Applying of Data Envelopment Analysis to study public administration effectiveness during a pandemic

Tamara Klebanova[1[0000-0002-0284-9839]], Nataliya Poluektova[2[0000-0001-5664-2131]], Olha Rudachenko[3[0000-0001-9597-5748]]

[1] Simon Kuznets Kharkiv National University of Economics, Ukraine,
t_kleb@ukr.net,
[2] V. I. Vernadsky Crimean Federal University, Ukraine,
npoluektova68@gmail.com,
[3] O. M. Beketov National University of Urban Economy in Kharkiv, Ukraine,
polkin87@ukr.net

Abstract. The article deals with the problem of assessing the effectiveness of the measures taken by the governments to overcome the crisis caused by the COVID19 pandemic. This problem is urgent since the governments and the international institutions have not defined common approaches and rules for state regulation during a pandemic. The varying degrees of restrictions and support measures applied by the governments of different countries have led to different results. The proposed model makes it possible to assess the effectiveness of government decisions by comparing the cost-benefit ratio with the maximum possible value reached in a group of similar countries. The mathematical apparatus used in this case is Data Envelopment Analysis, DEA. Several DEA-analysis models presented in this article allow us to assess the comparative efficiency for 20 European countries based on the ratio of inputs - the Government Stringency Index or individual policies of restrictions or support, and outputs - mortality rates and changes in the GDP. The study results show that this approach makes it possible to assess the effectiveness of state regulation and to suggest the directions of potential improvement.

Keywords: Pandemic, Public Adminisrtation efficiency, Data Envelopment Analysis (DEA).

1. Introduction

The world's main problem in 2020 was the coronavirus pandemic, which has put humanity before unexpected and complex challenges. Besides the main tragedy - the death of more than 2.5 million people around the world, the epidemic has caused unprecedented consequences in the political and socio-economic spheres: in most countries the GDP level sank, millions of people lost their jobs, there were global changes in the structure of employment and forms of labor activity. A crisis of non-payments is accumulating, many businesses, especially those related to transport, tourism, and recreation, are ruined.

The pandemic led to a very complex crisis, which revealed the unpreparedness of the international community for such tests, both at the level of individual states and governments, and at the level of international organizations responsible for global

Copyright © 2021 for this paper by its authors. Use permitted under Creative Commons License Attribution 4.0 International (CC BY 4.0).

CEUR-WS.org/Vol-2927/paper8.pdf

security, such as the United Nations, the World Health Organization, etc. National and international institutions still have not developed a unified approach to the management of citizens' security systems under the new conditions. The health systems of all countries without exception were not ready for the spread of the new virus, regardless of their economic development and political system. Governments were forced to find a balance between the actions to protect the population from the infection and the actions to ensure economic stability. Some countries, Sweden, for example, denied the necessity of quarantine measures, others, such as the UK, decided not to introduce a quarantine for a long time or made it not strict enough.

The coronavirus pandemic continues in the world - tens of thousands of new cases of infection are being detected every day in different parts of the world, and many epidemiologists are talking about the high probability of new pandemics. Under such circumstances, we need to find methods that allow us to analyze the effectiveness of the actions taken in individual countries and their communities so that we can identify patterns, which lead to unfavorable outcomes.

There are several aspects, which are important while assessing the effectiveness of government regulation during a pandemic.

First, it is necessary to take into account the ethical aspect. If we consider efficiency from this point of view, then the preservation of life and health of people should have the highest priority. Therefore, performance criteria that reflect the reduction of cases of infection and death should be used.

Second, the technical concept of cost efficiency as the ratio between costs and benefits assumes that the data is comparable and represented in the same units. However, the main metrics in assessing the effectiveness of management systems during a pandemic are obviously mortality and economic development indicators, and the main cost indicator is the degree of government efforts that contribute to the improvement of the outcome metrics. Quantifying such efforts is a difficult task, and ensuring comparability and uniformity of such diverse characteristics is even more difficult.

Considering these features, this paper proposes an approach that allows assessing the technical efficiency of public administration systems in an epidemic situation using the Data Envelopment Analysis (DEA) method. It is this approach, in our opinion, that makes it possible to overcome the above problems. It proposes to assess the effectiveness of governance in countries of very different size and level of development based on identifying the leading countries by a defined performance indicator, forming a shell or frontier of efficiency and the degree of deviation of other countries from this frontier, which serves as an indicator of inefficiency.

2. Literature Review

Data Envelopment Analysis (DEA) is a technique that is successfully used to assess the technical efficiency of complex systems. The method allows estimating the ratio between the costs and the results of any object’s activity, which are compared with the maximum possible ratio for a group of similar objects.

For the first time M.Farrell suggested this model to assess the comparative efficiency of the systems with one input and one output [1]. The works of A. Charns,

W. Cooper and E. Rhodes [2,3] and further studies offer multiplicative and additive versions of models of this type.

It is possible to present the interesting results of applying this approach to solve many different problems of evaluating effectiveness. Most of the works are devoted to the analysis of the production efficiency [4] and the efficiency of banking technologies or services [5]. However, in recent years more and more often this method is used to assess the effectiveness of different models for solving environmental [6, 7], and political problems. So, in the work of J.-M. Huguenin [8], the DEA method is used to analyze the comparative effectiveness of political decision-making models. The work of Maragos, Elias K., at all [9] is closest to this study. It is devoted to the study of the effectiveness of health policies in the EU countries, based on DEA method.

The main idea of the method for the problem considered in this paper can be presented as follows. Suppose, we need to compare the degree of effectiveness of public administration systems in 20 European countries during a pandemic. The Government Stringency Index, which is an indicator for government regulation, is used as an input. It is a composite indicator based on nine different response indicators, including school closings, job closings, travel bans, etc. on a scale from 0 to 100. Here the average values for the period from March 2020 to February 2021 are used. The inverse of the average death rate per million people, in the same countries, for the same period is used as an output or result.

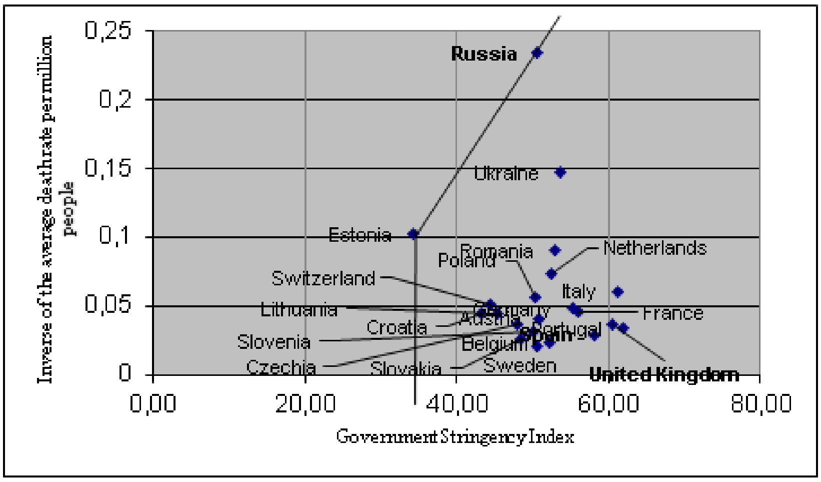

Fig. 1. Illustration of the efficiency frontier principle

Figure 1 shows a set of points that correspond to the costs and the benefits for each country. The figure shows that the two countries - Estonia and Russia form an efficiency frontier - the maximum result for a given amount of effort. These conclusions will not become final in further research and are used here only to illustrate the essence of the approach. The points, which do not lie on the frontier, correspond to the states whose activities can be considered ineffective. With the help of the DEA, we can identify the sources and the extent of inefficiency.

Below we will explain in more detail the essence of the method.

3. Methodology and Data

Let there be n objects, each of which has a certain amount (m) of resources, and t different results. Comparative efficiency is assessed based on the fact, that with a given amount of resources it is impossible to increase the performance indicators without a simultaneous deterioration in the performance of other objects.

To determine effectiveness, the DEA method considers a special ratio between the weighted sum of the results and the weighted sum of the costs:

$$Z = \frac{\sum_{r=1}^{t}(w_r y_{rj})}{\sum_{i=1}^{m}(v_i x_{ij})}, \qquad (1)$$

where $w_r$are the weights of the output parameters, $y_{rj}$are the values of the output parameters for each of the objects j, $v_i$are the weights of the input parameters, x_{ij} are the values of the input parameters for each of the objects j.

The effective object reaches the value of one in the ratio:

$$Z = \frac{\sum_{r=1}^{t}(w_r y_{r0})}{\sum_{i=1}^{m}(v_i x_{i0})} = \max\left\{\frac{\sum_{r=1}^{t}(w_r y_{rj})}{\sum_{i=1}^{m}(v_i x_{ij})} \mid j = \overline{1,n}\right\} \qquad (2)$$

The value of this ratio, which is less than one, suggests that the activity of other objects proves the relative inefficiency of the activity of the object under study.

The general formulation of the problem, in the formulation "to exit" (achieving the maximum result at a given value of resource consumption), thus has the form:

$$\max Z_0 = \frac{\sum_{r=1}^{t}(w_r y_{r0})}{\sum_{i=1}^{m}(v_i x_{i0})}, \qquad (3)$$

with constraints:

$$\frac{\sum_{r=1}^{t}(w_r y_{rj})}{\sum_{i=1}^{m}(v_i x_{ij})} \le 1, j = \overline{1,n} \qquad (4)$$

$$v_i, w_r > 0, i = \overline{1,m}, r = \overline{1,t}. \qquad (5)$$

Problem 3-5 can be transformed to linear form for practical reasons. The work of Charns - Cooper [2] describes the principle of such transformation.

Expressions 6-9 describe the corresponding linear programming problem.

$$\max G_0 = \sum_{r=1}^{t}(\omega_r y_{r0}), \qquad (6)$$

with constraints:

$$\sum_{i=1}^{m}(\mu_i x_{i0}) = 1 \qquad (7)$$

$$\sum_{r=1}^{t}(\omega_r y_{rj}) - \sum_{i=1}^{m}(\mu_i x_{ij}) \leq 0, j = \overline{1, n} \quad (8)$$

$$\mu_i, \omega_r > \varepsilon, i = \overline{1, m}, r = \overline{1, t}, \quad (9)$$

where ε is an infinitesimal constant, of the order of 10^{-5}.

This paper uses the model 6-9 as it makes it possible to solve the problems mentioned in the introduction - the problem of comparability of compared objects by determining the boundaries of comparative efficiency, which is defined for this set of objects and the problem of using indicators in different units by introducing weight coefficients.

The baseline data for the study was obtained from the following sources.

1. Data on mortality from COVID-19 by country, taken from the COVID-19 data repository of the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University (JHU) [5].

2. Data on excess mortality during the pandemic, taken from the Human Mortality Database [6].

3. Data on the decline in the level of gross domestic product (forecast for 2020) obtained from the International Monetary Fund [7].

4. Information about "Government Stringency Index" obtained from the studies of the Oxford Coronavirus Government Response Tracker (OxCGRT) [8]. The Government Stringency Index is calculated daily as the average of 9 indicators, including school closures; the closure of jobs; cancellation of public events; restrictions on public gatherings; the closure of public transport; requirements not to leave the place of residence; public information campaigns; restrictions on internal movement and international movement control. The method for calculating the index can be found in [9].

5. Information about the separate indicators forming the Government Stringency Index and some additional metrics were obtained from OxCGRT too. These indicators reflect the following policies:

1) School closures (0 - no actions, 1 - recommendation to close; 2 - requirement to close certain levels or categories; 3 - requirement to close all levels and categories of educational institutions).

2) Workplace closures (0 - no actions; 1 - recommendation to close (or work from home); 2 - demand to close (or work from home) for some sectors or categories of workers; 3 - demand to close (or work from home) for all jobs, except for the main ones (for example, grocery stores, doctors).

3) Cancellation of public events (0 - no actions; 1 - recommendation to cancel; 2 - demand to cancel).

4) Restrictions on public gatherings (0 - no restrictions; 1 - restrictions on meetings of more than 1000 people; 2 - restrictions on meetings from 100 to 1000 people; 3 - restrictions on meetings from 10 to 100 people; 4 - restrictions on meetings of less than 10 people).

5) Public transport (0 - no actions; 1 - recommendation to close or significantly reduce the volumes / routes / available vehicles; 2 - requirement to close or prohibit most citizens from using vehicles).

6) Public information campaigns (0 - no public information campaign about COVID-19; 1 -state officials urge caution in connection with COVID-19; 2 - coordinated public information campaign in traditional and social networks).

7) Stay at home requirements (0 - no actions; 1 - a recommendation not to leave the house; 2 - a requirement not to leave the house, with the exception of daily workouts, grocery shopping and "important" trips; 3 - a requirement not to leave the house with minimal exceptions, for example, it is allowed to go out only once every few days, or only one person can go out at a time, etc.).

8) Internal movement (0 - no actions; 1 - recommendation to restrict internal movements; 2 - requirement to restrict movement).

9) International travel controls (0 - no actions; 1 - screening; 2 - quarantine measures for those arriving from high-risk regions; 3 - a ban on travel to high-risk regions; 4 - complete closure of the border).

10) Testing policy (0 - no testing policy; 1 - only those who have symptoms and who meet certain criteria are tested (key staff, hospitalized, contacted with a known case, returned from overseas); 2 - testing any person with COVID symptoms -19; 3 - open public testing (for example, "end-to-end" testing available to asymptomatic people)).

11) Contract tracking (0 - no contact tracing; 1 - limited contact tracing - not performed for all cases; 2 - complex contact tracing - performed for all cases).

12) Face covering (0 - no policy; 1 - recommended; 2 - required in some specific public places outside the home where other people are present, or in some situations where social distancing is not possible; 3 - required in all public places outside the home where other people are present, or in all situations where social distancing is impossible; 4 - always required outside the home, regardless of the location or presence of other people).

13) Vaccination policy (0 - not available; 1 - accessibility for one of the categories: key workers / clinically vulnerable groups / elderly groups; 2 - accessibility for several of the following categories: key workers / clinically vulnerable groups / elderly groups; 3 - accessibility for the following three categories: key workers / clinically vulnerable groups / elderly groups; 4 - accessibility for all three plus partial additional accessibility for other categories or age groups; 5 - universal accessibility).

14). Income support (0 - no income support; government pays less than 50% of lost average wages; 2 - government pays 50 percent or more of lost wages).

15) Debt and contract relief (0 - no relief of debt obligations; 1 - relief, for one type of obligation; 2 - relief of many types of obligations).

All of the above data is collected and updated daily on the Our World in Data web resource [10].

The data is stored as daily metric values. In this study, we calculated the average values for three seasons - spring, summer and autumn, conventionally corresponding to the first wave of the pandemic, the weakening of the epidemic and the second wave. We also calculated the average values for all indicators for the entire observation period.

Data for some countries was not comprehensive enough in the reviewed sources, that’s why they were excluded from some models.

4. Results and analysis

During the study, several data envelope models were built.

The first model evaluates the effectiveness of public administration actions in 20 European countries based on the average Government Stringency Index as an input parameter and the average mortality rate in these countries, in the first version - according to the mortality statistics from COVID 19, and in the second – according to the excess mortality rate. The model includes 20 linear programming problems of the following form (10-12).

$$\max G_0 = \omega y_0 \quad (10)$$

with constraints:

$$\mu x_0 = 1 \quad (11)$$

$$\omega y_j - \mu x_j \leq 0, j = \overline{1, n} \quad (12)$$

$$\mu, \omega > \varepsilon$$

where y_0 - the mortality rate for the country under study (the inverse of), y_j - mortality for each country (the inverse of), x_0 - the Government Stringency Index for the country under study, x_j- the Government Stringency Index for each country, μ , ω are weight coefficients.

The efficiency values for each country are presented in Fig. 2.

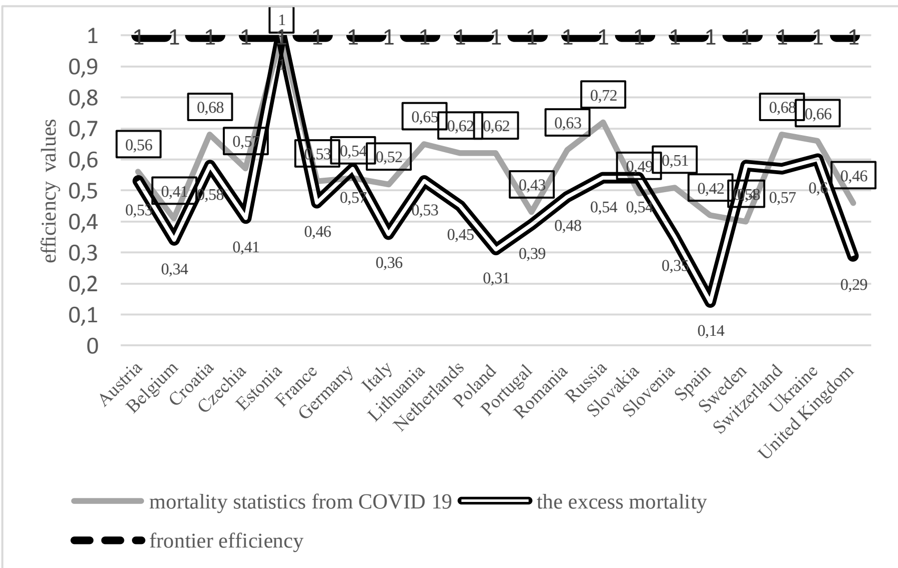

Fig. 2. Management efficiency based on average Government Stringency Index and average COVID mortality and excess mortality over the entire observation period

The presented results show that Estonia is at the maximum efficiency level not only in terms of mortality from COVID, but also in terms of excess mortality. Among other countries, the Baltic countries, Russia, Romania and Switzerland show higher management efficiency. However, given the excess mortality, the level of effectiveness falls in most countries, especially in Poland, Russia, Spain. This can be explained by the fact, that in the pain of coronavirus, governments have weakened overall health care efforts. In Sweden and Slovakia, these efforts have had a better effect on the relative excess mortality rate than on the Covid 19 death rate.

Next, the efficiency indicators were calculated using the same two outputs and the 15 policies described above as inputs. The results are presented in Fig. 3.

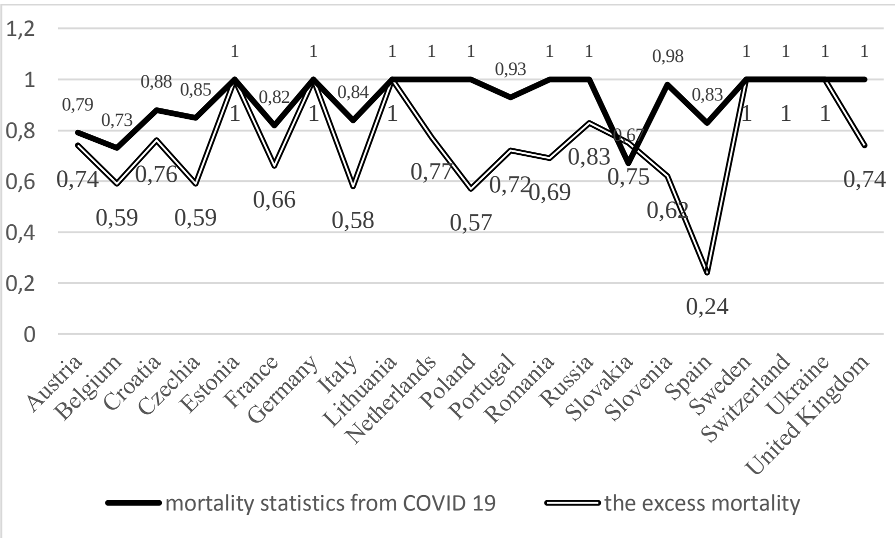

Fig. 3. Technical effectiveness of country management based on individual policies, taking into account restrictive and supportive measures

Based on the consideration of different regulatory policies, more countries are at the upper limit of effectiveness in terms of preventing deaths from COVID. Estonia, Germany, the Netherlands, Poland, Romania, Russia, Sweden, Switzerland, and Ukraine acted most effectively in terms of the level of statistically proven mortality from the virus. However, in terms of excess mortality, it turns out that Romania, the Netherlands, Poland, Portugal, Russia, and Great Britain made insufficient efforts in comparison to other countries. Perhaps, the reason is the imperfect methodology for collecting the mortality statistics from COVID. Such countries as Germany, Slovakia, Sweden, and Switzerland can serve as examples here.

Furthermore, it is interesting to analyze how governments were adapting to the changing situation by adjusting the measures taken. Fig. 4-8 represent some of the considered policies, averaged over three seasons. The first season, conditionally “spring”, considers the average daily scores of policies from the beginning of observations until 01.06.2020. The second season, “summer”, considers these indicators from 01.06.2020 until 01.10.2020, third season - "autumn" - data from October 2020 until February 2021.

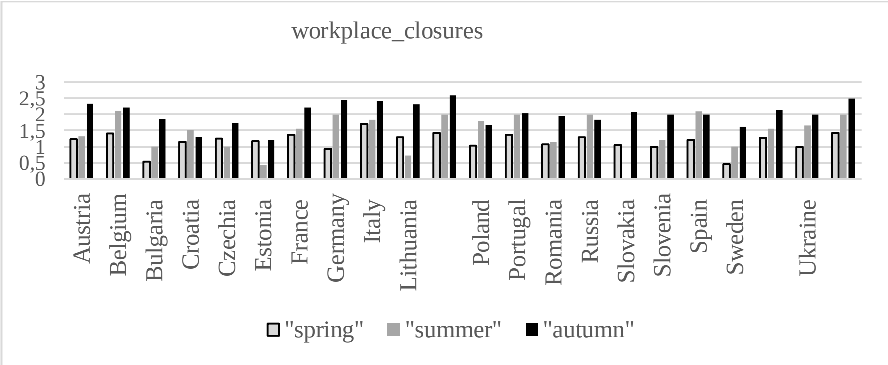

Fig. 4. Change in the policy of restricting access to work according to the seasons of the pandemic

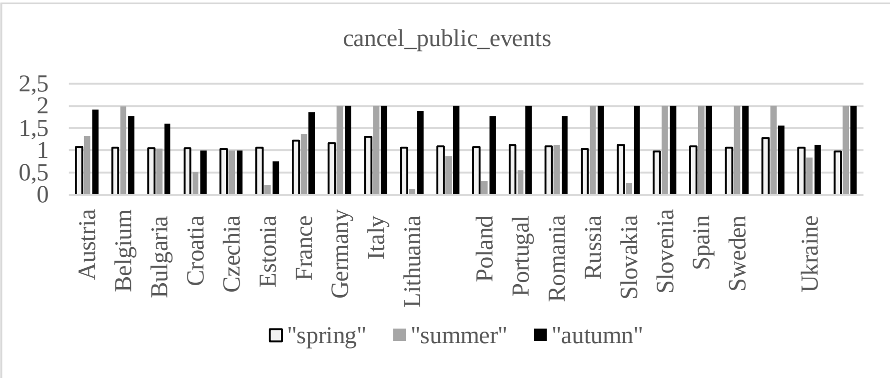

Fig. 5. Change in the policy of restricting public events for the seasons of the pandemic

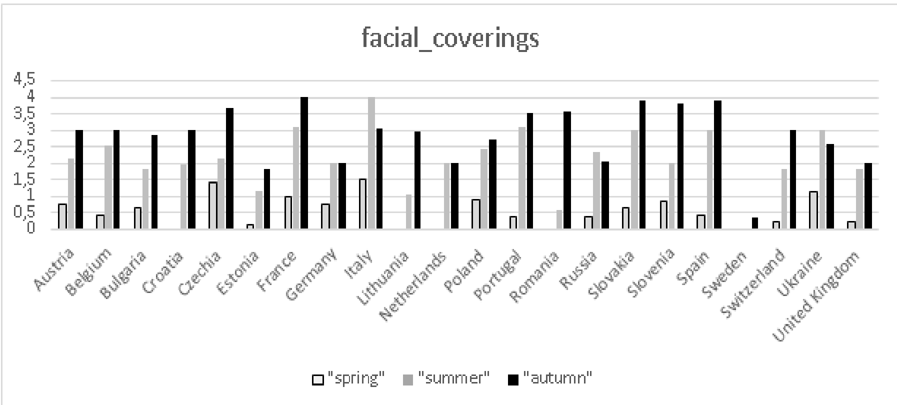

Fig. 6. Change of policy on the requirement of wearing masks according to the seasons of the pandemic

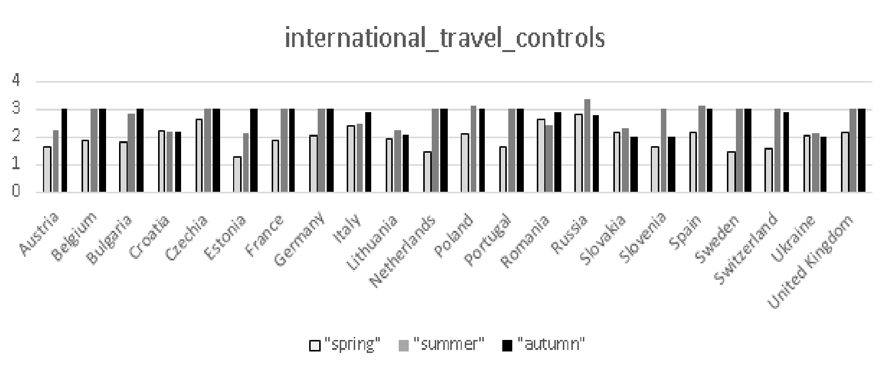

Fig. 7. Change of policy on control of international travel according to pandemic seasons

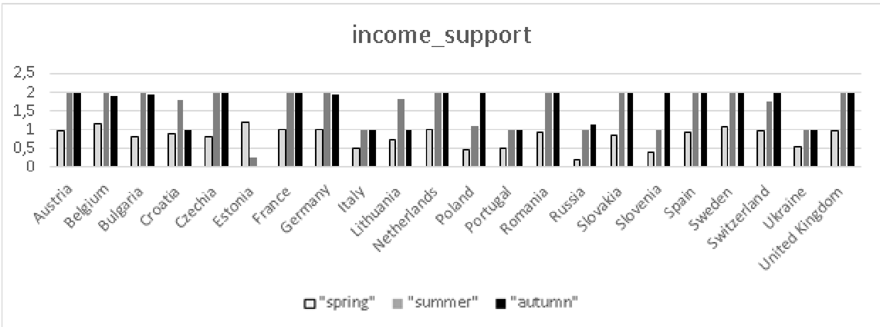

Fig. 8. Change in the policy on financial support of citizens according to the seasons of the pandemic

The figures do not represent all indicators, but we can see that most governments have stepped up their response over time, despite the weakening of the epidemic in the summer months. We can assess how effective such a policy was by constructing DEA analysis models for each of the seasons. The calculation results for these models are shown in Fig. 9-11.

As we can see, most countries in the first wave of the pandemic made little effort, which, even with excess mortality, led to maximum efficiency indicators. The exceptions are those countries that suffered the most in the first wave - Belgium, France, Italy, Spain and Great Britain.

In the summer period, which in most countries was characterized by a decrease in morbidity and mortality, governments did not weaken but even tightened restrictive actions, which was an overuse of resources.

On the other hand, the delayed problems of the health care systems emerged, which is shown by the values of the excess mortality factor. Namely, it can be seen in fig. 10, that in Russia, Romania, Slovakia and some other countries, the efficiency indicator for excess mortality is significantly lower than the indicator calculated according to official data on mortality from COVID. At the same time, most of the countries most affected by the first wave of the epidemic have improved management effectiveness.

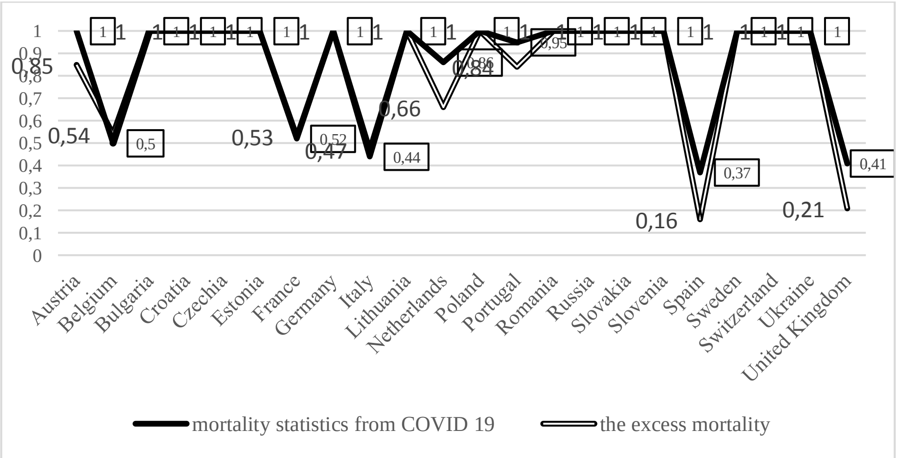

Fig. 9. Effectiveness of government management actions during the first wave of the coronavirus pandemic

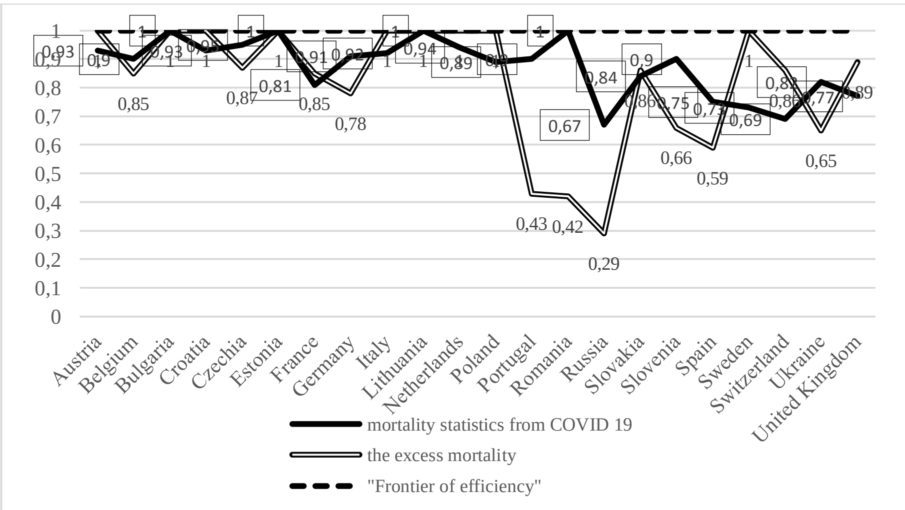

Fig. 10. The effectiveness of public administration actions in the summer period of the coronavirus pandemic

The second wave of the epidemic was much more severe than the first, and consequently the strengthening of restrictive actions in all countries led to an increase in efficiency.

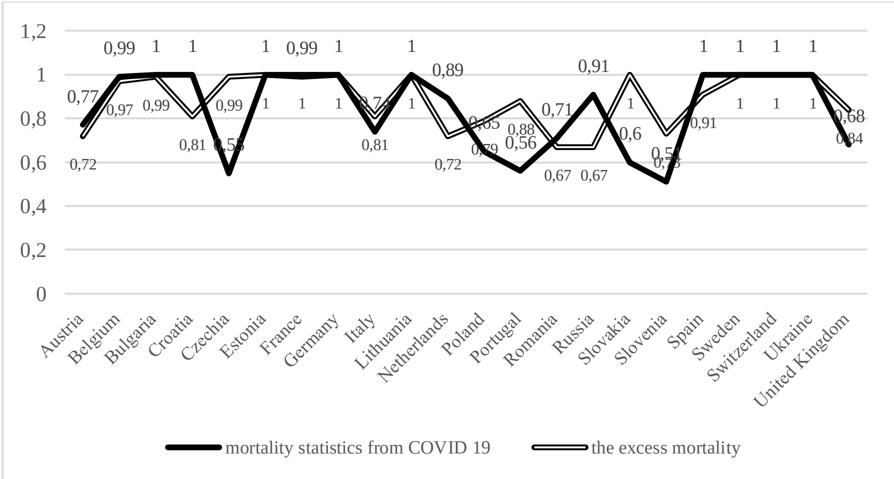

Fig. 11. Effectiveness of public administration actions during the second wave of the coronavirus pandemic

Only in some countries, there was a significant deviation from the general level. In Poland, Portugal, Czech Republic, and Slovenia, this is reflected in the death rate from COVID, while the level of measures to reduce excess mortality is sufficient. In Russia, the situation is opposite. This can be related to an insufficiently effective system for collecting statistics.

And, finally, the last model of DEA allows assessing the second result indicator - the level of change in gross domestic product. In all the countries under consideration, without exception, it decreased in relation to the previous year. In contrast to all the previous models, here both the mortality rate and the GDP change were used as output parameters. The outcome is shown in Fig. 12.

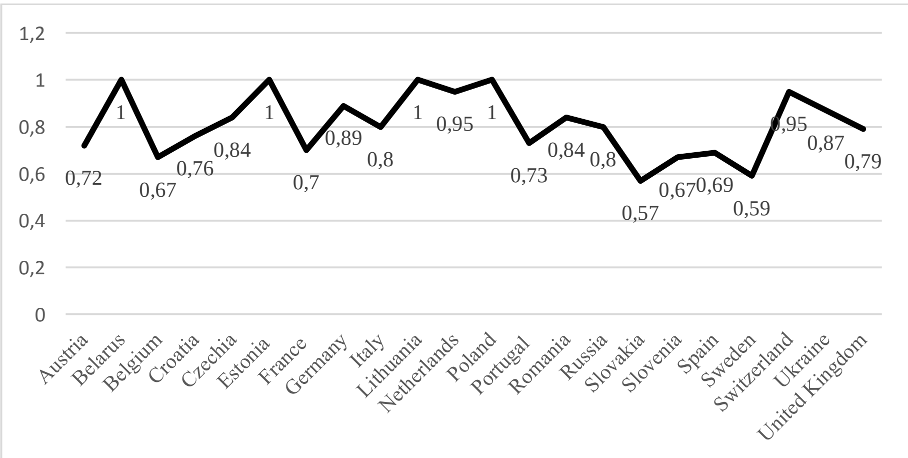

Fig. 12. Relative efficiency of public administration, taking into account mortality statistics from Covid and changes in GDP

In terms of the impact on the economy, Belarus, Estonia, Lithuania and Poland formed the efficiency frontier among the considered countries. The most ineffective were government regulations in Slovakia and Sweden.

5. Conclusions

Based on the results of the study, we can make a general conclusion that the DEA can be used as a tool for assessing the performance of government bodies in terms of the effectiveness of actions taken to achieve certain strategic goals. The method makes it possible to reveal the relative efficiency in comparison with the results of the activities of similar objects, taking into account the influence of factors expressed in various metrics.

In the context of this study, various indicators of the relative effectiveness of governance in European countries during the coronavirus pandemic were identified. For the countries outside of the efficiency frontier, the DEA efficiency indicator shows to which degree the input measures can be reduced without decay in output metrics.

Other DEA models, extended by age categories of the population, cultural and behavioral characteristics of countries and regions, can be built to identify the causes of inefficiency more accurately and to determine effective actions.

References

1. Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society*. Series A, 120, pp. 253–281.
2. Charnes, A.,.Cooper, W.W, Seiford, L.M.and oth. (1982). Multiplicative model for efficiency analysis. *Socio–Economic Planning Sciences*. 16(5), pp. 223-224.
3. Charnes, A., Cooper, W.W., Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*. 2, pp. 429-444.
4. Lie-Chien Lin, Lih-An Tseng (2005). Application of DEA and SFA on the Measurement of Operating Efficiencies for 27 International Container Ports. *Proceedings of the Eastern Asia Society for Transportation Studies*. Vol. 5, pp. 592 – 607.
5. Tsolas, I. E., Charles, V., Gherman, T. (2020). Supporting better practice benchmarking: A DEA-ANN approach to bank branch performance assessment *Expert Systems with Applications*. V. 160. doi:10.1016/j.eswa.2020.113599.
6. Yang M. et al. (2020). Assessment and optimization of provincial CO2 emission reduction scheme in China: an improved ZSG-DEA approach. *Energy Economics.* T. 91. doi:10.1016/j.eneco.2020.104931.
7. Guo, J. et al. (2021). Study on the distribution of PM emission rights in various provinces of China based on a new efficiency and equity two-objective DEA model. *Ecological Economics*. V. 183. doi: 10.1016/j.ecolecon.2021.106956.

8. Huguenin, J. M. (2015). Adjusting for the environment in DEA: A comparison of alternative models based on empirical data. *Socio-economic planning sciences*. V. 52, pp. 41-54 doi: 10.1016/j.seps.2015.10.004

9. Maragos, E. K., Maravelakis, P. E., Linardis, A. I. (2020). A DEA evaluation of the successful implementation of HEALTH2020 policies. *Socio-Economic Planning Sciences*. doi:10.1016/j.seps.2020.100968.

10. The Johns Hopkins University & The Johns Hopkins Health System. URL: http://COVID-19 Data Repository by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University

11. The Human Mortality Database. URL: https://www.mortality.org

12. International Monetary Found. URL: https://www.imf.org/en/Publications/WEO/weo-database/2020).

13. COVID-19 GOVERNMENT RESPONSE TRACKER. URL: https://www.bsg.ox.ac.uk/research/research-projects/coronavirus-government-response-tracker

14. Oxford Coronavirus Government Response Tracker. URL: https://github.com/OxCGRT/covid-policy-tracker/blob/master/documentation/index_methodology.md

15. Research and data to make progress against the world's largest problems. URL: https://ourworldindata.org/