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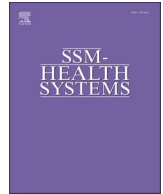
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Original research article

Healthcare system efficiency and drivers: Re-evaluation of OECD countries for COVID-19

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ABSTRACT

The Covid-19 pandemic has raised concerns about the resilience of health systems. The aim of this study is twofold: i) to measure and compare the resilience of health system efficiency of OECD countries before and during Covid-19 and ii) to determine the healthcare efficiency drivers (e.g., socio-economic) of health system performance. Using a dataset of 31 OECD countries for 2018 and 2020, we first estimate bias-adjusted efficiency scores, followed by a double bootstrap truncated regression procedure to study the drivers associated with health system efficiency. We find that the health system efficiency overall score decreased among OECD countries during the Covid-19 pandemic compared to before Covid-19. Estonia and Japan retained their full efficiency score during Covid-19. We find a negative association between health system efficiency and unemployment rate, share of health expenditure in GDP, and share of population over 65. Conversely, high vaccination rates contribute positively to health system efficiency during the Covid-19 period.

1. Introduction

The primary goal of public healthcare is to make healthcare resources more efficient and accessible. The unpredictability of diseases or pandemics, may cause problems for health systems to deliver suitable resource allocation (Rutter et al., 2020; Kimbell et al., 2015). At the same time, increasing movement of people for both economic and social reasons with globalization is causing a critical risk factor in increasing the prevalence of infection and epidemic risks for countries. This requires countries' health systems to allocate their policy-based resources for their own present health and well-being, as well as for possible future pandemics. In fact, although they have faced many pandemics (the plague epidemic in Venice, 14th century, England, 19th century, and more recently AIDS, SARS, MERS and Ebola), until the Covid-19 pandemic countries did not make big efforts with their health systems to overcome these crises. However, with the Covid-19 pandemic that emerged in 2019, health systems in the world for the first time faced an unpredictable and very large-scale health problem that required urgent mobilization of resources and affected the entire population. At the same time, for the first time in history, a health crisis shut down the global

economy, painfully demonstrating how inseparable health and the economy have become (Deloitte, 2020). The globalizing context of this crisis also requires periodic restructuring of inventories in terms of input/output relationships so that health decision makers' behaviour and governance systems can be adapted to the characteristics of each State (Lupu and Tiganasu, 2022). The Covid-19 pandemic has shown that the most affected and vulnerable countries are those whose healthcare systems suffer from an insufficient number of human resources and equipment (Razu et al., 2021; Tessema et al., 2021; OECD, 2020). The Covid-19 outbreak has highlighted the need to re-evaluate resources in health services and prioritize preventive processes that can reach all segments of society without compromising healthcare service efficiency. Right from the start, the most crucial input in dealing with the pandemic has been healthcare personnel, particularly doctors and nurses. Healthcare professionals involved in the care and treatment of Covid-19 patients have had to work longer hours than usual and overcome physical and psychological challenges. The effective management of the health system during the pandemic in many countries has been closely linked to the care and recognition given to doctors, nurses, and other healthcare personnel. This recognition also

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contributes to the overall efficiency of healthcare services. Furthermore, having fully equipped health facilities and infrastructure is another vital factor in combating the pandemic. Respiratory insufficiency has been a prevalent issue among individuals affected by Covid-19, emphasizing the need for an adequate supply of respirators (Shadmi et al., 2020). Additionally, the widespread distribution of vaccines, which is essential for eradicating the pandemic, is another critical success factor. All of these healthcare resource issues discussed above have reignited the debate on how countries should manage their health systems in an input-oriented manner to overcome pandemics and safeguard and improve public health.

OECD members, which can be counted among the countries with the most developed health systems, were exposed to significant problems during Covid-19 (e.g. Italy, Spain, France and USA). Especially the inadequacy of healthcare resources and the difficulties experienced in agility to mitigate the shock have left these countries in a difficult situation. However, OECD countries have succeeded in increasing the share of health expenditures of GDP in response to the decline in incomes. The share of health expenditure in GDP increased from 8.52% (2018) to approximately 9.7% (2020). The countries most severely affected by the pandemic reported unprecedented increases in the share of GDP allocated to health (United Kingdom increased from 10.2% to 12.8%, Slovenia from 8.5% to 10%, South Korea from 7.3% to 8.5%). At the same time, the rate of increase in the workforce of health and social services rose. The total density of the health- and social-care workforce was approximately 50 per 1000 people in 2018 (OECD, 2021a, 2021b). In terms of health outcomes, death rates per case vary greatly between countries, but significant progress has been made since the beginning of Covid-19. An input resource-oriented examination of health services in OECD countries is critical to reveal how countries with prosperous healthcare models are, or continue to be, efficient with Covid-19. There is a growing momentum in health research addressing a health system's capacity to meet challenges rather than addressing health risks (Kruk et al., 2015; Panter-Brick, 2014). The foremost of these challenges is the efficient management of healthcare and health systems.

The objective of this research is to estimate the efficiency of health systems in OECD countries before and during the Covid-19 pandemic. The study examines the effect of the Covid-19 outbreak on health outcomes, while also revealing the resilience of countries based on their healthcare efficiency. In contrast to prior studies that solely focused on the effect of Covid-19 on healthcare efficiency during the pandemic, this research evaluates the extent to which the efficiency of healthcare systems in OECD countries was affected prior to and during the Covid-19 period. In the analysis, we adopt the procedure developed by Simar and Wilson (2007) (Simar and Wilson, 2007), that consists of estimating, first bias-corrected efficiency scores, and then using a double bootstrap truncated regression estimating efficiency drivers. Efficiency estimations were conducted based on 2018 (pre-Covid-19) and 2020 (during Covid-19) health outcomes and resources for 31 OECD countries.

The rest of the paper is organized as follows: The first section presents a literature review on the efficiency of healthcare (micro-level) and health systems (macro-level) and then an extended literature review for healthcare efficiency studies for Covid-19. The second section details Simar and Wilson's (2007) method, and the data sets. Section three presents the results, and section four the discussion. The last section provides concluding remarks and study limitations.

2. Literature review

Health system efficiency can be assessed at both micro- and macro-levels. Micro-level studies focus on specific aspects such as public hospitals, health facilities, and medical practice, while macro-level studies compare the performance of health systems across different countries. At the micro level (Nedelea and Fannin, 2013; Nayar and Ozcan, 2008; Zhang et al., 2018; Manavgat and Demirci, 2020; Pereira et al., 2021; Guillon et al., 2022), the output concerns health facility activity (e.g.,

number of discharged patients, number of admissions, bed turnover rate, see Table A1 in appendix). At the macro level (Mirmirani and Lippmann, 2004; Mirmirani et al., 2008; Afonso and St. Aubyn, 2011; Hadad et al., 2013; Moran and Jacobs, 2013; Çetin and Bahce, 2016; Kaya Samut and Cafri, 2016; Behr and Theune, 2017; Lee and Kim, 2018; Ahmed et al., 2019; Top et al., 2020), the output is the health outcome (e.g., life expectancy at birth, infant mortality rate, see Table A1). Over the last decade the literature indicates that bootstrap DEA has become a robust method for measuring performance in health systems and health service providers (Guillon et al., 2022; Afonso and St. Aubyn, 2011; Lee and Kim, 2018).

Such studies commonly consider inputs such as doctors, nurses, beds, health equipment, and health expenditure, alongside health outcomes such as quality of life, infant survival and life expectancy at birth. However, there is a relatively limited number of studies that have specifically examined health system efficiency during the Covid-19 era. The Table A1 (on-line Appendix) describes for each paper of the literature review, the outputs or health outcomes, the inputs, the methodological approaches adopted and the results.

The number of studies examining the effect of the Covid-19 outbreak on healthcare and system efficiency is low. There have been many studies investigating the success of countries' health services and systems in the era of Covid-19 and after. Some studies focused on costs (Oksuz et al., 2021; Reddy et al., 2021) and many studies have dealt with the spatial spread and clustering of the coronavirus and its determinants (Amdaoud et al., 2021; Fonseca-Rodríguez et al., 2021; Kang et al., 2022; Poirier et al., 2020).

Healthcare system efficiency and its improvement are the main concerns that should be revisited for the Covid-19 pandemic. The specific method used to quantify the efficiency of health systems refers to DEA, which has been used by various researchers, to calculate the efficiency of health systems during the COVID-19 outbreak (Lupu and Tiganasu, 2022). Ordu et al (Ordu et al., 2021). compared the healthcare system efficiency scores of 16 countries. Population size, median age, doctors (per 1000 people), hospital beds (per 100,000), total confirmed cases of Covid 19, and weekly total confirmed cases of Covid 19 were used as input variables. Total confirmed deaths, weekly total confirmed deaths, and non-mortality rate of Covid-19 were used as output variables. Five weeks of observation were made. They indicated that the percentage of countries with efficient health systems decreased dramatically over time, from 43.75% in the first week to 25% in the fifth week. Mourad et al (Mourad et al., 2021). analysed the healthcare system efficiency of a spread of countries for the Covid-19 pandemic. In their paper, seven scenarios were adopted with DEA methodology with the number of medical practitioners (doctors and nurses), hospital beds, number of conducted Covid-19 tests as inputs, and the number of affected cases, recovered cases, and deaths as outputs. They showed that less than half of the considered countries are relatively efficient. Hamzah et al (Hamzah et al., 2021). investigated the efficiency level of managing Covid-19 in Malaysia, using network DEA. Martínez-Córdoba et al (Martínez-Córdoba et al., 2021). evaluated governments' ability to mitigate the impact of the pandemic on health system efficiency for many countries around the world. While European and American countries were less efficient than Asian and African countries, significant differences were observed based on a country's geographic location. They also showed that greater freedom of expression, a higher median age, and an unstable economy and labour market decrease efficiency. Likewise, Su et al (Su et al., 2021). analysed the effect of the measures implemented by countries in mitigating the pandemic consequences by using DEA for 23 selected countries. They showed that "Korea and Australia performed with the highest efficiency in preventing the diffusion of Covid-19 for the whole period covering". Lupu and Tiganasu (Lupu and Tiganasu, 2022), using DEA, analysed the efficiency of the health systems of 31 European countries in treating Covid-19 and researched to explain the efficiency score difference. They considered six major fields of influence: health care resources (doctors, nurses,

midwives, etc.), health status, population, economic, cultural, societal and governmental issues. They found that “western states, severely affected at the beginning of the pandemic, began to take adequate measures and improve the efficiency of their sanitary systems”. Pereira et al (Pereira et al., 2022), examined the health efficiency of 55 countries, including OECD countries, using the Network DEA method. They concluded that Estonia, Iceland, Latvia, Luxembourg, the Netherlands, and New Zealand exhibited higher average system efficiencies during the Covid-19 process. Additionally, they demonstrated that countries with a large population had worse average efficiency scores.

The variety of results given by the literature shows the initial nature of research on this subject. It is noteworthy that none of the studies conducted during the Covid-19 period utilized bootstrap DEA. We have adopted the bootstrapping approach in our study to account for measurement bias (Tziogkidis, 2012). Our study compares health system efficiency for pre and during Covid-19 with the same variables, and then searches to explain countries’ health system efficiency with external factors such as indicators in health, demographic, social, institutional, and economic factors. The objective is to reveal the impact of the Covid-19 pandemic on the efficiency of healthcare services and the resilience of health systems in OECD countries.

3. Method

For several decades, the standard Data Envelopment Analysis (DEA) approach has been widely used to estimate health facility and health system efficiency (Zhang et al., 2018; Mirmirani and Lippmann, 2004; Mirmirani et al., 2008; Ordu et al., 2021; Demirci, 2020). DEA is a non-parametric approach, which uses mathematical programming methods to estimate best practice production frontiers and to evaluate the relative (technical or allocative) efficiency of different decision-making units (DMUs). Technical efficiency, on which we focused, provides information on how efficiently DMUs use their physical inputs to produce outputs. DEA gives efficiency scores which represent the individual performance of DMUs (country health system -CHS - in our study) from 1 (CHS technically efficient) to 0 (CHS totally non-efficient). Developed by Farrell (Farrell, 1957), the DEA approach was improved by Charnes et al (Charnes et al., 1978). with a constant return to scale (CRS) model, and later by Banker et al. (1984) (Banker et al., 1984) with a variable return to scale (VRS). DEA has an advantage over other approaches, such as stochastic frontier analysis, because it does not require any assumption about the production frontier and is able to work with complex systems that have multiple inputs and outputs such as a healthcare system. Two orientation models are available: input or output orientation. As the management of outputs is more difficult than that of inputs for the planning of health systems, and the control of the resource level is crucial, it is appropriate here to use the input-oriented DEA model (Top et al., 2020; Chern and Wan, 2000; Ozcan, 2014). The VRS model is more used in the literature because the CRS model assumes that DMUs work at an optimal scale which is a big assumption. We adopted a VRS input-oriented model.

However, the standard DEA is recognized to suffer from some limitations. DEA is easily affected by the presence of outliers, especially with a small sample size, and does not account for measurement error. Moreover, as efficiency measurement is relative and the frontier relies on the best performers, it produces biased and serially correlated efficiency scores. Over the last decade, more studies have used the bootstrap DEA, considered to be a more robust method for measuring performance in the health sector (Guillon et al., 2022; Afonso and St. Aubyn, 2011; Lee and Kim, 2018). While the standard DEA frontier can be seen as an estimate of the true frontier based on a single sample drawn from an unknown population, the bootstrapped DEA frontier is based on independent samples (with replacement) drawn from the original dataset, used as a basis for bias corrected efficiency scores (Bogetoft and Otto, 2010). Indeed, according to Simar and Wilson (Simar and Wilson, 2007), a “naïve” bootstrap is not sufficient in a two-stage approach where

efficiency scores are, at the second stage, regressed on covariates (e.g., environmental variables or variables beyond the control of health authorities/governments). For these authors, due to serial correlated efficiency scores, standard and single bootstrap DEAs produce inconsistent inference methods in the second-stage regression. We adopt the double bootstrap procedure (based on Algorithm#2), developed by Simar and Wilson (Simar and Wilson, 2007), to improve the reliability of estimates. This procedure consists of generating bias-corrected efficiency scores for DEA (first stage) and then uses a double bootstrap truncated regression for estimating efficiency drivers (second stage). It was censored from the right at one. We used a re-sampling process 2000 times and obtained bias-corrected efficiency estimates which allowed improvement of the reliability of healthcare system efficiency estimates. Like in previous studies (Lupu and Tiganasu, 2022; Afonso and St. Aubyn, 2011; Kaya Samut and Cafrı, 2016; Lee and Kim, 2018; Ahmed et al., 2019), we included socioeconomic, demographic and environmental variables, which are all assumed to affect the health system efficiency.

3.1. Data and variables

The data are from the OECD, World Bank-World Development Indicators (WDI), and World Health Organization (WHO). The dataset consists of information from 31 OECD countries for the period of 2018 (before the Covid-19 pandemic) and 2020 (during the Covid-19 pandemic). Denmark, Portugal, Sweden, Chile, Colombia and Costa Rica are excluded, due to missing data. We estimate the efficiency model using four inputs and two outcomes. Inputs consist of physical controllable components that directly impact the healthcare services provided by health systems. Based on the literature review, we include the number of doctors, nurses, and midwives, total number of hospital beds, and computed tomography (CT) scanners. One of the fundamental challenges in health systems is to define health outcomes. Following the precedent set by earlier studies (e.g., (Mirmirani and Lippmann, 2004); Mirmirani et al., 2008; Moran and Jacobs, 2013; Çetin and Bahce, 2016; Kaya Samut and Cafrı, 2016) we use two health outcomes: life expectancy at birth and infant survival rate (calculated as one minus the infant mortality rate) (Kaya Samut and Cafrı, 2016; Lee and Kim, 2018). Although the indicator for infant survival rate is not directly collected, it is widely accepted and utilized in the literature (Hadad et al., 2013; Kaya Samut and Cafrı, 2016; Lee and Kim, 2018; Top et al., 2020). Sound health policies are expected to enhance the provision of high-quality health services, leading to increased life expectancy and improved infant survival. All input and output data were collected for before Covid-19 (2018) and during Covid-19 (2020). For some countries, 2020 data were missing, and we used the values from 2019.

We estimate the healthcare efficiency scores for before and during the Covid-19 with the same inputs and outcomes to allow a comparison. Studies on countries’ health system efficiency during the outbreak added as outcomes, the number of cases and deaths due to Covid-19 (Lupu and Tiganasu, 2022; Ordu et al., 2021). This approach is suitable only if the study focused on the health system performance during the outbreak without looking at pre-Covid-19 performance as we did. In the second stage, the estimated efficiency scores are regressed on potential exogenous, often called environmental, variables, considering information on causes for efficiency differences. These variables include socio-economics variables and country-specific factors thought to impact health system performance. Following previous studies, we employed key variables to explain country health system efficiency, such as health expenditure (Medeiros and Schwierz, 2015), education level (Moran and Jacobs, 2013), unemployment rate (Hadad et al., 2013; Moran and Jacobs, 2013; Top et al., 2020), tobacco use rate (Ahmed et al., 2019; Medeiros and Schwierz, 2015; Patavanich and Glantz, 2021), population over 65. We add, for the Covid-19 period, the Covid-19 mortality rate and the Covid-19 vaccination rate. The purpose was to examine the impact of the Covid-19 outbreak on health system

efficiency. By doing this, we tried to determine whether vaccination contributes significantly to the decrease in cases resulting in death and the efficiency of the OECD healthcare system. Definition and measurement of the variables used in both models can be found in the Appendix, Table A2.

4. Results

Table 1 presents the descriptive statistics for the variables used in the study. There is no significant change in the mean life expectancy at birth and infant survival rate between the pre- and during Covid-19 periods. Mexico and Lithuania exhibit the lowest infant survival rates, while Japan has the highest rate. Conversely, the mean of inputs shows a slight increment, particularly for CT scanners. In both periods, Türkiye has the lowest number of doctors per 1000 population, while Italy has the highest. Türkiye also has the lowest number of nurses and midwives in pre-Covid19, Mexico has the lowest number of them during the post-Covid-19 period. On the other hand, Norway has the highest number of nurses and midwives. Mexico lags behind in terms of the number of hospital beds and CT scanners, whereas Japan and Korea lead in terms of health physical resources and technology. It is noteworthy that Türkiye has the lowest share of health expenditure as % of GDP, and there has been no significant increase during the Covid-19 period. In contrast, the United States has the highest share of health expenditure among OECD countries, and it has increased after Covid-19. The vulnerable groups most affected by the Covid-19 crisis are tobacco users and individuals over 65. Iceland has the lowest smoking rate, and Latvia has the highest. Mexico has the lowest population percentage of individuals over 65, and Japan has the highest among OECD countries. Korea has been relatively successful in vaccination, a crucial precaution during the Covid-19 period. Iceland has the lowest Covid-19 death rate.

Table 2

Bootstrap DEA efficiency results for input-oriented under VRS, before Covid-19 period.

Countries	Efficiency score	Bias corrected	Bias	σ^2
Australia	0.882	0.680	0.203	0.144
Austria	0.806	0.619	0.187	0.059
Belgium	0.822	0.692	0.129	0.010
Canada	1.000	0.768	0.232	0.061
Czech Republic	0.879	0.685	0.194	0.127
Estonia	1.000	1.000	0.000	0.000
Finland	1.000	0.535	0.465	1.321
France	0.776	0.473	0.302	0.230
Germany	0.643	0.552	0.091	0.006
Greece	1.000	0.592	0.408	0.282
Hungary	1.000	0.716	0.284	0.104
Iceland	1.000	1.000	0.000	0.000
Ireland	1.000	0.825	0.175	0.102
Israel	1.000	0.119	0.881	1.777
Italy	0.989	0.740	0.249	0.374
Japan	1.000	1.000	0.000	0.000
Korea	1.000	0.665	0.335	0.188
Latvia	1.000	0.792	0.208	0.051
Lithuania	0.661	0.568	0.093	0.008
Luxembourg	0.977	0.802	0.175	0.065
Mexico	1.000	0.012	0.988	0.807
Netherlands	0.992	0.869	0.123	0.045
New Zealand	0.990	0.890	0.099	0.022
Norway	1.000	0.565	0.435	0.633
Poland	1.000	0.840	0.160	0.026
Slovak Republic	0.853	0.719	0.134	0.010
Slovenia	1.000	0.430	0.570	0.863
Spain	1.000	0.373	0.627	1.208
Türkiye	1.000	0.451	0.549	0.286
United Kingdom	1.000	0.742	0.258	0.102
United States	0.908	0.776	0.133	0.027
Average (μ)	0.941	0.661	0.280	0.288

Table 1

Descriptive statistics of inputs, health outcomes, and explanatory variables (31 countries).

2018 - Before Covid-19- Descriptive statistics of inputs, health outcomes &explanatory variables						
<u>Outcome variables</u>	Mean	Std. Dev.	Min		Max	
Life expectancy at birth	80.67	2.66	75	Mexico	84.3	Japan
Infant survival rate	0.996	0.002	0.987	Mexico	0.998	Estonia
<u>Inputs variables</u>	Mean	Std. Dev.	Min		Max	
Doctors	4.09	1.50	1.80	Türkiye	7.92	Italy
Nurses and midwives	9.48	4.05	3.00	Türkiye	18.2	Norway
Total hospital beds	4.86	2.70	0.97	Mexico	12.98	Japan
Computed Tomography (CT) scanners	23.49	13.79	5.92	Mexico	111.49	Japan
<u>Explanatory variables</u>	Mean	Std. Dev.	Min		Max	
Tertiary Education	77.23	23.06	41.52	Mexico	142.85	Greece
Unemployment rate	6.04	3.69	2.24	Czech Rep	19.29	Greece
Health expenditures in GDP	8.55	2.45	4.12	Türkiye	16.64	USA
Tobacco use	23.90	6.92	12.6	Iceland	37.2	Latvia
Population over 65	17.64	4.063	7.22	Mexico	27.57	Japan
2020- During Covid-19- Descriptive statistics of inputs, health outcomes &explanatory variables						
<u>Outcome variables</u>	Mean	Std. Dev.	Min		Max	
Life expectancy at birth	80.42	2.81	75.1	Lithuania	84.7	Japan
Infant survival rate	0.996	0.002	0.986	Mexico	0.998	Estonia
<u>Inputs variables</u>	Mean	Std. Dev.	Min		Max	
Doctors	4.11	1.43	1.81	Türkiye	8.01	Italy
Nurses and midwives	9.77	4.10	2.36	Mexico	18.34	Norway
Total hospital beds	4.84	2.71	0.99	Mexico	12.65	Korea
Computed Tomography (CT) scanners	28.51	21.00	6.69	Mexico	115.7	115.7
<u>Explanatory variables</u>	Mean	Std. Dev.	Min		Max	
Tertiary education	78.45	23.88	4.13	Mexico	148.53	Greece
Unemployment rate	6.67	3.35	2.54	Czech Rep	16.30	Greece
Health expenditures in GDP	9.57	2.75	4.61	Türkiye	18.81	USA
Tobacco use	23.44	6.98	12	Iceland	37	Latvia
Population over 65	18.33	4.10	7.61	Mexico	28.39	Japan
Covid – 19 death rate	0.007	0.0088	0.0008	Iceland	0.0474	Mexico
Vaccination	72.86	9.21	50.80	Slovak Rep.	87.07	Korea

4.1. Bootstrap DEA model

Table 2 shows large differences in results depending on the chosen performance estimation approach (standard DEA/bias-corrected efficiency scores). For example, the mean (μ) non-corrected-bias efficiency score of the 31 OECD countries at the pre Covid-19 era was 0.941 while it is 0.661, resulting in a difference of 0.280, with the bias-corrected approach. The magnitude of this difference varies across countries, with some experiencing relatively high differences. Thus, many countries, that are efficient with the standard DEA, are no longer so with the biased-corrected scores. It is the case for Türkiye, Mexico, Slovenia, Greece, and Spain, which get scores lower than 1 when considering bias correction. Only Estonia, Iceland, and Japan remain efficient under bias correction, and three countries Germany, Lithuania and France, maintain their poor health system performance whatever the approach. Except for Greece, these countries also exhibit the highest levels of bias correction (bias > 0.05). Although some previous studies (Hadad et al., 2013; Çetin and Bahce, 2016; Kaya Samut and Cafri, 2016; Behr and Theune, 2017) have demonstrated that countries such as Türkiye, Mexico, Slovenia, and Spain are efficient using the standard DEA method, it is important to note that this could be attributed to the methodological bias. This reinforces the need to use Simar and Wilson’s procedure. In the following, we only present and discuss the results from the unbiased efficiency scores.

Health system performance remained at the same level during the Covid-19 era as before. The mean efficiency unbiased score is 0.681. Of the five countries with poor performance (less than 0.500) in the Covid-19 period, two (Israel and Mexico) improved their performance despite the Covid-19 outbreak, one, Slovenia, continued its poor performance and two, Lithuania and Slovakia, had declines in performance. Two countries, Estonia and Japan, remain efficient between the two periods, while Norway increased its performance by 50%, becoming more efficient, and Iceland, which was efficient before Covid-19, saw a decline of its health system efficiency of about 20%. Finally, efficiency scores remained relatively stable and low for France, Germany and Greece (between 0.473 and 0.592) in both periods (Table 3). The good performance of Estonia and Japan have also been mentioned in a previous study (Pereira et al., 2022).

To observe the overall effect of the Covid-19 era for OECD countries, the relationship between health efficiency scores before Covid-19 and during Covid-19 was examined. This analysis aimed to determine whether the pandemic had an impact on the healthcare efficiency of OECD countries. The Spearman rank correlation coefficients (0.6959, Prob > |t|=0.0000) indicates a moderately high correlation (Spearman’s correlation, 2023). This suggests that, in general, the Covid-19 pandemic has influenced the healthcare efficiency of OECD countries. In other words, there is a significant difference observed in the efficiency of health services between the before Covid-19 and during Covid-19 periods for OECD countries.

According to (Böhm et al., 2013), whose classification of OECD health systems is based on three dimensions: regulation, financing, and service provision. They classified the OECD countries into five health system types: National Health Service (NHS), National Health Insurance (NHI), Social Health Insurance (SHI), Private Health System (PHS) and Etatist Social Health Insurance (ESHI). In the NHS type, the three core dimensions are totally controlled by the State, in the SHI type, societal (non-profit) actors, and PHS type, private actors, take charge of all the three dimensions. In the NHI system, if regulation and financing are controlled by the State, the service provision sector is taken in charge by private for-profit actors. The ESHI system is where the state dominates the regulatory sector and allows authority for financing to societal actors for the service provision to private actors (Lee and Kim, 2018; Böhm et al., 2013). The NHI has the highest average healthcare efficiency for OECD countries in both before and during Covid-19 periods (Table 4). Countries with this system are Australia, Canada, Ireland, New Zealand and Italy. Only the United States has the PHS type which also has a high

Table 3

Bootstrap DEA efficiency results for input-oriented under VRS, during Covid-19 period.

Countries	Efficiency score	Bias corrected	Bias	σ^2
Australia	0.847	0.674	0.173	0.018
Austria	0.784	0.569	0.215	0.030
Belgium	0.618	0.568	0.050	0.027
Canada	1.000	0.736	0.264	0.025
Czech Republic	0.840	0.575	0.265	0.027
Estonia	1.000	1.000	0.000	0.000
Finland	1.000	0.713	0.287	0.116
France	0.633	0.510	0.123	0.080
Germany	0.696	0.523	0.173	0.012
Greece	0.634	0.510	0.124	0.029
Hungary	1.000	0.610	0.390	0.048
Iceland	1.000	0.840	0.160	0.060
Ireland	1.000	0.847	0.153	0.033
Israel	1.000	0.499	0.501	0.112
Italy	1.000	0.753	0.247	0.045
Japan	1.000	1.000	0.000	0.000
Korea	1.000	0.786	0.214	0.037
Latvia	1.000	0.792	0.208	0.018
Lithuania	0.685	0.491	0.194	0.020
Luxembourg	0.923	0.785	0.138	0.013
Mexico	1.000	0.257	0.743	0.093
Netherlands	0.917	0.773	0.144	0.016
New Zealand	1.000	0.890	0.110	0.016
Norway	1.000	1.000	0.000	0.000
Poland	1.000	0.674	0.326	0.014
Slovak Republic	0.780	0.488	0.292	0.015
Slovenia	1.000	0.476	0.524	0.034
Spain	1.000	0.724	0.276	0.046
Türkiye	1.000	0.538	0.462	0.062
United Kingdom	1.000	0.783	0.217	0.035
United States	0.922	0.714	0.207	0.016
Average (μ)	0.912	0.681	0.232	0.035

Table 4

Average of efficiency score by the classification of the OECD healthcare systems (31 countries).

Type	2018	2020
National Health Insurance (NHI)	0.7806	0.810
Australia, Canada, Ireland, New Zealand, Italy		
Private Health System (PHS)	0.776	0.724
USA		
Social Health Insurance (SHI)	0.657	0.625
Austria, Germany, Luxembourg, Switzerland		
Etatist Social Health Insurance (ESHI)	0.667	0.652
Belgium, Estonia, France, Czech Republic, Hungary, the Netherlands, Poland, Slovakia, Israel, Japan, Korea, Türkiye, Lithuania, Slovenia Latvia		
National Health Service (NHS)	0.545	0.639
Finland, Iceland, Norway, Spain, UK, Mexico, Greece		
Kruskal-Wallis test* (chi-squared with ties- df. 4)	3.931	2.998
	[0.415]	[0.558]

Note: Countries in different system by Böhm et al. (2013). * [] p-value.

efficiency score. On the other hand, ESHI, the most widely used system for OECD countries where the state dominates the regulatory sector and private actors are empowered to provide health services, ranks as the second most effective in efficiently managing health resources, even during the Covid-19 pandemic. However, the efficiency scores of countries within this system have, on average, been negatively affected by Covid-19. We used the Kruskal-Wallis test statistic to determine whether there is a significant difference in efficiency between healthcare systems. Globally, the Kruskal-Wallis test showed no significant difference. However, a comparison between healthcare system sub-groups showed a significant difference (2.9, p = 0.09) between the subgroup (NHI+PHS) and the subgroup (SHI+ESHI) during Covid-19, and a significant difference (3.5, p = 0.06) between the subgroup (NHI+PHS) and NHS before the Covid-19.

Lastly, from the results, we calculated the targets and peers for each OECD country for the during Covid-19 period. Because that estimation, due to software, could only be done from non-bias-corrected scores, we considered the targets for the inputs and outputs for inefficient countries only when the difference between the bias-corrected efficiency score and the non-corrected bias efficiency score of the countries is less than 0.2 (bias <0.2). Also, it is important to consider that countries with high bias can lead to misleading interpretations of the targets. However, the efficiency scores of these countries are reliable when using the bootstrap DEA procedure. Additionally, the average bias of 0.2 is lower than the overall average bias of 0.232. The targets in the analysis identify the input and output levels that each country should achieve in order to be considered technically efficient, while the references represent the benchmark operations used to estimate these targets. Table 5 shows the percentage change in inputs and outputs that is required by countries with low bias in order to be fully efficient. The Table presents some countries that use the same health system and could refer to the most efficient country. Belgium needs to reduce all its inputs (doctors, nurse and midwives, hospital beds and CT) by an average of 38.2% in order to increase its performance. The countries that under the same healthcare system as Belgium and could be reference or peer to Belgium are Spain and Hungary in terms of operating health resources efficiently. France needs to decrease inputs, especially hospital beds, which should be reduced by an average of 52%. Lithuania should also reduce all its inputs by an average of 31.5% to improve life expectancy at birth by an average of 5.6%. Estonia, Hungary and Latvia are reference to Lithuania for improving inputs and outputs efficiently. It can be stated that the countries mentioned have sufficient health resources, but their achievement in improving health outcomes is relatively low.

4.2. Results for Efficiency Drivers

Bearing in mind possible drivers that may affect health efficiency scores, we used biased-corrected efficiency scores obtained from bootstrap DEA analysis as a dependent variable for the second stage and examine the socio-economic variables affecting efficiency scores. Results for the two periods are shown in Tables A3 and A4 in Appendix.

When considering both the before and during Covid-19 periods, an increase in the level of education contributes positively to the effective functioning of the health system, however an increase in the unemployment rate and the population aged over 65 rate contribute negatively to health system performance. A high share of elderly population remains a risk factor that negatively affects the efficiency of health services, both before and during Covid-19. While health expenditure as a share of GDP had no effect on health system performance before Covid-19, we found that during Covid-19, health expenditure had a significant, but negative effect on efficiency scores. Since high health expenditures

partly reflect the age structure of the population, a high over 65 rate induces higher death rates and decreases efficiency (Kaya Samut and Cafri, 2016). That result corresponds to the negative relation of health expenditure level and age structure of population. Moreover, the unexpected onset of Covid-19 has led to a significant increase of healthcare spending in all countries without making it possible to compensate for the destabilization of the health system due to the suddenness of this pandemic. It was only at the end of 2020 that the negative consequences of the focus on Covid-19, to the detriment of other healthcare began to be emphasized and debated. Finally, some previous studies show, particularly for OECD countries, that health spending does not increase efficiency, but decreases it (Afonso and Aubyn, 2005; Berger and Messer, 2002). Use of tobacco has no significant impact for the Covid-19 period. We found that there is a positive and statistically significant relation between vaccination rate and health system efficiency. Finally, a high Covid-19 death rate is the main factor which causes a low health efficiency score during the pandemic.

5. Discussion

The objective of this paper is to examine the impact of the Covid-19 outbreak on the health system efficiency of OECD countries, and determine the extent to which the socioeconomic conditions and Covid-19 vaccination were drivers of efficiency. To obtain unbiased efficiency scores, we employed the bootstrap DEA method and compared the results with those obtained from the standard DEA. A brief comparison between the two approaches, conventional DEA and bias-corrected, efficiency scores show some relatively high estimation differences that confirm the choice to use bias-free methods.

A comparison of our results with previous studies on OECD countries health system performance is difficult insofar as the approach chosen to estimate health system efficiency differs, in particular between the oldest and the most recent studies. None of these studies used bias-corrected efficiency scores, most of them adopted the conventional DEA approach (Mirmirani et al., 2008; Hadad et al., 2013; Çetin and Bahce, 2016; Kaya Samut and Cafri, 2016; Behr and Theune, 2017), and two adopted the bootstrap DEA approach (Afonso and St. Aubyn, 2011; Lee and Kim, 2018). Although Mirmirani et al (Mirmirani et al., 2008). found that OECD countries were efficient, during the 1997–2001 period, they compare their performance to transition countries. If the other studies only focus on OECD countries, they used data either from the 2000–2010 decade or 2012 and 2014 years (Table A1 in Appendix). Some results, however, seem recurrent. Two countries, Türkiye and Slovenia, appear efficient in all studies that have used the conventional DEA approach, but are not efficient with the bootstrap DEA model. Regardless of the chosen approach, three countries, Belgium, France and Germany, appear non-efficient, while two, Japan and Estonia, remain

Table 5
Percentage change of inputs and outputs required by non-efficient countries to become fully efficient, during Covid-19 period.

Countries	Efficiency Score	Bias	Reference	Life expectancy at birth (%)	Infant survival rate (%)	Doctors (%)	Nurses and midwives (%)	Total hospital beds (%)	Computed Tomography (CT) scanners (%)
Belgium	0.618	0.050	Hungary, Spain	0	0	-38.2	-38.2	-38.2	-38.2
France	0.632	0.123	Canada	0	0	-36.7	-40.2	-52	-36.7
Greece	0.634	0.124	Finland, New Zealand	0.5	0	-36.6	-36.6	-36.6	-56.3
Luxembourg	0.922	0.137	Canada, Japan, Spain	0	0.1	-7.7	-7.7	-7.7	-7.7
Netherlands	0.917	0.143	Canada, Estonia, Finland	0.8	0	-8.3	-12.1	-8.3	-8.3
Australia	0.846	0.172	Canada, Japan	0	0.1	-15.3	-15.3	-15.3	-24.2
Germany	0.696	0.172	Canada, Estonia, Korea	0	0	-30.4	-30.4	-30.4	-34.7
Lithuania	0.684	0.194	Estonia, Hungary, Latvia	5.6	0	-31.5	-31.5	-31.5	-31.5

efficient.

Concerning our study which compares health system performance before and during covid-19, several main points appear. First, the study highlights the frailty of some rich countries (e.g., France, Germany) which, despite a relatively large number of health personnel (doctors, nurses, midwives) and resources (hospital beds and other health facilities), struggle to transform their advantages into the best health welfare for their population. For Belgium, France and Germany, we observed that the source of the low performance is the bad management of the bed turnover rate or bed occupancy rate. A higher bed turnover rate would allow for improvement of the performance of the health system. A recent report, analysing variations in productivity and performance across OECD countries [65], shows that "poorly co-ordinated transitions from hospital to community health or social care services can lead to overuse of hospital beds and worse patient outcomes". This might show that management of resources of health in their health systems is weak. However, the main vulnerability lies in the management of healthcare facilities. The same report found high administrative costs for similar health providers within OECD countries, which hints at an inefficient use of resources in some facilities.

The result for efficiency drivers showed that education and the share of the population aged over 65 play a significant role. It is not surprising, as has been shown in the literature, that education is a significant determinant of health outcomes and system (Benito and Zheng, 2011; Groot and Van Den Brink, 2007; Manavgat and Çelik, 2017). Likewise, many studies show that both the effectiveness of health services and an old population are among risk factors for Covid-19 (Yanez et al., 2020). We found that, while it is a risk factor for health, especially after the Covid-19, tobacco use has no significant effect on health system efficiency. Although smoking and tobacco-related diseases are shown as prognostic factors for severe Covid-19 (Alla et al., 2020; Gupta et al., 2021), our results demonstrate that this variable is not disruptive on efficiency in terms of the health system. Another important finding is that an increase in the vaccination rate makes a positive contribution to health efficiency during the Covid-19 period. This highlights the significant impact of vaccination efforts on enhancing the overall efficiency of healthcare systems in combating the pandemic. There is ample evidence that vaccines are highly effective in reducing illness severity and deaths from Covid-19 (Razai et al., 2021; Troiano and Nardi, 2021). During the Covid-19 pandemic, the increase in Covid-19 vaccination rate has shown a positive impact on the efficiency of health services. This indicates that higher vaccination rates can potentially contribute to the success of a health system and its policies.

6. Conclusion

With the Covid-19 health crisis, countries have increasingly prioritized allocating a significant portion of their resources to health services. Given the uncertainty of the demand for health services, it is crucial to ensure the robustness of health systems against potential health shocks and effectively allocate healthcare resources. This debate has gained prominence during the Covid-19 era, raising questions about the resilience of even the richest countries' health systems.

One of the main results is that it is important to increase the Covid-19 vaccination rate for efficiency of healthcare services and contribute to the success of health systems and policies. The increased efficiency of health systems following the pandemic through higher vaccination rates instils greater confidence in vaccination enhancement policies. Vaccination also ultimately contributes to the effectiveness and sustainability

of healthcare systems.

The results of this study are useful for health policy authorities to re-evaluate and compare the health systems of OECD countries. It seems that the Covid-19 pandemic crisis has significantly affected the functioning of health services even in developed countries, and shows the continuing need for countries to review and develop their national and regional health plans for healthcare resource and finance. Considering the effects of the current pandemic, the issue of health efficiency will continue to be an interesting topic that can be usefully explored in future research. One of the most crucial policy recommendations is that policymakers pay more attention to resource allocation. Resource allocation should be increased or reduced based on health outcomes rather than the number of people treated in health facilities. Poorly coordinated transitions from hospitals to other healthcare services can lead to inefficiencies and negative patient outcomes. Enhancing the coordination and integration of care across different healthcare settings can improve overall system performance. Regular monitoring of health system performance over time is necessary to identify trends, track improvements, and address emerging inefficiencies. Furthermore, considering that the interest in health efficiency is likely to continue to increase, consistency in publishing and updating data on health statistics for future studies would help to establish a greater degree of accuracy.

Our study suffers from some limitations. The study may have used limited or incomplete data regarding the functioning of health services during the Covid-19 pandemic. Data availability, quality, and accuracy can significantly impact findings and conclusions. The unique circumstances of the Covid-19 pandemic might limit the applicability of the results to different health system settings. Long-term effects or trends may not have been fully captured in this study, and other situations could arise as this or forthcoming pandemics unfold further.

Ethics approval and consent to participate

Not applicable.

CRedit authorship contribution statement

GM: Gökçe Manavgat MA: Martine Audibert, Background: GM, MA, Methods: GM, MA, Discussion: GM, MA, Conclusion: GM, MA.

Declaration of Competing Interest

All authors have read and approved the manuscript.

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Consent for publication

Not applicable.

Appendix

Table A1

Synthesis of the literature review on the performance of health facilities and global health system.

Title	Objective	Method	Results
Micro-level studies: Performance of health facilities			
Nayar and Ozcan (2008) Nedelea and Fannin (2013)	Using 53 Virginia hospitals, performance measurement for 2003	DEA- input-oriented model <u>Outputs:</u> total hospital inpatient discharges, total outpatient visits, training full-time medical and dental trainee <u>Inputs:</u> hospital size, amount of operational expenses, total full-time and part-time staff, total assets	16 hospitals are efficient, and 37 hospitals are inefficient. The average efficiency score of the inefficient hospitals is 0.72.
Nedelea and Fannin (2013) (Nayar and Ozcan, 2008)	Efficiency measurement for Critical Access Hospital (CAH) Medicare cost-based reimbursement in U.S.	DEA- input-oriented model	Medicare cost-based reimbursement increases the allocative inefficiency of CAHs and longer participation in the CAH program increases hospital allocative inefficiency
Zhang et al. (2018) (Zhang et al., 2018)	Equity and efficiency of primary health care resource allocation in China for the period of 2012–2016	DEA – output-oriented model and Malmquist productivity index (MPI) <u>Outputs:</u> average number of visits, annual hospitalization rate <u>Inputs:</u> number of institutions and beds, health workers include doctors, nurses, other clinical staff, administrative staff, other nonclinical staff	From 2012–2016, the total amount of primary healthcare resource allocation and number of efficient provinces have increased year by year.
Manavgat and Demirci (2020) (Manavgat and Demirci, 2020)	Efficiency analysis of public hospitals (81 province) by the type of healthcare services (general healthcare and oral-dental healthcare) and spill-over effect in Türkiye for 2014 and 2017	DEA- input-oriented model <u>Outputs:</u> number of examinations, total birth-parturition, hospital bed turnover rate, tooth extraction per number of conservative treatments, endodontic treatments <u>Inputs:</u> number of beds, number of doctors, nurse and midwives, number of dentists, number of polyclinics	The relative efficiency score in 2017 is higher than in 2014, which is the year of the beginning of the decentralization shift in healthcare services in Türkiye. Also, there is a positive spatial spill-over between public hospitals
Pereira et al. (2021) (Pereira et al., 2021)	Measuring the efficiency of 27 Portuguese public hospitals	Network DEA input-oriented model <u>Outputs:</u> number of patients leaving the inpatient service, number of programmed surgeries, number of consultations conducted by a doctor in the medical appointments service, number of urgent medical assistance <u>Inputs:</u> adjusted labour cost, operating costs, clinical material cost, outsourcing costs	The efficiency scores of the institutions differ between public and other. A situation that creates a cluster in terms of efficiency and increases productivity in every region
Guillon et al. (2022) (Guillon et al., 2022)	Efficiency measurement of 31 district hospitals in Zimbabwe from 2015 to 2017	Bootstrap DEA output-oriented model and truncated regression <u>Outputs:</u> number of inpatients, number of outpatients, number of operations <u>Inputs:</u> number of beds, number of doctors, number of nurses.	The average technical efficiency score for the 2015–2017 period is 0.695. Efficiency scores of hospitals range from 0.370 to 0.990 and the standard deviation to the mean ratio is 0.16.
Macro-level Studies: performance of health systems			
Mirmirani and Lippmann (2004) (Mirmirani and Lippmann, 2004)	Analysis of the health care delivery system of G12 for the 1991–1995 period	DEA input -oriented <u>Outcome:</u> Life expectancy at birth, infant mortality <u>Inputs:</u> per capita health expenditures, population adjusted doctors, hospital beds, MRI, a proxy for the level of education	Japan and Spain scored the highest, and the US the lowest level of relative efficiency.
Mirmirani et al. (2008) (Mirmirani et al., 2008)	Efficiency of health systems of transition economies for the 1997–2001 period	DEA- output oriented <u>Outcomes:</u> life expectancy at birth, infant mortality <u>Inputs:</u> health expenditures, hospital beds & doctors per 1000 people, proportion of children vaccinated against measles	Efficient health systems are those of OECD countries, plus Albania and Armenia. The least efficient over an extensive period of time are Russia and Belarus, followed by Latvia and Romania.
Afonso and Aubyn (2011) (Afonso and St. Aubyn, 2011)	Health system efficiency of OECD members for the period 2005	Bootstrap DEA-Tobit Model <u>Outcomes:</u> life expectancy at birth, infant survival rate <u>Inputs:</u> number of practising doctors, nurses, acute care beds per thousand habitants, Magnetic Resonance Imagers (MRI).	Inefficiencies are quite high among OECD. On average, countries could have increased their results by 40% using the same resources
Hadad et al. (2013) (Hadad et al., 2013)	Efficiency of health systems of 31 OECD countries for 2010	DEA input-oriented approach – two different model specifications <u>Outcomes:</u> infant survival, life expectancy at birth <u>Inputs:</u> doctors' density, inpatient bed density, health expenditure per capita, GDP per capita, consumption of fruit & vegetables per capita	Healthcare systems in nine countries with large and stable economies are defined as efficient: Czech Republic, Estonia, Iceland, Japan, Korea, Poland, Portugal, Slovenia. For the other countries: Australia, Canada, Israel, Italy, Luxembourg, Spain, Sweden, Switzerland, UK, the results depend on the model
Moran and Jacobs (2013) (Moran and Jacobs, 2013)	Examine technical efficiency of inpatient mental healthcare systems in 32 OECD countries in 2010	DEA and truncated regression <u>Outputs:</u> number of discharges, alcohol consumption, income, education, unemployment rate <u>Inputs:</u> number of psychiatrists, psychiatric beds, average length of stay	Countries with higher efficiency are Slovenia, Korea, Poland, Denmark, Hungary, Italy, Chile, United States, Austria, Norway, Türkiye, Mexico, and Germany but wider confident interval (meaning clear?)

(continued on next page)

Table A1 (continued)

Title	Objective	Method	Results
Çetin and Bahçe (2016) (Çetin and Bahçe, 2016)	Efficiency of health systems of 34 OECD countries for 2011	DEA input-oriented approach <u>Outcomes:</u> life expectancy at birth, infant mortality rate <u>Inputs:</u> doctors per 1000 people, hospital beds per 100 people, health expenditure per capita (PPP, USD), share of health expenditures in GDP, number of MRIs, tobacco usage rate	11 of the 26 countries found to have efficient health systems, and there is room for efficiency improvements in health sector in the remaining 15 countries.
Kaya-Samut and Cafri (2016) (Kaya Samut and Cafri, 2016)	Analysis of the efficiency determinants of health systems in 29 OECD countries for the period of 2000–2010	DEA, Malmquist Productivity Index and Tobit Model <u>Outcomes:</u> number of discharges, infant survival rate <u>Inputs:</u> total hospital beds, number of doctors, nurses & midwives, number of Magnetic Resonance Imaging (MRI), number of computerized tomography (CT)	The efficiency scores achieved after 2000 began to decline in 2004 and reached their lowest levels between 2009 and 2010. Türkiye, Mexico, and the United Kingdom are most efficient. Japan, Iceland, France, and Belgium are below average
Behr and Theune (2017) (Behr and Theune, 2017)	Health system efficiency at the country level based on 34 OECD for 2012 period	DEA <u>Outcomes:</u> life expectancy at birth, infant mortality (survival) rate. <u>Inputs:</u> health expenditure per capita, practicing doctors, inpatient beds, MRI, pharmaceutical consumption, Gini coefficient, GDP per capita unemployment rate, obesity, tobacco consumption	Iceland, Türkiye and Estonia are the most efficient. The lowest mean efficiency scores are reported for Ireland and Germany.
Lee and Kim (2018) (Lee and Kim, 2018)	Assess the association between healthcare system efficiency and policy factors for 29 OECD countries in 2014	Bootstrap DEA input orientation and Tobit Model <u>Outputs:</u> infant survival rate, life expectancy at birth <u>Inputs:</u> expenditure on health per capita, practicing doctors per capita, number of beds per capita	Luxembourg, Greece, and Israel had the highest health system efficiency. Germany, Austria, and the Slovak Republic have the lowest efficiency.
Ahmed et al. (2019) (Ahmed et al., 2019)	Estimate the technical efficiency of health systems in 46 Asia countries.	DEA-output oriented approach and Tobit Model <u>Outputs:</u> healthy life expectancy at birth, infant mortality <u>Inputs:</u> health expenditure per capita	The main findings of this paper are that about 91.3% (42 of 46 countries) of the most efficient countries belong to the high-income group (Cyprus, Japan, and Singapore) and only one country belongs to the lower middle-income group (Bangladesh).
Top et al. (2020) (Top et al., 2020)	Efficiency measurement for 36 African countries in 2015	DEA input-oriented and Tobit Model <u>Outputs:</u> life expectancy at birth, one divided infant mortality rate (meaning clear?) <u>Inputs:</u> the ratio of total health expenditures to the gross domestic product, the number of doctors, nurses, and hospital beds, the unemployment rate, Gini coefficient	21 of 36 African healthcare systems are found to be efficient. Among the efficient countries, Senegal is the country most referenced for inefficient countries.

Table A2
Definition of inputs, health outcomes, and explanatory variables.

Efficiency model			
Health Outcomes	Definition	Measurement	Data Source
Life Expectancy at Birth	How long, on average, a new-born can expect to live, if current death rates do not change. The value is calculated using the unweighted average of life expectancy of men and women	At birth, total (years)	OECD Health Stat.
Infant Survival Rate	Calculated one minus infant mortality rate (IMR). IMR is the number of deaths of children under 1 year	1-Infant mortality Per 1000 live births	OECD Health Stat.
Inputs		Measurement	Data Source
Doctors	Doctors including generalist and specialist medical practitioners.	Per 1000 people	WDI
Nurses and midwives	Nurses and midwives include professional nurses, professional midwives, auxiliary nurses, auxiliary midwives, enrolled nurses, enrolled midwives and other associated personnel	Per 1000 population	WDI
Total hospital beds	Include curative (or acute) care beds, rehabilitative care beds, long-term care beds and other beds in hospitals.	Per 1000 population	OECD Health Stat.
Computed Tomography (CT) scanners	Number of CT includes the equipment in hospitals and the ambulatory care providers	Per 1000 000 population	OECD Health Stat.
Bootstrap truncated regression model - Dependent variable: Bias-corrected efficiency scores			
Independent variables		Measurement	Data Source
Health Expenditures	Current health expenditure in GDP	% of GDP	OECD Health Stat.
Tertiary Education	Calculated by dividing the number of students enrolled in tertiary education regardless of age by the population of the age group which officially corresponds to tertiary education and multiplying by 100.	% of gross	WDI
Unemployment rate	Total % of total labor force	% of labour force	WDI
Tobacco use	The % of the population aged 15 years and over who currently use any tobacco product (smoked and/or smokeless tobacco) on a daily or non-daily basis.	% of adults	WDI
Population over 65	Population aged 65 and above in the total population	% of total population	WDI
Covid-19 Era variables			
Covid – 19 death rate *	Cumulative total deaths divided by cumulative total cases	Per case	WHO
Vaccination*	Fully vaccinated people: Cumulative number of persons fully COVID-19 vaccinated per 100 population. All doses, including boosters, are counted individually	Per 100 people	WHO

* The data of the World Health Organization on 10 August 10, 2022, were used.

Table A3

Simar and Wilson (2007) Results of Bias corrected health system efficiency drivers, before Covid-19.

Variable	Coefficient	Bootstrap Standard Err.	P > z	95% confidence interval	
				Lower	Upper
Tertiary Education	.0013	.0013	0.039	-.0008	.0023
Unemployment rate	-.0297	.0008	0.000	-.0150	-.0465
Health Exp. in GDP	-.0108	.0101	0.285	-.0306	.0108
Tobacco use	-.0155	.0044	0.121	-.0245	-.0065
Population over 65	-.0378	.0079	0.000	-.0535	-.0021
Constant	1.9724	.2383	0.000	1.4899	2.4359
/sigma	.0919	.01482	0.000	.0548	.1126
Wald chi2(5): 37.76 Prob. > χ^2 (5): 0.000					

*Total number of replications= 2000.

Table A4

Simar and Wilson (2007) Bias corrected healthcare efficiency drivers, during-Covid-19.

Variable	Coefficient	Bootstrap Standard Err.	P > z	95% confidence interval	
				Lower	Upper
Tertiary Education	.0011	.0018	0.052	-.0023	.0047
Unemployment rate	-.0036	.0106	0.030	-.0246	.0169
Health Exp. in GDP	-.0097	.0127	0.043	-.1127	-.0365
Tobacco use	.0012	.0058	0.834	-.0099	.0129
Population over 65	-.0339	.0095	0.000	-.0527	-.0159
Covid – 19 death rate	-15.496	7.258	0.033	-29.8621	1.1124
Vaccination	.01018	.0044	0.021	.0019	.0147
Constant	1.971	.4286	0.000	1.119	2.8311
/sigma	.1381	.0195	0.000	.0815	.1573
Wald chi2(7): 24.21 Prob. > χ^2 (7): 0.0010					

*Total number of replications= 2000

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