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Research Article

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Evaluation healthcare system in facing COVID-19 with the help of data envelopment analysis

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Abstract

The healthcare organization is a basic factor for any community, as it highly acts on the socioeconomic development of any country. Beginning of coronavirus disease 2019 (COVID-19) was initial reported in December 2019. Until now, many medicines and plans have been used in the cure of the illness. The COVID-19 became a pandemic around the world and has giant effect on our industrial and social systems, particularly on the healthcare system. Data envelopment analysis (DEA) is a powerful nonparametric engineering tool for estimating technical efficiency and production capacity of service units. Therefore, in this study, to examine a relationship between healthcare and bed suitable in the COVID-19 is evaluated using DEA. In the first step, the efficiency values are calculated based on determines the production capacity of hospitals through data envelopment analysis. In the second, incorporates the complexity of needs in two categories for the reallocation of beds throughout the medical specialties. The proposed approach can provide a direction for governments to expand strategies based on a powerful production capacity measure.

Keywords: DEA, COVID-19, Health System, Technical Efficiency.

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1. Introduction

Covid-19 is an infectious disease, which at the first come out in Wuhan, in December 2019. This disease is a cause of novel coronavirus, which became pandemic and advanced very fast throughout China. thereafter, an increasing number of infected cases were also found in other countries throughout the world. In February 2020, this disease was labeled as COVID-19, and its virus is referred to as Severe Acute Respiratory Syndrome Corona Virus 2 (SARS-CoV-2) by the World Health Organization (WHO) [1]. the quick virus beginning basis a much bigger problem than lethality: a huge number of infected sick require hospitalization and confined to bed. When a lot of patients need such intensive care at the same time, the hospitals and other health service units with finite capability end up overloaded. Therefore, the health systems disintegration due to the unavailability of beds, ventilators, and technical source for new hospital admissions and weariness health teams. thus, hospital beds utilization and offloading are important to increase the response capacity to face the big trouble [2].

Data envelopment analysis (DEA) is a powerful technique in productivity management. It is a linear programming based methodology introduced by Charnes et al. [3] for measuring the relative efficiency of decision making units (DMUs). Specifically, DEA measures the efficiency of the i-th DMU under evaluation relative to the other DMUs of the set. DMUs use multiple inputs to produce multiple outputs, which can be measured in different units, such as financial institutions and health systems [4,5]. Hospitals are a great source of efficiency assessments. this study introduces a new profit to crates an optimal number of hospital beds technically feasible to be remove and appropriate for urgent hospitalizations through best practices, applicable during the COVID-19 crisis. the methodology is based on the Brazilian Healthy Complexity of Needs prioritization and can be extended to any health system with a similar or different classification of disease and medical specialties.

2. Literature Review

The extending pressure on restricted elements of health systems during the pandemic has highlighted the need for efficiency-based tools and methodologies to offer new combined perspectives on how to use the hospital's facilities, resources, and capabilities optimally. Ordu et al. [6] establish an elegant decision support tool for modelling capacity constraints, and allocating hospitals' resources, combining discrete event simulation and forecasting techniques.

The nonparametric frontier estimations of data envelopment analysis can aid managers and policy makers in attaining such a prospect. the weight optimization based on pairwise evaluations scales the used resources and generated products of each service unit, providing a robust measure for the technical efficiency, which can be adapted for inverse output/input relations, exogenous or nondiscretionary resources and time-series self-evaluations.

As a result, an estimation for the optimal production capacity for any size service unit is available for decision making. In the case of hospitalizations, this optimal capacity measure can be translated into an efficient number of hospital beds, equipment, costs, or human resources required for the production of health using internments as a proxy for this product.

This instrument, besides offering a relative measure for hospitals' technical efficiency based on the maximum, yet feasible, production configuration, can determine peers of efficiency for benchmarking performance metrics and identifying opportunities for improvement and support resource allocation schemas based on production slacks. Many assessments of health efficiency follow this avenue, for instance, the recommendations of Kounetas and Papathanassopoulos [7] regarding the efficiency of Greek hospitals and Zare et al. [8] using a hybrid data envelopment analysis and game theory methodology for performance measurement in health service units. this interesting perspective of frontier estimations can provide the optimal number of resources to be (re-) allocated from inefficient units through best practices during epidemic crises.

The most common variables considered in modelling the generation technology of health systems are the number of beds for hospitalizations, personal protective equipment (PPE) and other technical equipment, drugs, human capital (physicians, nurses, unlicensed assistants, and other staff), hospital infrastructure, costs of service (in many categories), and funding as inputs, and medical prescriptions, number of hospitalizations, outpatient procedures, inverse mortality rate, patients discharged, number of surgeries, and testing as outputs. Nevertheless, different combinations of output/input can be used in assessments of hospitals' performance, depending on the problem statement and purpose.

3. Research Findings

the technical efficiency is traditionally understood as a ratio between the generated outputs and used inputs of a production process. Charnes et al. [9] and Banker et al. [10] through a mathematical linear dual formulation for multiple outputs/inputs configurations in the efficiency problem introduced the so-called data envelopment analysis (DEA). Today, this is the most common approach to assess the efficiency and productivity of many decision-making units (DMUs) in the number of surveys, applications, methodologies, and computational developments [11]. The mathematical programming provides, among other results, the optimal amount of resources to save or products to increase so that an inefficient service unit becomes efficient.

The multidimensional production structure of hospitals and healthcare centers, however, requires a meticulous approach to define which resources need to be reduced in order to improve the health results. According to Lin & Kuo [12], different patient's complexity relies on different health service providers for different clinical specialties, which may jeopardize the slack reduction consistency in the technical efficiency analysis because potential performance improvements

in hospitalizations by equally reducing the hospital beds, for instance, for all specialties, may be neither feasible nor coherent for each particular hospital context. An interesting solution is suggested by Ferreira and Marques [13]. According to this study, there is no need for complexity adjustment if one accounts for the operational environment surrounding the hospital. Conditional frontier analysis [14] can add an interesting perspective by considering those environmental determinants in the frontier estimation.

An alternative avenue through a two-step methodology is proposed in this assessment. Estimations for the beds' evacuation is proposed by prioritizing the slack reduction according to the complexity of needs on the most common medical specialties to provide support for bed reallocations during an epidemic crisis. the first step consists of applying nonparametric frontier estimations for the full production capacity of the health service units (the maximum feasible production configuration for each hospital) based on hospital admissions as the main output and hospital beds as one of the many discretionary resources. Similar to many assessments of health systems efficiency, the number of beds is considered a proxy for hospital capital [15]. that way, depending on the scale of operations and keeping everything else constant, the lower the usage of this resource, the higher the efficiency for the health service unit. Following similar resource optimization approaches [16], the objective in this assessment is to provide an optimal number of beds to be evacuated and allocated for potential COVID-19 cases, instead of reduction.

For the second step, the optimal number of beds to be reallocated (based on best practices) are prioritized according to the complexity of needs for each medical specialty. the complexity of needs in the Brazilian Health System is the degree of complexity each health problem presents and the requirement for specialized knowledge. there are three categories: basic care, moderate complexity, and high complexity. Each category is defined in Table 1.

Hospitalizations have moderate $\left(\varepsilon_{low}\right)$ or high $\left(\varepsilon_{high}\right)$ complexity of needs admissions. Consider a set of $j=1,\dots,m$ health service units using $x_i, i=1,\dots,n$ hospital inputs to produce $y_r, r=1,\dots,s$ outputs.

Consider "*o*" the service unit under evaluation and "*ε*," the sum of both moderate and high complexity of needs hospitalizations, a proxy for the prioritization of beds evacuation. the optimal feasible contraction (evacuations) of high complexity hospitalization beds is as follows:

$$Ev_{A^+} = \begin{cases} \varepsilon(1-\theta^*) - \varepsilon_{low} & \varepsilon(1-\theta^*) - Ev_{A^-} \\ 0 & O.W \end{cases} \quad (1)$$

$$Ev_{A^-} = \begin{cases} \varepsilon_{low} & (1-\theta^*) - \varepsilon_{low} \geq 0 \\ 0 & O.W \end{cases} \quad (2)$$

Where

$$\theta^* = \min(\theta)$$
$$\sum_{j=1}^{m} z_j x_{ji} \leq \theta x_{io}$$
$$\sum_{j=1}^{m} z_j y_{rj} \geq y_{ro}$$
$$\sum_{j=1}^{m} z_j = 1$$
$$z_j \geq 0$$

Equations (1) and (2) state that the optimal number for beds evacuation of high complexity admissions depends on the number of evacuated beds of moderate complexity. In other words, the optimal number for beds evacuation of high complexity hospitalizations are the remaining feasible contraction of beds after all moderate complexity admissions are evacuated. As an example, considering an efficiency score $\theta^* = 0/8$, the service unit may improve efficiency by producing the same result using (1– 0.8) = 20% fewer resources. Considering 100 hospital beds allocated to admissions of both low and high complexity of needs as the discretionary input $\varepsilon_{low} = 15$ and $\varepsilon_{high} = 85$, the number of beds to be evacuated having moderate complexity is $Ev_{A-} = \varepsilon_{low} = 15$ beds and the number of beds to be evacuated having high complexity is the remaining $Ev_{A+} = \varepsilon(1-\theta) - \varepsilon_{low} = 20 - 15 = 5$ beds. Adding (1) and (2) into the DEA formulation, we can infer the optimal number for beds evacuation (Ev_A) based on the complexity of needs prioritization:

Table 1- Table

Basic care	the first level is characterized by a set of actions and practices using low-density technologies to solve health issues of greater frequency but low severity, including a list of simpler and cheaper procedures. the procedures in this category are capable of meeting most of the community's common health problems.
Moderate Complexity	composed of actions and services aiming at meeting the main public health issues whose assistance in the clinical practice requires the availability of specialized professionals and the usage of technological resources for diagnostic, support, and treatment.
High Complexity	common for more severe health issues; this category is characterized by a set of procedures involving high technology and high cost, aiming at providing access to highly specialized knowledge and qualified services.

$$Ev_A(x,y,\varepsilon)=\begin{cases} Ev_{A^-}=\varepsilon\left[1-\min(\theta)\left|\begin{array}{ll}\sum_{j=1}^{m} z_j x_{ji}\le \theta x_{oi} & \forall i=1,2,...,n\\ \sum_{j=1}^{m} z_j y_{rj}\ge y_{ro} & \forall r=1,2,...,s\\ \sum_{j=1}^{m} z_j & \forall j=1,2,...,m\end{array}\right.\right] & \text{when} \quad \varepsilon(1-\theta^*)-\varepsilon_{low}\le 0 \\ Ev_{A^+}-Ev_{A^-}=(\varepsilon)\left[1-\min(\theta)\left|\begin{array}{ll}\sum_{j=1}^{m} z_j x_{ji}\le \theta x_{oi} & \forall i=1,2,...n\\ \sum_{j=1}^{m} z_j y_{rj}\ge y_{ro} & \forall r=1,2,...,s\\ \sum_{j=1}^{m} z_j=1 & \forall j=1,2,...m\end{array}\right.\right] -\varepsilon_{low}+Ev_{A^-} & \text{OW}\end{cases} \quad (3)$$

4. Conclusion

The assessment provided a framework for the application of nonparametric frontier methods of the DEA family to estimate the technically feasible capacity of hospitalizations, which, combined with prioritization methodologies for medical specialties such as the complexity of needs in Brazil, can disclose valuable support for policymakers to prevent an eventual collapse of health systems during the COVID-19 epidemic crisis. the methodology can be adapted to other localities, or decision criteria, providing a systematic approach for resource allocation through hospitals during the pandemic.

A valuable extension for the assessment of the health service unit technical efficiency is the frontier estimation based on time-series production data instead of pairwise comparisons. Due to the many particular differences regarding the production technology of hospitals, an approach based on internal rather than industrial capacity can be more deductive and coherent.

Another interesting value can be added by the definition of beds' evacuation based on multiple decision criteria besides the complexity of needs. Important clinical aspects of hospital internments such as the gravity of diseases, flexibility for resource transfer among the medical specialties, and substitution potential can orientate decisions of managers and policymakers closer to each health unit reality. In addition, the usage of fuzzy data for the assessment of network system such as a hospital can aid valuable support. this analysis can provide a direction for public administrations to perform some of their strategies based on an objective quantitative production capacity measure and support subjective decision-making with the inclusion of such aspects.

An extension of the current application investigating the efficiency evolution and the hospitalization efficacy against COVID-19 can be very useful for policymakers. A time series evaluation, as suggested by Nepomuceno et al. [17], can be performed using time-series data regarding the period before and after the implementation of beds reallocation schema based on each specialty complexity of needs. The first results of this assessment were disclosed to state authorities, hoping to contribute to how to mitigate the drastic effects of the current crisis in the available resources.

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