoV-2). On 11 February 2020, the WHO announced "COVID-19" as the name of this disease and declared the outbreak of COVID-19 a global pandemic on 11 March 2020 (https://www.who.int/emergencies/diseases/novel-coronavirus-2019/).

COVID-19 is currently one of the most significant healthcare problems worldwide. As of 18 December 2020, the total confirmed number of cases is 75,371,570, and the death toll is 1,670,455 (https://www.worldometers.info/coronavirus). There are still 107,229 people in serious or critical condition. The countries have not been able to stop the growth of the pandemic within their boundaries. In fact, Huang et al. (2020) use a novel deep neural network framework to forecast the COVID-19 outbreak in Germany, Italy, and Spain and show that there is a disproportionate burden across countries, suggesting that important factors positively or negatively influence the countries' attempts to respond to this pandemic.

This research aims to identify the efficiency of nations against the COVID-19 pandemic and determine the factors that affect their efficiency. Nations are initially clustered based on the twelve competitiveness pillars of the Global Competitiveness Index published by the World Economic Forum (WEF) (Schwab, 2019). Then, a Data Envelopment Analysis (DEA) output-oriented model with assurance region (Zanakis et al., 2007) is run separately for each cluster, taking health-related variables as inputs and COVID-19 response outcomes as outputs. Finally, the relationship between nations' performance in 66 variables published in the Human Development Report of the United Nations (Conceição, 2019) and COVID-19 response efficiency is estimated using Tobit regression (Zeng et al., 2016) to inform policies developed for each nation.

In fact, a country's ability to rapidly detect and isolate infected persons and cure them immediately could end the outbreak. Therefore, the DEA establishes international comparisons on the efficiency of nations to reduce the number of COVID-19 victims and inform nations to prepare for a similar pandemic in the future. For this purpose, the authors collected the data of 107 nations in June and December 2020 and investigated variations among nations in curbing the pandemic through their resources using a novel three-stage methodology. The authors initially clustered nations into highly competitive, competitive, and non-competitive nations to allow each country to be evaluated in a group of comparable countries. The authors found that the USA was the worst performer in the highly competitive nations cluster based on the data until June 2020, whereas the UK was the worst performer based on the data until December 2020. Chile was the worst performer in the competitive nations cluster based on the data until June 2020 while Peru is the worst performer based on the data until December 2020. Brazil was the worst performer in the non-competitive nations cluster based on the data until June 2020 but based on the data until December 2020, Mozambique has the lowest efficiency scores. Air pollution, international inbound tourists, urban population significantly reduce efficiency scores whereas domestic credit and gross national income per capita significantly increase efficiency. On the other hand, the political governance regime of a country does not affect its efficiency.

The DEA is widely used in the performance analysis of healthcare systems. One of the primary reasons for this is related to its ability to consider multiple inputs and outputs to measure efficiency. The DEA categorises the evaluation criteria as inputs and outputs, where inputs represent the resources used, and outputs represent outcomes of resource transformation. The specification of efficient and inefficient units is based on a simple efficiency frontier analysis, and the model does not require any assumptions about the production function to be used between inputs and outputs. It does not require too much data and can use data with different measurement units simultaneously. Unlike other performance evaluation methods, the DEA does not require any subjective assignment of weights to each performance criterion to calculate an efficiency score. The optimal weights are calculated automatically for all inputs and outputs of each decision-making unit (DMU) by solving a linear programming model. In addition to an efficiency score, the DEA also identifies benchmark DMUs that can serve as a reference for underperforming ones to identify necessary improvements.

The rest of the paper is organised as follows. The second section provides the literature review on pandemic-related studies. The third section presents the proposed methodology. The fourth section presents the cluster analysis results, followed by the efficiency scores from the DEA output-oriented model with assurance region, and Tobit regression analysis results that explain the variation in the efficiency of nations in their struggle against the COVID-19 pandemic. Finally, the fifth section presents the discussion and conclusions.

BACKGROUND

Several researchers analysed the impact of global pandemic on countries' economies as well as the efficiency of national programmes in their fight against this pandemic. The search for efficiency and effectiveness in using resources for prevention, treatment, and care programmes to curb the pandemic has been an essential driver in recently published research. However, only a few studies assess and compare the efficiency of the countries in their ability to use their available resources to combat the pandemic (Santos et al., 2016). Many relevant previous studies focused on the Human Immunodeficiency Virus (HIV) Infection and Acquired Immune Deficiency Syndrome (AIDS) pandemics.

Verikios (2020) uses computable general equilibrium model using quarterly period data in 27 countries and 30 sectors in order to understand the impact of a pandemic and shows that the largest economic impacts are driven by reduced travel and tourism, and lost workdays. The analysis also highlights that travel and tourism reductions are more important in the influenza scenario and that lost workdays are more important in the coronavirus scenario.

To analyse the growth trends in the COVID-19 pandemic and fatalities in West Africa, Bankole et al. (2020) used cross-sectional data on the total reported cases of COVID-19 infection and the number of deaths for Burkina Faso, Ivory Coast, Niger, Ghana, Nigeria, and Senegal at intervals of seven days from 15 March through 19 April 2020. They concluded that the COVID-19 cases were underreported, and the region was not well prepared for the pandemic.

The risk factors associated with deaths from COVID-19 were investigated in four countries: The USA, Italy, Spain, and Germany (de Fátima Cobre et al., 2020). For this purpose, the data from the Institute for Health Metrics and Evaluation with projection information from January to August 2020 were used in a multivariate logistic regression to compare these countries in terms of the number of beds needed for the hospital services, the number of intensive care units (ICU) required, the number of ventilation devices needed, and the number of both hospital and ICU admissions due to COVID-19. The low number of both beds in ICU and ventilation devices available per day was associated with an increase of 100-fold in mortality from COVID-19 in all four evaluated countries.

An on-line survey with 4,624 Turkish citizens between 17 March and 1 April 2020 revealed the citizens' most preferable source of information (Geçer et al., 2020). Although the preferences depended on demographic factors such as age, educational attainment, and economic level, Internet journalism and social media were the most preferable sources of information. However, the use of only on-line survey made these results biased due to the fact that only respondents who had access to the Internet were able to respond.

The efficiency of countries in their fights against pandemics has been generally analysed through the DEA method. For example, the efficiency of HIV prevention services across nations was assessed using a DEA model on data from 2008, with five inputs and four outputs to compare the efficiency of 52 low- and middle-income countries in preventing mother-to-child HIV transmission (Santos et al., 2012). Results indicated that to prevent the infection of children, the resources should be used more effectively, and each nation should learn from its peers. A DEA output-oriented model was used to evaluate the efficiency of national HIV/AIDS programmes in transforming funding into services (Zeng et al., 2012). Then a Tobit model was implemented to identify the factors that influenced the efficiency in 68 low- and middle- income countries. A greater participation of civil society in policy making would increase the efficiency of the HIV/AIDS programmes. Similarly, an increase by approximately 40% in the gross national income of the lowest quartile countries would increase the efficiency of AIDS programmes by approximately 45%. A DEA input-oriented model was used to evaluate and compare 45 countries in terms of three types of gaps: performance, resource, and efficiency (Zeng et al., 2016). In line with Zeng et al. (2012), the efficiency of HIV/AIDS programmes should be assessed to reduce the resource needs for HIV/AIDS prevention.

The performance of the health system in 165 countries were evaluated using a refined version of the DEA: the value efficiency analysis (González et al., 2020). For this purpose, healthy life expectancy and disability-adjusted life years were used as health outcomes while health expenditure and education were treated as inputs. The analysis showed that the high-income OECD countries had higher efficiency and lower dispersion of efficiency scores. Additionally, the increase in public share of the health expenditure as well as the weight of health expenditure within the total public budget were found to influence the performance of the healthcare system positively. Also, the healthcare sector efficiency in rural Burkina Faso were analysed using DEA and Tobit to specify the basic reasons for inefficient performance (Marschall & Flessa, 2009). Only quantitative inputs and outputs were used and qualitative variables such as patients' perceptions of the quality of service as well as their satisfaction were not considered.

A DEA model was used to measure healthcare efficiencies of transition economies and then potential policy implications were discussed (Mirmirani et al., 2008), highlighting the importance of making changes in government policies, health education, and public awareness to reduce the absence of sound policies, rising social stress, and an unhealthy lifestyle. Zhao et al. (2020) evaluated the efficiency of Chinese hospitals at the macro and micro levels during 2011–2015 using the DEA. They used the number of hospitals, hospital staff, and hospital beds as input variables whereas the annual number of treatments and discharged patients, bed use, and the average length of hospitalisation as output variables and showed that although the hospital efficiency in China increased during this period there were geographical differences.

The research on the efficiency of nations in their fight against the COVID-19 is scarce. One of the first papers analysed the most seriously affected countries' performance in terms of their contagion control and treatment of COVID-19 using the DEA (Shirouyehzad et al., 2020). Countries in which at least a month is passed after their first confirmed case of COVID-19 and have had at least 10 confirmed cases as of 25

March 2020 were included in the analysis as the population of the study. In the first stage, a DEA model with two inputs (population density and average of International Health Regulations Core Capacity Scores) and one output (the number of confirmed cases) was built. The solutions to this model were used as the contagion control efficiency for each country. In the second stage, another DEA model was built with one input, which was the number of confirmed cases, and two outputs, which were the number of recovered cases and the number of deaths. However, the analysis was conducted in a limited time period and, hence, the generalization of the results would be inappropriate. Additionally, the selection of the inputs and outputs was not based on scientific analysis. The efficiency of the countries in their fight against COVID-19 was also analysed using the confirmed case fatality rate and the confirmed case recovery rate as the main performance criteria (Jouzdani, 2020). The data were analysed utilising statistical confidence intervals implemented in Python. However, the author did not provide a comparison of the efficiency of the countries using the DEA.

A three-stage methodology based on data envelopment and machine learning algorithms was used to evaluate the performance of 142 countries in the struggle against the COVID-19 outbreak (Aydin & Yurdakul, 2020). Detailed analyses were performed using weighted stochastic data envelopment analysis, decision trees, and random forests. Aydin & Yurdakul (2020) found that 20 out of 142 countries were efficient and parameters such as the stringency index, diabetes prevalence, and the number of hospital beds have a remarkable effect on the fight against the COVID-19 pandemic while GDP, smoking rates, and the rate of diabetes patients did not have a significant impact. However, the authors also underlined that the impact of other factors such as air pollution, air travel, tourism intensity rates should also be analysed in further studies. Table 1 provides a summary of the literature covering the analysed topic, the method used, and the inputs and outputs selected for the DEA analyses if the DEA was used in the study.

As can be seen from the literature, the evaluation of countries in terms of their efficiency in controlling and preventing the pandemics are generally based on HIV/AIDS epidemics, and the DEA is selected for evaluating the efficiency of countries. The DEA is a method of measuring the relative efficiency of a group of DMUs where the relative weights of the variables are unknown. It accommodates multiple inputs and outputs. The DEA utilises the fundamental concept of a production function, and since it uses linear programming as a nonparametric technique, it does not require assumptions about the statistical properties of the variables (Retzlaff-Roberts et al., 2004). On the other hand, except the research conducted by Zanakis et al. (2007), the inputs and the outputs of DEA are generally arbitrarily selected, and there is no built-in test for their appropriateness. However, the selection of inputs and outputs directly influence the expression of DMUs as efficient and inefficient.

Table 1 The evaluation of nations in fighting against pandemics

Source	Scope	Method(s)	Input Variables	Output Variables	Countries
Zanakis et al. (2007)	Assessing each country's efficiency when fighting against the HIV/AIDS pandemic considering the influence of economic and social factors	Hypothesis Tests + Canonical Correlation + Stepwise Regression Models + DEA output-oriented model with assurance region	• Health system performance index with existing resources • Health private expenditure (% total health expenditure) • Health public expenditure tax-funded (%) • Doctors per capita • Nurses per capita • Adult literacy rate (% of the total adult population) • GNP per capita • Radios per capita	• Percentage of adults living with HIV/AIDS • HIV/AIDS cases per capita • AIDS-related death rate for adults and children	116
Mirmirani et al. (2008)	Newly independent states (former Soviet Union countries) and the Eastern European countries. compared to member countries of the Organisation for Economic Co-operation and Development (OECD)	Output oriented DEA Model (Charnes, Cooper Rhodes model)	• Per capita health care expenditure in U. S. dollars after adjustment for purchasing power parity • Number of inpatient hospital beds per thousand population • Number of physicians per thousand population • Immunizations (Proxy: the percentage of children with measles inoculation)	• The average male life expectancy • The average male female life expectancy • Infant mortality rates	8 countries + OECD average
Marschall & Flessa (2009)	Health care sector efficiency in rural Burkina Faso	DEA and Tobit model	• Personnel Costs • Area • Equipment Depreciation • Vaccine	• Number of General Consultation • Number of deliveries • Number of other care services • Number of vaccinations	1

Source	Scope	Method(s)	Input Variables	Output Variables	Countries
Santos et al. (2012)	Using 2008 data, aimed to offer an updated overview of the efficiency of recent efforts in fighting against the HIV/AIDS epidemic carried out by Zanakis et al. (2007) who used data from 1998	DEA	• Prevention of mother-to-child HIV transmission domestic spending from public and international financing sources (million US$) • People aged 15 years and older who can, with understanding, both read and write a short simple statement on their everyday life (millions) • People living in urban areas (millions) • Total health expenditure (million US$) • Political stability and absence of violence/terrorism	• Reported number of pregnant women tested for HIV • Number of pregnant women living with HIV who received antiretrovirals for preventing mother-to-child transmission • Reported number of infants born to women living with HIV receiving antiretrovirals for preventing mother-to-child transmission; • Reported number of infants born to women living with HIV receiving co-trimoxazole prophylaxis within 2 months of birth	52
Zeng et al. (2012)	Evaluating the efficiency of HIV/AIDS programmes	DEA and Tobit model	• National HIV/AIDS spending (standardized expenditures into 2007 international dollars after adjusting for purchasing power parity and inflation)	• Volume of voluntary counselling and testing • Prevention of mother to child transmission Antiretroviral treatment	68
Zeng et al. (2016)	Estimated resource needs and decomposed the performance gap into efficiency gap and resource gap of 45 countries	Input oriented DEA Model	• National HIV/AIDS spending (2007 international dollars)	• Volume of voluntary counselling and testing • Prevention of mother to child transmission • Antiretroviral treatment	45

Source	Scope	Method(s)	Input Variables	Output Variables	Countries
Aydin & Yurdakul (2020)	Assessing countries' performances against COVID-19	DEA Machine Learning Algorithms	• Total deaths • Stringency Index • Extreme Poverty • Covid-19 death rate • Diabetes prevalence • Female smokers • Male smokers	• Population • GDP • Hospital Beds • Total Recovered • Total test	142
Gonzalez et al. (2020)	The performance of the health system by using value-efficiency analysis	DEA	• Health expenditure • Education	• Healthy life expectancy • Disability-adjusted life years	165
Jouzdani (2020)	Evaluated the performance of countries' responses to the COVID-19	Confidence Interval	• Confirmed cases • Recovered cases • Deaths	• Confirmed Case Fatality Rate • Confirmed Case Recovery Rate	90
Shirouyehzad et al. (2020)	The efficiency of countries affected by COVID-19 was evaluated using their health system infrastructures and population density	First Step DEA Second Step DEA	• Population density • Average of 13 International Health Regulations Core Capacity Scores • Confirmed cases	• Confirmed cases • Deaths • Recovered cases	29
Zhao et al. (2020)	The efficiency of Chinese hospitals at the macro and micro levels during 2011–2015	DEA	• Number of Hospitals • Number of Hospital Staff • Number of Hospital Beds	• Annual Number of Treatments • Discharged Patients • Number of beds used • Average length of Hospitalization	1

Source	Scope	Method(s)	Input Variables	Output Variables	Countries
This paper	COVID-19 Pandemic of 2020.	Cluster Analysis ↓ DEA ↓ Tobit Regression	12 pillars of the WEF Global Competitiveness Index for cluster analysis DEA Inputs: WEF data: Government Health Expenditure Percent, Private Health USD Base, Domestic Private Health Expenditure, Current Health Expenditure, hospital beds per 1K population for DEA DEA Outputs: OWID data: total cases, new cases, total deaths, new deaths, total cases per million, new cases per million, total deaths per million, new deaths per million Efficiency scores from DEA (dependent variables); Human Development Variables (66 variables from Human Development Report of the United Nations Development Programme), country cluster, and political regime tested as independent variables	Three clusters for nations COVID-19 Efficiencies Policies for nations in each cluster	107

To address issues such as the comparability of DMUs, the authors initially performed a cluster analysis to produce meaningful peer sets of nations. Then, to be able to assess the efficiency of nations in their struggle against the COVID-19 pandemic, the authors selected health variables published by the World Bank as the inputs and the COVID-19 response variables as the outputs. The authors used a DEA output-oriented model with assurance region because it prevents extreme weighting divergences in input weights and output weights (Cooper et al., 2007). In line with the literature, the authors then regressed efficiency scores on variables relevant to human development to produce meaningful policies for nations in their struggle against the COVID-19.

PROPOSED METHODOLOGY AND DATA

In this research, the authors used a three-step integrated methodology to analyse and compare the countries with respect to their efficiency in the struggle against the COVID-19 pandemic. To be able to work with a comparable set of nations to assess their efficiency in curbing the COVID-19 pandemic, the authors performed a cluster analysis in the first stage. Cluster analysis ensures that the set of nations within the cluster have comparable competitiveness performance. The authors then used the DEA output-oriented model with assurance region to avoid near-zero weights for some input variables which hinder the discriminatory power of the classical DEA output-oriented model. In selecting inputs for the nations, the authors considered two perspectives: the maximum number of new cases and the maximum number of new deaths while the authors extracted data for each country to consider variations in the spread of the disease. Finally, the authors applied Tobit regression to explain the variability in efficiency scores with independent variables that reflect a nation's position in achieving human development. The authors also considered the cluster effects and the long-debated concept of political governance regime. The authors used Tobit regression since the efficiency scores are bounded at 1. The proposed methodology for assessing the efficiency of nations in their struggle against the COVID-19 pandemic is presented in Figure 1.

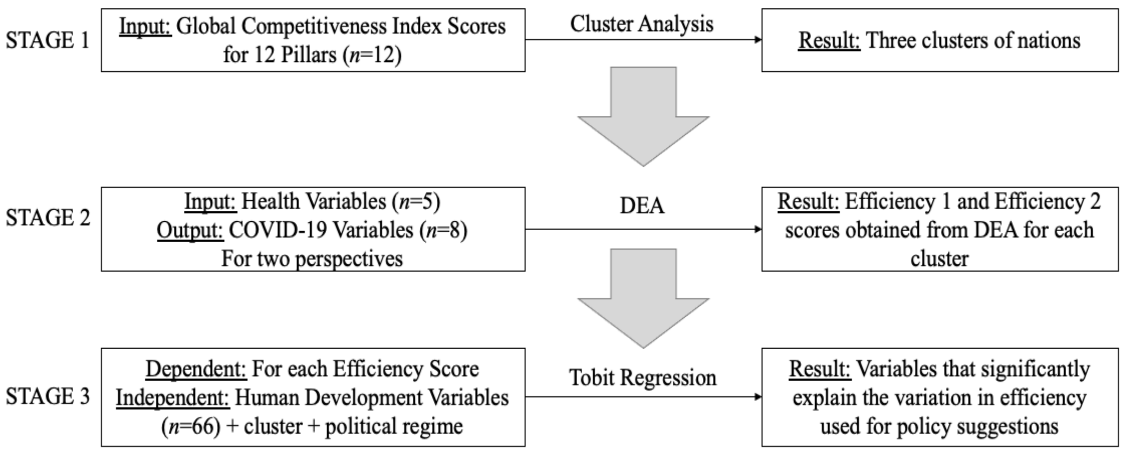


Figure 1 Proposed methodology repeated for June and December datasets

For cluster analysis data in the first stage, the authors used the 12 pillars of the WEF's Global Competitiveness Index. The 12 pillars capture the attributes and qualities of an economy that allow effective use of factors of production (Schwab, 2019). These pillars are

1. Institutions,
2. Infrastructure,
3. Information and Communication Technology (ICT) adoption,
4. Macroeconomic stability,
5. Health,
6. Skills,
7. Product market,
8. Labour market,

9. Financial system,
10. Market size,
11. Business dynamism, and
12. Innovation capability.

These 12 pillars are all rated on a 0-100 scale. For further explanation of the derivation of these scores, the authors refer the reader to the WEF Global Competitiveness Report (Schwab, 2019). The authors used a model-based approach to perform the cluster analysis, where each component of a finite mixture density is associated with a cluster and executed the analysis using the `mclust` package in `R` software (Scrucca et al., 2016). This package allows the modelling of data as a Gaussian finite mixture with different covariance structures and different numbers of mixture components, which captures the compactness, orientation, and shape of the clusters.

In the second stage, for health-related variables, the authors used the latest available WEF health data and selected variables to maximise the number of nations included in the analysis. For COVID-19 variables, the authors used the daily updated data from the Our World in Data (https://ourworldindata.org/coronavirus), which collates data from reputable sources such as the European Centre for Disease Prevention and Control, World Health Organization, Johns Hopkins University, and national government reports.

As countries and territories around the world reported their first cases of COVID-19 on different days of 2020 varying from January to May and the global number of confirmed cases and deaths are still increasing as of December 2020, it would not be meaningful to compare nations' efficiencies based on the total number of cases on the same day for all nations. It would not be appropriate to take daily new cases on any given day, too. For example, China hit a milestone with no new local infections on 19 March 2020 while the coronavirus cases in the USA passed 10,000 on the same day.

On the other hand, the maximum numbers of cases are critical for hospitalisation due to the capacities of doctors, nurses, beds, and ICUs. For instance, Liu et al. (2020) estimated the maximum values of cases of COVID-19 around the world. Juranek & Zoutman (2020) analysed the effectiveness of social distancing measures on the spread of COVID-19 in Scandinavian countries, and they focused on the maximum number of hospitalisations and ICU patients. Zhan et al. (2020) estimated the maximum cases of the global pandemic for South Korea, Italy, and Iran. Casares and Khan (2020) built a model that analysed the effect of isolation measure on the delay of the peak day of COVID-19. Therefore, in this study, to be able to derive meaningful comparisons of nations, the authors used eight COVID-19 variables in two perspectives:

1. values on the day the nation observed the maximum number of new cases (Perspective 1) and
2. values on the day the nation observed the maximum number of new deaths (Perspective 2).

Hence, the authors ran the DEA output-oriented model with assurance region six times, once for each cluster based on Perspective 1 and then Perspective 2. The authors referred to the efficiencies calculated from each perspective as Efficiency 1 and Efficiency 2, respectively. The DEA output-oriented model finds the optimal output and input weights for each nation to maximise the nation's weighted output while using no more than the number of inputs observed for all nations. The DEA output-oriented model with assurance region imposes lower (L) and upper (U) bounds on the ratios of two input weights to avoid questionable results with a single input or few inputs with positive weights in a nation's optimal solution. The lower and the upper bounds are also imposed on the ratios of two output weights.

The mathematical model of the DEA output-oriented model with assurance region (Cooper et al., 2007) is as follows. In a problem with n DMUs, m inputs, and s outputs, x_{in} denotes the value of the i^{th} input for the n^{th} DMU ($i = 1, \dots, M, n = 1, \dots, N$). Similarly, y_{kn} denotes the k^{th} output of the n^{th} DMU ($k = 1, \dots, S, n = 1, \dots, N$). Finally, μ_s denotes the weight of the output s and $\nu_m$denotes the weight of the input m. The following DEA output-oriented model with assurance region is solved for each DMU o to find its efficiency.

$$\max_{\mu,\nu} \theta = \mu_1 y_{1o} + \cdots + \mu_s y_{so} \qquad \text{Eq. 1}$$

subject to

$$\nu_1 x_{1o} + \cdots + \nu_m x_{mo} = 1 \qquad \text{Eq. 2}$$

$$\mu_1 y_{1n} + \cdots + \mu_s y_{sn} \leq \nu_1 x_{1n} + \cdots + \nu_m x_{mn} \quad (n = 1, \dots, N) \qquad \text{Eq. 3}$$

$$L \times \nu_i \leq \nu_j \quad \forall i, j \in M, \quad i < j \qquad \text{Eq. 4}$$

$$\nu_j \leq U \times \nu_i \quad \forall i, j \in M, \quad i < j \qquad \text{Eq. 5}$$

$$L \times \mu_i \leq \mu_j \quad \forall i, j \in S, \quad i < j \qquad \text{Eq. 6}$$

$$\mu_j \leq U \times \mu_i \quad \forall i, j \in S, \quad i < j \qquad \text{Eq. 7}$$

$$\nu_1, \nu_2, \dots, \nu_m \geq 0 \qquad \text{Eq. 8}$$

$$\mu_1, \mu_2, \dots, \mu_s \geq 0 \qquad \text{Eq. 9}$$

Eq. 1 is the objective function to maximise the efficiency of DMU o. Eq. 2 ensures the weighted sum of inputs is equal to 1 (input unity) for the DMU in question (DMU o). Eq. 3 is the ratio between the inputs and the outputs for each DMU. Eq. 4 is the lower bound of the ratios of input weights and Eq. 5 is the upper bound of the ratios of input weights. In a similar vein, Eq. 6 and Eq. 7 are the lower and the upper bounds of the ratios of output weights. Finally, Eq. 8 and Eq. 9 are the non-negativity constraints.

From five input variables (h1-h5) the model has $n \times (n-1) = 5 \times 4 = 20$ constraints to manage the ratios of the weights of two inputs and from eight output variables (c1-c8 for Perspective 1 and d1-d8 for Perspective 2) the model has $8 \times 7 = 56$ constraints to manage the ratios of the weights of two outputs in the assurance region extension of the DEA output-oriented model.

Finally, in the third stage, Tobit regression models were built to explain the variability in Efficiency 1 and Efficiency 2 using 66 variables published in the Human Development Report (Conceição, 2019) as well as the country cluster from Stage 1 and the political governance regime of the country as independent variables. For this purpose, regression models were built from a set of candidate predictor variables by entering and removing predictors based on *p*-values, in a stepwise manner until there is no variable left to enter or remove for Efficiency 1 and Efficiency 2 separately. The full list of these variables is given in Appendix B. For brevity, the authors report in Table 2, only those that were identified as significant to explain the variation in Efficiency 1 and Efficiency 2 scores. The authors report the descriptive statistics of these variables in the Results section.

Table 2 Variables used in the methodology and their definitions and respective stages

Variable	Definition	Stage	Variable	Definition	Stage
p1	Institutions	1	h5	Hospital beds (per 1,000 people)	2
p2	Infrastructure	1	c1, d1	Total number of cases	2
p3	ICT Adoption	1	c2, d2	Number of new cases	2
p4	Macroeconomic stability	1	c3, d3	Total number of deaths	2
p5	Health	1	c4, d4	Number of new deaths	2
p6	Skills	1	c5, d5	Total number of cases per million	2
p7	Product market	1	c6, d6	Number of new cases per million	2
p8	Labour market	1	c7, d7	Total number of deaths per million	2
p9	Financial system	1	c8, d8	Number of new deaths per million	2
p10	Market size	1	cluster	Cluster of the nation from Stage 1	3
p11	Business dynamism	1	regime	Political regime	3
p12	Innovation capability	1	airp	Mortality rate attributed to household and ambient air pollution	3
h1	Domestic general government health expenditure (% of current health expenditure)	2	tourist	International inbound tourists	3
h2	Domestic private health expenditure per capita (current US$)	2	urban	Urban population	3
h3	Domestic private health expenditure (% of current health expenditure)	2	fincredit	Domestic credit provided by the financial sector	3
h4	Current health expenditure per capita (current US$)	2	gni	Gross national income (GNI) per capita	3

RESULTS

Country Clusters

The cluster descriptive statistics of the WEF pillars is given in Table 3. The first four pillars, namely, Institutions, Infrastructure, ICT Adoption, and Macroeconomic Stability are considered as Enabling Environment (Schwab, 2019).

Table 3 Descriptive statistics of cluster analysis input variables

WEF Pillar	Min	Max	Mean	Standard Deviation
Institutions	25.72	81.22	57.13	11.80
Infrastructure	26.88	95.45	69.64	14.98
ICT Adoption	20.12	92.84	58.83	18.12
Macroeconomic Stability	0.00	100.00	83.00	17.54
Health	33.14	100.00	79.68	15.63
Skills	30.25	86.72	64.55	13.33
Product Market	36.42	81.21	56.51	8.23
Labour Market	41.33	81.23	60.50	8.90
Financial System	38.73	91.27	64.94	13.55
Market Size	32.27	100.00	59.02	15.66
Business Dynamism	14.07	84.21	62.12	10.84
Innovation Capability	18.90	86.83	46.34	17.10

In terms of Institutions pillar, Venezuela is the worst performer and Finland is the best performer. When it comes to Infrastructure pillar, Haiti is at the bottom of the list whereas Singapore is at the top. The picture shifts to Ethiopia and Korea as the worst and the best performers for ICT Adoption pillar. Venezuela is again the worst performer in Macroeconomic Stability pillar whereas 30 countries scored 100 in this pillar.

The next two pillars, Health and Skills are considered as pillars that represent the Human Capital of a nation (Schwab, 2019). In the Health pillar, the worst performer is Mozambique, and the best performers are Spain, Japan, and again Singapore with a full score of 100. Mozambique is again at the bottom in the Skills pillar whereas Switzerland is the highest performer for this pillar.

The next four pillars, namely Product Market, Labour Market, Financial System, and Market Size represent the overarching concept of Markets (Schwab, 2019). In terms of the Product Market pillar, Venezuela is once more at the bottom and Singapore is again at the top. The picture changes a bit for the Labour Market pillar, where the worst performer is Iran this time while the top performer is still Singapore. In terms of the Financial System pillar, the worst and the best performer couple is again Venezuela and Singapore. The bottom and the top performers change for the Market Size pillar, where this time Iceland is at the bottom and China is at the top.

The last four pillars, Business Dynamism and Innovation Capability represent the Innovation Ecosystem of a nation (Schwab, 2019). The worst and best performers for the Business Dynamism pillar are Haiti and the USA, respectively. The picture does not change much for the Innovation Capability pillar, where the worst performer is still Haiti, but the best performer is Germany.

Cluster analysis suggested three clusters. Significant differences exist between clusters across WEF competitiveness pillars (see boxplots of the performance of nations in each pillar in Figure 2). Hence, these three clusters are named as highly competitive, competitive, and non-competitive as was suggested in Onsel et al. (2008).

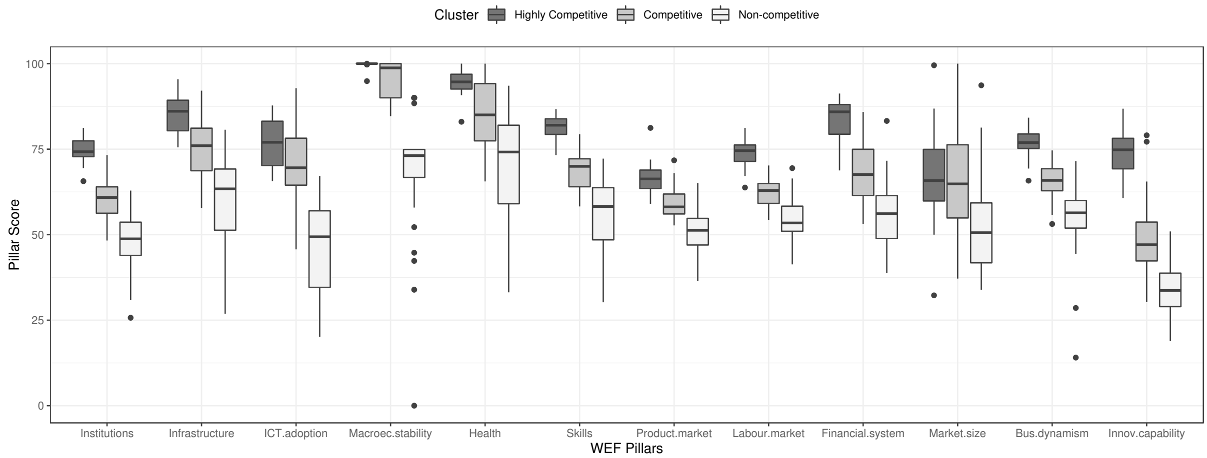


Figure 2 Performance comparison of nations in each cluster across 12 WEF pillars

In Figure 2, highly competitive nations cluster has 20 countries, competitive nations cluster has 33 countries, and non-competitive nations cluster has 54 countries. The cluster analysis model separates the nations into three meaningful groups where the nations in the non-competitive cluster perform worse than the nations in the competitive and the highly competitive clusters in all of the pillars. Highly competitive nations perform better than competitive nations across all pillars except market size and ICT adoption. Table 4 presents the best and the worst performers of each pillar in each cluster.

Table 4 Best and Worst Performers by Cluster

	Highly Competitive		**Competitive**		**Non-competitive**	
WEF Pillar	**min**	**max**	**min**	**max**	**min**	**max**
Institutions	64.64 Israel	81.22 Finland	48.29 Mexico	73.26 UAE	25.72 Venezuela	62.90 Bahrain
Infrastructure	75.53 New Zealand	95.45 Singapore	57.83 Philippines	92.09 Korea	26.88 Haiti	80.68 Hungary
ICT Adoption	65.63 Austria	87.78 Sweden	45.7 Peru	92.84 Korea	20.12 Ethiopia	67.19 Bahrain
Macroeconomic Stability	94.89 Japan	100 (16 nations)	84.66 Italy	100 (14 nations)	0.00 Venezuela	90 (5 nations)
Health	83.02 United States	100 (2 nations)	65.58 Philippines	100 Spain	33.14 Mozambique	93.54 Greece
Skills	73.28	86.72	58.25	79.36	30.25	72.25

	Highly Competitive		Competitive		Non-competitive	
WEF Pillar	**min**	**max**	**min**	**max**	**min**	**max**
	Japan	Switzerland	Mexico	Estonia	Mozambique	Argentina
Product Market	59.03 Iceland	81.21 Singapore	52.70 (2 nations)	71.74 UAE	36.42 Venezuela	65.11 Bahrain
Labour Market	63.78 Belgium	81.23 Singapore	54.35 Kuwait	70.23 Estonia	41.33 Iran	69.44 Azerbaijan
Financial System	68.77 Ireland	91.27 Singapore	53.07 Kazakhstan	85.87 France	38.73 Venezuela	83.25 S. Africa
Market Size	32.27 Iceland	99.53 United States	37.16 Malta	100 China	33.92 Haiti	93.67 India
Business Dynamism	65.79 Luxembourg	84.21 United States	53.12 Saudi Arabia	74.63 Malaysia	14.07 Haiti	71.52 Azerbaijan
Innovation Capability	60.65 New Zealand	86.83 Germany	30.30 Kuwait	70.47 Korea	18.90 Haiti	50.94 India

Although in Table 4, the authors report the best and the worst performer for each pillar in each cluster, for some pillars, there are multiple best performers. For example, for Macroeconomic Stability, 16 countries score 100 in the highly competitive nations cluster, and three nations (Singapore, the USA, and Ireland) score above 99. The worst performer, Japan, still scores quite high, at 94.89. For highly competitive countries, there is not a difference in performance under the macroeconomic stability pillar. The two highly competitive countries that score 100 in the Health pillar are Japan and Singapore.

Similar to the highly competitive nations cluster; 14 nations (Peru, Chile, Poland, the Czech Republic, Slovenia, the Slovak Republic, Saudi Arabia, Kuwait, Malta, Estonia, Latvia, Lithuania, the United Arab Emirates, Korea) in the competitive nations cluster have Macroeconomic Stability at 100. Two nations share the lowest performance in Product Market: Colombia and the Slovak Republic.

In the non-competitive nations cluster, five nations score the highest in Macroeconomic Stability: India, Morocco, Panama, Croatia, and Hungary. Venezuela is ranked the worst in four pillars, Haiti is ranked the worst in three pillars, and Mozambique is ranked the worst in two pillars. On the other hand, Bahrain is ranked the first in three pillars, Azerbaijan and India each ranked the first in two pillars.

The clustering analysis in this stage produced meaningful clusters to run the DEA in the second stage where nations are compared to their peers in terms of their performance in the 12 pillars of competitiveness. To avoid repetition, the full list of countries in each cluster is presented in the next subsection on Stage 2 results along with their efficiency scores in Table 10-15 in Appendix A.

Efficiencies of Countries

Descriptive statistics of the data for the DEA output-oriented model with assurance region are given in Table 5. The input data of health variables is downloaded from the WEF, and the output data of the COVID-19 variables is from Our World in Data's GitHub repository (https://github.com/owid/covid-19-data/tree/master/public/data). At the table, the input variables are abbreviated as h1-h5. On the other hand, in Perspective 1, the output variable abbreviations (jc1-jc8) represent the values on the day the nation observed the maximum number of new cases until 15 June 2020, and the abbreviations (dc1-dc8) represent the values on the day the nation observed the maximum number of new cases until 17 December 2020. Finally, in Perspective 2, the output variable abbreviations (jd1-jd8) represent the values on the day the nation observed the maximum number of new deaths until 15 June 2020, and the abbreviations (dd1-dd8) represent the values on the day the nation observed the maximum number of new deaths until 17 December 2020.

Table 5 Descriptive statistics of DEA input and output variables

	Highly Competitive				**Competitive**				**Non-competitive**			
var	**min**	**Max**	**mean**	**sd**	**min**	**max**	**mean**	**sd**	**min**	**max**	**mean**	**sd**
h1	30	85	72	14	32	87	64	13	12	88	46	19
h2	663	6920	1616	1556	58	1003	398	287	2	601	142	143
h3	14	47	23	9	13	66	35	13	9	85	47	19
h4	2619	10246	5405	1973	115	4380	1240	939	21	1517	347	367
h5	2	13	4	3	1	12	4	3	0	9	2	2
jc1	647	939053	64392	207088	295	221344	41217	59879	212	498440	28655	81245
jc2	95	48529	4106	10674	36	15141	2763	3932	40	33274	1872	5030
jc3	1	53189	4061	11908	0	16448	1471	3073	0	28834	1042	4088
jc4	0	2172	190	504	0	795	109	208	0	956	40	140
jc5	53	4040	1424	1180	24	19181	1760	3657	8	10149	899	1692
jc6	11	374	137	98	4	817	100	154	2	654	67	128
jc7	0	450	78	129	0	174	29	45	0	136	18	29
jc8	0	24	4	6	0	14	2	4	0	5	1	1
jd1	432	639664	57465	142825	124	387623	46620	78811	115	614932	29076	93310
jd2	8	30148	2208	6664	3	8875	1832	2781	2	30916	1416	4516
jd3	2	30985	3590	7933	3	11728	1813	3209	1	34021	1130	4745
jd4	2	4928	406	1098	2	2004	242	480	1	1473	68	213
jd5	74	5224	1676	1353	18	24949	1961	4437	5	10149	772	1574
jd6	2	290	59	66	0	597	73	125	0	628	40	90
jd7	0	298	85	94	0	214	37	53	0	160	19	33
jd8	0	47	11	13	0	34	5	8	0	23	2	4
dc1	797	16964180	1127171	3749241	314	2439163	357422	548394	480	7040608	382114	1182256
dc2	89	247403	21743	54250	41	106091	13813	21208	155	823225	22205	112227
dc3	1	307429	21777	68319	1	81877	10304	18518	16	183735	8045	27725
dc4	0	3656	295	822	0	2789	224	498	0	1132	107	224
dc5	165	51251	17626	14767	9	35364	12489	9497	8	46340	11167	13056
dc6	18	3142	824	910	3	1672	570	488	3	9761	510	1338
dc7	0	976	299	324	0	775	222	234	0	864	186	230
dc8	0	15	5	5	0	22	6	7	0	111	5	15
dd1	1366	16964180	1005975	3769103	143	2574319	364159	558249	414	4657702	252699	685324
dd2	17	247403	16046	54972	15	28206	6477	8686	30	66338	4657	10074

	Highly Competitive				Competitive				Non-competitive			
var	min	Max	mean	sd	min	max	mean	sd	min	max	mean	sd
dd3	9	307429	19066	68185	5	81877	11244	19031	14	139808	5992	19782
dd4	2	3656	388	833	2	4143	513	903	3	3351	256	599
dd5	283	63959	15292	19713	28	42299	13882	12830	8	46878	11002	13087
dd6	3	2494	353	592	0	1672	313	358	1	1763	238	336
dd7	2	929	248	279	0	960	284	300	0	971	195	236
dd8	0	45	14	14	0	126	16	24	0	142	12	26

INPUTS h1: Domestic general government health expenditure (% of current health expenditure), h2: Domestic private health expenditure per capita (current US$), h3: Domestic private health expenditure (% of current health expenditure), h4: Current health expenditure per capita (current US$), h5: Hospital beds (per 1,000 people)
OUTPUTS based on max number of new cases jc1, dc1: Total number of cases, jc2, dc2: Number of new cases, jc3, dc3: Total number of deaths, jc4, dc4: Number of new deaths, jc5, dc5: Total number of cases per million, jc6, dc6: Number of new cases per million, jc7, dc7: Total number of deaths per million, jc8, dc8: Number of new deaths per million
OUTPUTS based on max number of new deaths jd1, dd1: Total number of cases, jd2, dd2: Number of new cases, jd3, dd3: Total number of deaths, jd4, dd4: Number of new deaths, jd5, dd5: Total number of cases per million, jd6, dd6: Number of new cases per million, jd7, dd7: Total number of deaths per million, jd8, dd8: Number of new deaths per million

A few interesting observations can be made for each cluster. In the highly competitive nations cluster (Table 5, left four columns); for h1, domestic general government health expenditure (% of current health expenditure), the highest value (85.47) is observed in Norway and the lowest value (30.49) is observed in Switzerland; for h2, domestic private health expenditure per capita (current US$), the highest value (6920.31) is observed in Switzerland and the lowest is value (663.18) is observed in Japan; for h3, domestic private health expenditure (% of current health expenditure), the highest value (47.13) is observed in Singapore and the lowest value (13.79) is observed in Luxembourg; for h4, current health expenditure per capita (current US$), the highest value (10246.14) is observed in the USA, and the lowest value (2618.71) is observed in Singapore; and for h5, hospital beds (per 1,000 people), the highest value (13.05) is observed in Japan, whereas the lowest value (2.22) is observed in Sweden.

In the competitive nations cluster (Table 5, middle four columns), on the other hand; for h1, the highest value (87.39) is observed in Kuwait, and the lowest value (31.91) is observed in the Philippines; for h2, the highest value (1003.31) is observed in France, and the lowest value (58.41) is observed in Thailand; for h3, the highest value (65.5) is observed in the Philippines, and the lowest value (12.62) is observed in Kuwait; for h4, the highest value (4379.73) is observed in France, and the lowest value (114.97) is observed in Indonesia; and for h5, the highest value (12.27) is observed in Korea whereas the lowest value (1) is observed in the Philippines.

Finally, in the non-competitive nations cluster (Table 5, right four columns); for h1, the highest value (87.87) is observed in Oman, and the lowest value (11.86) is observed in Haiti; for h2, the highest value (601.21) is observed in Greece, and the lowest value (1.89) is observed in Mozambique; for h3, the highest value (85.47) is observed in Armenia, and the lowest value (8.96) is observed in Mozambique; similar to h2, for h4, the highest value (1516.59) is observed in Greece whereas the lowest value (21.07) is observed in Mozambique; and for h5, the highest value (8.80) is observed in Ukraine and the lowest value (0.10) is observed in Mali.

In a similar vein, as can be seen in Table 6, the authors report the highest and the lowest-performing countries in variables jc1-jc8 and dc1-dc8 for Perspective 1 calculations and jd1-jd8 and dd1-dd8 for Perspective 2 calculations. The last row of the table represents the number of different countries (Frequency row) in each column.

Table 6 The Best and the Worst Performers of COVID-19 Output Variables by Cluster

	Highly Competitive		**Competitive**		**Non-competitive**	
COVID-19	**min**	**max**	**min**	**max**	**min**	**max**
jc1	New Zealand	United States	Uruguay	Russia	Jordan	Brazil
jc2	New Zealand	United States	Uruguay	China	Jordan	Brazil
jc3	New Zealand	United States	Latvia	Mexico	Jordan	Brazil
jc4	Australia	United States	Estonia	Italy	Cameroon	Brazil
jc5	Japan	Sweden	Thailand	Qatar	Tanzania	Bahrain
jc6	Japan	Luxembourg	Thailand	Qatar	Mozambique	Ecuador
jc7	New Zealand	Sweden	Latvia	Chile	Jordan	Brazil
jc8	Australia	Belgium	Estonia	Spain	Cameroon	Brazil
jd1	Singapore	United States	Cyprus	Russia	Sri Lanka	Brazil
jd2	New Zealand	United States	Malta	Peru	Costa Rica	Brazil
jd3	Singapore	United States	Cyprus	Mexico	Sri Lanka	Brazil
jd4	Iceland	United States	Malta	France	Sri Lanka	Brazil
jd5	Singapore	Luxembourg	Indonesia	Qatar	Sri Lanka	Bahrain
jd6	New Zealand	Iceland	China	Qatar	Costa Rica	Bahrain
jd7	Singapore	United Kingdom	Thailand	Spain	Mozambique	Brazil
jd8	Australia	Ireland	Thailand	Chile	Mozambique	Ecuador
dc1	New Zealand	United States	Mauritius	Russia	Tanzania	Brazil
dc2	New Zealand	United States	Mauritius	France	Mali	Turkey
dc3	New Zealand	United States	Thailand	Mexico	Tanzania	Brazil
dc4	Iceland	United States	Kazakhstan	Mexico	Ghana	India
dc5	New Zealand	United States	Thailand	Czech Rep.	Tanzania	Panama
dc6	New Zealand	Luxembourg	Thailand	Lithuania	Tanzania	Turkey
dc7	New Zealand	Belgium	Thailand	Spain	Tanzania	Brazil
dc8	Iceland	Sweden	Kazakhstan	Mexico	Ghana	Kyrgyzstan
dd1	New Zealand	United States	Mauritius	Russia	Burkina Faso	Brazil
dd2	New Zealand	United States	Mauritius	Russia	Burkina Faso	Brazil
dd3	New Zealand	United States	Mauritius	Mexico	Guinea	Brazil
dd4	Singapore	United States	Mauritius	Peru	Guinea	Argentina
dd5	New Zealand	Luxembourg	Thailand	Slovenia	Tanzania	Georgia
dd6	Australia	Luxembourg	China	Lithuania	Burkina Faso	Kyrgyzstan
dd7	New Zealand	United States	Thailand	Italy	Tanzania	Macedonia

	Highly Competitive		Competitive		Non-competitive	
COVID-19	**min**	**max**	**min**	**max**	**min**	**max**
dd8	Singapore	Ireland	Thailand	Peru	Tanzania	Bolivia
Frequency	5	7	10	12	10	11

OUTPUTS based on max number of new cases jc1, dc1: Total number of cases, jc2, dc2: Number of new cases, jc3, dc3: Total number of deaths, jc4, dc4: Number of new deaths, jc5, dc5: Total number of cases per million, jc6, dc6: Number of new cases per million, jc7, dc7: Total number of deaths per million, jc8, dc8: Number of new deaths per million
OUTPUTS based on max number of new deaths jd1, dd1: Total number of cases, jd2, dd2: Number of new cases, jd3, dd3: Total number of deaths, jd4, dd4: Number of new deaths, jd5, dd5: Total number of cases per million, jd6, dd6: Number of new cases per million, jd7, dd7: Total number of deaths per million, jd8, dd8: Number of new deaths per million

In the highly competitive nations cluster, there are five best performers in the COVID-19 output variables (the minimum of the variable) based on the data until June 2020. New Zealand has the lowest records in six outputs (jc1-jc3, jc7, jd2, and jd6) while Singapore in four outputs (jd1, jd3, jd5, and jd7); Australia in three outputs (jc4, jc8, and jd8); Japan in two outputs (jc5 and jc6); and Iceland in one output (jd4) have the lowest records. Based on the data until December 2020, four countries have the lowest records, namely New Zealand in 11 outputs (dc1-dc3, dc5-dc7, dd1-dd3, dd5, and dd7); Singapore in two outputs (dd4 and dd8), Iceland in two outputs (dc4 and dc8), and Australia in one output (dd6).

Regarding to the worst performers of the highly competitive nations cluster in the COVID-19 output variables (the maximum of the variable), based on the data until June 2020, there are seven countries in the list. The USA has the highest records in eight outputs (jc1-jc4 and jd1-jd4). In two outputs each, Luxembourg (jc6 and jd5) and Sweden (jc5 and jc7) have the highest records. The highest records belong to Belgium in jc8, to Iceland in jd6, to the UK in jd7, and to Ireland in jd8. Based on the data until December 2020, the number of countries in the worst performers list drops to five, namely the USA in 10 outputs (dc1-dc5, dd1-dd4, and dd7); Luxembourg in three outputs (dc6, dd5, and dd6); and Belgium, Sweden, and Ireland in one output each (dc7, dc8, and dd8, respectively). Iceland and the UK are no longer in the worst performers list.

In the competitive nations cluster, there are eight best performers in the COVID-19 output variables based on the data until June 2020: Thailand in four outputs (jc5, jc6, jd7, jd8); Uruguay in two outputs (jc1, jc2); Latvia in two outputs (jc3, jc7); Estonia in two outputs (jc4, jc8); Cyprus in two outputs (jd1, jd3); Malta in two outputs; and Indonesia and China in one output each (jd5 and jd6, respectively). Based on the data until December 2020, the best performers list consists of just four countries. Thailand has the lowest records in seven outputs (dc3, dc5-dc7, dd5, dd7, and dd8). Mauritius enters the best-performing countries list in six outputs (dc1, dc2, and dd1-dd4) and Kazakhstan enters the list in two outputs (dc4 and dc8). China is still the best performer in the 6^{th} output of Perspective 2 (dd6).

There are nine countries in the worst performers of competitive nations cluster, based on the data until June 2020, namely, Qatar in four outputs (jc5, jc6, jd5, jd6); Russia in two outputs (jc1, jd1); Mexico in two outputs (jc3, jd3); Chile in two outputs (jc7, jd8); Spain in two outputs (jc8, jd7); and China, Italy, Peru, and France in one output each (jc2, jc4, jd2, and jd4, respectively). Based on the data until December 2020, the worst performers are still nine countries but instead of Qatar, Chile, and China, there are three new countries in the list, namely the Czech Republic, Lithuania, and Slovenia. Mexico performs worst in four outputs (dc3, dc4, dc8, dd3) while Russia in three outputs (dc1, dd1, and dd2), Peru in two outputs (dd4 and dd8), and Lithuania in two outputs (dc6 and dd6). In the list Italy, Spain, France, the Czech Republic, and Slovenia performs worst in one output (dd7, dc7, dc2, dc5, and dd5, respectively).

Finally, in the non-competitive nations cluster, the best performers of the COVID-19 output variables based on the data until June 2020 are six countries as follows: Jordan in four outputs (jc1-jc3, jc7); Sri Lanka in four outputs (jd1, jd3-jd5); Mozambique in three outputs (jc6, jd7, jd8); Cameroon in two outputs (jc4, jc8); Costa Rica in two outputs (jd2, jd6); and Tanzania in one output (jc5). Based on the data until December 2020, there are five countries in the list. Except Tanzania that has the lowest records in eight outputs (dc1, dc3, dc5-dc7, dd5, dd7, and dd8) at this time, four new countries become best performers: Burkina Faso in three outputs (dd1, dd2, dd6), Ghana in two outputs (dc4, dc8), Guinea in two outputs (dd3, dd4), and Mali in one output (dc2).

Three countries are the worst performers of the non-competitive nations cluster, based on the data until June 2020: Brazil in 11 outputs (jc1-jc4, jc7, jc8, jd1-jd4, and jd7), Bahrain in three outputs (jc5, jd5, and jd6), and Ecuador in two outputs (jc6 and jd8). Based on the data until December 2020, Brazil performs worst in six outputs (dc1, dc3, dc7, dd1-dd3). Besides Brazil, there are eight more countries in the list: Turkey in two outputs (dc2, dc6); Kyrgyzstan in two outputs (dc8, dd6); India, Panama, Argentina, Georgia, Macedonia, and Bolivia in one output each (dc4, dc5, dd4, dd5, dd7, and dd8, respectively).

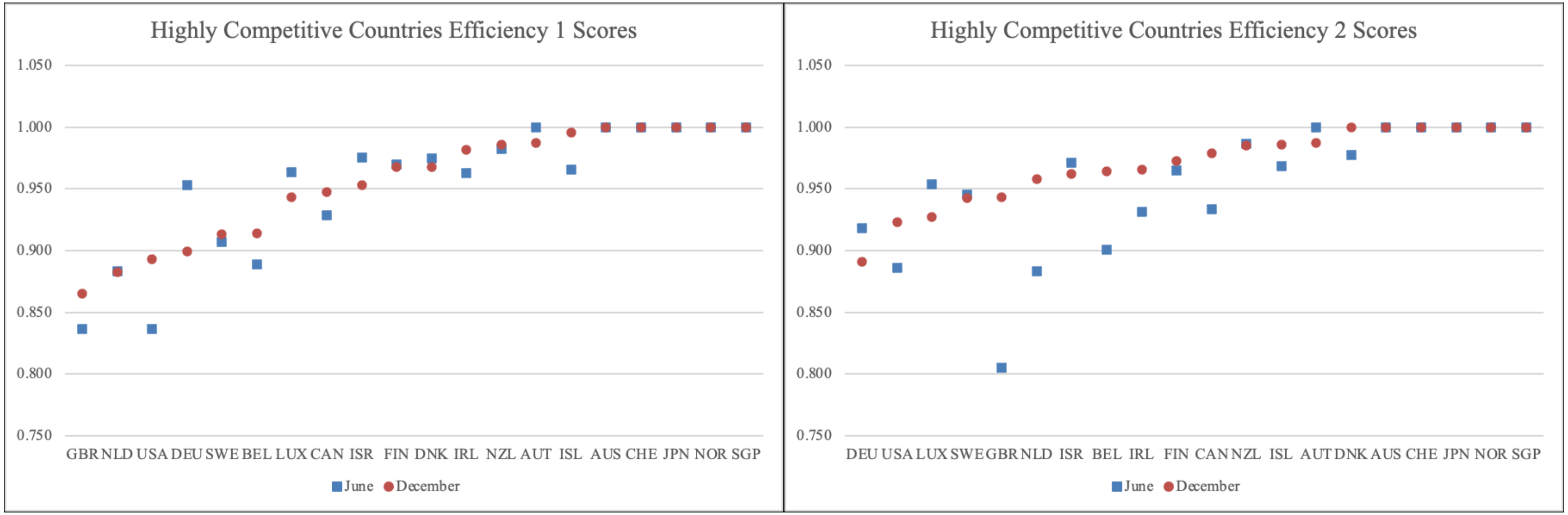
Totally, the numbers of the highly competitive countries performing best and worst in COVID-19 output variables are five and seven, respectively. For competitive countries, these figures are 10 and 12; for non-competitive ones, 10 and 11. Compared to the highly competitive nations cluster, the worst and the best performers in the competitive nations cluster as well as non-competitive nations cluster are more varied.

The authors converted each input (h1-h5) and output (jc1-jc8 and dc1-dc8 for Perspective 1; and jd1-jd8 and dd1-dd8 for Perspective 2) variable to standardized scores ([value – mean] / standard deviation) to avoid scaling problems in DEA (Zanakis et al., 2007). Thus, large positive standardized numbers imply worse COVID-19 performance. For example, in June 2020, in the highly competitive nations cluster, the UK's total number of cases in Perspective 1 (jc1) is 0.07 standard deviations above the mean whereas Finland's total number of cases in the same period and perspective (jc1) is 0.50 standard deviations below the mean.

To avoid negative signs in DEA, standard values were subtracted from 5 for highly competitive nations, 6 for competitive nations, and 7 for non-competitive nations clusters in the models built using the data until June 2020. In a similar vein, the standard values were subtracted from 5, 6, and 8 for highly competitive, competitive, and non-competitive nations in the models built using the data until December 2020. These values were chosen so that the maximum value in the standardized dataset for each cluster was slightly less than the selected number. This transformation also changed the directions from the minimum COVID-19 rates with more resources to the maximum outputs with same or less input (shortages), thus complying with the DEA directive. A problem in DEA output-oriented model with assurance region is to determine the values for the lower and the upper bounds on the ratios of two input weights and two output weights (for each combination of two weights). The standardised scores of the inputs and the outputs ranged from -2.87 to 7.14, so the authors selected a k-fold range (Zanakis et al., 2007) where $k = 2.87 + 6.93 = 10.01$ and hence used $L = 0.1$ and $U = 10$.

Table 10 in Appendix A shows Perspective 1 and Perspective 2 efficiency scores of highly competitive countries obtained based on the data until June and December 2020. Table 11 and 15 in Appendix A show the efficiency scores of competitive and non-competitive countries, respectively.

Figure 3a and Figure 3b show the countries and their efficiency scores in Perspective 1 and Perspective 2 respectively, sorted by the efficiency scores obtained in December 2020 for highly competitive countries. As can be seen in Figure 3a (for detail please see Table 10 in Appendix A), the top performers of the highly competitive nations cluster in both perspectives are Australia, Austria, Switzerland, Japan, Norway, and Singapore based on the data until June 2020. Based on the data until December 2020, among these countries, only Austria loses its top performer status in both perspectives. Denmark also becomes one of the top performers in Perspective 2.



a: Perspective 1 **b: Perspective 2**

Figure 3 Efficiency comparison of highly competitive countries from June to December

The worst performers of the highly competitive nations cluster in both perspectives are the UK, the Netherlands, and the USA based on the data until June 2020. Based on the data until December 2020, the same countries are the worst performers in Perspective 1 and Germany, the USA, and Luxembourg are the worst performers in Perspective 2.

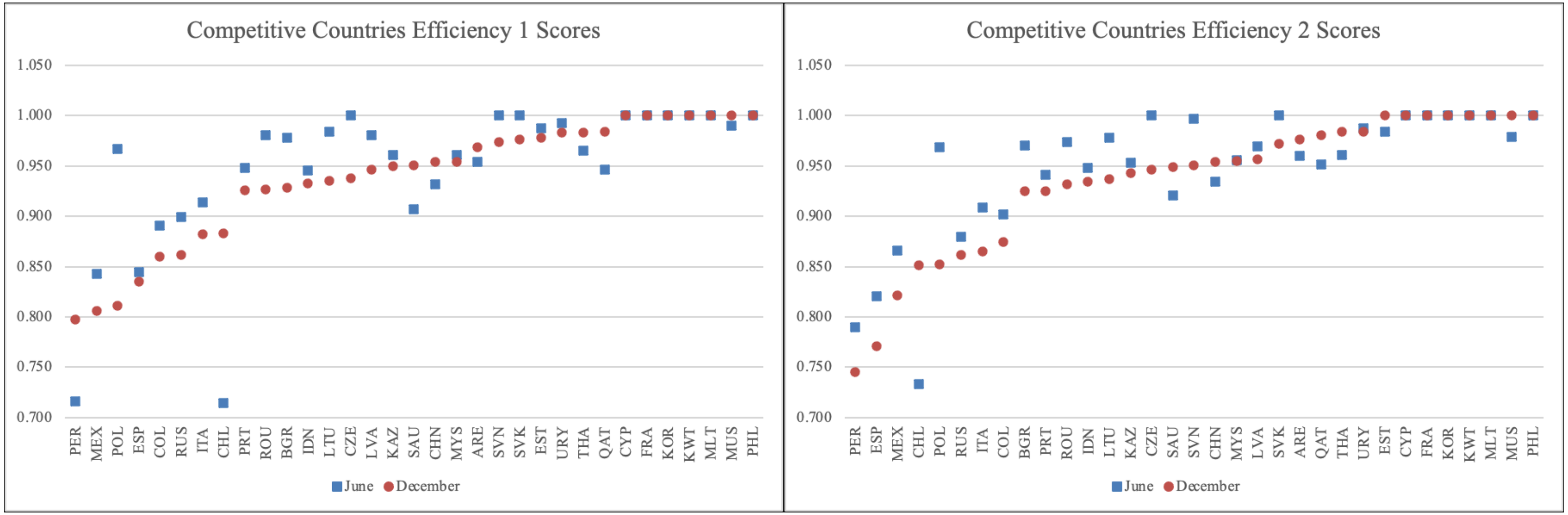
It can be observed from Figure 3a, among 20 highly competitive countries, efficiency scores of eight of them increase and efficiency scores of five of them decrease in Perspective 1 from June 2020 to December 2020. The biggest improvement is observed in the USA' efficiency, which is improved from 0.837 in June to 0.893 in December. The authors also observe that besides the USA, the efficiencies of the UK, Sweden, Belgium, Canada, Ireland, New Zealand, and Iceland improved. On the other hand, the biggest decline in Efficiency 1 is observed for Germany as from 0.953 to 0.899. Efficiency 1 scores of Luxembourg, Israel, Denmark, and Austria also declined.

In terms of Perspective 2, the authors observe from Figure 3b that efficiency scores of nine countries increased and those of five countries decreased from June to December 2020 in the highly competitive nations cluster. The biggest improvement is observed in the UK's efficiency, which improved from 0.805 in June to 0.943 in December. Many other countries such as the USA, the Netherlands, Belgium, Ireland, Finland, Canada, Iceland, and Denmark improved their efficiency, too. On the other hand, like Efficiency 1 scores, the biggest decline in Efficiency 2 scores belongs to Germany (from 0.918 to 0.891), as well. Efficiency 2 scores of Sweden, Luxembourg, Israel, and Austria also declined from June to December.

The correlation between Efficiency 1 and Efficiency 2 scores was 0.931 and the correlation between the ranks of the countries according to Efficiency 1 and Efficiency 2 was 0.984 in June 2020. In December 2020, the correlation between Efficiency 1 and Efficiency 2 scores was 0.796 and the correlation between the efficiency ranks was 0.901. The reduction in efficiency scores and ranks suggest that the two perspectives, Perspective 1 based on the data available on the day the maximum number of new cases was observed and Perspective 2 based on the data available on the day the maximum number of new deaths was observed, have become more discriminatory to assess the efficiency of countries in their struggle against the COVID-19.

Figure 4a and Figure 4b (for detail see Table 11 in Appendix A) show the countries in the competitive nations cluster with their Efficiency 1 and Efficiency 2 scores, respectively, sorted by the efficiency scores obtained in December 2020. The top performers of the competitive nations cluster in both perspectives are Cyprus, the Czech Republic, France, Korea, Kuwait, Malta, Philippines, the Slovak Republic based on the data until June 2020. Slovenia is a top performer only in Perspective 1 in June. According to the analysis results based on the data until December 2020, the top performers in both perspectives are Cyprus, France, Korea, Kuwait, Malta, Mauritius, and the Philippines. Mauritius also joins the top performer countries in both perspectives in December. Additionally, Estonia becomes one of the top performers in Perspective 2 only. The Slovak Republic and the Czech Republic that are among the top performers in both perspectives in June lose their top performer status in December.

The worst performers of the competitive nations cluster in both perspectives are Chile, Peru, Mexico, and Spain based on the data until June 2020. Based on the data until December 2020, the same countries are the worst performers in Perspective 2. Poland enters the worst performers list instead of Chile in Perspective 1 in December. It can be observed from Figure 4a that among 33 competitive countries, Efficiency 1 scores of eight of them increase and Efficiency 1 scores of 19 of them decrease from June to December 2020. The biggest improvement in Efficiency 1 scores is observed for Chile from 0.715 in June 2020 to 0.883 in December 2020. Similarly, Peru, Saudi Arabia, China, United Arab Emirates, Thailand, Qatar, and Mauritius improved their Efficiency 1 scores. On the other hand, the biggest decline in Efficiency 1 scores is observed for Poland from 0.967 to 0.811.



a: Perspective 1 **b: Perspective 2**

Figure 4 Efficiency comparison of competitive countries from June to December

Figure 4b shows that Efficiency 2 scores of eight countries increased and those of 18 countries decreased from June to December 2020 in the competitive nations cluster. The biggest improvement and the biggest decline in Perspective 2 belong to the same leading countries of Perspective 1: Chile had an increase from 0.733 to 0.852, while Poland had a decrease from 0.969 to 0.852. Besides Chile, many other countries such as Estonia, Saudi Arabia, China, the United Arab Emirates, Thailand, Qatar, and Mauritius improved their Efficiency 2 scores.

The correlation between Efficiency 1 and Efficiency 2 scores of competitive nations is 0.981, and the correlation between the ranks of the countries was 0.989 in June 2020. The correlation between efficiency scores in December is 0.963 and efficiency ranks was 0.973. Although the correlation coefficients reduced from June to December, they have not reduced as much as is observed for the highly competitive nations cluster.

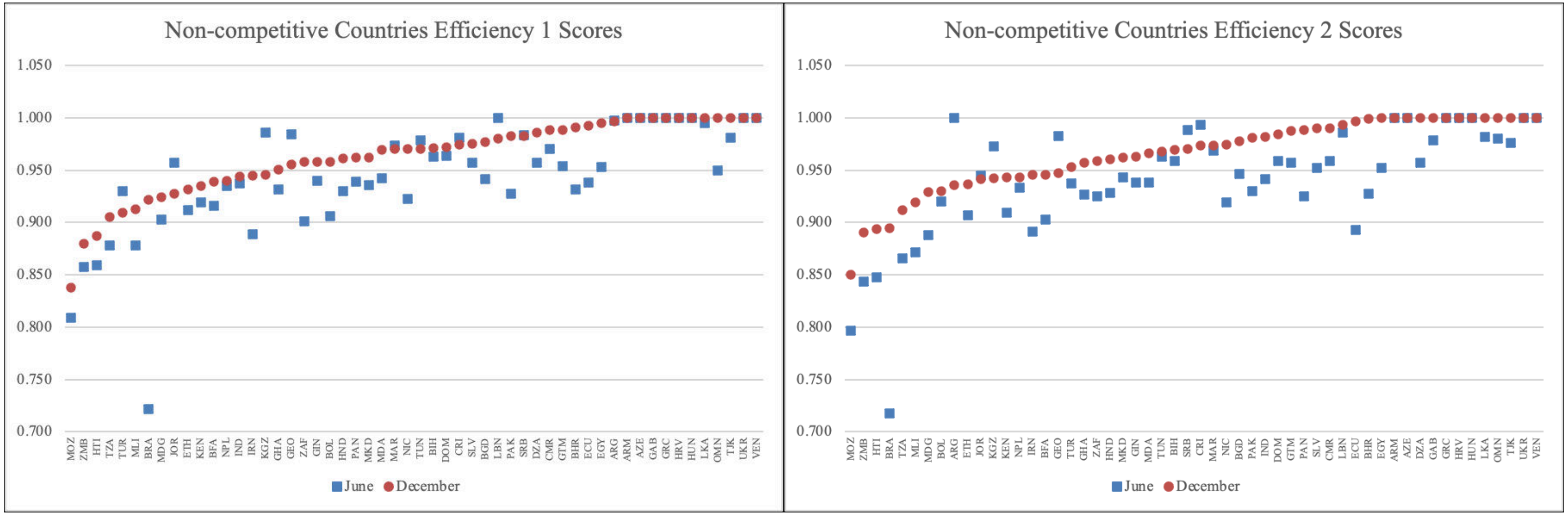
Figure 5a Figure 5b show the countries and their Efficiency 1 and Efficiency 2, respectively, sorted by the efficiency scores obtained in December 2020 for non-competitive countries. As can be seen in Figure 5a and Figure 5b (for detail see Table 12 in Appendix A), the top performers of the non-competitive nations cluster in both perspectives were Armenia, Azerbaijan, Greece, Croatia, Hungary, Ukraine, and Venezuela based on the data until June 2020. Gabon and Lebanon were also top performers in Perspective 1 but not in Perspective 2. Argentina was a top performer only in Perspective 2. On the other hand, based on the data until December 2020, the top performers were Armenia, Azerbaijan, Gabon, Greece, Croatia, Hungary, Sri Lanka, Oman, Tajikistan, Ukraine, and Venezuela in both perspectives. Algeria also entered the top performers list in terms of Perspective 2.

The countries with the lowest efficiency were Brazil, Mozambique, Zambia, and Haiti in both efficiency perspectives based on the data until June 2020. Based on the data until December 2020, the same countries were taking the last places in terms of Perspective 2 and Tanzania entered the worst performers list instead of Brazil in terms of Perspective 1.

It can be observed from Figure 5a that among 54 non-competitive countries, Efficiency 1 scores of 36 of them increased and Efficiency 1 scores of nine of them decreased from June to December 2020. The biggest improvement in Efficiency 1 scores was observed in Brazil, from 0.722 in June to 0.921 in December. On the other hand, the biggest decline in Efficiency 1 scores was observed for Kyrgyzstan, from 0.986 in June to 0.946 in December. Efficiency 1 scores of Turkey, Jordan, Morocco, Tunisia, Costa Rica, Lebanon, and Serbia also decreased. Figure 5b shows that Efficiency 2 scores of 41 countries increased and those of six countries decreased from June to December 2020 in the non-competitive nations cluster. Again, Brazil showed the greatest improvement from 0.718 in June to 0.894 in December.

On the other hand, the biggest decline in Efficiency 2 was observed for Argentina, one of the top performers in June: Efficiency 2 score of Argentina decreased from 1 in June to 0.935 in December. Efficiency 2 scores of Kyrgyzstan, Jordan, Georgia, Costa Rica, and Serbia also declined.

The correlation between the two efficiency scores of countries in the non-competitive nations cluster was 0.980, and the correlation between the ranks of countries was 0.962 in June 2020. In December 2020 the correlation between efficiency scores was 0.918 and between efficiency ranks was 0.918, reflecting the difference between being able to curb the spread (Efficiency 1) and prevent deaths (Efficiency 2) compared with the scores in June 2020.



a: Perspective 1 **b: Perspective 2**

Figure 5 Efficiency comparison of non-competitive countries from June to December

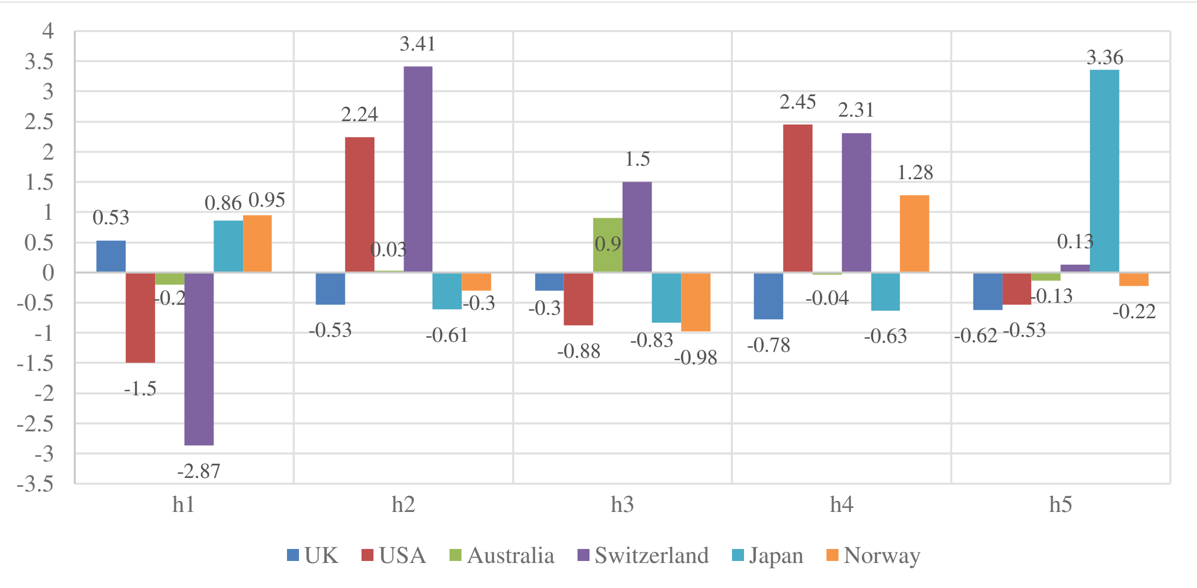
In DEA, inefficient countries can learn from efficient countries in their peer set. Table 7 shows peer countries for selected non-efficient countries in each cluster in Perspective 1. The UK and the USA were selected in the highly competitive countries for the varying policies each country followed in the first and the second waves. In the competitive countries cluster, Italy and Spain were among the most discussed countries owing to the rapid spread of the disease. In the non-competitive countries cluster, Turkey and Brazil drew the attention of the media owing to the different policies they had followed.

Table 7 Peer analysis of selected inefficient countries in Perspective 1

Cluster	Country	June Peers	December Peers
Highly competitive	United Kingdom	Australia, Switzerland, Japan	Australia, Japan
Highly competitive	United States	Switzerland, Norway	Switzerland, Norway
Competitive	Italy	Czech Republic, France, Korea	Korea, Kuwait
Competitive	Spain	Czech Republic, France, Korea	France, Korea, Kuwait
Non-competitive	Turkey	Greece, Croatia	Greece, Oman
Non-competitive	Brazil	Azerbaijan, Greece	Armenia, Greece

Peer Analysis of Highly Competitive Countries

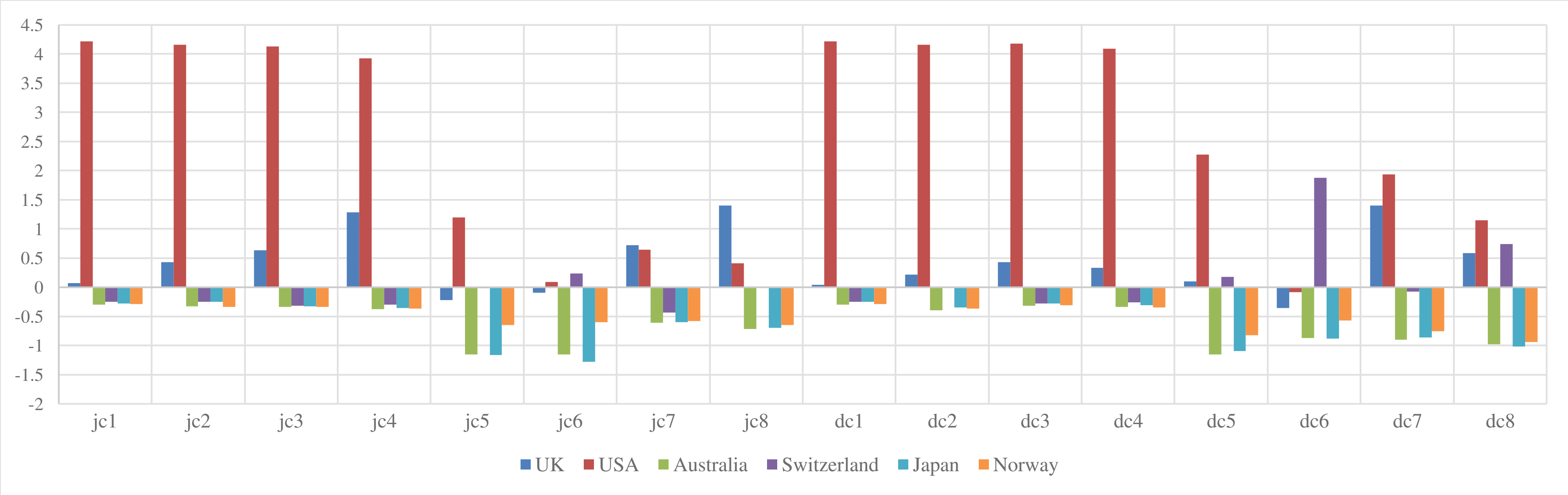
The authors investigate the performance of inefficient countries in relation to the performance of their peer countries. Figure 6 presents the standardized scores of these countries in each input variable. The UK is above-average in h1, and below-average in h2, h3, h4, and h5, showing the lack of investment in healthcare resources compared with its peers. The USA, on the other hand, is above-average in h2 and h4, and below-average in h1, h3, and h5.



INPUTS h1: Domestic general government health expenditure (% of current health expenditure), h2: Domestic private health expenditure per capita (current US$), h3: Domestic private health expenditure (% of current health expenditure), h4: Current health expenditure per capita (current US$), h5: Hospital beds (per 1,000 people),

Figure 6 Comparison of UK and US with their peers in inputs

Figure 7 presents the output variables in the two analysis periods for peers with respect to Perspective 1. In June, the UK is above-average in jc1-jc4, jc7-jc8, dc1-dc5, dc7, dc8 and below-average only in jc5-jc6 and dc6. The UK was ranked 19th in June and 20th in Perspective 1 among the 20 countries in the highly competitive nations cluster.



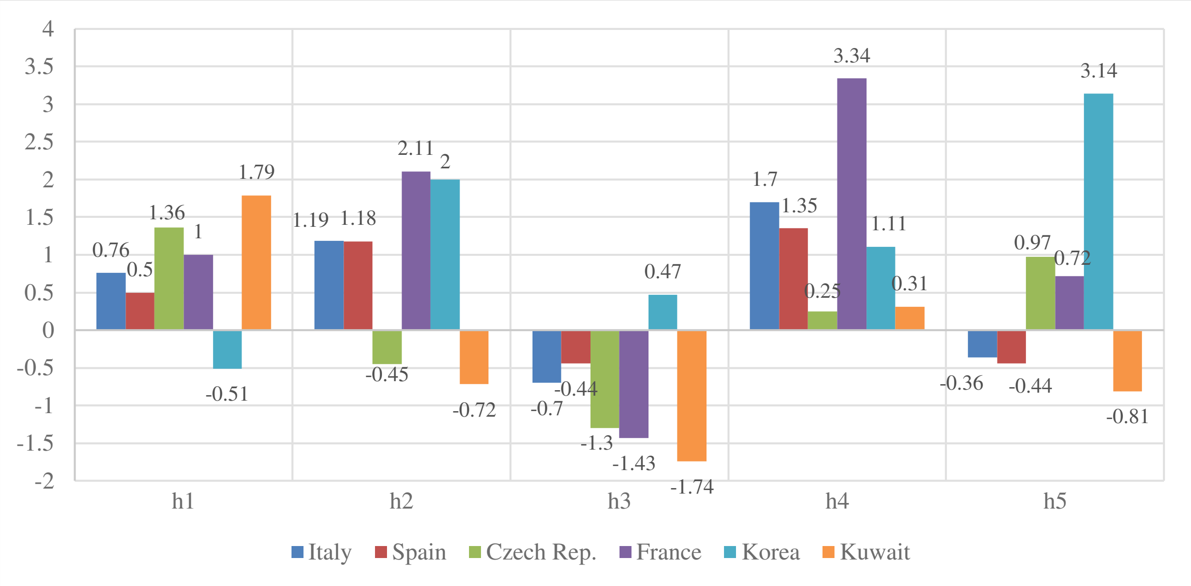
OUTPUTS based on max number of new cases jc1, dc1: total number of cases, jc2, dc2: number of new cases, jc3, dc3: total number of deaths, jc4, dc4: number of new deaths, jc5, dc5: total number of cases / million, jc6, dc6: number of new cases / million, jc7, dc7: total number of deaths / million, jc8, dc8: number of new deaths / million

Figure 7 Comparison of the UK and the USA with their peers in standardised outputs in Perspective 1 in June and December 2020

In Figure 7, the USA is above-average in all COVID-19 variables except dc6. The USA was ranked 20th in June and 18th in December in Perspective 1 within the highly competitive nations cluster. Although one of USA's peers, Switzerland, has above-average performance in four COVID-19 output variables (jc6, dc5, dc6, dc8), the DEA model still identified it as an efficient country and one of the USA's two peers. None of the rest of the peers (Australia, Japan, and Norway) had any COVID-19 variable that was above the average.

Peer Analysis of Competitive Countries

A similar picture can be seen when Italy and Spain within the competitive nations cluster are compared to their peers: the Czech Republic, France, and Korea. The comparison of these countries in input variables is given in Figure 8.

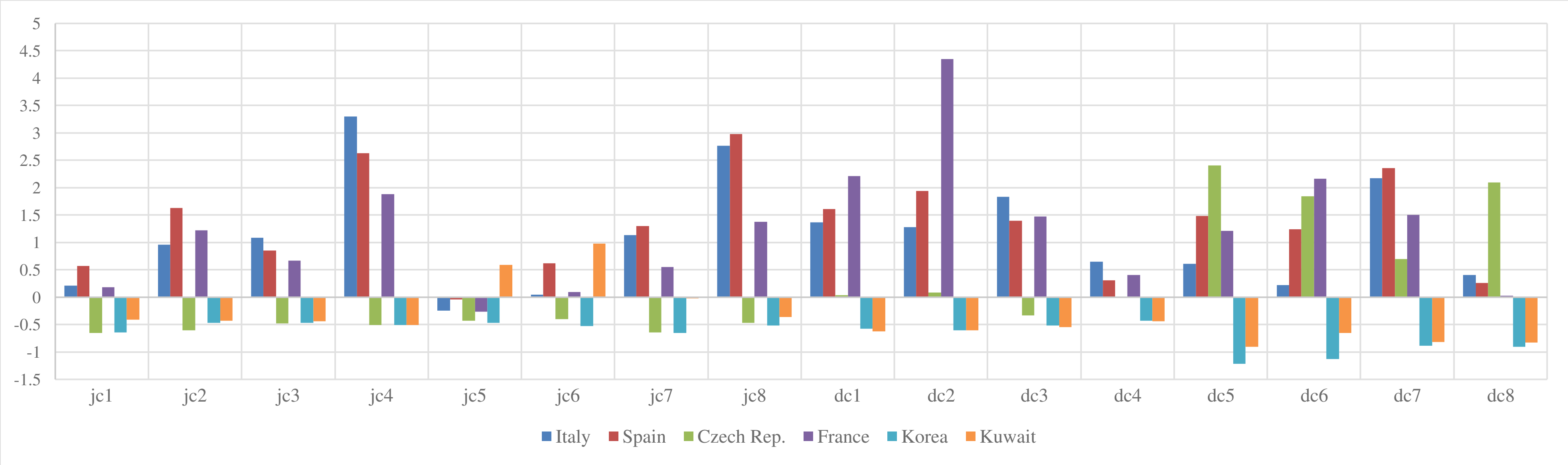


INPUTS h1: Domestic general government health expenditure (% of current health expenditure), h2: Domestic private health expenditure per capita (current US$), h3: Domestic private health expenditure (% of current health expenditure), h4: Current health expenditure per capita (current US$), h5: Hospital beds (per 1,000 people),

Figure 8 Comparison of Italy and Spain with their peers in inputs

Contrary to the comparison in the highly competitive nations cluster, in the competitive nations, the two inefficient countries selected for comparison, Italy and Spain have above-average performance in h1, h2, and h4; however, they are below-average in h3 and h5. In fact, in h3, not only Italy and Spain but also their peers except Korea also have below zero standardised scores. In Figure 8, the input variable h3 indicates the domestic private health expenditure as a percentage of current health expenditure and only Korea has higher scores in this variable, showing that in these countries, although private health expenditure does exist, it does not have a high proportion within the current health expenditure. France has the highest scores in h2 and h4, and peers tend to score higher than Italy and Spain in h1, h2, and h5. France has the highest current health expenditure per capita, and Korea among the peers has the highest hospital beds per thousand people.

Figure 9 presents the standardised scores of Italy and Spain along with the scores of their peers in June and December for the COVID-19 outputs in Perspective 1. Italy was ranked 26th in June and 27th in December in Perspective 1 among the 33 countries in the competitive nations cluster. Spain, on the other hand, was ranked 30th both in June and December in Perspective 1. It can be observed in Figure 9 that Italy and Spain did not have any COVID-19 outputs below the average except for jc5.



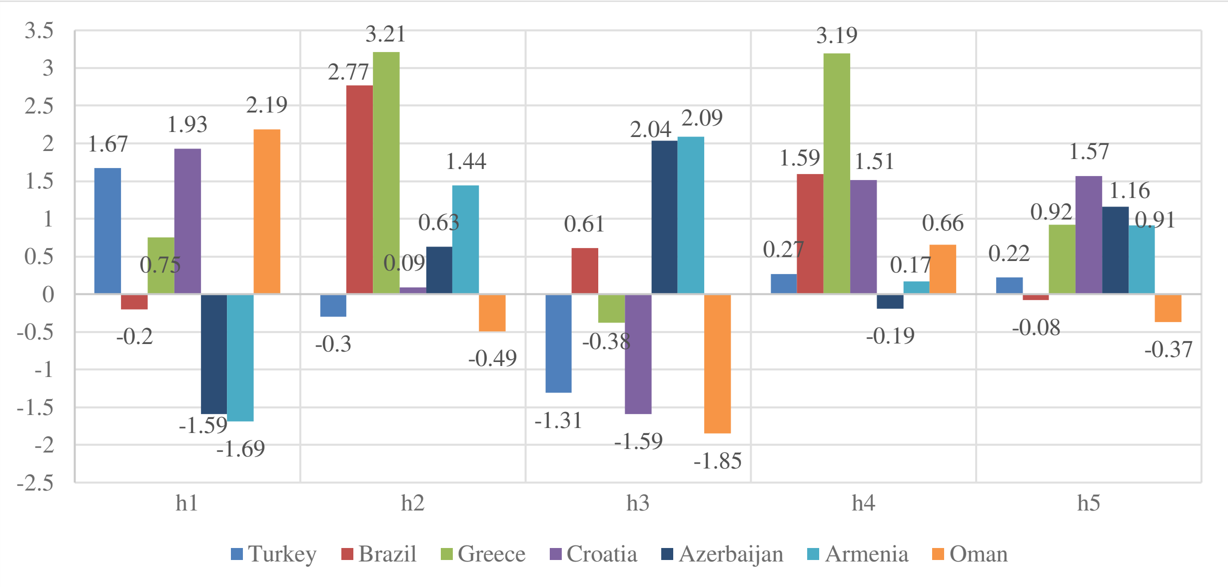
OUTPUTS based on max number of new cases jc1, dc1: total number of cases, jc2, dc2: number of new cases, jc3, dc3: total number of deaths, jc4, dc4: number of new deaths, jc5, dc5: total number of cases / million, jc6, dc6: number of new cases / million, jc7, dc7: total number of deaths / million, jc8, dc8: number of new deaths / million

Figure 9 Comparison of Italy and Spain with their peers in outputs in Perspective 1 in June and December 2020

In Figure 9, the Czech Republic had all COVID-19 variables below-average in June, but its poor management of the outbreak resulted in all of its output variables except dc3 and dc4 to become above-average in December. In fact, the Czech Republic was among the efficient countries in June but is no longer a peer to any of the inefficient countries in December since itself has become inefficient. Among the efficient peers, France's situation is different from Korea and Kuwait. France had above-average scores in all of the COVID-19 output variables in both periods except for jc5. However, its scores were lower than those of Italy in all of the COVID-19 output variables except jc2, jc6, dc1, dc2, dc5, and dc6. Although the number of new cases for France is the highest in December, its scores in other variables are lower than Italy and Spain. France's investment levels in the health resources variables resulted in it being efficient in both analysis periods. Korea, with no exception, had all of its COVID-19 output variables in both analysis periods below-average while Kuwait also had all of its COVID-19 output variables except jc5 and jc6 below-average.

Peer Analysis of Non-competitive Countries

In the non-competitive nations cluster, the countries selected for comparison, Turkey and Brazil, are presented along with their peers: Greece, Croatia, Azerbaijan, Armenia, and Oman. Figure 10 shows the comparison of Turkey and Brazil with their peers in terms of health input variables. Turkey has above-average performance in h1, h4, and h5 but below-average in h2 and h3. Specifically, in h3, domestic private health expenditure as a percentage of current health expenditure, Turkey is 1.31 standard deviations below the mean. However, its peers, Greece, Croatia, and Oman are also below-average in h3, -0.38, 1.59, and 1.85 standard deviations below-average, respectively.

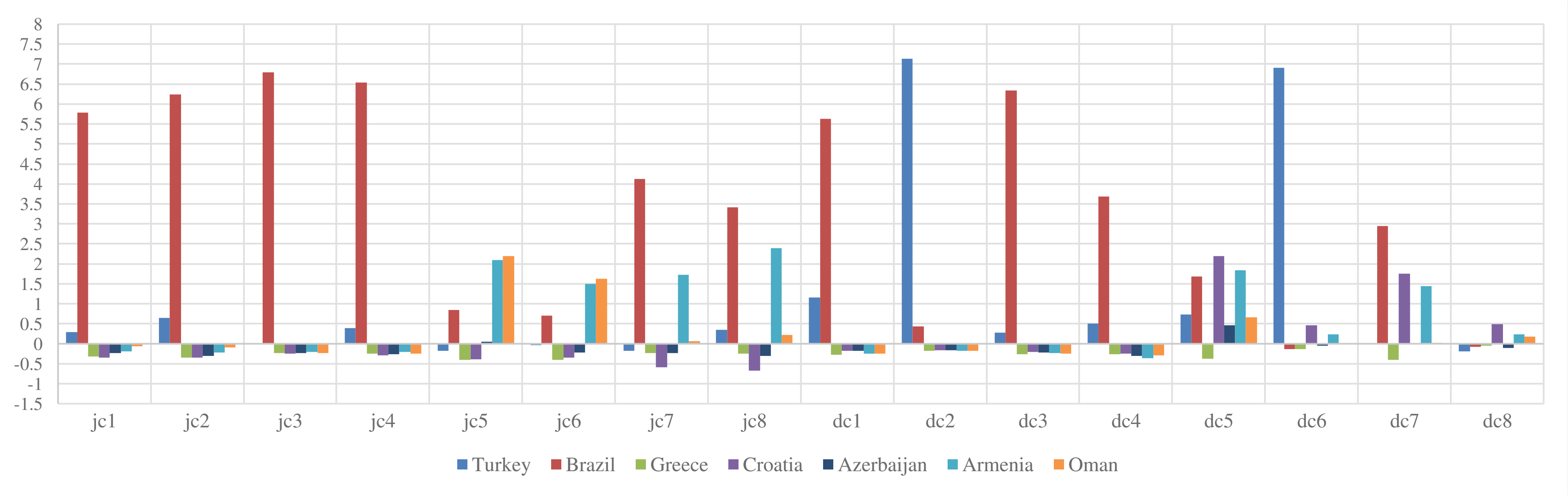


INPUTS h1: Domestic general government health expenditure (% of current health expenditure), h2: Domestic private health expenditure per capita (current US$), h3: Domestic private health expenditure (% of current health expenditure), h4: Current health expenditure per capita (current US$), h5: Hospital beds (per 1,000 people),

Figure 10 Comparison of Turkey and Brazil with their peers in inputs

In Figure 10, Brazil is below-average in h1 and h5 but above-average in h2, h3, and h4. Specifically, in h2, domestic private health expenditure per capita, Brazil is 2.77 standard deviations above the average. In terms of h5, the number of hospital beds per thousand people, Croatia is the highest with 1.57 standard deviations above the average.

Figure 11 shows Turkey and Brazil, along with their peer countries in terms of the standardised scores in COVID-19 output variables. Turkey was ranked 39th in June and 50th in December in Perspective 1 among the 54 countries in the non-competitive nations cluster while Brazil was ranked 54th in June and 48th in December in Perspective 1. The striking underperformance of Brazil and Turkey are visible. Brazil is above-average in all COVID-19 variables across the two analysis periods, except dc6 and dc8. In June, Brazil scored more than three standard deviations above the mean in jc1-jc4, jc7, and jc8. In December, it was more than three standard deviations in dc1, dc3, dc4 and almost three standard deviations in dc7.



OUTPUTS based on max number of new cases jc1, dc1: total number of cases, jc2, dc2: number of new cases, jc3, dc3: total number of deaths, jc4, dc4: number of new deaths, jc5, dc5: total number of cases / million, jc6, dc6: number of new cases / million, jc7, dc7: total number of deaths / million, jc8, dc8: number of new deaths / million

Figure 11 Comparison of Turkey and Brazil with their peers in outputs in Perspective 1 in June and December 2020

In Figure 11, Turkey had the highest extremes in dc2 (7.14 standard deviations above the average) and dc6 (6.91 standard deviations above the average). Among Turkey's COVID-19 variables, only jc5- jc7, dc7, and dc8 were below-average. Greece, which is in the peer set of both Brazil and Turkey, had no COVID-19 output variables that were above-average. Croatia had only dc5-dc8 above-average, Azerbaijan only had jc5, dc5, and dc7 above-average. For Armenia and Oman, jc5-jc8 and dc5-dc8 were above-average.

Turkey and Brazil are expected to have lower levels of deaths and cases related to COVID-19 using the same level of health-related expenditures as well as hospital beds. The rapid increase of the confirmed cases in Turkey did not overburden the public healthcare system, and the preliminary case-fatality rate remained lower. This was most probably due to the country's relatively young population and the high number of available ICUs.

Relationship Between Human Development and Efficiency

In the third stage, the authors tested the explanatory power of 66 independent variables published in the Human Development Report (Conceição, 2019) together with cluster and political regime categorical variables on the two efficiency scores using Tobit regression models by entering and removing predictors based on their *p*-values. The variables included in the Tobit regressions are as follows:

- **Mortality rate attributed to household and ambient air pollution (airp):** Age-standardised mortality rate resulting from exposure to ambient (outdoor) air pollution and household (indoor) air pollution from solid fuel use for cooking, expressed per 100,000 people. Ambient air pollution is due to emissions from industrial activity, households, cars and trucks.
- **International inbound tourists (urban):** Arrivals of non-resident visitors (overnight visitors, tourists, same-day visitors and excursionists) at national borders.
- **Urban population (urban):** De facto population living in areas classified as urban according to the criteria used by each country or area.
- **Domestic credit provided by financial sector (fincredit):** Credit to various sectors on a gross basis (except credit to the central government), expressed as a percentage of GDP.
- **Gross national income (GNI) per capita (gni):** Aggregate income of an economy generated by its production and its ownership of factors of production, less the incomes paid for the use of factors of production owned by the rest of the world, converted to international dollars using purchasing power parity rates, divided by midyear population.
- **Country Clusters:** The three country clusters obtained in Stage 1 of the methodology. Cluster 1: highly competitive nations, Cluster 2: competitive nations, Cluster 3: non-competitive nations. Competitive nations cluster is considered as the reference, and the coefficients for highly competitive and non-competitive clusters are reported.
- **Political regime:** Indicates the political regime of a country as published by the Our World in Data (https://ourworldindata.org/democracy). Regime 0: closed autocracy (reference variable), Regime 1: Electoral Autocracy, Regime 2: Electoral Democracy, Regime 3: Liberal Democracy. Table 8 shows the number of nations in each regime under each competitiveness cluster.

Table 8 Number of Nations in each cluster and each political regime

	Highly Competitive	Competitive	Non-competitive	Total
Closed Autocracy	0	6	4	10
Electoral Autocracy	1	3	24	28
Electoral Democracy	0	13	24	37
Liberal Democracy	19	11	2	32

All of the variables above except political regime were significant in the Tobit regression. One of the reasons for this could be the relatively few observations in each cluster – regime combination (Table 8). While all countries except Singapore in the highly competitive nations cluster are governed by liberal democracy, only two countries (Costa Rica and Ghana) in the non-competitive nations cluster are governed by liberal democracy. The six countries governed by closed autocracy in the competitive nations cluster are the United Arab Emirates, China, Kuwait, Qatar, Saudi Arabia, and Thailand.

The results of the Tobit regression analyses are given in Table 9. The authors report the standardized coefficients of the independent variables, hence the authors could comment on the strength of the explanatory variables. For both efficiency scores, the coefficients are quite similar:

- For one standard unit increase in the mortality rate attributed to household and ambient air pollution (airp), the efficiency score decreases by 0.029 units in both models.
- For one standard unit increase in the international inbound tourists (tourist), the Efficiency 1 score decreases by 0.021 units and the Efficiency 2 score decreases by 0.022 units.
- For one standard unit increase in urban population (urban), there is a 0.019 unit decrease in Efficiency 1 and 0.021 units decrease in Efficiency 2.
- Gross national income per capita (gni) has a greater positive impact than domestic credit provided by the financial sector (fincredit). For one standard unit increase in gross national income per capita, the efficiency score increases by 0.022 units in both perspectives.
- For one standard unit increase in domestic credit provided by the financial sector (fincredit), the Efficiency 1 score increases by 0.016 units and the Efficiency 2 score increases by 0.018 units.

Table 9 Tobit Regression Results

	Efficiency 1, R^2 = 0.392				**Efficiency 2, R^2 = 0.396**			
	Estimate	**Std. Err**	**z value**	**Pr(>|z|)**	**Estimate**	**Std. Err**	**z value**	**Pr(>|z|)**
Intercept1	0.935	0.009	104.743	0.000***	0.934	0.009	99.331	0.000***
Intercept2	-3.109	0.083	-37.317	0.000***	-3.058	0.085	-35.930	0.000***
airp	-0.029	0.007	-4.242	0.000***	-0.029	0.007	-3.951	0.000***
tourist	-0.021	0.006	-3.819	0.000***	-0.022	0.006	-3.626	0.000***
urban	-0.019	0.007	-2.742	0.006**	-0.021	0.007	-2.855	0.004**
fincredit	0.016	0.007	2.267	0.023*	0.018	0.007	2.375	0.018*
gni	0.022	0.009	2.414	0.016*	0.022	0.010	2.274	0.023*
Highly Competitive	-0.016	0.018	-0.899	0.369	0.003	0.019	0.149	0.881
Non-Competitive	0.054	0.013	4.003	0.000***	0.058	0.014	4.075	0.000***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1

There is no difference between the competitive and highly competitive cluster but being in the non-competitive cluster is significant to explain the variability in efficiency scores in Efficiency 1 and in Efficiency 2. Efficiency 1 score is predicted to be 0.054 unit higher, and Efficiency 2 score is predicted to be 0.058 unit higher when a country is in the non-competitive cluster. This can be explained by the fact that many countries in the non-competitive cluster did increase their efficiency scores and the efficiency scores ranged [0.838, 1] for Efficiency 1 and [0.850, 1] for Efficiency 2 while the same ranges for the competitive countries cluster are [0.798, 1] and [0.745, 1], respectively. Considering the ranges of the efficiency scores, these decreases and increases from each of the independent variables entered into the model are significant. The explanatory power of the Tobit regression models is similar at $R^2 = 0.392$ for Efficiency 1 and $R^2 = 0.396$ for Efficiency 2.

FUTURE RESEARCH DIRECTIONS

In this paper, the authors evaluated the response of countries to the COVID-19 pandemic using data from the first and the second waves. As of submission date of this paper, the pandemic is still evolving, and mass vaccination has started. This methodology can be repeated in the short term once the pandemic is under control to assess how the efficiency of nations has changed over time further with new vaccines and medicines. Such an analysis could provide policy suggestions with long term investment implications in healthcare and mobile applications for contract tracing.

CONCLUSION

This study set out to investigate the COVID-19 response of countries and identify the association between the response performance of a nation and its competitiveness using data from June and December 2020. The authors proposed a novel three-stage approach for assessing the COVID-19 response efficiency of nations. In the first stage, the countries were clustered according to 12 competitiveness pillars, and in the second stage, DEA analyses were conducted separately for each cluster in two perspectives. Finally, in the third stage, Tobit regression models were built to explain the differences in the efficiency scores of nations testing 66 variables from the Human Development Report.

The results show that even the countries being in the same cluster show wide variations in their efficiency of curbing the COVID-19. The governments of all inefficient countries in each cluster could find their peers to take as a role model and can, thus, allocate their resources more efficiently.

Additionally, the regression results show that countries with lower air pollution, lower inbound tourists, lower population density, higher gross national income per capita, and higher credit rate from financial institutions are showing better performance in the fight against the COVID-19. In fact, these findings support the policy suggestions underlined by the special edition of the WEF's Global Competitiveness Report (Schwab and Zahidi, 2020). This special edition encompasses several policy areas to establish synergies across different reform objectives. As such, it provides a road map for the policymakers for the post-covid recovery of the countries. In reality, those policies also highlight the factors which were at the background of the efficiency of the countries during their struggle against COVID-19.

In parallel to the suggestions of Schwab and Zahidi (2020), our study also finds out that lower population density is important to fight against COVID-19. Increasing population in the developing world and ageing population in the developed world resulted in lower performance of the countries in their struggle against COVID-19. In fact, lower population density permits higher public expenditure on childcare and education as well as on healthcare. It also provides better protection against job loss, disability, old age, and poverty. The coverage rates of child and maternity benefits, support for persons without a job, persons with disabilities, victims of work injuries, and older persons increase with lower population density. This also permits to realise an education with critical and creative thinking ability to the young generation and increase digital skills of the active population.

Additionally, higher credits from financing agents such as central/federal, state/provincial/regional, and local/municipal authorities; extrabudgetary agencies, social security schemes can increase general government expenditure and, this, in turn, enhances the health status of the population and/or the distribution of medical care goods and services among the population.

As is also suggested by Schwab and Zahidi (2020), our research findings underline that the countries should manage climate change, provide more dialogue on travel and migration, and prepare new trade policies for reforming international governance in the long run for better prosperity and efficiency. In fact, net-zero emission importance is also highlighted by D'Aprile et al. (2020). In the post-covid era, companies and consumers should make investments in lower-emitting technologies; the government should provide stimulus programs that accelerate investments in infrastructure, R&D, and supply chain.

The IMF estimates that allocating an additional 1% of GDP to public investment could create approximately 7 million jobs directly, and 20 million jobs indirectly worldwide. Maintaining and, where possible, expanding investments in transport, healthcare, housing, digitalisation, and energy transition would improve competitiveness, create more employment and prepare countries to become more resilient and sustainable (Schwab and Zahidi, 2020). Therefore, as is also highlighted in our research the highly competitive countries that have allocated a significant percentage of their GDP to public investment showed better performance in their struggle against COVID-19 and will also recover faster in the post-covid era.

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Ethical Approval: The research is conducted on publicly available secondary data. A formal ethics approval was not needed in accordance with the policies of the authors' institutions.

Authors Contributions: The second author lead the conceptualisation and design with contribution from all authors. Material preparation and data collection were done by the third author and the fourth author. The first author performed the analysis and wrote the first draft of the manuscript. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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KEY TERMS AND DEFINITIONS

Country Clusters: The three country clusters obtained in Stage 1 of the methodology. Cluster 1: highly competitive nations, Cluster 2: competitive nations, Cluster 3: non-competitive nations. Competitive nations cluster is considered as the reference, and the coefficients for highly competitive and non-competitive clusters are reported.

Domestic credit provided by financial sector: Credit to various sectors on a gross basis (except credit to the central government), expressed as a percentage of GDP.

Gross national income (GNI) per capita: Aggregate income of an economy generated by its production and its ownership of factors of production, less the incomes paid for the use of factors of production owned by the rest of the world, converted to international dollars using purchasing power parity rates, divided by midyear population.

International inbound tourists: Arrivals of non-resident visitors (overnight visitors, tourists, same-day visitors and excursionists) at national borders.

Mortality rate attributed to household and ambient air pollution: Age-standardised mortality rate resulting from exposure to ambient (outdoor) air pollution and household (indoor) air pollution from solid fuel use for cooking, expressed per 100,000 people. Ambient air pollution is due to emissions from industrial activity, households, cars and trucks.

Political regime: Indicates the political regime of a country as published by the Our World in Data (https://ourworldindata.org/democracy). Regime 0: closed autocracy (reference variable), Regime 1: Electoral Autocracy, Regime 2: Electoral Democracy, Regime 3: Liberal Democracy.

Urban population: De facto population living in areas classified as urban according to the criteria used by each country or area.

APPENDIX 1 EFFICIENCY SCORES IN JUNE AND DECEMBER 2020

Table 10 shows the efficiency scores of highly competitive countries in Perspective 1 (Efficiency 1) and Perspective 2 (Efficiency 2) sorted by the December Efficiency 1 scores.

Table 10 Efficiency Scores of Highly Competitive Countries in both Perspectives

	Efficiency 1 (Rank)		**Efficiency 2 (Rank)**	
Country	**June**	**December**	**June**	**December**
Australia (AUS)	1.000 (1)	1.000 (1)	1.000 (1)	1.000 (1)
Switzerland (CHE)	1.000 (1)	1.000 (1)	1.000 (1)	1.000 (1)
Japan (JPN)	1.000 (1)	1.000 (1)	1.000 (1)	1.000 (1)
Norway (NOR)	1.000 (1)	1.000 (1)	1.000 (1)	1.000 (1)
Singapore (SGP)	1.000 (1)	1.000 (1)	1.000 (1)	1.000 (1)
Iceland (ISL)	0.965 (11)	0.996 (6)	0.968 (10)	0.986 (8)
Austria (AUT)	1.000 (1)	0.987 (7)	1.000 (1)	0.987 (7)
New Zealand (NZL)	0.982 (7)	0.985 (8)	0.986 (7)	0.985 (9)
Ireland (IRL)	0.962 (13)	0.981 (9)	0.931 (15)	0.966 (12)
Denmark (DNK)	0.974 (9)	0.968 (10)	0.977 (8)	1.000 (1)
Finland (FIN)	0.969 (10)	0.968 (11)	0.965 (11)	0.972 (11)
Israel (ISR)	0.976 (8)	0.953 (12)	0.971 (9)	0.962 (14)
Canada (CAN)	0.928 (15)	0.948 (13)	0.933 (14)	0.979 (10)
Luxembourg (LUX)	0.963 (12)	0.944 (14)	0.954 (12)	0.927 (18)
Belgium (BEL)	0.889 (17)	0.914 (15)	0.901 (17)	0.964 (13)
Sweden (SWE)	0.907 (16)	0.913 (16)	0.945 (13)	0.943 (17)
Germany (DEU)	0.953 (14)	0.899 (17)	0.918 (16)	0.891 (20)
United States (USA)	0.837 (20)	0.893 (18)	0.886 (18)	0.923 (19)
Netherlands (NLD)	0.883 (18)	0.883 (19)	0.884 (19)	0.958 (15)
United Kingdom (GBR)	0.837 (19)	0.865 (20)	0.805 (20)	0.943 (16)
Min	**0.837**	**0.865**	**0.805**	**0.891**
Max	**1.000**	**1.000**	**1.000**	**1.000**
Mean	**0.951**	**0.955**	**0.951**	**0.969**
Standard Deviation	**0.054**	**0.045**	**0.052**	**0.031**

Table 11 presents the efficiency scores of countries in the competitive cluster, sorted by scores in Perspective 1 in December.

Table 11 Efficiency Scores of Competitive Countries in both Perspectives

	Efficiency 1 (Rank)		**Efficiency 2 (Rank)**	
	June	**December**	**June**	**December**
Cyprus (CYP)	1.000 (1)	1.000 (1)	1.000 (1)	1.000 (1)
France (FRA)	1.000 (1)	1.000 (1)	1.000 (1)	1.000 (1)
Korea, Rep. (KOR)	1.000 (1)	1.000 (1)	1.000 (1)	1.000 (1)
Kuwait (KWT)	1.000 (1)	1.000 (1)	1.000 (1)	1.000 (1)
Malta (MLT)	1.000 (1)	1.000 (1)	1.000 (1)	1.000 (1)
Mauritius (MUS)	0.990 (11)	1.000 (1)	0.979 (12)	1.000 (1)
Philippines (PHL)	1.000 (1)	1.000 (1)	1.000 (1)	1.000 (1)
Qatar (QAT)	0.946 (23)	0.984 (8)	0.951 (22)	0.98 (11)
Thailand (THA)	0.965 (18)	0.983 (9)	0.961 (18)	0.984 (10)
Uruguay (URY)	0.993 (10)	0.983 (10)	0.987 (10)	0.984 (9)
Estonia (EST)	0.988 (12)	0.978 (11)	0.984 (11)	1.000 (1)
Slovak Republic (SVK)	1.000 (1)	0.976 (12)	1.000 (1)	0.973 (13)
Slovenia (SVN)	1.000 (1)	0.974 (13)	0.997 (9)	0.951 (17)
United Arab Emirates (ARE)	0.955 (21)	0.969 (14)	0.960 (19)	0.977 (12)
Malaysia (MYS)	0.961 (19)	0.954 (15)	0.956 (20)	0.955 (15)
China (CHN)	0.932 (25)	0.954 (16)	0.934 (25)	0.954 (16)
Saudi Arabia (SAU)	0.907 (27)	0.95 (17)	0.921 (26)	0.949 (18)
Kazakhstan (KAZ)	0.961 (20)	0.949 (18)	0.954 (21)	0.943 (20)
Latvia (LVA)	0.98 (15)	0.947 (19)	0.97 (16)	0.957 (14)
Czech Republic (CZE)	1.000 (1)	0.937 (20)	1.000 (1)	0.947 (19)
Lithuania (LTU)	0.984 (13)	0.935 (21)	0.978 (13)	0.937 (21)
Indonesia (IDN)	0.945 (24)	0.932 (22)	0.948 (23)	0.934 (22)
Bulgaria (BGR)	0.978 (16)	0.928 (23)	0.970 (15)	0.925 (25)
Romania (ROU)	0.980 (14)	0.927 (24)	0.973 (14)	0.932 (23)
Portugal (PRT)	0.948 (22)	0.926 (25)	0.941 (24)	0.925 (24)
Chile (CHL)	0.715 (33)	0.883 (26)	0.733 (33)	0.852 (30)
Italy (ITA)	0.914 (26)	0.882 (27)	0.909 (27)	0.865 (27)
Russian Federation (RUS)	0.899 (28)	0.861 (28)	0.879 (29)	0.861 (28)
Colombia (COL)	0.891 (29)	0.860 (29)	0.902 (28)	0.875 (26)
Spain (ESP)	0.845 (30)	0.835 (30)	0.821 (31)	0.771 (32)
Poland (POL)	0.967 (17)	0.811 (31)	0.969 (17)	0.852 (29)
Mexico (MEX)	0.843 (31)	0.806 (32)	0.866 (30)	0.821 (31)
Peru (PER)	0.716 (32)	0.798 (33)	0.790 (32)	0.745 (33)
Min	**0.715**	**0.798**	**0.733**	**0.745**
Max	**1.000**	**1.000**	**1.000**	**1.000**
Mean	**0.945**	**0.937**	**0.946**	**0.935**
Standard Deviation	**0.074**	**0.062**	**0.065**	**0.068**

Table 12 presents the efficiency scores of countries in the non-competitive cluster, sorted by December Perspective 1 scores.

Table 12 Efficiency Scores of Non-competitive Countries in both Perspectives

Country	**Efficiency 1 (Rank)**		**Efficiency 2 (Rank)**	
	June	**December**	**June**	**December**
Armenia (ARM)	1.000 (1)	1.000 (1)	1.000 (1)	1.000 (1)
Azerbaijan (AZE)	1.000 (1)	1.000 (1)	1.000 (1)	1.000 (1)
Gabon (GAB)	1.000 (1)	1.000 (1)	0.979 (15)	1.000 (1)
Greece (GRC)	1.000 (1)	1.000 (1)	1.000 (1)	1.000 (1)
Croatia (HRV)	1.000 (1)	1.000 (1)	1.000 (1)	1.000 (1)
Hungary (HUN)	1.000 (1)	1.000 (1)	1.000 (1)	1.000 (1)
Sri Lanka (LKA)	0.995 (11)	1.000 (1)	0.982 (13)	1.000 (1)
Oman (OMN)	0.950 (27)	1.000 (1)	0.980 (14)	1.000 (1)
Tajikistan (TJK)	0.981 (16)	1.000 (1)	0.976 (16)	1.000 (1)
Ukraine (UKR)	1.000 (1)	1.000 (1)	1.000 (1)	1.000 (1)
Venezuela (VEN)	1.000 (1)	1.000 (1)	1.000 (1)	1.000 (1)
Argentina (ARG)	0.997 (10)	0.996 (12)	1.000 (1)	0.935 (46)
Egypt (EGY)	0.953 (26)	0.995 (13)	0.952 (26)	0.999 (13)
Ecuador (ECU)	0.938 (32)	0.992 (14)	0.893 (46)	0.996 (15)
Bahrain (BHR)	0.931 (37)	0.991 (15)	0.927 (37)	0.999 (14)
Guatemala (GTM)	0.954 (25)	0.989 (16)	0.957 (24)	0.987 (20)
Cameroon (CMR)	0.97 (19)	0.988 (17)	0.959 (20)	0.990 (17)
Algeria (DZA)	0.957 (22)	0.986 (18)	0.957 (23)	1.000 (1)
Serbia (SRB)	0.984 (14)	0.982 (19)	0.988 (10)	0.970 (28)
Pakistan (PAK)	0.927 (40)	0.982 (20)	0.930 (35)	0.981 (23)
Lebanon (LBN)	1.000 (1)	0.980 (21)	0.986 (11)	0.994 (16)
Bangladesh (BGD)	0.942 (29)	0.976 (22)	0.946 (27)	0.977 (24)
El Salvador (SLV)	0.957 (24)	0.975 (23)	0.952 (25)	0.990 (18)
Costa Rica (CRI)	0.981 (15)	0.975 (24)	0.993 (9)	0.973 (27)
Dominican Republic (DOM)	0.963 (20)	0.972 (25)	0.959 (22)	0.984 (21)
Bosnia and Herzegovina (BIH)	0.963 (21)	0.971 (26)	0.959 (21)	0.969 (29)
Tunisia (TUN)	0.978 (17)	0.970 (27)	0.963 (19)	0.967 (30)
Nicaragua (NIC)	0.923 (41)	0.970 (28)	0.919 (42)	0.974 (25)
Morocco (MAR)	0.973 (18)	0.970 (29)	0.969 (18)	0.974 (26)
Moldova (MDA)	0.942 (28)	0.970 (30)	0.938 (31)	0.966 (31)
Macedonia, FYR (MKD)	0.936 (34)	0.962 (31)	0.943 (29)	0.962 (33)
Panama (PAN)	0.939 (31)	0.962 (32)	0.925 (39)	0.988 (19)
Honduras (HND)	0.930 (38)	0.961 (33)	0.928 (36)	0.960 (34)
Bolivia (BOL)	0.906 (45)	0.958 (34)	0.920 (41)	0.930 (47)
Guinea (GIN)	0.940 (30)	0.958 (35)	0.938 (32)	0.963 (32)

Country	Efficiency 1 (Rank)		Efficiency 2 (Rank)	
	June	December	June	December
South Africa (ZAF)	0.901 (47)	0.958 (36)	0.925 (40)	0.959 (35)
Georgia (GEO)	0.984 (13)	0.955 (37)	0.982 (12)	0.947 (38)
Ghana (GHA)	0.931 (36)	0.950 (38)	0.927 (38)	0.957 (36)
Kyrgyz Republic (KGZ)	0.986 (12)	0.946 (39)	0.973 (17)	0.943 (43)
Iran, Islamic Rep. (IRN)	0.889 (48)	0.945 (40)	0.892 (47)	0.945 (40)
India (IND)	0.937 (33)	0.944 (41)	0.942 (30)	0.981 (22)
Nepal (NPL)	0.935 (35)	0.940 (42)	0.934 (34)	0.943 (41)
Burkina Faso (BFA)	0.916 (43)	0.939 (43)	0.903 (45)	0.946 (39)
Kenya (KEN)	0.919 (42)	0.935 (44)	0.909 (43)	0.943 (42)
Ethiopia (ETH)	0.912 (44)	0.932 (45)	0.907 (44)	0.936 (45)
Jordan (JOR)	0.957 (23)	0.928 (46)	0.945 (28)	0.941 (44)
Madagascar (MDG)	0.902 (46)	0.924 (47)	0.888 (48)	0.929 (48)
Brazil (BRA)	0.722 (54)	0.921 (48)	0.718 (54)	0.894 (51)
Mali (MLI)	0.878 (49)	0.913 (49)	0.872 (49)	0.919 (49)
Turkey (TUR)	0.93 (39)	0.909 (50)	0.937 (33)	0.953 (37)
Tanzania (TZA)	0.878 (50)	0.905 (51)	0.866 (50)	0.912 (50)
Haiti (HTI)	0.859 (51)	0.887 (52)	0.847 (51)	0.894 (52)
Zambia (ZMB)	0.858 (52)	0.880 (53)	0.843 (52)	0.890 (53)
Mozambique (MOZ)	0.809 (53)	0.838 (54)	0.796 (53)	0.850 (54)
Min	**0.722**	**0.838**	**0.718**	**0.850**
Max	**1.000**	**1.000**	**1.000**	**1.000**
Mean	**0.943**	**0.963**	**0.939**	**0.965**
Standard Deviation	**0.053**	**0.036**	**0.055**	**0.035**

The efficiency of nations in the struggle against the COVID-19 pandemic

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