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Evaluation of the Allocation of Public Resources Destined to the Fight against COVID-19 in the Brazilian Regions Using Data Envelopment Analysis (DEA)

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Abstract

This work presents an exploratory analysis concerning the understand of which Brazilian states have proven efficient in combating the Covid-19 pandemic, based on the treasury provided to them by the federal government, along with the understand of the association between input and output variables. As mathematical modeling support, the Data Envelopment Analysis (DEA) methodology is used as aid in the exploratory analysis. In this scenario, the states were analyzing based on the data of the treasury provided in the portal transparency of the federal government as well as the data of contamination and deaths available in the site informing health also of the government. The results show that with the CCR model, seven states are efficient while eleven are exposed in the BCC model. After the reduction in the number of *inputs* and *outputs*, the BCC model showed a decrease in the number of efficient states, being seven the new number to demonstrate an increase in inefficiency aspects.

Keywords: DEA; Covid-19; Data envelopment analysis.

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1. Introduction

The novel coronavirus and its variants have had several negative impacts, one of them on global economies, first observed in the city of Wuhan in China. On January 3, 2020, the WHO (World Health Organization) received a Chinese notification regarding the contamination of patients with a hitherto unknown type of pneumonia [1].

Since then, the virus has been spreading and giving rise to new variants that endanger the lives of several people in the world, requiring a rapid contingency response from various world leaders [2]. From this situation, it is necessary to seek an effective and efficient way to use public funds, allocating them to reduce the impacts on mortality and the country's economy. In Brazil, the case is aggravated due to socioeconomic problems and political fights between the main leaders of cities, states, and the federation [3].

The methods from Operational Research are useful to support the decision-making process in complex problems because they consider value judgments and not only technical issues. These methods were employed to support the decision-making process in several recent complex problems, such as [4–13].

Thus, the objective of this work is to present a study on the efficiency of the 5 Brazilian regions (South, Southeast, Northeast, Midwest, and North), composed of 27 states that make up the Federative Republic of Brazil, including the Federal District, in the fight against Covid-19, to recognize the regions that obtained the best results in controlling mortality and cases of contamination, given the money distributed to them [14].

To carry out this study is applied the DEA (Data Enveloped Analysis) technique in Portuguese known as Data Envelopment Analysis, using two methods known as CCR (Charnes Cooper Rhodes) works with constant returns and BCC (Banker, Charnes, and Cooper) works with variable returns [15]. Also, according to Costa [5][16]have behaved successfully.

2. Literature Background

In the year 2021, the region of Manaus capital of the state of Amazonas, went through serious difficulties, registering more than 4,000 deaths caused by the auto number of infected in serious conditions because of SARS-CoV-2, the crisis in the Amazon was a result of the poor application of prevention measures, the great increase of infected generated a demand higher than available oxygen in hospitals, that had an occupancy rate of 100% of the clinical beds and 95.8% of the ICU (Intensive Care Unit) [17].

Access to public health is increasingly precarious due to many factors, such as abrupt budget cuts and the suppression of R$2.2 Billion from the Ministry of Health, which have made the fight against the virus even more difficult [18]. At the peak of the pandemic, more than 300,000 health insurance contracts were canceled between March and July 2020, resulting in a major overwhelm on public health systems. For Almeida [19], some problems with abortion to insufficient funding for the SUS (single system of care) to be a system with the capacity to comply with its principles and that has universality, in terms of any and equity.

On the transparency portal website, the Federal Government reports having distributed about R$ 605,125,747.00 to the five regions of Brazil only in benefits such as Covid-19 emergency aid [18]. It also reports having transferred R$ 9,977,096,698.66 to the Brazilian states and municipalities so that the money could be used for measures against Covid-19 [18].

The Brazilian regions and states have adopted several measures to balance the impacts on the economy and the number of deaths and contamination of their population, as said by Maêda [20], over time several actions were taken, such as the closure of the f establishment, lockdown decrees among others. Still, according to the same that addressed as one of the strategies of social isolation, it is reported that the Brazilian states had different positions and strategies in the fight against the spread of the SARS-CoV-2 virus [21]. Using the models of data envelopment analysis based on constant returns (CCR) and variables (BCC), it sought to broadly analyze the relationship of efficiency of the Brazilian states in the use of the treasury in the fight against the virus [22].

To determine the efficiency, this work used the technical data of elopement analysis, also known as data evoenvelopmentalysis (DEA) that was developed by Charnes et al. [23], which aims to evaluate the efficiency of decision-making units (DMU) [24].

The sample has 5 Brazilian regions, namely: South, Southeast, Northeast, Midwest, and North, where these add up to 27 states. To determine the efficiency of the states was used as comparative input of benefits by locality and resources transferred by locality of favored, both data available in the portal transparency, a site with official data of the federal government [25]. Regarding the outputs were considered the number of registered cases and several deaths available on the site "inform health" of the federal government, the decision to consider both values as outputs are related to the ability of the states to take preventive actions for the contraction of the disease by the population [26]. After the preliminary study, the output-oriented BCC or VRS (Variable Return of Scale) is output-oriented since the model in question considers increasing or decreasing yields at the efficiency frontier, and its orientation is related to maximizing the product without changing the current level of input [27]. Also, according to the authors, AED models are being widely used to analyze health services, being the same ability to provide benchmarks for each decision variable [28].

DEA is a mathematical programming technique developed by Charnes, Cooper, and Rhodes[23] It is defined as a nonparametric method, and through the decision variables known as DMU, it is possible to measure the relative efficiency, which it vas between 0 and 1, being inefficient and efficient respectively [29].

It is worth mentioning, according to Moreira [30], the DMUs to be with stops need to be homogeneous, that is, they use the same input to produce the results.

In the present work, the efficiency will be evaluated in 4 optics, the first considering the CCR model of constant returns guiding to input and another to output, and the same logic applies to the BCC model, where it will be evaluated in the same way as the previous one. Also, as commented by Araújo et al. [14], to compare and measure efficiency, respecting the Golden Rule established by Banker, Charnes, and Cooper [31]

2.1 The CCR and BCC model

The CCR model also called the model of constant returns of scale, is premised on the fact that the values of the *inputs* generate constant variations in the *outputs*. This model can be oriented to inputs when the efficiency is defined by the DMU that consumes less resource to produce the best output, a characteristic of this model is not to present variability when oriented to the output [32–34]. The BCC developed by Banker, Charnes, and Cooper [35] considers a scale variation where the output variable is not constant in the input change. It is important to understand the difference between the models so that an adequate answer to the analyzed problem can be obtained.

Using the software SIAD – Integrated Decision Support System, created by Ângulo-Meza *et al*. [36], during the mathematical process in the program, he reformulates the models as classical and transforms them into a linear programming problem.

3. Case Study

After collecting the data, they were sorted in a spreadsheet, in ms-excel and formatted to be saved in a file of the type "txt separated by tab", format accepted by SIAD, according to the table below:

It is important to emphasize that the same data were considered for both the CCR model and the BCC model.

3.1 CCR Analysis

After running the model, we can realize that only 7 states used their resources efficiently that is, given the due resources presented a good performance about the other states, this can be caused by several factors, political and or social, which we will not address in this article.

As stated initially by the fact that the CCR model is constant and does not assign weight to the inputs or outputs, its results do not vary when we change its orientation from input to output due to its characteristic of constant returns [37].

Table 1: Output and input-oriented CCR model result

DMU	State	Pattern	Reversed	Composed
DMU3	Amazon	1.00	0.51	0.74
DMU7	Federal District	1.00	1.00	0.50
DMU13	Mato Grosso	1.00	0.48	0.76
DMU18	Parana	1.00	0.63	0.68
DMU19	Rio de Janeiro	1.00	0.95	0.53
DMU21	Rondônia	1.00	0.73	0.64
DMU24	Santa Catarina	1.00	0.70	0.65
DMU22	Roraima	0.98	0.70	0.64
DMU4	Amapá	0.96	0.80	0.58
DMU27	Tocantins	0.94	0.80	0.57
DMU23	Rio Grande do Sul	0.93	0.79	0.57
DMU8	Holy Spirit	0.89	0.87	0.51
DMU12	Mato Grosso do Sul	0.89	0.69	0.60
DMU26	São Paulo	0.84	0.79	0.52
DMU6	Ceará	0.80	0.66	0.57
DMU9	Goiás	0.79	0.80	0.50
DMU14	Stop	0.73	1.00	0.36
DMU1	Acre	0.72	0.88	0.42
DMU25	Sergipe	0.72	0.91	0.40
DMU17	Piaui	0.71	0.72	0.50
DMU11	Minas Gerais	0.69	1.00	0.34
DMU2	Alagoas	0.68	0.81	0.44
DMU16	Pernambuco	0.64	0.87	0.39
DMU15	Paraiba	0.64	0.90	0.37
DMU20	Rio Grande do Norte	0.60	1.00	0.30
DMU5	Bahia	0.59	1.00	0.30
DMU10	Maranhão	0.49	1.00	0.25

3.2 BBC analysis

In the BCC model, we have an interesting factor, when we consider the *input-oriented* model, we assign the inputs a greater weight, so the characteristic of economy of scale prioritizes the optimization of the consumption of input in the production of the outputs, and when we run this model, we have 11 states that are efficient in the consumption of funds about cases of contamination and deaths:

Running the output-oriented problem, we obtained an interesting event even assigning the weight of efficiency in the output, we obtained the same result, this is an interesting fact because the relationship between consumption and output does not present variation. In this situation, the BCC model uses the inclusion of scale factors μ when oriented to input and α when oriented to output. These factors act as intercepts on the efficiency frontier [38].

Table 2: Result of the input-driven BCC model

DMU	State	Pattern	Reversed	Composed
DMU1	Acre	1	1	0.5
DMU3	Amazon	1	0.535991	0.732004
DMU7	Federal District	1	1	0.5
DMU13	Mato Grosso	1	0.484661	0.757669
DMU18	Parana	1	0.726159	0.636921
DMU19	Rio de Janeiro	1	1	0.5
DMU21	Rondônia	1	0.736154	0.631923
DMU22	Roraima	1	0.813672	0.593164
DMU24	Santa Catarina	1	0.781426	0.609287

DMU26	São Paulo	1	1	0.5
DMU27	Tocantins	1	0.891764	0.554118
DMU4	Amapá	0.998805	0.906396	0.546205
DMU23	Rio Grande do Sul	0.937046	1	0.468523
DMU11	Minas Gerais	0.919907	1	0.459953
DMU6	Ceará	0.901951	0.731694	0.585129
DMU12	Mato Grosso do Sul	0.894267	0.694097	0.600085
DMU8	Holy Spirit	0.893524	0.867367	0.513079
DMU9	Goiás	0.804469	0.827879	0.488295
DMU17	Piaui	0.777032	0.723512	0.52676
DMU14	Stop	0.752528	0.889743	0.431393
DMU2	Alagoas	0.749018	0.836779	0.456119
DMU25	Sergipe	0.742062	0.933377	0.404342
DMU16	Pernambuco	0.716141	1	0.358071
DMU15	Paraiba	0.65219	0.908078	0.372056
DMU5	Bahia	0.631106	1	0.315553
DMU20	Rio Grande do Norte	0.607375	1	0.303687
DMU10	Maranhão	0.506	1	0.253

Running the output-oriented problem, we obtained an interesting event even assigning the weight of efficiency in the output, we obtained the same result, this is an interesting fact because the relationship between consumption and output does not present variation. In this situation, the BCC model uses the inclusion of scale factors μ when oriented to input and α when oriented to output. These factors act as intercepts on the efficiency frontier.

Table 3: Output-oriented BCC model result

DMU	State	Pattern	Reversed	Composed
DMU1	Acre	1	1	0.5
DMU3	Amazon	1	0.52408	0.73796
DMU7	Federal District	1	1	0.5
DMU13	Mato Grosso	1	0.486807	0.756596
DMU18	Parana	1	0.69731	0.651345
DMU19	Rio de Janeiro	1	1	0.5
DMU21	Rondônia	1	1	0.5
DMU22	Roraima	1	0.968017	0.515992
DMU24	Santa Catarina	1	0.759108	0.620446
DMU26	São Paulo	1	1	0.5
DMU27	Tocantins	1	0.904133	0.547933
DMU4	Amapá	0.99874	0.956802	0.520969
DMU11	Minas Gerais	0.949493	1	0.474746
DMU23	Rio Grande do Sul	0.937785	0.884318	0.526733
DMU6	Ceará	0.917828	0.70223	0.607799
DMU8	Holy Spirit	0.891545	0.865761	0.512892
DMU12	Mato Grosso do Sul	0.889773	0.759553	0.56511
DMU9	Goiás	0.819778	0.882681	0.468548
DMU14	Stop	0.780506	1	0.390253
DMU16	Pernambuco	0.75648	1	0.37824
DMU17	Piaui	0.742831	0.735092	0.503869
DMU25	Sergipe	0.719025	1	0.359513
DMU2	Alagoas	0.714053	0.860952	0.42655
DMU5	Bahia	0.676278	1	0.338139
DMU15	Paraiba	0.645224	0.906271	0.369476
DMU20	Rio Grande do Norte	0.59802	1	0.29901
DMU10	Maranhão	0.5334	1	0.2667

3.3 BBC analysis from another perspective

After evaluating the results obtained by the two models, it was decided to run once again the BCC model oriented to input and output, but this time the number of beneficiaries was disregarded as input and the number of cases as output, choosing to keep only the number of deaths. Considering the changes already mentioned, we can witness a change in the scenario, where we went from 11 to 7 efficient states in the input-oriented model.

What aroused greater interest was that by removing these variables, the results of the BCC remain constant even for input and output orientation, in the same scenario, the regions are efficient. A point of attention is that when we put greater weight on the output, we are assigning a greater weight to the number of deaths that each state had.

Table 4: Result of the input-oriented BCC model after the exclusion of parameters

DMU	State	Pattern	Reversed	Composed
DMU1	Acre	1	1	0.5
DMU3	Amazon	1	0.504033	0.747984
DMU7	Federal District	1	1	0.5
DMU13	Mato Grosso	1	0.466292	0.766854
DMU19	Rio de Janeiro	1	0.710927	0.644536
DMU22	Roraima	1	0.813672	0.593164
DMU26	São Paulo	1	1	0.5
DMU4	Amapá	0.961786	0.862463	0.549661
DMU21	Rondônia	0.892692	1	0.446346
DMU18	Parana	0.846612	0.724835	0.560888
DMU6	Ceará	0.79948	0.687566	0.555957
DMU12	Mato Grosso do Sul	0.789315	0.739932	0.524692
DMU17	Piaui	0.783168	0.623337	0.579915
DMU27	Tocantins	0.771961	0.891764	0.440098
DMU14	Stop	0.74211	0.721933	0.510089
DMU9	Goiás	0.732625	0.811474	0.460576
DMU25	Sergipe	0.690398	1	0.345199
DMU24	Santa Catarina	0.678876	0.774739	0.452069
DMU23	Rio Grande do Sul	0.672262	1	0.336131
DMU2	Alagoas	0.670563	0.759402	0.455581
DMU11	Minas Gerais	0.61837	1	0.309185
DMU16	Pernambuco	0.608304	0.860948	0.373678
DMU8	Holy Spirit	0.568027	0.8464	0.360813
DMU5	Bahia	0.56053	1	0.280265
DMU15	Paraiba	0.549357	0.867241	0.341058
DMU10	Maranhão	0.506	0.927958	0.289021
DMU20	Rio Grande do Norte	0.48134	1	0.24067

4. Final Considerations

The study in question enabled the presentation of the implementation of the DEA approach under the context of evaluation of a real problematic situation, clarifying aspects of return on the investment of public resources of the states of Brazil. Through the implementation of the DEA methodology, it became possible to perceive the association between the inputs and outputs of the system as a whole.

Public spending, whether at the municipal or state level, needs to be well managed, especially in situations that are not considered normal, so it is recommended that more work be done evaluating, in general, the performance of regions and states, seeking to understand if the way the funds are being allocated is the most efficient for the population. Another important point is to deepen more about the residual analyses and the impacts

they have on research and, finally that this information serves as a tool to support the decision-making of the leaders who make up these regions.

For future studies, the implementation of the DEA methodology will be sought in other case studies based on the application of public resources for the common good of society, exposing their possible associations, dependent variables, and possibilities for improvements in social aspects of modern Brazilian society.

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