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Management of the Health System in Poland and the Role of Public Measures in Implementation During the Pandemic Process*

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Abstract

Countries aiming to control the Covid-19 pandemic, have implemented a number of public measures and restrictions to prevent the further spread of the disease, simultaneously with processes such as case detection and treatment. The health infrastructures and administrative skills of the countries are pretty decisive in controlling the pandemic. This research examines the impact of public measures in the fight against the pandemic, based on Poland's relative performance in combating Covid-19. Within this study, which covers the 63-week period (pre-vaccination) between the dates of April 1, 2020, and June 15, 2021, a two-stage data envelopment analysis was used. According to the results obtained, Poland ranked 8th out of 31 countries in terms of minimizing the number of cases and deaths and maximizing the number of recovered patients, with a technical efficiency score of 0.4683. Also, it has been determined that among public restrictions, the elderly protection index makes a positive contribution to the technical efficiency scores of Poland in the fight against Covid 19. The research has implications for the public administration, health policy, and health economics literature.

Keywords: Covid-19, Health Policy, Administrative Skill, Public Regulation, Two-Stage Data Envelopment Analysis

Introduction

Most of the research about the Covid-19 pandemic has been insufficient to measure the impact of public measures on the pandemic and to produce results that evaluate the reaction and possessiveness of the public, businesses, and institutions against public regulations (Song et al., 2020; Kadomatsu, 2022; Rind et al., 2020; Duguet et al., 2020; Obiedat et al., 2021; Mourad et al., 2021). Current studies have mainly focused on the determinants of the number of cases and deaths related to the pandemic (Sun et al., 2021; Pell et al., 2022) and the socio-economic problems caused by the pandemic period (Su et al., 2022; Lee et al., 2022). Additionally, some Covid-19 studies have examined the changes in the perceptions and attitudes of the affected segments during the pandemic process (Mo et al., 2020; Reddy et al., 2021; Bagdatli and Ipek, 2022; Caplanova et al., 2021).

However, in the recent period, there has been an increase in studies aiming to fill the lack of information about evaluating the relative success of countries in the fight against Covid-19 and revealing the factors affecting success, although to a

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lesser extent (Gordon et al., 2021; Neogi, 2021; Shin and Park, 2022; Lee and Lim, 2022; Klump, 2022). Our comparative knowledge of assessing the relative success of developed and developing countries in the fight against Covid-19 is still limited, and we need more empirical evidence. Furthermore, studies focusing on this issue are insufficient to explain the different attitudes of the parties towards the public measures implemented during the pandemic period. Additionally, these studies did not provide comprehensive findings in revealing the success of implementing public measures and the role played by these regulations in the success of the health systems.

This research focuses on determining the effect of public measures implemented by Poland in the fight against the pandemic. The study discusses, firstly, the health infrastructure of the countries in the fight against the pandemic, as well as the administrative skills in implementing the public measures put into practice. It also examines the resistance of the people against these measures. The research primarily focuses on the extent to which governments, caught between economic and health concerns, are resolutely able to implement restrictions, rather than solely focusing on the economic problems caused by the pandemic. Secondly, the aim is to measure the relative success of countries in minimizing the number of cases and deaths and maximizing the number of recovered patients in the fight against Covid-19. Finally, based on Poland's relative performance, the study empirically tests the impact and success of the government's restrictions against the pandemic. The obtained results are then compared with the existing literature studies, and policy recommendations are conveyed to the stakeholders.

Literature Review and Hypothesis Development

Literature Review

In the literature, it is emphasized that the pandemic has important social impacts as well as economic effects (Hernández-Solano et al., 2022; Rollè et al., 2022). It is inevitable to apply some social measures in order to minimize the spread of the outbreak. Governments are taking social life restrictive measures such as the cancellation of public events, curfews, closure of gyms, restrictions on nursing homes for the elderly, and national/international travel bans as part of the fight against the pandemic (Diallo et al., 2022; Değer et al., 2021; Velias et al., 2022). In our research, we are interested in how quickly governments can take measures against epidemics and how the parties subject to restrictions respond to these measures. Additionally, we are interested in the extent to which governments can announce and enforce the social life-regulating calls for "stay at home," "life fits at home," and "distance social life" (Tran et al., 2021; Rahman et al., 2021).

Within his study, Morales (2021) determined the relative success of 23 countries, including Iran, Spain, Pakistan, and Nigeria, in the fight against Covid-19, with 19 countries in the G20, using the data envelopment analysis method. As the public measures were implemented, it was observed how the order of events changed at each stage. While Korea, Australia, Japan, and China implemented the measures successfully, it was determined that the USA, Brazil, Russia, and Spain were relatively unsuccessful countries. Lupu and Tiganasu (2022) examined the performance of 31 European countries in the fight against Covid-19 in two stages in their study. In the first stage, data envelopment analysis compared the country performances in the period when the epidemic started, during the relaxation period, and in the second wave period. Then, in the second stage, the effect of 15 indicators, which are 6 main areas of influence, on performance was determined with the Tobit model. As a result, it was concluded that the health systems of Italy, Belgium, Spain, and England were inefficient, but there were relative improvements in these countries in the second wave. It has been determined that the elderly population, the government's restrictive measures, and community sensitivity to the pandemic have an impact on performance. In the studies of Klumpp et al. (2022), the struggles of 19 countries in the OECD, depending on the perspective of health, population, and economy, were determined by data envelopment analysis. Also, it has been emphasized that population size, population density, and economic development are not determinants in the fight against the pandemic, but pre-pandemic health policies are determinative. It has been concluded that countries with a strong primary health care infrastructure and countries that choose the public financing method are more successful than others. So, it has been determined that restrictions and quarantines do not have direct effects on the efficiency of health services. It has been determined that limited quarantine practices produce more successful results than general quarantines in terms of the economy. In their study, Lee and Lim (2022) used Data envelopment analysis to determine the relative success level of Southeast Asian Countries (ASEAN) in their fight against the pandemic. It was emphasized that Singapore, where fewer social restrictions were applied, stood out from the others in the fight against the pandemic. It has been stated that mass restrictions cannot be the only solution in the fight against the pandemic, and that high income support and effective public campaigns stand out in the fight. Lee (2022) analyzed the struggle of 52 countries against Covid-19 with the data envelopment method using 16 indicators (the public, business, and community).

Hypothesis Development

Our study includes a two-stage process. In the first stage, the relative performance of the health infrastructure in selected countries against the pandemic was determined. To measure the health infrastructure against the pandemic, the number of cases, the number of deaths, the number of recoveries, the positivity rate, the number of hospitalized patients with Covid-19, the number of Covid patients in the intensive care unit, and the number of new tests were used. These parameters, chosen to measure the resistance of the health infrastructure against the pandemic, have also been used in many studies (Dlouhy, 2020; Mbunge, 2020; Chowdhury, 2020; Mahendradhata et al, 2021; Baqal and Farouk, 2022; Breitenbach et al, 2021). We assume that the health equipment of the countries will have an impact on the number of cases, deaths, and recoveries. In this regard, we propose the following hypothesis.

> *H1: The health infrastructure of countries affects their relative performance (minimizing the number of cases and deaths and maximizing the number of recoveries) in the fight against Covid-19.*

The success of the public measures and restrictions carried out during the pandemic period contributes positively to the relative success of the countries in the fight against the pandemic by making a positive contribution to the health infrastructure, and on the other hand, it reveals the administrative skills of the governments in times of crisis. Based on this, we determined our second hypothesis as follows.

> *H2: The success of public measures and restrictions affects the relative performance of countries in their fight against the pandemic.*

During the pandemic period, each country has carried out a different strategy. While some countries implement more drastic and radical measures, others follow softer and more moderate strategies (Lee and Lim, 2022). So, it is necessary to compare different country experiences to understand which strategies are more effective in combating the pandemic. Poland has implemented public measures since March 4, 2020, when Covid-19 cases began to appear. Based on the assumption that the implemented measures are effective in alleviating the burden on the health system, the third hypothesis has been formed as follows.

> *H3: Public measurements and restrictions imposed by the Polish Government positively affect the country's relative performance in the fight against the pandemic.*

Our research covers the pre-vaccination period to better demonstrate the success of public measures. Inequalities in access to vaccines were effective in limiting the review period of the study.

The Covid-19 Pandemic Period and the Policies Implemented by Poland

To address the economic impact of the pandemic and respond to the public health crisis, the Polish government proposed three legislative acts at the end of March, mid-June, and mid-July. The proposed acts aimed to provide financial assistance to the unemployed, who lost their jobs due to the pandemic, through a special solidarity scheme offering a cash benefit of 1,400 PLN (approximately EUR 350) per month for a maximum of 3 months, starting from June 1, 2020 (Solidarity supplement, 2020). Additionally, the government prepared financial aid for entrepreneurs under the "anti-crisis shield" to manage unemployment and create new jobs (Kubiczek & Derej, 2021).

However, several sectors of the economy experienced financial strain. Lockdowns and travel restrictions, not only cross-border but also within the country, contributed to a significant decline in the tourist and recreational sector. Similarly, the commerce industry faced a noticeable decline in financial results. In response, state aid policies for entrepreneurs, particularly support programs such as subsidies, low-interest loans, and tax exemptions, played a crucial role in countering the effects of the COVID-19 pandemic (Barczyk & Urbanowicz, 2021).

Following the Regulation of the Council of Ministers on March 25, 2022, concerning specific restrictions, orders, and prohibitions related to the state of the epidemic (Polish Journal of Laws, item 673), all restrictions were lifted from March 28, 2022 onwards (Government, 2022).

Data and Methodology

Data

In this study, the "Two-Stage Bootstrap Estimation Data Envelopment Analysis (DEA)" method was utilized to determine the relative performance of Poland in its fight against Covid-19 and assess the impact of public measures on this performance. The dataset used for the analysis was collected from two different sources. The first stage involved data related to new cases, new deaths, number of recoveries, number of new tests, number of Covid patients in hospitals, number of Covid patients in intensive care units, and the contagiousness coefficient. These data were retrieved from the following sources: https://github.com/owid/covid-19-data/tree/master/public/data and https://ourworldindata.org/coronavirus.

Data for the second stage, which included the tightness index, government response index, restraint and health index, elder protection index, public information index, and workplace closure index, were obtained from the Blavatnik School of Government (https://www.bsg.ox.ac.uk/research/research-projects/covid-19-government-response-tracker).

The entire dataset used in both stages covered a 63-week period, starting from April 1, 2020, and ending on June 15, 2021. This date range was chosen for two main reasons: firstly, by April 2020, Covid-19 cases had emerged in all countries, making it a suitable starting point for analysis; secondly, by June 2021, vaccination efforts had begun in some countries, marking the period before widespread vaccination, which allowed for homogeneity in the dataset due to disparities in vaccine access across countries.

The first stage involved analyzing the relative performance of 31 countries, including Poland, in their fight against Covid-19. In the second stage, the focus shifted specifically to Poland, where the effect of public measures on the country's fight against Covid-19 was assessed. For this stage, only the dataset specific to Poland was used. This included the technical efficiency scores obtained from the first phase and the public measure and restraint indexes implemented in Poland during the relevant period.

For the first stage analysis, three output variables and four input variables were selected. The output variables were the number of new cases, new deaths, and recovered Covid patients. The input variables comprised the number of new tests, the number of Covid-19 patients hospitalized, the number of Covid patients hospitalized in intensive care units, and the positivity rate. The selection of these variables was based on references from existing literature studies (Mahendradhata et al, 2021; Baqal and Farouk, 2022; Breitenbach et al, 2021). The variables and their definitions used in the first stage are summarized in Table 1.

Table 1: First Stage Data Table: Input and Output Variables

First Stage (Bootstrap Estimated Data Envelopment Analysis)		
Input Variables	***Output Variables***	**Source**
* Number of New Test * Number of Hospitalized Covid-19 Patients * Number of Covid-19 Patients in the Intensive Care Unit * The Positivity Rate	* New Cases Corrected per Million * New Deaths Corrected per Million * Number of patients Recevering	ourworldindata.org

One of the output variables, the new case variable represents the number of newly confirmed COVID-19 cases per 1 million people of the countries. The new death variable refers to the number of new deaths from COVID-19 per 1 million people in countries. The variable of the number of patients recovered refers to the number of patients discharged after completing their Covid-19 treatment. Due to the new case and new death variables are output variables that need to be minimized, they are used as $\frac{1}{new\ cases\ per\ million/death}$ in the analyzes to be compatible with the number of recovered patients.

The number of new tests, which is one of the input variables, represents the number of Covid-19 tests sampled weekly. The Number of Covid-19 Patients Inpatients in the Hospital and the Number of Covid-19 Patients Inpatients in the Intensive Care Unit are other input variables. The last input variable is positivity rate. It indicates the rate of positive cases among the total number of new tests. This ratio also includes information about the contamination coefficient, and an increase in the ratio also indicates that the contamination coefficient is high.

The two-stage DEA analysis involves a parametric regression in the second stage, with both stages embedded in a double-bootstrap. The second stage regression assesses the factors that determine the differences in the efficiency scores of each country, calculated from the first stage DEA. The second stage involves truncated regression analysis, due to the limited range of the efficiency scores (between 0 and 1) and some lumpiness in the estimated values. The second stage explains the efficiency score differences as a function of environmental factors. In the second stage of the analysis, the relative technical efficiency scores of Poland obtained in the first stage were used as the dependent variable. The variables of firmness index, government response index, limitation and health index, elderly protection index, public information index and workplace closure index, which include public restrictions to measure managerial capacity, are used on

Bootstrap estimated technical efficiency scores. The dependent and independent variables used in the second stage, in which the Simar and Wilson Algorithm 2 methodology was applied, are shown in Table 2.

Table 2: Second Stage Data Table: Public Measures and Restrictions

Second Stage (Simar and Wilson Algorithm 2 Methodology)	
Dependent Variables	***Independent Variables***
* Technical Effectiveness Score	* The Government Response Index * Stringency Index * Limitation and Health Index * Elderly Protection Index * Workplace Closure Index

The Technical Effectiveness Score is Poland's Bootstrap predictive technical efficiency score obtained from the first stage. The Strictness Index is a composite index based on 9 indicators, including government school closures, workplace closures, cancellations of public events, restrictions on public gatherings, abolition of public transport, curfew, public information campaigns, and national and international travel bans. This index is in the range of 0 to 100 and it is understood that the government adopts a strict attitude as it approaches to 100 and a smooth attitude as it approaches to 0. The Government Response Index, on the other hand, is an index that measures the government's response to Covid indicators within the framework of 16 parameters. The index is between 0-100 and as it approaches to 100, it shows that the government is more sensitive (reactive) to Covid-19. Containment and Health Index is an index that includes 4 health indicators (testing policy, contact tracing, mask requirement and vaccination policy) in addition to the tightness index. This index ranges from 0 to 100, indicating that the limits become tighter as they approach 100. The Elderly Protection Index expresses visits and similar restrictions for the elderly who stay in long-term care facilities (such as nursing homes). Within this variable, the numbers mean; 1: no precautions, 2: recommended isolation, hygiene and visitor restriction measures are taken for the elderly to stay at home, 3: isolation, narrow restrictions for hygiene, some restrictions for outside visitors and/or restrictions that protect the elderly at home, 4: isolation and comprehensive restrictions on hygiene, prohibition of all non-essential external visitors and/or all elderly people staying at home and not leaving the house or accepting visitors from outside, with minimum exceptions. This means that as the index approaches 4, the measures for the elderly are increased. The Workplace Closure Index is an index that includes the Government's measures to close workplaces due to Covid-19. A value of 0 for this variable means that no measures have been taken for workplaces, 1. Working from home or all workplaces are open due to Covid-19, 2: closing of business in some sectors or working from home, 3: closing all non-essential workplaces or working from home.

Methodology

In the first stage of the study, the relative performance of Poland in the fight against Covid-19 was determined using three output and four input variables. Data envelopment analysis, which is a nonparametric method that is frequently used in measuring the relative performance of decision units, was used. The Bootstrap Technique was used to determine whether the effectiveness scores were resistant or not. In the second stage, the effectiveness scores were used as the dependent variable. The Truncadet Regression model proposed by Simar and Wilson was used, since the technical efficiency scores ranged from 0 to 1.

To apply the bootstrap procedure, the original sample data is assumed to be generated by the DGP, and from this data set, a 'new' or pseudo data set is derived for simulation. The DEA model is then re-estimated by incorporating this new data set. By repeating this process multiple times, an empirical distribution of bootstrapped values can be derived, providing a Monte Carlo approximation of the sampling distribution. This allows for better inference measures and statistical consistency.

The efficacy of the bootstrapped methodology and the accuracy of the statistical inference largely depend on how well it specifies the true DGP and how accurately it simulates the re-sampling process to mimic the DGP (Mujaddad and Ahmad, 2016). Below, the algorithms for the methods used in both stages are briefly explained.

Technical Efficiency, originally developed by Farrel (1957), assesses the extent to which a decision-making unit achieves the maximum output using a given combination of inputs or the minimum combination of inputs to produce a specific output. Traditional Data Envelopment Analysis (DEA), developed by Cooper, Charnes, and Rhodes (1978), is a widely used nonparametric efficiency method for measuring the relative efficiency of decision-making units. DEA is a linear programming-based technique designed to evaluate the relative efficiency of decision units with multiple inputs and outputs that have different units of measure (Badunenko & Mozharovskyi, 2016).

When conducting technical efficiency analysis, the concept of Returns to Scale (RTS) is essential, particularly in manufacturing technology. The Constant Returns to Scale (CRS) model proposed by Charnes, Cooper, and Rhodes (CCR) is used when decision units operate at an optimal scale. However, real-world conditions like imperfect competition, financial constraints, and scale differences often prevent decision units from operating at an optimal scale. To address this, Banker, Charnes, and Cooper (BCC) (1984) introduced the BCC model, which adds the convexity constraint to the CCR model, assuming variable returns to scale. The BCC model, based on the assumption of variable returns, has been widely used in various studies (Fancello et al., 2020; Lertworasirikul et al., 2011; Asmild et al., 2009). The major advantages of this approach are its ability to handle multiple outputs and inputs without imposing a specific functional form on the production function, and it provides meaningful targets for improvement among inefficient decision-making units (DMUs). The standard formulation of the DEA program can take various forms depending on different criteria. The dual output-oriented version of the DEA model, considering the existence of variable returns to scale (VRS) (Banker et al., 1984), can be represented as follows:

$$Max\ 0 + \varepsilon\left(\sum_{i=1}^{m} \mathrm{s}_i^{\,-} + \sum_{i=1}^{s} \mathrm{s}_r^{\,+}\right)$$

s.t.

$$\begin{aligned}
&\sum_{j=1}^{n} \lambda_j X_{ij} + \mathrm{s}_i^{\,-} = xi0 \qquad i = 1,2,\ldots.,m \\
&\sum_{j=1}^{n} \lambda_j y_{ij} - \mathrm{s}_r^{\,+} = \theta_{yi0} \qquad r = 1,2,\ldots.,s \\
&\sum_{j=1}^{n} \lambda_j = 1 \qquad J = 1,2,\ldots.,n \\
&\mathrm{s}_i^{\,-} \geq 0 : \mathrm{s}_r^{\,+} \geq 0 \qquad i = 1,2,\ldots\ldots,m : r = 1,2,\ldots\ldots,s
\end{aligned} \tag{1}$$

where i denotes input and r represents output, $1/\theta_0$ is the efficiency score (between 0 and 1), λ_j are the weightings, $\mathrm{s}_i^{\,-}$ and $\mathrm{s}_r^{\,+}$ are the inputs and outputs slacks, respectively, and ε is a non- Archimedean small positive number. If the score equals one the producer is relatively efficient compared to other units. If the score is lower than one, the unit evaluated is inefficient as the sample contains other units that perform better (Cordero-Ferrera at. all, 2010).

The DEA model is relatively straightforward to estimate, but it has faced long-standing criticism for being a non-statistical or deterministic technique (Barros et al., 2012). Making statistical inferences about technical efficiency using traditional DEA methods is challenging for several reasons. Firstly, all technical efficiency estimates are specific to individual instances. Despite being deterministic, technical efficiency scores are calculated based on estimated limits rather than the actual limit. Consequently, efficiency scores derived from a finite sample are subject to sampling variation of the estimated limit (Badunenko and Mozharovskyi, 2016; Simar and Wilson, 1998, 2007, 2011). According to Simar and Wilson (2007), the predictions of the traditional DEA estimators have been deviated from the outset due to biased and serially correlated estimates.

Simar and Wilson (2002) demonstrated that an incorrect assumption about Constant Returns to Scale (CRS) can lead to inconsistent effectiveness scores, and an incorrect assumption about Variable Returns to Scale (VRS) can result in a loss of statistical efficiency. Additionally, DEA efficiency scores, being non-parametric, do not provide information on statistical significance or the reasons for inefficiency (Simar and Wilson, 2007). To address these limitations, Simar and Wilson (1998, 1999, and 2000) proposed a solution by introducing the "bootstrap" approach, which allows obtaining statistical properties for DEA. The basic idea of bootstrapping is to approximate the distribution of the estimator through re-sampling and recalculation of the parameter of interest, which in this case is the DEA efficiency score (Barros and Couto, 2013; Badunenko and Tauchmann, 2019; Simar and Wilson, 2011; Daraio and Simar, 2014). Within this study, the approach known as "Algorithm 2 based on the bootstrap technique" proposed by Simar and Wilson was adopted to correct the biased efficiency scores and increase the precision in measuring the production possibilities limit determined in the non-parametric analysis. Simar and Wilson (2007)'s approach combines the DEA method with the bootstrap technique to obtain deviation-corrected efficiency scores and their confidence intervals. Consequently, the bootstrap technique not only corrects deviating efficiency scores but also addresses the autocorrelation problem (Simar and Wilson, 2007: 42). In the first stage, starting from the traditional DEA estimator $\hat{\lambda}_{CRS}(x, y)$, the bootstrap deviation estimation values are calculated as follows (Halkos and Trezemes, 2013: 111; Chowdhury and Zelenyuk, 2016: 113) :

$$B\hat{I}AS_B\left(\hat{\lambda}_{CRS}(x,y)\right) = B^{-1}\sum_{b=1}^{B}\hat{\lambda}^{*}{}_{CRS,b}\,(x,y) - \hat{\lambda}_{CRS}(x,y) \quad \textbf{(2)}$$

In the equation $\hat{\lambda}^{*}{}_{CRS,b}(x,y)$ represents the bootstrap value, and b represents the number of bootstrap repetitions. The deviation-corrected estimator $\lambda(x,y)$, can be calculated as follows:

$$\hat{\hat{\lambda}}_{CRS}(x,y) = \hat{\lambda}_{CRS}(x,y) - B\hat{I}AS_B\left(\hat{\lambda}_{CRS}(x,y)\right)$$
$$= 2\hat{\lambda}_{CRS}(x,y) - B^{-1}\sum_{b=1}^{B}\hat{\lambda}^{*}{}_{CRS,b}\,(x,y) \quad \textbf{(3)}$$

In the first stage, the deviation-corrected efficiency scores estimated by the bootstrap algorithm are regressed against environmental factors in the second stage. The discrete (Truncated) regression model to be estimated can be shown as follows:

$$\hat{\theta}_t = \alpha + Z_i\delta + \varepsilon_i, \quad i = 1, \ldots, n \quad \textbf{(4)}$$

In Equation 7, $\varepsilon_i \sim N(0, \sigma_\varepsilon^2)$ left-dashed represents $1 - Z_i\delta$ the error term, α represents the error term, and Z_i represents the vector of environmental variables that affect the efficiency of the decision-making unit (i). Algorithm 2 estimation method developed by Simar and Wilson (2002) and based on two-way bootstrap discrete regression is shown in Appendix 1 (Simar and Wilson 2007: 42-43; Simar and Wilson 2020: 293):

To analyse the determinants of, the relative performance of Poland in the fight against Covid-19 and the effect of public measures affecting, Algorithm 2, as proposed by Simar and Wilson [55], is used according to the procedures described in Fig. 1.

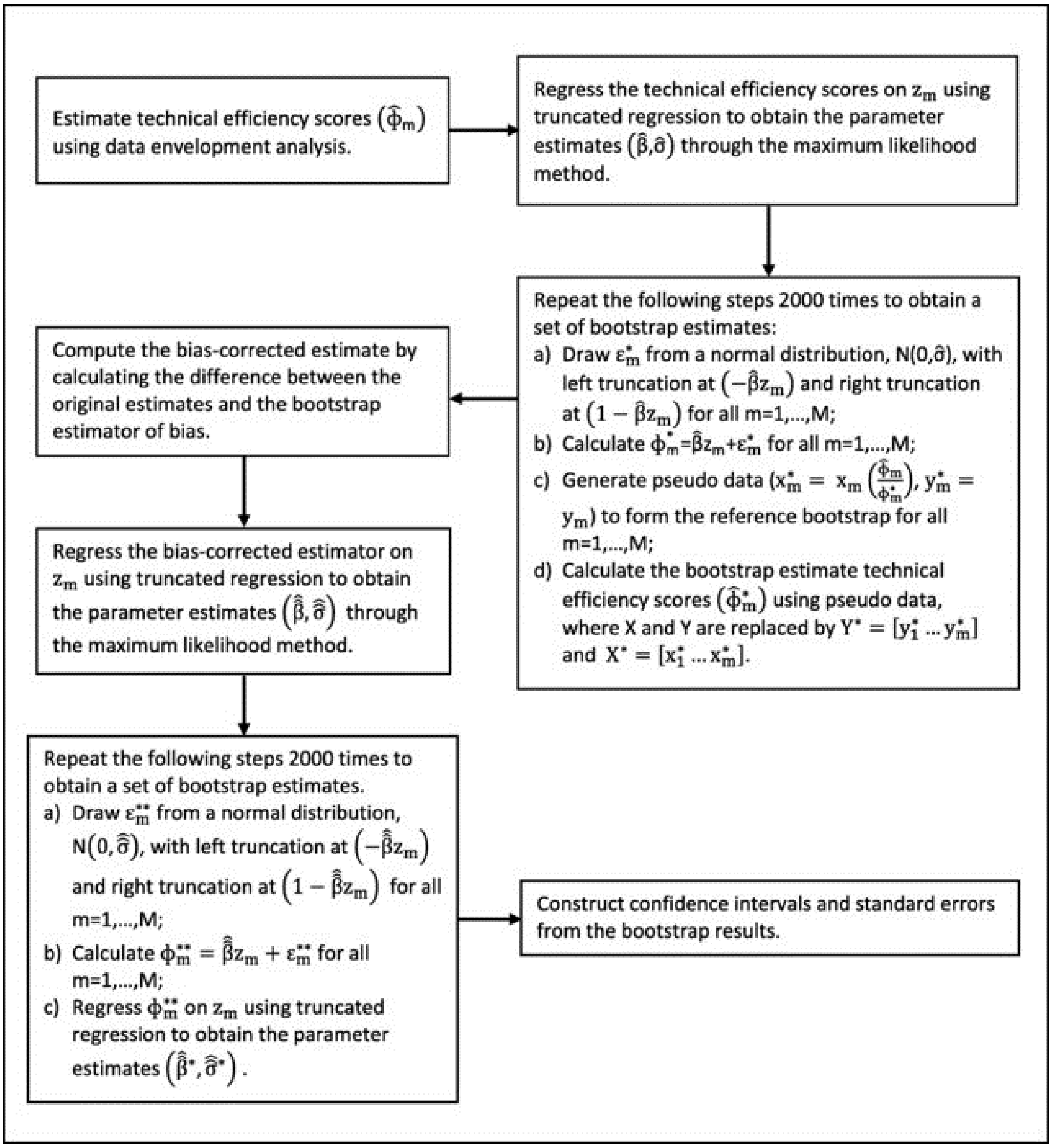

Fig. 1 Double-bootstrap DEA using the algorithm 2 (Simar– Wilson Approach)

Source: Hamzah, N. M., & See, K. F., 2019

In analyzing the determinants of efficiency, we follow the approach of Simar and Wilson (2007) Here, we assume and test the following specification (Peypoch at.all., 2012):

$$TE_j = \alpha + Z_j\delta + \varepsilon_j \qquad J = 1,2, \ldots., n \tag{5}$$

which can be understood as the first-order approxi true relationship. In equation, α is the constant term ε_j is statistical noise, and Z_j is a (row) vector of observation-specific variables for DMU j that we expect is related to the DMU's efficiency score, TE_j through the vector of parameters δ (common for all j) that we need to estimate. Simar and Wilson (2007) demonstrated that using the traditional Tobit-estimator to estimate the model in (4) is inappropriate and fails to address the dependency problem of DEA efficiency scores. Along this line, we note that the distribution of ε_j is restricted by the condition $\varepsilon_j \geq 1 - \alpha - Z_j\delta$ and assume that this distribution is truncated normal with zero mean (before truncation), unknown variance, and (left) truncation point determined by this very condition. Furthermore, we replace the true but unobserved regressand in (6), TE_j by its DEA esti mate $T\widehat{E}_j$. Thus we have:

$$T\hat{E}_j = \alpha + Z_j\delta + \varepsilon_j \qquad J = 1,2, \dots, n \tag{6}$$

$$\varepsilon_j \sim N(0, \sigma_\varepsilon^2), such\ that\ \varepsilon_j \geq 1 - \alpha - Z_j\delta, J = 1, \dots, n \tag{7}$$

(7) is estimated by the maximum likelihood method, with respect to (δ , σ_ε^2) . Confidence intervals can also be constructed for the model parameters (δ , σ_ε^2) with the bootstrap approach. The technical details are not provided here but can be easily obtained from Simar and Wilson (2007)

Analysis Results

Countries' relative performance in the fight against Covid-19 has been calculated in two stages. In the first stage, the impact of the health infrastructures of the countries on the number of cases, deaths and recovered patients was analyzed. Successful and unsuccessful countries in the fight against Covid-19 were listed according to the bootstrap estimated technical efficiency scores obtained. Then, in the second stage, the success of the public restrictions and measures implemented by Poland against Covid-19 were measured. Depending on the results obtained, the administrative skills and abilities of the country in the fight against Covid-19 were assessed.

In the first stage, the performance of countries in minimizing the number of deaths and cases and at the same time maximizing the number of patients recovered was analyzed. Output variables at this stage; New cases corrected per million, new deaths corrected per million, and the number of discharged covid patients. As input variables; positivity rate, number of new tests, number of patients with Covid-19 hospitalized, number of patients with Covid-19 hospitalized in the intensive care unit were used. The estimated technical efficiency scores of Bootstrap are shown in Table 3.

Table 3: First Stage Bootstrap Predictive Technical Efficiency Results

	Countries	Technical Efficiency Scores		Countries	Technical Efficiency Scores
1	Spain	0.517190465	17	Turkey	0.408155441
2	United Kingdom	0.490279336	18	Netherlands	0.404909929
3	Israel	0.489251521	19	Luxembourg	0.399084943
4	Canada	0.488044161	20	Estonia	0.394220041
5	Slovakia	0.479017770	21	Cyprus	0.388932146
6	Czechia	0.478827757	22	Portugal	0.384153914
7	Slovenia	0.469955736	23	Finland	0.37403150
8	**Poland**	**0.468382769**	24	Belgium	0.365348139
9	Sweden	0.454153547	25	Bulgaria	0.361451997
10	Denmark	0.449627914	26	Germany	0.348154564
11	Avustria	0.446543610	27	Latvia	0.333767443
12	Norway	0.435110476	28	Ireland	0.317686253
13	Croatia	0.430953159	29	Hungary	0.297966183
14	Romania	0.420924632	30	United States	0.295587568
15	Italy	0.415635959	31	France	0.162355825
16	Lithuania	0.408920687			

When Table 3 is examined, it is seen that the three most successful countries in the fight against Covid-19 on average (to minimize the number of deaths and cases and to maximize the number of recoveries) during the 63-week period are Spain (0.51719), United Kingdom (0.490279) and Israel (0.48927), respectively. On the other hand, it has been determined that the three most unsuccessful countries are France (0.16235), America (0.29558) and Hungary (0.29796). According to the results of the analysis, it is seen that Poland is in the 8th place (0.46838) among 31 countries.

In the second stage of the analysis, external parameters (public measures and restrictions) that affect Poland's relative performance in the 63-week period are modeled. In the second stage, Poland's technical efficiency scores in the first stage were used as the dependent variable. Discrete regression analysis was used to determine the effect of public measures and restrictions on these relative efficiency scores. Technical efficiency scores, which are the dependent variable, are in the range of 0 to 1, and the efficiency score approaching 1 means that Poland has performed better in the fight against Covid-19 compared to other countries. The independent variables in the model are Contagious Coefficient, Tightness Index, Government Response Index, Restraint and Health Index, Elderly Protection Index, and Workplace Closure Index. The independent variables consist of public measures and restrictions imposed by the government. The results of the second stage discrete regression analysis are shown in Table 4.

Table 4: Truncadet Regression Analysis Results (Poland)

Truncadet regression **Limit: lower = 0** **upper = 1**				**Number of obs: 63** **Wald chi2(5) : 13.85** **Prob > chi2 : 0.0166** **Log likelihood : 20.7478**		
Variables	Coefficients	Bootsrap Std. Err.	z	p> l z l	Normal- based (95% Conf. Interval)	
Stringency Index	0.008261	0.0108	0.76	0.447	-0.0130	0.02955
The Government Response Index.	-0.0144	0.0245	-0.59	0.557	-0.0624	0.03361
Limitation and Health index.	0.001555	0.0376	0.04	0.967	-0.0721	0.07527
Elderly protection index	0.139752	0.0497	2.81	0.005	0.04229	0.23721
Workplace Closure index	0.009667	0.0631	0.15	0.878	-0.1140	0.13341
_cons	0.310238	0.1536	2.02	0.043	0.00906	0.61141
/sigma	0.1918	0.0221	8.64	0.000	0.14837	0.23538

According to the results obtained using the Simar and Wilson methodology, it is seen that the elderly protection index is statistically meaningful. The elderly protection variable is an index expressing restrictions such as visiting and going out for the elderly staying in long-term care facilities. Increases in this index mean that protections for the elderly have increased. According to the results of the analysis, it is understood that the increase in Elderly Protection measures positively affects (0.139752) the performance of countries in the fight against Covid-19. It is a known fact that Covid-19 affects the people over a certain age more. This result shows that the number of personnel to carry out long-term care services in the country is sufficient, adequate care services can be provided for the elderly, and the isolation process for this segment is managed correctly.

When Table 4 is examined, it is seen that the tightness index, government response index, restraint and health index, and workplace closure index are statistically meaningless except for the elderly protection index. Specific to Poland, it is seen that other public measures other than the restrictions for the elderly do not make a meaningful contribution to the country's relative performance in the fight against Covid-19. This result should not mean that public measures and restrictions do not contribute to the health system in the fight against Covid-19. Our study focuses on whether public measures and restrictions affect Poland's relative performance compared to other countries. As a matter of fact, the results obtained only show the effect on the relative performance of Poland. Since many countries implement similar public measures and restrictions simultaneously, it may not have made a significant difference in relative performance. But, the results show that Poland's restrictive measures on elderly protection are managed better than other countries. The findings obtained from the results of the two-stage analysis can be evaluated together with other applications and studies in the literature. In this way, it will be possible to contribute to the discussion of the results obtained in Poland and to form a general opinion for policy makers.

Conclusion

When examining Table 2, it becomes evident that Spain, the United Kingdom, and Israel were the three most successful countries in combating Covid-19 on average during the 63-week period. These countries achieved a high level of effectiveness in minimizing the number of deaths and cases while maximizing the number of recoveries, with efficiency scores of 0.51719, 0.490279, and 0.48927, respectively. On the other hand, France, the USA, and Hungary were identified as the three most unsuccessful countries in managing the Covid-19 process, with efficiency scores of 0.16235, 0.29558, and 0.29796, respectively. The analysis results positioned Poland at the 8th rank among the 31 countries studied, with an efficiency score of 0.46838.

As a result of the first model's effectiveness scores, created to measure the performance of countries in minimizing the number of cases, deaths, and maximizing the number of recovered patients during the Covid-19 pandemic, it was concluded that Spain, England, and Israel were the top three countries that effectively managed the Covid-19 process, respectively. Conversely, it was determined that France, America, and Hungary were the three most unsuccessful countries in handling the pandemic. According to the results of the analysis, Poland is among the relatively successful countries, ranking 8th out of the 31 countries studied.

Furthermore, the study concluded that the elderly protection index, as one of the public restrictions and measures, is the most significant variable positively influencing Poland's relative success in combating Covid-19. Based on these findings, it is understood that in the event of similar pandemics, Poland should strive to implement additional effective restrictive measures beyond those targeting the elderly and address any existing shortcomings.

Another critical aspect that emerged with Covid-19 is the vulnerability of many developed countries in economic and social aspects when facing an epidemic. Health infrastructures collapsed in several nations, and businesses struggled to adapt their working conditions to the pandemic's challenges. This predicament has led to a delicate balance between economic concerns and public health consequences. Consequently, there is a need for comprehensive studies to develop models that consider epidemics' impact when formulating economic policies, particularly those related to employment, in the future. Furthermore, the experience of inadequacies in health infrastructure during the pandemic highlights the necessity for increased investment in preventive health services within health systems in the upcoming period. This proactive approach aims to address the shortcomings and vulnerabilities exposed during the Covid-19 crisis.

Appendix 1: Bootstrap algorithm for total slacks (Algorithm 2):

1. Technical efficiency scores $\hat{\theta}_i$ up to i=1,…,N are calculated for each decision making unit over the function in Equation 1.

2. When $\hat{\delta}_i > 1$olduğu, the estimated $\hat{\beta}$value of the β value in the discrete regression model showing the effect of Z_i's on $\hat{\theta}_i$'s using the maximum likelihood method and the estimated $\hat{\sigma}_i$ values of the σ_i value are obtained.

3. A set of bootstrap estimates satisfying the case $\mathcal{A} = \left\{\left(\hat{\beta}^*, \hat{\sigma}_\varepsilon^*\right)_b\right\}_{b=1}^{L_1}$ is calculated by looping the following four steps L_1 .

a) For each decision-making unit, the ε_i value is obtained from the $\varepsilon_i(i = 1, \dots, n)$, left-dashed $(1 - Z_i\beta)$ and $N(0, \hat{\sigma}_\varepsilon^2)$ distributions.

b) For each decision-making unit, the regression $\theta_i^* = z_i\hat{\beta} + \varepsilon_i$ is calculated for $i = 1, \dots, n$ values.

c) For $i = 1, \dots, n$ values, $x_i^* = x_i, y_i^* = y_i\hat{\theta}_i/\theta_i^*$ is calculated.

d) $\hat{\theta}_i^*$ is obtained for each decision-making unit by replacing the x_i and y_i values in equation (1) with $x_i^*\ ve\ y_i^*$.

4. Deviation corrected efficiency scores are calculated for each decision-making unit.

$$\hat{\theta}_i = \ddot{\hat{\theta}}_\iota - \left(\frac{1}{B}\sum_{b=1}^{B}\hat{\theta}_{ib}^* - \hat{\theta}_i\right)$$

5. To find the discrete regression of $\hat{\hat{\theta}}_i$ and z_i with respect to z_i , the maximum probability method is used and the values of $\hat{\hat{\beta}}_i$ and $\hat{\hat{\sigma}}_i$ are calculated.

6. To obtain the bootstrap estimate $\ell = \{(\hat{\beta}^*, \hat{\sigma}_\varepsilon^*)_b\}_{b=1}^{L_2}$ the following 3 steps are repeated for $B(b = 1, \dots B)$ cycles.

a) For each decision-making unit i values from 1 to n, $\varepsilon_i(i = 1, \dots, n)$ is drawn from the left with a dashed $(1 - z_i\hat{\hat{\beta}})$ distribution with $N(0, \hat{\hat{\sigma}})$.

b) For each decision-making unit i values from 1 to n, the regression $\theta_i^{**} = z_i\hat{\hat{\beta}} + \varepsilon_i$ is calculated.

c) Using the maximum probability method, the discrete regression of $\delta\theta_i^{**}$with respect to z_i is estimated and the values of $\hat{\hat{\beta}}^*$ ve $\hat{\hat{\sigma}}^*$ are calculated.

7. Finally, confidence intervals for β ve σ_ε values are created using the bootstrap results$\left(\hat{\hat{\beta}}_b^*, \hat{\sigma}_b^*, b = 1, \ldots, B\right)$.

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