Márcia Nayara Fidelis da Silva Manoel

Evaluation of the Performance of Brazilian States in the Delivery of Transplant Services Using DEA and MPI

UNIVERSITY OF ALGARVE
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Márcia Nayara Fidelis da Silva Manoel

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Professor Carla Alexandra E. Filipe Amado

Professor Sérgio Pereira dos Santos

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Work Authorship Declaration

I declare myself to be the author of this work, which is unique and unprecedented. Authors and works consulted are properly cited in the text and are included in the listing of references.

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ABBREVIATIONS LIST

ABTO- Brazilian Association of Organ Transplantation

AIH - Hospital Internment Authorizations

BCC - Banker, Charnes and Cooper

CCR - Charnes, Cooper and Rhodes

CIHDOTT- Intra-Hospital Commission for Organ and Tissue Donation for Transplantation

CNCDOs - Organ Notification, Procurement and Distribution Centres

CNES- National Register of Health Establishments

CRS - Constant Returns to Scale

DATASUS- Department of Informatics of the Unified Health System

DMU - Decision Making Unit

DRS - Decreasing Returns to Scale

EMS - Efficiency Measurement System

FTEs - Full-Time Equivalents

GDP - Gross Domestic Product

ICU - Intensive Care Unit

IRS - Increasing Returns to Scale

MPI - Malmquist Productivity Index

ODT- Organ donation and transplantation

OECD - Organisation for Economic Cooperation and Development

OPOs- Organ Procurement Organizations

RBT- Brazilian Transplant Registry

SIH/SUS- System of Hospital Admissions of the SUS

SNT- National Transplant System

SOT- Solid Organ Transplant

SUS - Unified Health System ("*Sistema Único de Saúde*")

TE - Technical Efficiency

UF- Federative Unit

VRS - Variable Returns to Scale

RESUMO

O transplante de órgãos é uma das melhores opções para muitas condições médicas e, em muitos casos, pode ser a única opção de tratamento. O programa de transplante de órgãos e tecidos no Brasil é um dos maiores do mundo, sendo o único sistema público que atende uma população com mais de 200 milhões de pessoas e é financiado em sua maioria pelo sistema público de saúde. O primeiro transplante de órgãos no Brasil foi realizado há mais de 50 anos, e ao longo das últimas décadas, assistiu-se a uma evolução significativa quer ao nível dos procedimentos médicos relacionados com os transplantes quer ao nível da própria legislação, permitindo que o país se tornasse o segundo em números absolutos de transplantes realizados no mundo. No entanto, apesar do crescente número de transplantes e das melhorias nos processos, o número de transplantes realizados no Brasil ainda não é suficiente para suprir a procura e acabar com as longas filas de espera; ou seja, medidas estratégias devem ser introduzidas com a finalidade de diminuir o tempo de espera para transplante de órgãos.

A doação de órgãos para a realização de transplantes pode ocorrer através de doadores vivos ou doadores falecidos, sendo esta última opção o modo mais comum de doação para transplante de órgãos sólidos, requerendo a confirmação do diagnóstico de morte encefálica e consentimento da família. No entanto, estruturas hospitalares precárias, falta de Unidades de Tratamento Intensivo, emergências lotadas e disparidade de neurologistas entre cidades e regiões brasileiras, comprometem o atendimento de pacientes vivos e, muitas vezes, impossibilitam a adoção dos protocolos necessários para o processo de doação de órgãos e tecidos. Além disso, o Brasil apresenta um baixo número de consentimentos familiares para doação de órgãos e tecidos, o que gera um longo tempo de espera nas filas de transplantes, podendo resultar na morte de pacientes enquanto aguardam pelo transplante de órgãos.

Devido ao impacto que a saúde tem na sociedade, à natureza transformadora e muitas vezes salva-vidas dos transplantes de órgãos, assim como ao alto impacto financeiro que tais procedimentos têm no sistema público de saúde brasileiro, torna-se cada vez mais importante fomentar melhorias nos serviços de coleta e transplante de órgãos em todas as regiões brasileiras, visando tornar os serviços de

saúde mais eficientes. Para isto, torna-se necessário avaliar o desempenho dos processos relacionados com a doação e o transplante de órgãos nos estados brasileiros a fim de proporcionar informações relevantes aos profissionais de saúde e aos formuladores de políticas na tomada de decisões sobre iniciativas futuras, a fim de fornecer um serviço melhor e atingir os objetivos de saúde.

Nos últimos anos, um crescente número de estudos tem utilizado a técnica *Data Envelopment Analysis* (DEA) para comparar o desempenho dos sistemas de saúde a nível mundial e também no Brasil, no entanto, ainda são poucos os estudos efetuados para avaliar o desempenho dos sistemas de saúde nos serviços relacionados com a doação e o transplante de órgãos. Neste sentido, o objetivo principal desta dissertação é explorar o potencial da metodologia DEA para avaliar o desempenho dos serviços brasileiros de doação e transplante de órgãos, bem como o Índice de Produtividade de Malmquist para avaliar as mudanças de produtividade ao longo do tempo e o efeito da COVID-19 nesses serviços. Para este efeito, utilizamos dados de 17 estados brasileiros e do Distrito Federal sobre o processo de doação e transplante de órgãos. A avaliação é feita por recurso a três modelos diferentes os quais nos permitem analisar aspectos que vão desde a equidade na alocação de recursos até ao procedimento do transplante propriamente dito.

A técnica DEA é aplicada aos dados de forma a construir uma curva das melhores práticas observadas, ou seja, de máximo desempenho, utilizando os estados selecionados e calculando um índice de desempenho para cada um dos estados brasileiros analisados. O índice de desempenho assume um valor entre 0 e 1, sendo que os estados com melhor desempenho são aqueles que apresentam um índice igual a 1, equivalente a 100%. Estes estados podem servir como referência para estados com piores desempenhos. Esta análise permite não só a comparação entre os estados brasileiros e a identificação de benchmarks, mas propicia também comparações entre diferentes períodos. Além disso, auxilia na definição de metas, na identificação das variáveis que contribuem para melhores desempenhos e na identificação dos pontos fortes e pontos fracos relativos a cada um dos estados.

Os resultados obtidos neste estudo apontam para uma grande variação no desempenho entre os estados brasileiros e entre os três modelos utilizados, sugerindo

a necessidade de uma melhor integração entre as etapas necessárias para a realização de transplantes de órgãos - desde a identificação de possíveis doadores até a realização do transplante de órgãos. Um melhor uso dos recursos pode levar a mais e melhores serviços de transplante e, em última instância, aumentar a qualidade e o acesso a esses serviços para os pacientes que precisam. No que diz respeito à produtividade do setor, os resultados dos modelos 1 e 2 sugerem uma degradação do nível de produtividade geral de 2018 para 2020.

Os resultados obtidos através deste estudo demonstram que a técnica DEA pode fornecer informações muito valiosas para ajudar os formuladores de políticas e gestores de saúde a melhorar o desempenho dos estados brasileiros em relação à doação e transplante de órgãos. Além disso, este estudo complementa os resultados de estudos anteriores e serve como base para estudos futuros que pretendam aprofundar a análise deste tópico.

Palavras-chave: Sistema Único de Saúde, Processo doação-transplante de órgãos, *Data envelopment analysis*, Avaliação de desempenho, Índice de produtividade de Malmquist, COVID-19.

ABSTRACT

Organ transplant is one of the best options for many medical conditions, and in many cases, it may be the only treatment option. However, the process related to organ transplantation is complex and involves not only the recipient but also the donor. The main purpose of this dissertation is to explore the potential of the Data Envelopment Analysis methodology to assess the performance of Brazilian organ donation and transplantation services, as well as the potential of the Malmquist Productivity Index to assess productivity changes over time and the effect of COVID-19 in these services. To do this we use data from 17 Brazilian states and the Federal District regarding the solid organ donation and transplantation process. Our results show that there is a wide variation in performance among Brazilian states and among the models used, suggesting that better use of resources can lead to more and better transplant services and, ultimately, increase the quality and access to these services for patients who need this procedure. In addition, this study complements findings from previous studies and serves as a basis for future studies to delve into this topic.

Keywords: Unified Health System, Organ donation-transplantation process, Data envelopment analysis, Performance assessment, Malmquist Productivity Index, COVID-19.

1. INTRODUCTION

The Brazilian public health system has the most extensive public organ transplant program in the world, which serves more than 90% of transplants and offers full coverage of all the costs involved, from organ donation to post-transplant follow-up (Almeida, Araujo, Roza, Siqueira and Rocha, 2021; Garcia, Abbud-Filho, Felipe and Pestana, 2015). However, there is a strong inequality in terms of access and inefficiency of health services within and among States due to social, geographic, logistical and infrastructure challenges that affect the organ donation-transplantation (ODT) process (Almeida *et al.*, 2021; Stopa, Malta, Monteiro, Szwarcwald, Goldbaum and Cesar, 2017). Due to the impact that health has on society and the escalating costs of providing health services to the population, such as transplants, it becomes increasingly important to foster improvement in the health sector, aimed at making health services more efficient (Macêdo, Moura, Sant'ana and Silva, 2015). Consequently, performance measurement of health services is crucial to better manage resource allocation and cost reduction, whilst maximizing the quantity and quality of the services delivered and improving outcomes in organ donation and transplantation.

In recent decades, the measurement of efficiency and productivity in the healthcare sector has expanded (Hamzah and See, 2019) and methods such as Data Envelopment Analysis (DEA) and the Malmquist Productivity Index (MPI) have been widely used. These tools can assist health professionals and policymakers decide on future initiatives in order to provide a better service and achieve health objectives. By measuring performance, health organizations can assess whether they are progressing towards predetermined objectives, detect deviations from the plan and pinpoint areas of strengths and weaknesses (Purbey and Bhar, 2007). Making comparisons among different health organizations - such as the Brazilian States transplant service delivery - offers the possibility to explore new options and different strategies, allows technology transfer and can be an opportunity to reconsider and reformulate current policies, health programs and initiatives in light of comparative evidence (Papanicolas and Smith, 2013).

This study is justified by the relevance of organ transplantation as a treatment for several medical conditions (Almeida *et al.*, 2021), the life-changing and often life-saving nature of this type of treatment, as well as the financial impact such procedures have on the Public Health System of Brazil. Despite the clinical and financial relevance of organ donation and transplantation, there are still limited studies on this topic around the world, and in Brazil, only a few studies have assessed the

performance of the ODT process, and those who have studied this topic have focused primarily on kidney transplantation. Furthermore, the studies that exist have not carried out an in-depth analysis of the process and its glitches, along with the fact that they have not considered some important indicators in the analysis (e.g. number of patient survivors and transplantation waiting list). The models proposed in this study are different from all the models used in previous studies. Furthermore, using data from 2018 to 2020 provides an updated overview of the ODT process and the impact of the COVID-19 in the sector, which can help in understanding important aspects of the organ donation and transplantation process. In this respect, this study fills in a gap in the literature regarding solid organs transplantation (SOT). In addition, it also illustrates how regional differences in human resources and medical infrastructure lead to disparities in the ODT processes among states.

The objective of this research is to evaluate the performance of solid organ transplant services offered in Brazilian states and the Federal District, using Data Envelopment Analysis. In particular, this study seeks to provide new evidence related to the performance of solid organ transplantation more broadly, assessing the six types[1] of solid transplants performed in the Brazilian public system between 2018 and 2020, including an analysis of the impact of the COVID-19 pandemic on the provision of ODT services. The study also assesses the impact of the scale of operations and the geographic variations on access and quality of the ODT services delivered. Finally, the results obtained by the best performer states can serve as a benchmark for other states regarding the use of financial and human resources, infrastructure and processes to help health professionals, managers and policymakers better plan resource allocation.

The remainder of the dissertation is organized as follows: Section 2 provides the background of the Brazilian public health system and its organ donation-transplantation services and provides an overview of performance measurement in the health sector. In addition, it briefly introduces the general aspects of the DEA and the previous studies that used this method in the health sector. Section 3 presents the models used in this study and their results in order to highlight the value and need to improve the current health system including the suggestion of targets for some of the underperforming states. Section 4 draws the concluding remarks.

[1] By solid organs we consider kidney, liver, heart, lung, pancreas and simultaneous pancreas and kidney transplantation.

2. LITERATURE REVIEW

2.1 The Brazilian public health system and its organ donation-transplant services

Brazil has a universal public health system called Unified Health System ("*Sistema Único de Saúde*"; SUS) and it is "considered to be the only country with a population of more than 200 million people to have a universal health care system" (Donida, Costa and Scherer, 2021: 2). The SUS allows the Brazilian population to have access to free health services at the point of service provision "which includes a full ambulatory and hospital medical care along with the provision of several drugs, including those listed in the exceptional drug program, part of the high-complexity outpatient treatment of rare or low-prevalence diseases" (Medina-Pestana, Galante, Tedesco-Silva Jr., Harada, Garcia, Abbud-Filho, Campos and Sabbaga, 2011: 473). Also, individuals who are covered by private health plans often receive complex and costly surgical procedures such as organ transplants, cancer care and hemodialysis through the public health system, due to limited coverage of these procedures by private insurance plans (Marinho and Araujo, 2021; Massuda, Hone, Leles, Castro, Atun, 2018).

Although the Brazilian public health system provides care for more than 70% of the population (IBGE, 2020), the country has one of the lowest proportions of public spending on health when compared to Latin America and Organisation for Economic Cooperation and Development (OECD) countries (Massuda *et al.*, 2018). It is also the only country with a universal health system where public health expenditure is lower than private sector expenditure (Castro, Massuda, Almeida, Menezes-Filho, Andrade, Noronha, Rocha, Macinko, Hone, Tasca, Giovanella, Malik, Werneck, Fachini, and Atun, 2019). This underfunding is expected to increase in the coming years, as the Constitutional Amendment 95 of 2016 set a limit on federal spending on primary healthcare from 2018 to 2036, to 15% of the Net Revenue in 2017 with spending levels adjusted for inflation, representing a projected decline in the health budget of R$415 billion by 2036 (Massuda *et al.*, 2018). These austerity measures pose a threat to the further expansion and sustainability of the SUS with consequences for equity and health outcomes (Castro *et al.*, 2019).

The Unified Health System is one of the most complex public health systems in the world due to its reach and multiplicity of health services (Ministry of Health of Brazil, 2021a). Consequently, some of its programs and initiatives have been largely recognized as an international reference and have been studied, such as the programs

on tobacco control, AIDS and organ transplantation (Paim, 2015; Medina-Pestana *et al.*, 2011).

Brazil has the most extensive public organ, tissue and cell transplant program in the world, which is guaranteed to the entire population by the SUS, and ranks second in the absolute number of transplants performed, behind the United States (Almeida *et al.*, 2021; Ministry of Health, 2021b). The first organ transplant in Brazil was a kidney in 1964 (Garcia *et al.*, 2015). Since then, the number of organ and tissue transplants has been growing considerably. In 2020 alone, 5,833 solid organ transplants were performed, of which 3,813 were kidney transplants (Ministry of Health, 2021c). Garcia *et al.* (2015) report a growth rate of about 10% in solid organ transplants from 1999 to 2014. Other organs such as bone marrow, heart valves, bones, tendons and skin are also transplanted by the public health system (Ministry of Health, 2021c). Over 95% of all transplantations in Brazil are performed by the SUS, which provides patients with full coverage of costs of organ transplantation, from the search for a potential donor to the post-transplant follow-up, including preparatory exams, surgery, follow-up and post-transplant medication (Almeida *et al.*, 2021; Ministry of Health, 2021b). From 2016 to 2019, public spending on these activities has increased by 20% (Almeida *et al.*, 2021).

The increased demand for organ transplants may be associated with ageing and population growth, the growth in chronic diseases such as diabetes and hypertension and also bad habits (Marinho and Araujo, 2021; Gómez, Jungmann and Lima, 2018) which means an increment of demand for health services, health professionals, medicines and hospitals. At the same time, this increased demand for health services requires a redesign of care to deal more effectively with chronic diseases (Gragnolati, Lindelow and Couttolenc, 2013). An increase of more than 4% of the GDP in health spending in Brazil is foreseen by 2050, with factors related to population growth and ageing and the increase in chronic diseases having the highest impact on spending in the coming years (World Bank, 2018; Gragnolati, Jorgensen, Rocha and Fruttero, 2011).

The private sector can participate in the SUS in a complementary way when the public sector does not have sufficient availability to guarantee care coverage for the population in a given area (BRAZIL, 1990a). In many cases, part of the physical structure used to provide medium and high complexity health care services is private but funded by the SUS (Barbosa, 2013). Regarding organ transplants, private hospitals

frequently are employed to perform organ donation and transplants such as liver transplants (Gómez *et al.*, 2018).

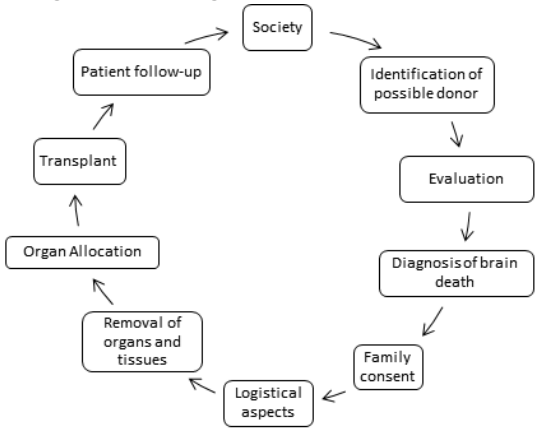
The National Transplant System (SNT) coordinates all organ donation and transplantation activities of all states and municipalities and provides the appropriate logistics to ensure that organs and tissues are delivered in adequate conditions to allow transplants to take place (Moura, 2021). The SNT manages a single waiting list for "organ transplantation that includes patients covered by both the public and private healthcare sector" (Garcia *et al.*, 2015: 1535). This waiting list considers technical, geographic and urgency criteria specific to each organ, in order to select the most appropriate organ receiver (Costa, Balbinotto Neto, Sampaio 2014; Marinho and Cardoso, 2007). "It should be emphasized that the patient waiting list is not defined by patient UF [Federative Units] of residence, but rather by the UF of the transplant unit for which the patient is on the waiting list" (Soares, Brito, Magedanz, França, Araújo and Galato, 2020: 3).

Despite the large volume of surgeries performed in Brazil, the number of people on the waiting list to receive an organ is still large (Ministry of health, 2021b). The total number of patients on the active patient waiting list in December 2020 for solid organs amounted to 28,658 people, with 12,757 new entries and only 31% of potential donors becoming effective donors (ABTO, 2020). In Brazil, organ donation from the deceased can only be done after the donor's brain death[2] and with the family's authorization (Ministry of health, 2021b). In 2020, 42% of family members refused to donate organs (ABTO, 2020). These numbers indicate underutilization of potential donated organs that can occur due to the inefficiency of the donation process or due to the low rate of organ donation approval by the families of the potential donors (Almeida *et al.*, 2021). The low availability of organs can result in long waits for a transplant, in patients dying while they wait for organs and in patients being removed from the transplant list due to deterioration of their clinical status (Siqueira and Araujo, 2018; Ozcan, Begun, McKinney, 1999). One factor that contributes to the "growing waiting list is inefficient management of available organ supply" (Marinho and Araujo, 2021: 570).

[2] Brain death is defined as the total and irreversible arrest of the activity of the brain trunk and hemispheres, requiring two clinical neurological exams and a complementary graphic exam to confirm it. When no contraindications that pose risks to the receptors are identified, we will have a potential donor. During this process, the cardiorespiratory function is maintained through medical devices and medications, in order to guarantee the viability and quality of organs and tissues that can be used (Pereira, Fernandes and Soler, 2009).

The ODT process begins with the identification of a patient with clinical criteria for brain death in a hospital, a potential donor, who must be notified to the Organ Notification, Procurement and Distribution Centres (CNCDOs)[3], whereas the Intra-Hospital Commission for Organ and Tissue Donation for Transplantation (CIHDOTT)[4] or Organ Procurement Organizations (OPOs)[5] are responsible for identifying the potential donor until their conversion into an effective donor (Pereira *et al.*, 2009). After confirming the brain death, in case of family approval for organ donation, the CNCDOs establish the distribution of donated organs and tissues and identify the corresponding teams for their removal and the OPO or CNCDO will inform which organs will be removed as well as the start time of the procedure (Pereira *et al.*, 2009). Figure 2.1.1 illustrates the stages of the ODT process.

Figure 2.1.1 Stages of the organ donation-transplantation process



Source: Adapted from Garcia (ed), 2017

It is estimated that logistical problems are responsible for 5 to 10% of the causes of non-accomplishment of organ donation (Pereira *et al.*, 2009). "Although the states cannot directly control the number of transplants and of brain death notifications, they are responsible for managing all available resources to ensure that donor conversion occurs" (Marinho and Araujo, 2021: 574). The states can maximise available resources through a combination of training and practical steps. Such steps include raising public awareness about the clinical need for organ donors as well as the procedures and authorisation needed to undertake them. In addition, they can enhance the training of the health professionals on how to identify suitable donors, as

[3]CNCDOs are "responsible for coordinating transplant activities at the state level, promoting the registration of potential recipients of organs and tissues. Its duty is to communicate to the SNT the registrations made for the organization of the national list of recipients; receive notifications of brain death and determine the referral and arrange the transport of organs" (Ministry of Health, 2021b).
[4]CIHDOTT must be created in hospitals with more than 80 beds, with the aim to detect possible organ and tissue donors and enable the diagnosis of brain death (Ministry of Health, 2021a).
[5]OPOs are responsible for organizing the search for organ and tissue donors in hospitals located in their area of operation under the management of the Transplant Centre and the National System of Transplants (Moura, 2021).

well as improve the allocation of all necessary resources for organ donation and transplantation, such as intensive care unit (ICU) beds, medical teams and timely laboratory tests for diagnosis of brain death (Marinho and Araujo, 2021; Siqueira and Araujo, 2018).

Despite the contribution of the SUS in expanding access to health services and improving the health of the population, there are still real inequalities in access to health services across the country (Stopa *et al.*, 2017). The size of Brazil amplifies disparities in access to health services and health outcomes across states, with worse outcomes in lower socioeconomic populations (Siqueira and Araujo, 2018; Massuda *et al.*, 2018). Brazil is a country with continental dimensions that is divided into five geographic regions, 26 states plus the federal district with different demographic, climatic, economic, social, and health conditions, on top of widespread internal inequalities (Paim, Travassos, Almeida, Bahia and Macinko, 2011). People residing in the South and Southeast regions - the more developed and wealthier regions- have greater access to health services when compared to residents of other regions (Siqueira and Araujo, 2018; Stopa *et al.*, 2017). The South and Southeastern regions cover about 20% of Brazil's territory but concentrate 57% of the Brazilian population, 73% of the Gross Domestic Product (GDP) and most professionals affiliated to the Brazilian Transplantation Society, while the North region, which covers the largest part of the Brazilian territory, has the lowest population density and is the second poorest region (Medina-Pestana *et al.*, 2011; Paim *et al.*, 2011).

With regard to transplants, states in the South and Southeast regions have one of the lowest rates of family refusal to donate organs and one of the highest rates of conversion of potential donors into real donors among the Brazilian states (ABTO, 2020). These regions also have better performance in providing transplant services (Siqueira and Araujo, 2018) and have the highest national rates of brain death notification rates (ABTO, 2020). In addition, areas with greater population density and easier access to health systems allow for a high number of transplant services and organ donation and harvesting services, as these patients need to travel less for pre-and post-transplant appointments. Furthermore, in these areas, there is a greater number of nearby donors and a greater number of health professionals trained in transplantation (Gómez *et al.* 2018; Marinho, Cardoso and Almeida, 2011, Medina-Pestana *et al.*, 2011).

Currently, there are 586 establishments authorized for the removal of organs and tissues in Brazil, 380 establishments authorized to perform solid organ transplants (Ministry of Health, 2021c). Regarding distributions among States, the vast majority of transplant centres are located in the Southeast (190) and Northeast regions (78), followed by the South (73), Midwest (30) and the North regions (9) (Ministry of Health, 2021c). There is also an uneven distribution of CNCDOs among states and regions (Ministry of Health, 2021c).

Many limitations and difficulties of different nature still remain in the Brazilian public health system, such as poor infrastructure, management and structural problems, low public funding, fragmentation and poor quality of service, long waits for medical care and neurological examinations, limited access to diagnostic services and specialist care, insufficient human resources, overcrowded ICU, broken equipment, delay in laboratory tests (Gómez *et al.*, 2018; Siqueira and Araujo, 2018; Gragnolati *et al.*, 2013). Consequently, health outcomes are lower than they could be (Gómez *et al.*, 2018; Siqueira and Araujo, 2018; Gragnolati *et al.*, 2013). Considering that universalization and equity in the access to health care services are key principles of the SUS, which are constitutionally guaranteed and regulated, the redesign of the health policies is essential to reduce disparities among regions and different social levels (Stopa *et al.*, 2017).

2.2 Performance measurement in the healthcare sector: an overview

There is an assumption that healthcare institutions' inefficiency has contributed to the high and escalating costs of health services (Worthington, 2004). In order to deal with this issue in delivering public services, the pursuit of efficiency and productivity has become of interest to policymakers in many countries (Hamzah and See, 2019) and consequently to healthcare managers.

Pablos-Heredero, Renedo and Merodio (2015: 4871) define efficiency in the healthcare context as "the ability of the observed health care unit to maximize the results of the service delivery subject to some resources and constraints, or conversely the ability to maintain the service delivery with lower levels of resource consumption". Gragnolati *et al.* (2013: 7) state, in turn, that "an efficient health system is one that produces the greatest improvement for a given level of spending". However, the Brazilian public health system is still struggling to find an equilibrium between public

spending and the achievement of better outputs for the resources invested in the sector (World Bank, 2018).

In fact, it is unquestionable that the SUS faces challenges to offer a quality, efficient, effective and sustainable health service that meets the needs of its population (World Bank, 2018). Using Data Envelopment Analysis - DEA, a World Bank study (World Bank, 2018), in Brazil, estimates the efficiency level of primary health care at 63% and at 29% for medium and high complexity levels, which indicates an annual waste of approximately 20% of the total expenditure on health, equivalent to about R$22 billion. These results show that the health system operates with relatively high levels of inefficiency. Therefore, there is some evidence that the public health system could obtain better results even within the current financing if the inefficiencies were acknowledged and addressed, which is particularly important in an underfunding system like the SUS (World Bank, 2018).

According to Gragnolati *et al.* (2013), there is a broad agreement on the need to improve the performance of the health care sector to be able to properly respond to the needs of the population, to meet the expectations of different stakeholders, to increase service quality and access to care. Performance in the health sector is a general term to describe the success of healthcare delivery, which can take into account efficiency as well as other facets of a health system assessment (Cylus and Smith, 2013).

The performance of health systems can be assessed with reference to a broad range of indicators relating to inputs (resources), outputs (results) and outcomes (impacts) (Gragnolati *et al.*, 2013). In addition, health performance measures can relate to many different aspects of the health system under observation (e.g. efficiency, effectiveness, equity, responsiveness, quality, access). All these aspects can make it difficult for stakeholders to objectively analyse the data available, which has led to the use of composite indicators in order to obtain an overall view of the performance of the organizations (Smith, Mossialos, Papanicolas and Leatherman, 2009). Composite indicators combine separate performance indicators into a single index or measure and are used to compare the performance of different professionals, organizations or systems, providing a more complete view of performance (Smith *et al.*, 2009).

One methodology broadly used in the health field that incorporates into a single metric a wide variety of inputs and outputs is Data Envelopment Analysis (DEA);

it also can encompass measures related to quality (Schumock, Shields, Walton and Barnum, 2009) and socioeconomic characteristics. According to Cordero, García-García, Lau-Cortés and Polo (2021) and Worthington (2004), this is one of the reasons why most studies that measure the productivity and efficiency of health institutions have chosen this method rather than parametric methods.

2.3 The data envelopment analysis - general aspects

Data envelopment analysis is a technique for analysing the efficiency of services and organizations (Charnes, Cooper and Rhodes, 1978). The DEA method was created by Charnes, Cooper and Rhodes (CCR) in 1978, and the pioneering model is known as the CCR model. This programming technique can use multiple outputs and inputs without requiring preassigned weights and comprehends both technical and scale inefficiencies (Banker, Charnes and Cooper, 1984). "Efficiency of a decision making unit is measured as the ratio of the sum of its weighted outputs to the sum of its weighted inputs" (Hamzah and See, 2019: 464). In 1984, Banker, Charnes and Cooper extended the CCR model, originating the BCC model (Amado and Santos, 2009). DEA is a very effective and practical tool since it allows evaluating the performance levels quantitatively as well as qualitatively and in an objective manner (Yang, Yeung, Chan, Chiang and Chan, 2010).

The basic idea behind the DEA technique is to determine the relative efficiency levels of different units - named decision-making units (DMUs)[6] by constructing an 'efficient frontier' which envelops all inefficient DMUs and indicates the best practices (Kohl, Schoenfelder, Fügener and Brunner, 2019; Safdar, Emrouznejad and Dey, 2016). An efficiency score ranging from 0 to 1 or 100% is assigned to all units by measuring their distances from the efficient frontier. "Units which lie on the frontier are said to be 100% efficient, while others which are away from the frontier are inefficient, with efficiency scores below 100%" (Safdar *et al.*, 2016: 3). The most efficient DMUs become benchmarks for inefficient units (Silva, Moretti and Schuster, 2016). After solving the DEA model, for each inefficient DMU it is possible to identify its "benchmarking group"; "that is, a group of units that are following the same objectives and priorities but performing better. In this regard, DEA aims to respect the priorities of each DMU by allowing each one of them to choose the weight structure for inputs and outputs that most benefits its evaluation" (Amado and Santos, 2009: 45). Another interesting

[6] DMUs can be business organizations, universities, hospitals, pharmacies, cities, countries, departments, professionals, among others.

feature of this method is that it allows the calculation of target values of inputs or outputs required for inefficient units to reach the efficiency level (Safdar *et al.* 2016).

There are a number of considerations involved in developing a DEA model. In particular, it is important to (1) define decision-making units for analysis (Schuster, Muller and Rodrigues Junior, 2018); (2) define the model, which means selecting the input and output variables (Schuster *et al.*, 2018; Cantor and Poh, 2018); (3) select the model orientation, which can be output-oriented or input-oriented (Kalinichenko, Amado and Santos, 2021; Cantor and Poh, 2018; Schuster *et al.*, 2018); (4) select the scale assumption, which can be Constant Returns to Scale (CRS) or Variable Returns to Scale (VRS) (Kalinichenko *et al.*, 2021; Cantor and Poh, 2018; Schuster *et al.*, 2018). It is of paramount importance to perform these steps properly, as each of them has the power to affect the insights gained through the analysis (Cantor and Poh, 2018). According to Souza, Scatena and Kehrig (2016) and Silva, Costa, Abbas and Galdamez (2017), it is essential for a correct application of the method that the units are comparable and operate under the same conditions in order to ensure homogeneity among the units that make up the study. In addition, it is important to use accurate and reliable data to ensure exactness and comparability of data, unreliable data can compromise all the analyses (Hollingsworth, Dawson and Maniakakis, 1999). One of the limitations of health performance assessments is related to the scarcity, quality and "lack of consistency of data over time (due to definitional, measurement or data quality issues)" (Gragnolati *et al.*, 2013: 20).

Regarding the selection of input and output variables, this is considered one of the most important steps of the analysis (Kohl *et al.*, 2019; Cantor and Poh, 2018). "Determining whether a factor is an input or an output is not straightforward" (Kohl *et al.*, 2019: 251). Safdar *et al.* (2016) argue that these variables can impact the results and the ability of a specific methodology to provide useful information. Inputs must include all the necessary resources to characterize the analysis and whose variation causes variations in the outputs, while the outputs depend on the objectives of the DMUs being evaluated (Kohl *et al.*, 2019; Schumock *et al.*, 2009).

Kohl *et al.* (2019), Silva *et al.* (2017) and Souza *et al.* (2016) bring attention to the number of inputs and outputs used in the analysis, as the number of these variables can interfere in data discrimination. They recommend that the number of DMUs should be at least twice the multiplication of inputs and outputs to ensure sufficient

discrimination between units. “An operationalized model with many variables tends to be more benevolent, allowing many DMUs to achieve an efficiency score of 1” (Souza *et al.*, 2016: 292).

A DEA model can be either input-oriented or output-oriented. An input-oriented model aims to estimate the minimum possible level of resources used to produce a certain amount of outputs while an output-oriented model aims to determine the maximum level of outputs produced with a certain quantity of inputs (Silva *et al.*, 2017; Safdar *et al.*, 2016; Souza *et al.*, 2016). Basically, the model type will be chosen according to the controllability related to the variables (Hamzah and See, 2019).

Regarding the returns to scale assumption, the two basic DEA models are the CCR and the BCC. “Despite countless extensions, these early models are still the most frequently utilized models” (Kohl *et al.* 2019: 253). The models with “constant returns to scale [CCR] assume that changes in the inputs result in proportional changes in the outputs, while variable returns to scale [BCC] assume that an increase (or decrease) in the inputs does not necessarily lead to proportional changes in the outputs” (Kalinichenko *et al.*, 2021: 5). The efficiency estimate obtained by the CCR model is called technical efficiency, in which DMUs are compared to each other, regardless of the size at which each one operates (Schuster *et al.*, 2018; Silva *et al.*, 2016; Souza *et al.*, 2016). Conversely, in the BCC model, the DMUs are compared only with DMUs that operate on a scale similar to their own. Consequently, the size of the operations is relevant. This efficiency is named pure technical efficiency (Schuster *et al.*, 2018; Silva *et al.*, 2016; Souza *et al.*, 2016). The BCC model makes it possible to assess technical inefficiency from two perspectives, which are through scale inefficiency and management inefficiency (Silva *et al.*, 2016). According to Cantor and Poh (2018), most studies in the health literature use both assumptions for analysis.

The CCR and the BCC models, as initially proposed, only establish that the weights to be attributed to the inputs and to the outputs must be positive. However, this can lead to evaluations based on a weight structure that is not consistent with prior knowledge about the relationship between inputs and outputs. For example, some important inputs or outputs may end up with a very small weight. For this reason, some authors have proposed the introduction of weight restrictions in DEA models (see, for example, Dyson and Thanassoulis, 1988; Podinovski, 2004). The use of weight restriction ensures that variables that have a major impact on the study are

assigned a weight of no less than a predetermined percentage, meaning that all units will be evaluated at those same pre-specified weights (Schumock *et al.*, 2009). In other words, weight restrictions reflect preferences over variables, provide more reliable results and lead to a better representation of a real-life scenario (Safdar *et al.*, 2016).

Another important characteristic of the DEA method is that it can be used to measure changes in productivity over different periods of time using the Malmquist Productivity Index (MPI) (Cordero *et al.*, 2021; Amado, Santos and Sequeira, 2013) which is an index obtained by multiplying two indices: the 'catch-up index' and the 'frontier shift index'. A MPI greater than one suggests progress in productivity, less than one suggests a decrease in productivity, while equal to one means maintenance of the status quo (Amado *et al.*, 2013). The MPI allows us to determine whether the changes in productivity were driven by changes in technological production also named frontier shift effect or by technical efficiency changes, known as the catching-up effect (Cordero *et al.*, 2021). The catch-up effect indicates whether a particular DMU is moving closer or further away from its corresponding efficiency frontier through increases or decreases in its technical efficiency from one period to another while the frontier-shift effect shows changes in the frontier itself which occur when there is a change in the industry to which this unit belongs (Siqueira and Araujo, 2018; Cordero *et al.*, 2021; Amado *et al.*, 2013). When the frontier improves considerably in the period evaluated, it may indicate that there has been significant technological progress or legal changes in the sector. Changes in the frontier can also reflect the impact of environmental factors such as COVID-19 in the health sector.

Among the advantages of using DEA is the possibility of using multiple inputs and outputs without the analysis becoming too complex (Silva *et al.*, 2016) and it does not require any of the rigorous model tests that are required by statistical techniques (Cylus and Smith, 2013). However, the use of the DEA technique in the health care context also shows some significant limitations as it assumes that it is possible to fully characterize the production of health care by identifying a set of inputs, outputs and outcomes of production. However, as pointed out by Amado and Santos (2009), some of these outputs and outcomes are not easily measurable. The analysis can also be vulnerable to data errors. If the data of an efficient DMU is incorrect, this can negatively influence the result of many of the inefficient DMUs (Cylus and Smith, 2013). Amado and Santos (2009: 46) argue that "awareness of these limitations and of their potential impact on the results is necessary if useful information is to be obtained".

2.4 The related studies on the use of DEA

Due to the complexity of services provided by hospitals and the high financial volume invested by the government, the interest in evaluating the efficiency of healthcare services has increased in recent years. According to Silva *et al.* (2016), data envelopment analysis is the most suitable methodology to evaluate healthcare. In fact, a review of the literature shows that the DEA technique has been extensively used to assess the efficiency of the healthcare sector. In this regard, there are many international studies using DEA to measure efficiency in the healthcare sector such as in hospitals, pharmacies, primary care providers, just to name a few.

According to Hollingsworth *et al.* (1999), the first study using DEA to measure the efficiency and productivity of healthcare services is by Nunamaker (Nunamaker, 1983), which focuses on routine nursing services for patients admitted in some hospitals in Wisconsin. Since then, a number of studies in this field have been carried out such as Ozcan (1995) who evaluated technical efficiency across United States metropolitan hospitals to assess the degree of duplication and redundancy in hospital resources and Marinho (2003) who assessed healthcare services delivered in ambulatories and hospitals of the state of Rio de Janeiro in Brazil.

Schumock *et al.* (2009) used, in turn, DEA to evaluate performance across hospital pharmacies and defended the use of this method since it aggregates data into a single comprehensive measure, which enables a comparison of pharmacies' overall relative productivity. The most used performance metric in hospital pharmacy, at the time, was the ratio (output/input), which was a challenge to compare overall performance among pharmacies due to the vast number of different ratios needed to cover the entire scope of activities performed in the sector. For this reason, the use of DEA was considered advantageous.

Other worldwide examples of the use of DEA related to the health sector are: (1) Safdar *et al.* (2016) who demonstrate, by assessing the queuing process in a hospital, a distinctive application of the DEA model, moving away from its traditional usage in analysing a pure ‘production’ process where inputs are turned into outputs; (2) Hamzah and See (2019) who measured the technical efficiency (TE) level of pharmacy services in public hospitals using Double-bootstrap DEA; (3) Cordero *et al.* (2021) who used the Malmquist productivity index (MPI) to measure the changes in efficiency, technology and productivity over time in public hospitals in Panama.

Regarding Brazilian studies using DEA to assess the public health system, one of the first works was carried out by Marinho (1998) who analysed the efficiency of 4 public and 2 private hospitals. Marinho (1998) stated that although DEA was used on a large scale around the world, its use was still scarce in Brazil. Silva *et al.* (2017) reinforce the idea that in Brazil there are few empirical studies using DEA to assess the performance and/or efficiency in the healthcare field.

In recent years, however, some studies have emerged that use DEA to assess and compare the efficiency of public hospitals in Brazil, such as the study by Souza and Barros (2013), which analysed the efficiency of public expenditure on hospital care in Brazilian states in 2009 and 2010. Souza *et al.* (2016), also used DEA but with the purpose of identifying which type of hospital was more efficient: public or private. Silva *et al.* (2016), in turn, evaluated the productive efficiency of 139 hospitals affiliated to the Brazilian Unified Health System in the Southern region in 2014 and 2015 and Silva *et al.* (2017), for the same period of time, assessed the technical efficiency of SUS hospitals in the five Brazilian regions.

In regard to the use of DEA to assess the performance of organ transplant providers, the literature is very scarce. In fact, to the best of our knowledge, only a very few studies have been documented. The first study in this context is that by Ozcan *et al.* (1999), which used this methodology to benchmark organ procurement organizations based on the level of technical efficiency. In Brazil, one of the first studies to measure the efficiency of organ transplantation by the SNT was by Marinho and Cardoso (2007), who evaluated the technical efficiency and scale efficiency of the Brazilian National Transplant System from 1995 to 2003. The results demonstrated a reduction in the efficiency of the SNT during the period, with recovery between 2001 and 2003 and a variation in efficiency related to different types of transplants was also observed.

Costa *et al.* (2014) measured the efficiency in the public kidney transplant system across Brazilian states and their productivity trends from 2006 to 2011. The results of this study show that the states of the South and Southeast regions carry out organ harvesting and transplant activities more efficiently. The results also indicate a large variability between the states and the Federal District, pointing to disparities in the management of resources applied in this sector. This study also identified a change in the efficiency frontier from 2006 to 2011 but did not reveal progress in productivity.

Siqueira and Araujo (2018), found similar results in a study from 2013 to 2015 that examined the technical and scale efficiency of Brazilian public services in kidney transplantation, which showed that states from the South and Southeast regions in Brazil performed better when compared to the poorest states from the North and the Northeast. The research also pointed to decreased efficiency during the aforementioned period and a lack of progress in efficiency in recent years.

Arteaga, Di Caprio, Cucchiari, Campistol, Oppenheimer, Diekmann and Revuelta (2020) used 485 kidney transplant patients from living donors as DMUs to determine the potential success of the transplantation process. A more recent study by Marinho and Araujo (2021) in the Brazilian states and the Federal District applied DEA and the bootstrap method to quantify the efficiency in providing transplant services by converting potential organ donors into real donors in 2018. The study shows variability in terms of the level of efficiency among states, which is in line with the results of the other studies mentioned above. It also indicates that it is possible to increase by 45% the number of transplanted organs performed without increasing the pool of potential donors, which shows that the inefficiency of converting potential donors into real donors contributes to the insufficient offer of organs for transplantation.

The use of the DEA in the health sector to assess efficiency and productivity is essential for better use and prioritization of limited health resources. The literature review above shows us that, despite the widespread use of DEA in the health sector, there is still a gap in the literature related to organ donation and transplantation, especially studies that assess different types of solid organ transplants. Furthermore, studies in Brazil, so far, have used only one kind of output, which is the number of transplants performed and, as inputs, expenses related to hospital and professional services, number of medical teams, OPOs, ICU beds, effective donors and potential donors. The present study addresses these limitations as several output indicators are used and, by disaggregating the ODT process, the study allows a more comprehensive and informative assessment of the performance of the states. Furthermore, in this study, we explore the impact of the COVID-19 pandemic on the productivity of the ODT process. This has not been done previously by other studies, being extremely relevant and contributing to the knowledge in the field.

By measuring performance, the health units, such as Brazilian states, can identify in which areas they are performing above or below expectations, providing

information to the managers in order to understand what is driving reported performance and guidance on where to look for potential solutions (Papanicolas and Smith, 2013). In a nutshell, the purpose of performance measurement is to use the information obtained to enhance the process, improve service quality and increase the efficiency of the health system.

Some of the studies mentioned in this section are presented in Table 1A – in Appendix 1 – which summarizes the information about the studies that have used DEA to evaluate the organ donation and transplantation processes. This table includes the identified studies, the type of DMUs used, the model orientation, the main objectives of the studies, as well as the inputs and outputs used in the analysis.

3. EMPIRICAL ANALYSIS

3.1 The DEA model

Regarding the conceptual model to compare organ donation and transplantation, the framework proposed in this study aims to encompass the performance dimensions considered relevant to be measured in order to compare the transplant service system in Brazilian states. These dimensions are related to the population's needs and demand, resources used, services delivered, access to services, service capacity, quality of service, and outcomes achieved in ODT.

The population's needs for transplants refer to the estimated need for transplants in the period under analysis. The demand for transplants refers, in turn, to the number of new registrations on the transplant waiting list. The resources used by the organ donation and transplantation services include financial, physical and human resources; and the services delivered can be measured using indicators such as the value of hospital services provided, number of transplants performed, number of brain death diagnosis, number of complications treated due to the medical procedure. An indicator of access to ODT services can be the number of establishments authorized to perform transplants and one related to the capacity of the service can be the number of transplant teams. Regarding the quality of the services provided, one classic indicator is the hospital mortality rate (Marinho, 2003). Finally, the health outcomes achieved should measure the change in the health status of the patient attributed to the medical intervention. In other words, they measure the impact of the transplant on the patient's life which can be physical or psychological and related to the quantity and quality of life. As emphasized by Amado and Santos (2009: 47), "the outcomes of care may be of a subjective nature, posing increased challenges for measurement" due to their characteristics. Based on these dimensions and on the performance indicators that they encompass, several measures of performance such as equity of access, economy, efficiency and cost-efficiency can be developed.

The accuracy of the estimated performance measures depends on the use of appropriate and well-specified models, relevant variables, and accurate data (Hollingsworth *et al.*, 1999). The analysis we propose uses three complementary models to evaluate the ODT process in Brazilian states. The first model is related to the organ harvest and donation process, the second model concerns the organ transplant service itself, while the third is a relative equity assessment model in the allocation of

resources for transplantation. Table 3.1.1 shows the research construct model, which lists the inputs and outputs used in the study. Despite the fact that no previous study analysed these three performance dimensions, some of these indicators have been included in performance assessment in this context. In this respect, the last column of Table 3.1.1 indicates previous studies that adopted similar variables.

Table 3.1.1 - Research construct model

Model 1 - Organ Harvest and Donation Process		
Type of Variable	**Description of Variables**	**Previous studies that used the variable**
Inputs {I}	Number of ICU beds	Siqueira and Araujo (2018)
	Number of transplant teams[7]	Siqueira and Araujo (2018)
	Number of family consents for OD[8]	-
Outputs {O}	Number of effective donors	Siqueira and Araujo (2018)
	Donors whose organs were transplanted	Marinho and Araujo (2021)
Model 2 -Organ Transplant Service		
Inputs {I}	Transplant service expenses (Hospital and professional)	Costa *et al.* (2014); Marinho and Cardoso (2007)
	Number of transplant beds[9]	-
	Number of transplant teams	Siqueira and Araujo (2018)
	Number of effective donors	Siqueira and Araujo (2018)
Outputs {O}	Number of transplants performed (AIH)	Marinho and Araujo (2021); Siqueira and Araujo (2018); Costa *et al.* (2014); Marinho and Cardoso (2007)
	Number of patient survivors[10]	-
Model 3 - Equity in the Allocation of Resources for Organ Transplantation		
Inputs {I}	Transplantation waiting list (in December)	-
Outputs {O}	Number of transplant beds	-
	Number of transplant teams	Siqueira and Araujo (2018)

Note: OD = Organ Donation

As discussed previously, the choice of variables is one of the most fundamental steps of the analysis and it should include all the variables deemed important for the performance assessment. In this particular study, the selection of variables was based on our understanding of the ODT process and on previous studies in the area and it took into account data availability. In particular, the outputs were chosen in consistency with the main objectives of the study. Then, we identified the inputs necessary to ensure the delivery of the chosen outputs.

[7] The number of medical teams related to solid organ transplantation is derived from the sum of teams for each of the types of solid organ transplantation.
[8] The number of family consents is calculated from the difference between potential donors and family refusals to donate organs and tissues.
[9] For the variable number of transplant beds, the data are available monthly, so the annual average was calculated.
[10] The number of patient survivors is calculated from the difference between transplants performed and hospital deaths.

In which regard to the inputs and outputs, this definition is not always straightforward, as we are working with three different models, some variables may appear as inputs in one of the models and outputs in another, according to what each model is evaluating. Model 1 seeks to assess the organ donation and harvest process in the Brazilian states and the Federal District, so for this model, the input number of ICU beds represents the physical infrastructure necessary to provide organ transplantation. According to Siqueira and Araujo (2018), ICU beds are necessary for the identification and maintenance of deceased donors with brain death and are essential resources to reduce avoidable loss of potential donors and increase the number of brain death notifications. The other two inputs, number of transplant teams and number of family consents for organ donations, respectively, represent the human resources necessary for the service provision whilst the latter, indirectly, represents the resources needed to perform transplants. With regards to the outputs, the number of effective donors[11] represents the conversion of potential donors into real donors which is a necessary resource for a transplant to be performed (Siqueira and Araujo, 2018). The variable number of donors whose organs were transplanted represents the effective use of the organs that were harvested, in other words, it indicates that the organ was given to a compatible organ receiver on its ischemia time[12].

In model 2, the input hospital and professional services expenses correspond to the financial resources necessary to promote transplant surgeries; the number of transplant beds and the number of transplant teams represent the physical and human resources, respectively, while the number of effective donors represents the real capacity of the organ donation services. The number of transplants performed (included as an output) represents the entire ODT process, which is directly linked to the other variables, and the number of patient survivors is the final objective of the organ transplantation service, as the objective is not just to offer the highest number of transplants possible to those who need them, but to ensure that the transplant recipients survive the procedure. Finally, the objective of model 3 is to evaluate the equity in the distribution of resources for transplantation, in order to verify if the resources available are consistent with the needs. In this respect, in model 3 the

[11] Effective donors: "the number of brain death notifications minus the number of potential donors lost because of factors such as medical contraindications, family refusal, and maintenance failure" (Siqueira and Araujo (2018: 7).
[12] Ischemia time is the time it takes to remove an organ and transplant it into another person. Each organ and tissue have a maximum time for removal, some of which must be removed before the donor cardiac arrest and others up to 6 hours after cardiac arrest. Furthermore, there is a maximum extracorporeal preservation time that varies from 4 to 6 hours for heart and lung and up to 5 years for bones (Ministry of Health, 2021b).

transplantation waiting list is used as an input related to population needs and the number of beds and transplant teams represent the results related to equity of resources.

To measure each Brazilian state's performance, we have used the Efficiency Measurement System (EMS) software (Scheel, 2000), version 1.3.0., and DEA models with output orientation. Having taken into account that the ODT process goals are to maximize the quantity and quality of the transplant services provided rather than to minimize the resources used in the process, the output-oriented models are the most appropriate models for this study. This is also in line with the studies by Marinho and Araujo (2021), Siqueira and Araujo (2018) and Costa *et al.* (2014). Regarding the scale assumption, CRS and VRS assumptions were used in the study, since one of the objectives of the study is to assess the impact of scale by dividing the performance scores obtained with the CRS assumption by the scores obtained with the VRS assumption. Using both assumptions allows us to verify whether the states poor performance is related to management problems, scale problems or both. We also used weight restrictions related to some inputs and outputs, in order to guarantee reliable results, discrimination in the analysis and also to incorporate some production trade-offs between variables (Podinovski, 2004). Please, refer to Appendix 2 - Table 2A - for more details about the weight restrictions incorporated in the models.

3.2 Data and results

3.2.1 Data

The research sample consists of 17 Brazilian States and the Federal District, in the five Brazilian regions that acted in the process of organ donation and transplantation services linked to the Brazilian Unified Health System and the analysis period is from 2018 to 2020. Each of these states and the Federal District is called DMU in the DEA models used in this study. The sample selection criterion was the participation of the UF in the ODT services and the complete availability of information. The States of Amapá, Roraima and Tocantins were excluded from the analysis because; according to the Brazilian Transplant Registry (RBT) (ABTO, 2020), they do not perform solid organ transplants. The states of Amazonas, Alagoas, Mato Grosso and Sergipe were excluded from the analysis because they did not have information available on transplant teams in some of the years analysed. As indicated previously, transplant teams represent a fundamental resource of the ODT process.

Excluding these states allowed us to present a balanced panel for all the years analysed and perform a dynamic analysis. Acre and Rondônia were initially included in the analysis but they were later excluded as a result of being identified as outliers in some of the models. In order to identify the outliers, we used the procedure proposed by Banker and Chang (2006). Table 3A, presented in Appendix 3, shows the data used in the models.

The data used in this study was collected from the website of the Department of Informatics of the Unified Health System (DATASUS) of the Ministry of Health of Brazil, on the basis of the System of Hospital Admissions of the SUS - SIH/SUS[13], and the National Registry of Health Establishments - CNES[14]; and from the Brazilian Transplant Registry (RBT) available on the Brazilian Association of Organ Transplantation[15] (ABTO) website.

Although we believe that the variables and models used in the analysis allow us to obtain a fairly comprehensive view of the performance of the 17 States and the Federal District, some caution needs to be exercised in the analysis of the results. This is due to the fact that some of the data used in the study might eventually be a source of some potential injustices. For example, in Models 1 and 2, the number of transplant teams is used as an input. However, different teams might have different sizes. Therefore, in future studies, it would be important to collect information about the size of the teams that operate in each state and in the Federal District as this has the potential to promote a fairer assessment. Another limitation related to the data refers to the fact that the transplant beds, registered in Datasus, do not distinguish transplant beds among the different types of transplants, and may be related to any type of transplant, solid or not. Because in our analysis the output variables focus on the transplant of solid organs, that means that if some states have a high proportion of beds allocated to non-solid organ transplants, they might be penalized in the analysis. In addition, the output number of survivors was calculated from the number of transplants performed instead of the number of organ recipients, due to the lack of

[13] The SIH/SUS is the system that records hospital admissions that occur in the SUS. Its basic document is the Hospital Admission Authorization (AIH), which enables the patient's admission and generates amounts for payment (OPAS, 2008).
[14] The National Register of Health Establishments - CNES registers the characteristics of the establishments, allowing a broad view of the existing physical and human resources, in SUS and non-SUS. CNES queries can be made through the Datasus website (OPAS, 2008).
[15] ABTO is a civil medical society, which aims to encourage the development of all activities related to ODT in Brazil, contributing to the establishment of standards, as well as the creation and improvement of legislation related to the subject (Moura, 2021).

this information, which leads us to assume that each transplant performed corresponds to a different recipient. Therefore, in cases where a recipient received more than one transplant, this contributes to a bias in the estimate of the number of survivors, however, as the number of recipients who received more than one transplant is expected to be residual, the way in which we estimated this variable is likely not to impact on the quality of the output and, consequently, on the quality of the analysis.

3.2.2 Descriptive statistics of the performance scores

Table 3.2.2.1 shows the descriptive statistics of the variables used in the study. To begin with model 1, these results reveal some significant discrepancies among the inputs and outputs used to deliver ODT services in the Brazilian states under analysis. For instance, the analysis of the full data set allows us to conclude that in 2018, the majority of the DMUs had ICU beds well below the average, the same is observed in 2019 and 2020. Likewise, in regard to the other variables, at least half of the states had a lower number than the average of the variables used in the study from 2018 to 2020. However, the states of Minas Gerais, Paraná, Rio de Janeiro, Rio Grande do Sul and São Paulo presented numbers higher than the average, or at least very close, for all variables and years in the analysis, not only for model 1 but also for models 2 and 3.

While the average number of ICU beds in 2018 was 2291.5, the states with the highest number of ICU beds are states in the Southeast region with 12024 for São Paulo, 6091 for Rio de Janeiro and 4348 for Minas Gerais, while the lowest numbers and much lower than the average are found in states in other regions, such as Piauí with 323 ICU beds, Mato Grosso do Sul with 488 and Rio Grande do Norte with 549. The number of transplant teams presents the same discrepancy profile. Analysing data from 2018, we can observe that while São Paulo and Minas Gerais had 79 and 30 transplant teams respectively, Piauí and Mato Grosso do Sul had 1 transplant team each. Consequently, this deviation also occurs at the output level, for example, for the same period São Paulo performed 2418 transplants, Paraná 986 and Minas Gerais 716, while the smallest number of transplants performed was in Piauí (18) and Mato Grosso do Sul (17).

Table 3.2.2.1 - Summary statistics for the variables used in the study

MODEL 1					
	Nº of ICU beds {I}	Nº of transplant teams {I}	Nº of family consents for OD {I}	Nº of effective donors {O}	Donors whose organs were transplanted {O}
2018					
Mean	2291.5	14.28	423.56	192	164.78
Standard-deviation	2845	18.68	522.32	262.74	219.17
Maximum	12024	79	2268	1089	923
Minimum	323	1	71	7	6
2019					
Mean	2301.94	14.78	457.89	204.61	173.56
Standard-deviation	2865.19	17.73	544.11	260.34	210.31
Maximum	12515	73	2382	1080	885
Minimum	296	1	60	4	4
2020					
Mean	3511.67	14.56	442.94	182.05	152.11
Standard-deviation	4040.54	18.97	569.51	260.77	205.66
Maximum	17471	81	2478	1094	875
Minimum	620	1	42	4	4

MODEL 2						
	Transplant Service Expenses {I}	Nº of Transplant Beds {I}	Nº of transplant teams {I}	Nº of effective donors {I}	Nº of Transplants Performed (AIH) {O}	Nº of patient survivors {O}
2018						
Mean	24706946.56	53.45	14.278	192	425.28	405.5
Standard-deviation	34136310.91	63.1	18.68	262.74	578.81	550.15
Maximum	140532758	256.33	79	1089	2418	2301
Minimum	534427.43	3	1	7	17	16
2019						
Mean	25807768.97	53.79	14.78	204.61	439.28	420.94
Standard-deviation	34224939.36	62.89	17.73	260.34	569.1	545.57
Maximum	141025384.2	259.25	73	1080	2374	2278
Minimum	239041.49	4	1	4	8	7
2020						
Mean	20050325.75	53.01	14.56	182.06	323.56	309.44
Standard-deviation	29634660.81	61.02	18.97	260.77	476.13	454.41
Maximum	124236810.6	253.33	81	1094	2012	1917
Minimum	126204.14	4	1	4	4	4

MODEL 3			
	Transplant waiting list (December) {I}	Nº of Transplant Beds {O}	Nº of transplant teams {O}
2018			
Mean	1349.83	53.45	14.28
Standard-deviation	2872.51	63.1	18.68
Maximum	12531	256.33	79
Minimum	78	3	1
2019			
Mean	1492.61	53.79	14.78
Standard-deviation	3020.3	62.88	17.73
Maximum	13258	259.25	73
Minimum	78	4	1
2020			
Mean	1576.5	53.01	14.56
Standard-deviation	3562.99	61.02	18.97
Maximum	15587	253.33	81
Minimum	126	4	1

It is possible to see both in the table above and in table 3A, in Appendix 3, great variability in the data among Brazilian states. Regarding the impact of COVID-19 on the ODT process in Brazil, we can observe in terms of absolute numbers, in Table 3A, that the number of transplant teams and the number of family consent for OD did not vary in the Brazilian average compared to the previous period, however, the number of effective donors and transplants performed suffered a reduction of 11% and 26%, respectively, being in line with the RBT (ABTO, 2020). In fact, the Brazilian Transplant Registry claims that the drop in the rates of ODT from deceased donors was not as large as feared at first and varied between regions according to the regional severity of the pandemic, while transplants from living donors, as they represent elective surgeries, were suspended for varying periods in most states, showing, thus, a bigger drop. The impact of the COVID-19 pandemic on the ODT process performance will be discussed in subsection 3.2.7, which is related to the dynamic analysis.

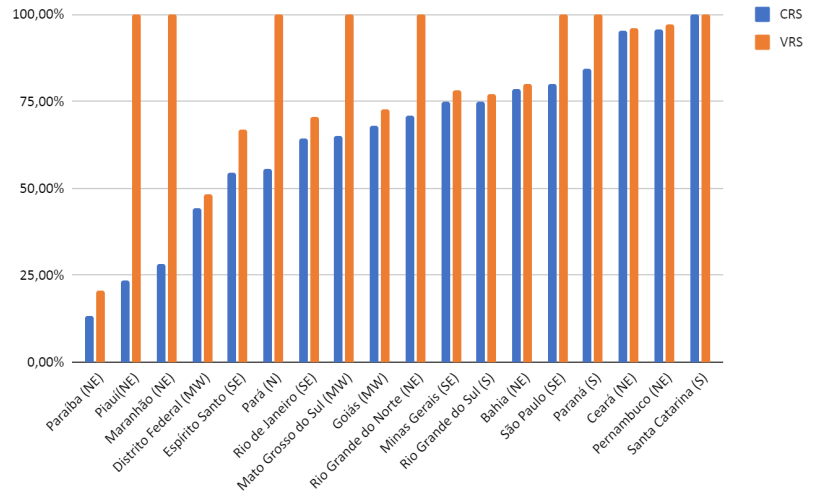
The summary statistics for the results obtained by the models used in the study are presented in Table 4A, Appendix 4. Regarding the overall average score for the three models, model 2 shows the best average which means the smallest variation among the results, and model 3, the worst, resulting in the greatest standard deviation among the results. In other words, this means that model 2 presents the most homogeneous results among Brazilian states, with less variation among DMUs, while model 3 presents a greater discrepancy in terms of performance of the states in the equity of distribution of resources for organ transplantation. The mean scores obtained range from moderate to weak performance, with the exception of the scores in Model 3, which indicate a relatively poor performance for the three-year period. This shows that the performance of the states related to models 1 and 2 still has some room for improvement, but the equity of resource allocation is the performance dimension that requires the most attention, as it reveals the worst results. This is very relevant because an inequitable distribution of resources for organ transplantation has a direct impact on the organ harvest and transplantation process.

3.2.3 Geographical distribution of the performance scores

Despite the summary statistics for the results, Table 4A, in Appendix 4, presents the DEA performance scores for the CCR and BCC models as a result of our analysis for each one of the states used in the study from 2018 to 2020, as well as the peers and lambdas relative to the CRS model. Regarding the three models used, we can see in

Table 4A that there was an increase in the number of states considered best practices in the VRS models when compared to the CRS models. This indicates that some states, such as São Paulo, might have a good management performance, but do not have the right scale of operations in regards to the ODT process. Another important finding was the large difference between the CRS and VRS scores observed for some states, which confirms the effect of scale on their results. Furthermore, a number of states present poor performance scores under both assumptions, which indicates that they suffer from managerial and scale problems. Figure 3.2.3.1 shows a comparison between the results obtained by the CRS and VRS models.

Figure 3.2.3.1 Model 1 - 2018: CRS vs VRS performance scores



Note: Vs=versus, N=North Region, NE=Northeast Region, MW=Midwest Region, SE=Southeast Region and S=South Region.

For analysis purposes, we chose to use the efficiency scale suggested by Silva *et al.* (2016), according to which DMUs with a score between 0 and 59% have strong inefficiency; DMUs with a score between 60% and 79% have a moderate inefficiency; DMUs with a score between 80 and 99% have a weak inefficiency and DMUs with a score equal to 100% are fully efficient.

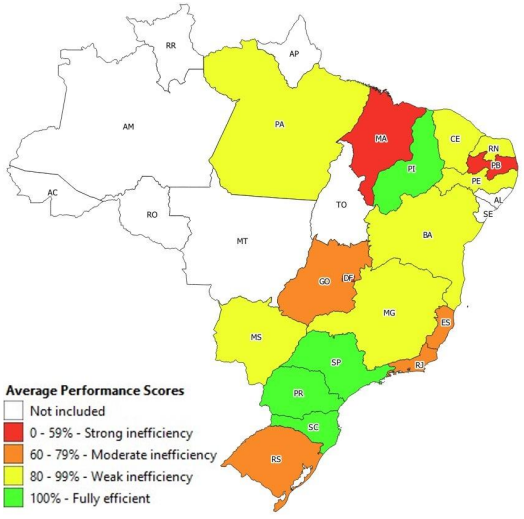
To begin with model 1, Santa Catarina is the only fully efficient state under technical and scale assumptions in the period under analysis. The state of Ceará is technically and scale efficient in the years 2019 and 2020. From 2018 to 2020, in the CRS assumption, less than a third of the states achieved scores above 80%, however this number increases in the VRS assumption where Paraná, Piauí, Santa Catarina and São Paulo are efficient. However, we can see that states in the North and Northeast regions tend to present lower scores in the CRS model, which leads us to consider that much of the inefficiency of these states is related to the scale. The year 2020 was the year in which a smaller number of states reached the efficiency score or showed a

weak inefficiency, which may be related to the beginning of the COVID-19 pandemic, as it generated a sudden change in hospital logistics, access to ICU beds, and the addition of new protocols for performing organ donation and transplantation. For instance, Pará - which was fully efficient in the previous years, under the VRS assumption - presents in 2020 strong inefficiency. For the inefficient DMUs, what the results of model 1 show us is that considering the installed capacity in terms of ICU beds, transplant teams and family consents for organ donation, the states are not managing to transform their capacity into effective donors and into donors whose organs are transplanted.

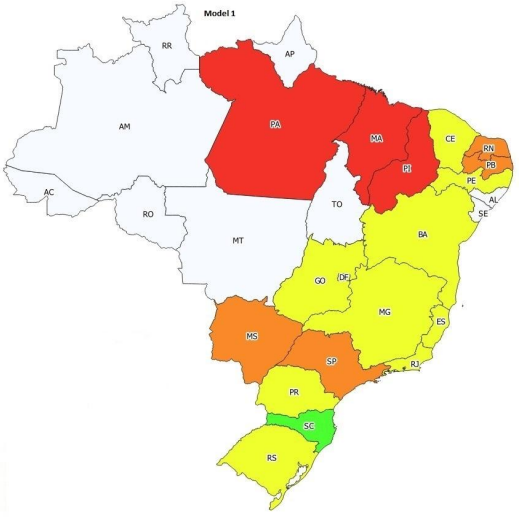
To assist in the analysis of the geographical distribution of the performance scores obtained in the study, figure 3.2.3.2, 3.2.3.3 and 3.2.3.4 display the average performance scores related to VRS assumptions and related to scale (CRS/VRS) from 2018 to 2020. Figure 3.2.3.2 exhibits the results obtained for Model 1. This Figure shows that under VRS assumption and related to scale, the state of Santa Catarina shows maximum performance (100%), whilst states in the North and Northeast regions present the lowest performance scores (within the range of 0 to 59%). However, the variation observed in the average of the performance scores of the Brazilian states does not allow us to establish a performance profile directly related to each of the Brazilian regions.

Figure 3.2.3.2 Model 1: Average performance scores

Related to VRS assumption



Related to scale (CRS/VRS)

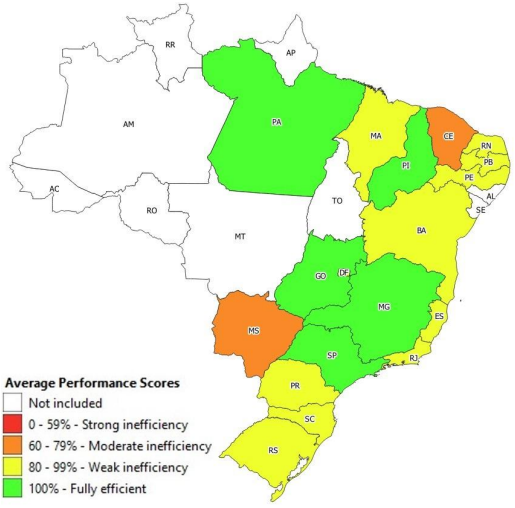


Note: North Region - AM= Amazonas, AP= Amapá, RR= Roraima, PA= Pará, AC= Acre, RO= Rondônia, TO= Tocantins. Northeast Region - MA= Maranhão, PI= Piauí, CE= Ceará, RN= Rio Grande do Norte, PB= Paraíba, PE= Pernambuco, AL= Alagoas, SE= Sergipe, BA= Bahia. Midwest Region - MT = Mato Grosso, MS = Mato Grosso do Sul, DF = Federal District, GO = Goiás. Southeast Region - MG = Minas Gerais, ES = Espírito Santo, RJ = Rio de Janeiro, SP = São Paulo. South Region - PR= Paraná, SC= Santa Catarina, RS= Rio Grande do Sul.

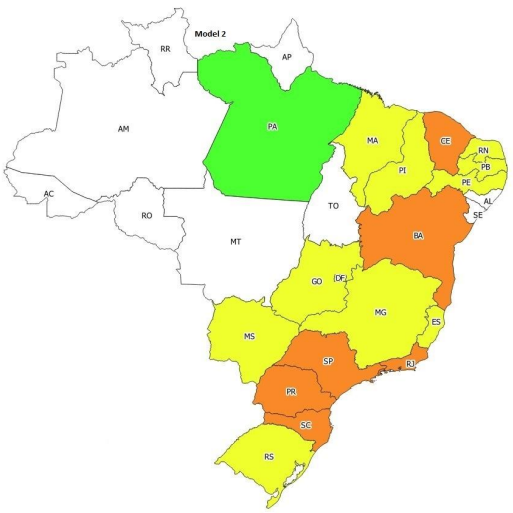
Regarding model 2, Table 4A, in Appendix 4, shows that the state of Pará achieved maximum performance, both under the CRS and VRS assumptions, for the years under analysis, while Paraíba achieved the maximum score in 2018, Maranhão and Minas Gerais in 2019 and Rio Grande do Norte in 2020. Some states have a low score in the CRS model and reach a 100% score in the VRS model, which indicates that the performance problems observed in these states are exclusively related to size. Some of the states that achieve maximum performance in model 1 also achieve maximum performance in model 2, in particular when we consider the VRS assumption. As model 1 focuses more on evaluating the states regarding organ donation and harvesting and model 2 has a greater focus on the number of transplants performed and patients that survive, the results of both models may not necessarily be consistent. However, it is important that health managers and policymakers seek strategies and corrective actions inherent in each of the models, which can be substantially different. Although both models are directly related to the ultimate goal of offering organ transplants to patients in medical conditions that require this procedure, they focus on different parts of the process. Similarly to what happened for model 1, we were also unable to establish a performance profile according to the ranges analysed in figure 3.2.3.3 for the Brazilian regions in model 2.

Figure 3.2.3.3 Model 2: Average performance scores

Related to VRS assumption



Related to scale (CRS/VRS)



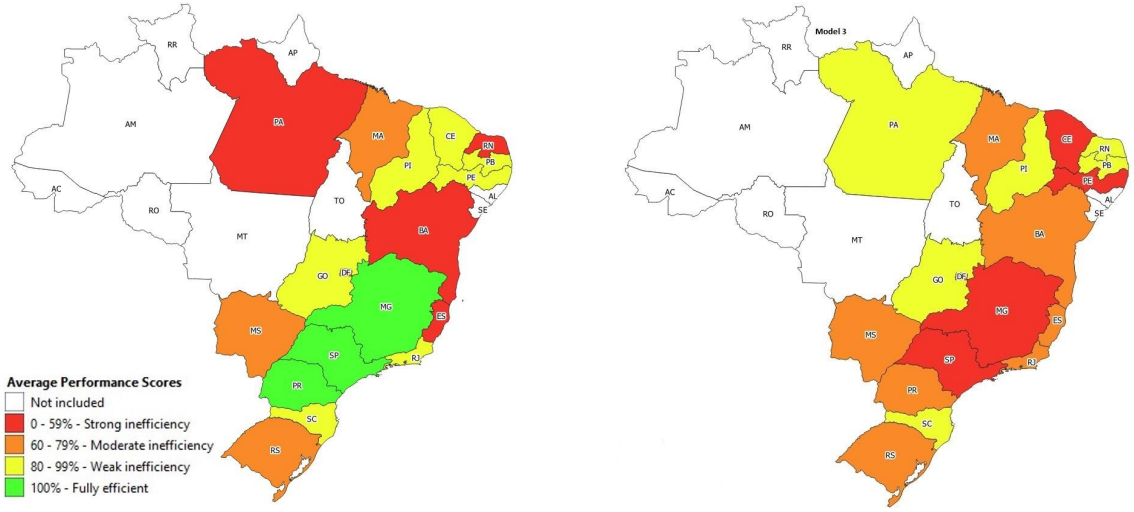
Note: North Region - AM= Amazonas, AP= Amapá, RR= Roraima, PA= Pará, AC= Acre, RO= Rondônia, TO= Tocantins. Northeast Region - MA= Maranhão, PI= Piauí, CE= Ceará, RN= Rio Grande do Norte, PB= Paraíba, PE= Pernambuco, AL= Alagoas, SE= Sergipe, BA= Bahia. Midwest Region - MT = Mato Grosso, MS = Mato Grosso do Sul, DF = Federal District, GO = Goiás. Southeast Region - MG = Minas Gerais, ES = Espírito Santo, RJ = Rio de Janeiro, SP = São Paulo. South Region - PR= Paraná, SC= Santa Catarina, RS= Rio Grande do Sul.

With regard to model 3, Table 4A shows that Santa Catarina reaches the score of 100% both in the model with a CRS assumption and a VRS assumption in 2018. Paraíba, Piauí and Santa Catarina reach a score of 100% in 2019 and, in 2020, only the state of Goiás reaches the maximum performance. In the VRS model. Minas Gerais, Paraná and São Paulo were among the best performers during the three years under analysis. In addition, there are a number of states which show management and scale problems, such as Bahia and Rio Grande do Sul while others show problems exclusively related to scale such as Minas Gerais. With the exception of the state of Goiás, all other Brazilian states would benefit from a reduction in the scale of operations in 2020. The excessive scale might be related to the impact of COVID-19 on organ donation and transplantation. Analysing Figure 3.2.3.4, São Paulo, Minas Gerais and Paraná are among the states that show the lowest performance related to scale for model 3. However, these states show high performance for the VRS model, which indicates that their performance problems are not due to the way the organ donation and transplantation process is being managed but instead with the scale of operations. Furthermore, despite the existence of inequality in physical and human resources as well as logistical limitations among the states for the provision of organ donation and transplantation services, based on the analysis developed, it is not possible to identify clear geographical patterns related to scale performance for the Brazilian regions.

Figure 3.2.3.4 Model 3: Average performance scores

Related to VRS assumption

Related to scale (CRS/VRS)



Note: North Region - AM= Amazonas, AP= Amapá, RR= Roraima, PA= Pará, AC= Acre, RO= Rondônia, TO= Tocantins. Northeast Region - MA= Maranhão, PI= Piauí, CE= Ceará, RN= Rio Grande do Norte, PB= Paraíba, PE= Pernambuco, AL= Alagoas, SE= Sergipe, BA= Bahia. Midwest Region - MT = Mato Grosso, MS = Mato Grosso do Sul, DF = Federal District, GO = Goiás. Southeast Region - MG = Minas Gerais, ES = Espírito Santo, RJ = Rio de Janeiro, SP = São Paulo. South Region - PR= Paraná, SC= Santa Catarina, RS= Rio Grande do Sul.

3.2.4 Benchmarks for performance improvement

Another important piece of information provided by Table 4A, Appendix 4, concerns the identification of benchmarks for each of the inefficient Brazilian states. Benchmarks are the states classified as best performers and that have implemented best practices that can be used to improve the performance of underperforming states. In particular, the states that serve as benchmarks for a higher number of underperforming states should be given special consideration for further investigation. For example, in Model 1, with the CRS assumption, Santa Catarina and Ceará stand out as benchmarks for other states in 2020. Ceará was referred to as a benchmark for the highest number of states such as Pernambuco, Paraíba, Goiás and Minas Gerais. As we can see, Ceará can be used as a benchmark for states from different regions or within its own region, as it is the case of Paraíba and Pernambuco, which are neighbouring states of Ceará and share socio and economic commonalities, suggesting that similar strategies can be applied. In addition, these states show similar weight profiles.

Whilst some states serve as a benchmark to a large number of states, others serve as a reference for a small number of states or, in some cases, they can have such specific characteristics that no other states can learn from them. Since the resources and time to invest in studying best practices are not unlimited, it is important that policymakers understand the strategies and processes used in the states that are referred to as benchmarks to a higher number of units.

3.2.5 Targets for performance improvement

In addition to the information related to the benchmarks used as best practices, we can extract from Table 4A information regarding the value of the lambdas that can be used to define the resources and results that a state needs to achieve to be considered at the level of the best performers. For instance, the lambda coefficient of the benchmark associated with Pernambuco (i.e. 0,7368), model 1, in 2020, represents the proportion of the service levels of Ceará that Pernambuco is required to achieve to reach the best practice frontier. The calculated targets for the number of ICU beds and effective donors show that the values of these variables should decrease from 3005 to 1485 ICU beds and increase from 121 to 142 effective donors to achieve the best practice frontier in the ODT processes. In other words, the lambdas allow us to calculate the ideal targets for inputs and outputs for the underperforming states to achieve the best performance, through the reference standards. The results show a

huge variation in the outputs achieved among Brazilian states, although some of them seem to have almost the same resources. Thus, there is a gap between the outputs some states can achieve and their actual performance. Furthermore, the lambda values are also useful to define the returns to scale of the analysed states, that is, to define whether they are operating in Increasing Returns to Scale (IRS), Constant Returns to Scale (CRS) or Decreasing Returns to Scale (DRS). Take, for example, Goiás and São Paulo, in model 2, which would benefit from operating on a smaller scale, while Piauí would benefit from an increase in the scale of operations. The analysis of this information leads us to conclusions about the need to increase or decrease the operating capacity, which is a strategy to obtain better results and avoid wasted resources.

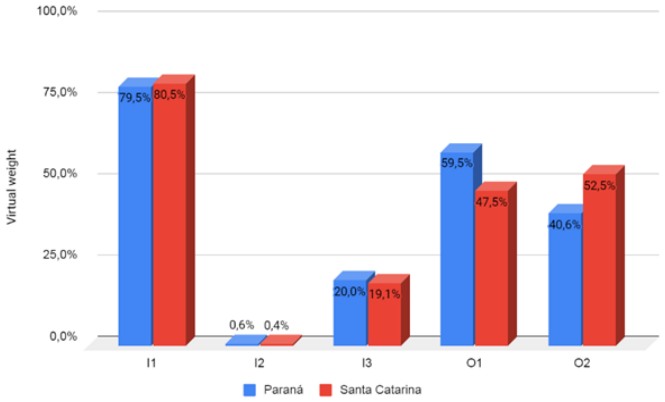
3.2.6 Optimal weight profiles

In order to have a full picture of the results obtained, it is important to identify the optimal weight structure chosen by each state. This can be useful to identify different service delivery strategies among ODT processes in Brazilian states. Table 5A, in Appendix 5, which used the CRS model assumption to produce the weights, reveals some of these different strategies. By analysing the weight that the states place on each of the variables, we can identify the relative strengths and weaknesses of each Brazilian state. However, before discussing the weights that each state assigns to the variables, it is important to recall that some weight restrictions were imposed to guarantee reliable results.

In model 1, most states placed almost all the input weight on just one input - "family consent for OD" – specifically, about 90% of states put more than 96% of the weight on this input. Ceará is an example of one of the states that placed all the input weight in family consent for OD, being classified among the best performers in 2019 and 2020, which indicates that the number of ICU beds and transplant teams are relative weaknesses of this state. Conversely, Santa Catarina was the other Brazilian state that reached a score of 100% in the period, however, it divided the weight among the three inputs, placing more than 70% of the weight in the variable "number of ICU beds". With regard to the outputs, the majority of states placed the weights in only one of the outputs, most of them in "donors whose organs were transplanted". Figure 3.2.6.1 shows the only two states - Paraná and Santa Catarina - which distributed their weights among all inputs and outputs in 2020, the latter being considered one of the

best performers while the former slightly underperforming. However, when we analyse their weight structure, we can see differences between them, particularly in terms of the weights attributed to outputs, in which Santa Catarina puts 12% more weight on O2 - “donors whose organs were transplanted” - than Paraná. This means that Santa Catarina is best in converting the donated organs into effective transplants.

Figure 3.2.6.1 Optimal virtual weight structure distribution of two states - Model 1, 2020



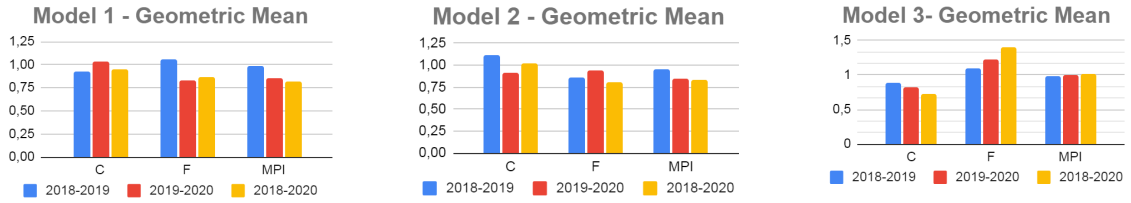
Note: I= input, O= outputs.

In model 2, we can see that all states distribute the weights only between two inputs - transplant service expenses and number of effective donors - completely ignoring the variables number of transplant beds and number of transplant teams. This reveals a weakness in terms of these two inputs. In relation to the outputs, most states placed weights in both outputs. Regarding the third model, more than half of the states chose to place 100% of the weights in a single output in 2018 and 2020, however, there was a significant change in the weight profile in the year 2019. In this year, 17 states - with the exception of Paraíba - chose to divide the weight between the outputs, however, the vast majority of states put above 80% weights in the output number of transplant teams.

3.2.7 Dynamic performance analysis

In order to do a dynamic analysis, the Malmquist Productivity Index was used, which allows comparisons of data from different years. Figure 3.2.7.1 contrasts the geometric mean values for the MPI and its components - catch-up effect and frontier shift effect - for the three years under analysis, in each model used.

Figure 3.2.7.1 Productivity changes



Note: C - Catch-up Effect (Efficiency change); F - Frontier Shift (Technological Change); MPI - Malmquist Productivity Index

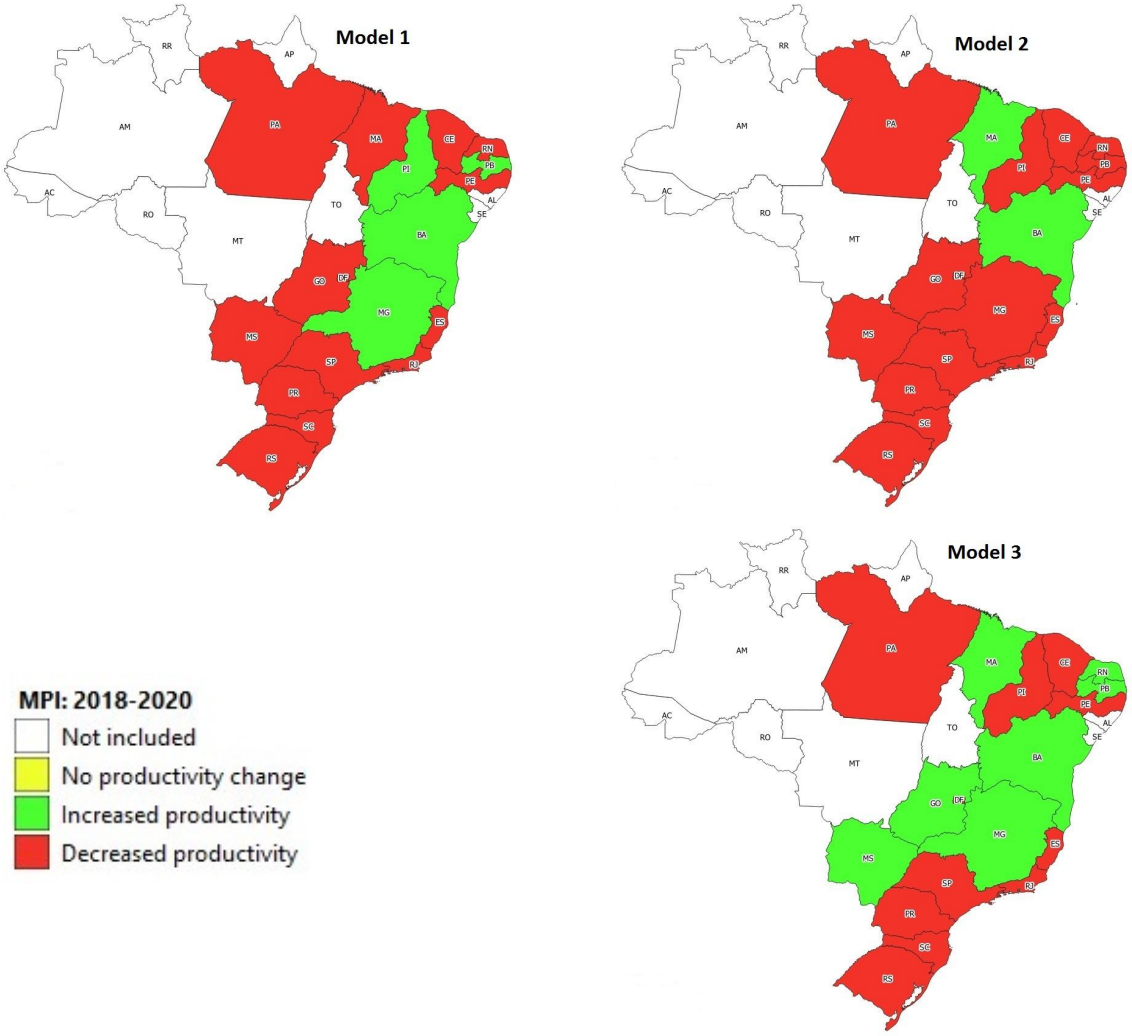
In models 1 and 2, from 2018 to 2020 there was a significant decrease in the average productivity of the states. This decrease is mainly explained by a regression in the best practice frontier in 2020 compared to 2018, which, at least in part, is believed to be due to the Covid-19 outbreak. In model 1, although capacity seems to have increased in some states, this growth was not matched by a similar increase in the number of effective donors and donors whose organs were transplanted. In regards to the productivity of the states in terms of the variables captured by Model 2, the average performance of the states is very similar to the one observed for Model 1. When it comes to Model 3, we can conclude that the average productivity of the states from 2018 to 2020 remained mostly unchanged. Please refer to Appendix 6 - Table 6A - for more details on the MPI results obtained for each DMU.

In 2018-2019, 10 Brazilian states achieved productivity equal or higher than one, in the other periods, only 4 states reached it. The state of Paraíba was one of the states that had a productivity score greater than 1, resulting from a 2.87 catch-up effect index and 0.91 of the frontier shift effect in 2018-2020 in model 1. This means that despite the fact that the best practice frontier regressed to a lower performance level, the state of Paraíba had productivity gains because it is closer to the best practice frontier. Meanwhile, the state of Pará suffered the most significant loss of productivity in 2018-2020 for model 1, drastically moving away from the best practice frontier, because it presented a catch-up effect index of 0.35 and the frontier shift effect was 0.93. Figure 3.2.7.2 shows the effect of COVID-19 on the decrease in productivity related to organ donation and harvest in all Brazilian regions. In specific, the Northeast region shows the best productivity, with a growth of 8% - however, this productivity gain is mainly due to the fact that Paraíba shows a 3 fold growth in the period -, while all other regions show a reduction in productivity. With regards to the productivity index, we can observe that the North region, represented exclusively by the state of Pará, suffered the greatest loss of productivity while the Southeast region suffered the least. However, all Brazilian states showed a decrease in the frontier shift index. It is

important to emphasise that, on average, according to model 1, Brazilian productivity had a large loss.

According to model 2, in 2018-2019, 8 states achieved productivity equal or higher than 1, while in period 2, 2019-2020, no state has achieved productivity equal to or greater than 1 and in 2018 - 2020 only two states - Maranhão and Bahia, had an increase in productivity, both in the Northeast region. The 5 Brazilian regions showed a loss in the MPI component, with the South and North regions (state of Pará) presenting the least impact. With regard to the frontier shift effect, all states showed a reduction in this component, while most states showed some increase in the catch-up effect index.

Figure 3.2.7.2 MPI results for the 2018-2020 period



Note: North Region - AM= Amazonas, AP= Amapá, RR= Roraima, PA= Pará, AC= Acre, RO= Rondônia, TO= Tocantins. Northeast Region - MA= Maranhão, PI= Piauí, CE= Ceará, RN= Rio Grande do Norte, PB= Paraíba, PE= Pernambuco, AL= Alagoas, SE= Sergipe, BA= Bahia. Midwest Region - MT = Mato Grosso, MS = Mato Grosso do Sul, DF = Federal District, GO = Goiás. Southeast Region - MG = Minas Gerais, ES = Espírito Santo, RJ = Rio de Janeiro, SP = São Paulo. South Region - PR= Paraná, SC= Santa Catarina, RS= Rio Grande do Sul.

In terms of model 3, this was the only model that presented an increase in the geometric means for the frontier shift index and MPI components. The Midwest and Northeast regions showed gains in productivity, 64% and 19%, respectively, while the other regions showed productivity losses which were more pronounced in the North Region.

In a nutshell, most Brazilian regions show a drop in productivity in terms of the organ donation and transplantation process as well as in the equity in the allocation of resources for organ transplantation, most probably due to the impact of COVID-19, with the exception of the Midwest region in model 3 and the Northeast Region in model 1 and model 3. However, in model 1, if we exclude the state of Paraíba, which presented a considerable gain in productivity in the period 2018-2020, from the average productivity calculation of the Northeast region, this region would also present a loss of productivity.

3.3 The practical and policy implications of the results

The results shown previously lead us to the conclusion that there is potential for states to improve their performance and achieve better outputs related to the entire process of organ donation and transplantation. This conclusion applies to all parts of the process ranging from the equity in the allocation of resources to the procedure of the transplant itself. The results indicate that there is a gap between the results some states can achieve and their current performance. Those states, which present potential for performance improvement in some of the dimensions, can benefit from learning from states that score 100% in the models studied. Furthermore, the information obtained from the results can be a beneficial source for policymakers, program planners, and health managers. Through the identification of best practices, the study shows the states whose actions related to the ODT processes should be studied with the intention of being replicated by states that have not yet reached high levels of performance.

As this study worked with different models, ranging from models able to assess the equity in the allocation of resources for organ transplantation (model 3) to models focused on organ harvest and donation process (model 1), and organ transplantation services (model 2), the results of our analysis indicate that some of the states that perform very well in a model, do not perform well in other models, suggesting

opportunities for reciprocal learning. There is no Brazilian state that has achieved a score of 100% for the three models, from 2018 to 2020, in CRS and VRS assumptions. For model 1, Santa Catarina was the only state that achieved a 100% score during the full period analysed in both scale assumptions and Pará for model 2. In relation to model 3, no state scored 100% in all years analysed, from 2018 to 2020. Santa Catarina scored 100% in 2018 and 2019 in model 3, while Goiás was the only state to reach a score of 100% in 2020. If we analyse the performance only under the VRS assumption, São Paulo achieved a score of 100% in the three models of the period studied, which means that São Paulo does not present management problems, although scale problems were identified.

However, given the results obtained in the models, we cannot establish a single state that deserves to be studied for all three models. For model 1, Santa Catarina and Ceará appear as important benchmarks for a considerable number of states, which make them states of interest related to best practices. These two states have a high number of family consents for OD, as well as more than 50 per cent of the family consents for organ donation becoming effective donors, which can be considered as strengths in the organ harvest and donation process. In relation to model 2, Pará stands out, serving as a benchmark for a large number of the states. Regarding the last model, Santa Catarina is one of the states that presents the best results for this model in the period before the COVID-19 pandemic. However, in addition to the states mentioned above, which can be used as benchmarks, it may be interesting that states with the potential to improve their performance learn from their respective benchmarks within the same region, since they present very similar characteristics and may form the basis to develop improvement plans.

The Malmquist Productivity Index allows us to perform dynamic analyses and evaluate the productivity changes of each state through the catch-up effect index and the frontier shift index. Due to the fact that our study used the years from 2018 to 2020 as the time frame for analysis, it enabled us to measure the changes in productivity before the COVID-19 outbreak as well as the impact of the pandemic on this index for each state, in relation to each of the models studied. When analysing the results from model 1, period 2018-2019, we see that 6 states had a catch-up index greater than 1, which means that these states reduced their distance to the best practice frontier, that is, their performance scores in 2019 were higher than the performance scores obtained in 2018. And yet, for this same period, we can see that 10 states showed an increase in

productivity in 2019 compared to 2018, which is something positive and shows an encouraging evolution in the organ transplant sector. However, when we analyse the period 2019-2020, the number of states that got nearer to the best practice frontier more than doubled compared to 2018-2019. Unfortunately, this is due to the fact that the frontier regressed, likely due to the COVID-19 pandemic, and, additionally, only 4 states increased productivity. For Model 2, for the period of 2018-2019, 15 states had a catch-up effect greater than 1. In relation to productivity, 8 states had an increase in productivity, however, the frontier suffered a reduction in the period. As for the year 2019-2020, no state showed productivity gains, and both the frontier and the catch-up index had a geometric mean of less than 1. This shows the high impact that COVID-19 has had in relation to transplant surgeries in Brazil. Regarding model 3, for the period of 2018-2019, most states had a lower performance score in 2019 than in 2018, but there was technological progress in the period. In 2019-2020, technological progress continued, but an even greater number of states increased their distance to the best practice frontier.

The results obtained with our study highlight that DEA is a practical approach that Brazilian states can use to measure current performance, to determine deviations from plan and to help health managers and policymakers make informed decisions on how to improve their performance, set strategies to augment the number of effective donors and transplants performed, as well as defining ideal targets to reach their full potential. In particular, DEA has the potential to contribute to performance improvement in the organ donation and transplantation process if it is used with a formative purpose.

4. CONCLUSION

Despite the relevance of organ transplantation as a treatment option for a large and growing number of medical conditions and the fact that the Unified Health System has the largest public transplant program in the world, Brazilian states are still facing challenges that affect organ donation and transplantation process. It is estimated that the Brazilian annual need for solid transplants - kidney, liver, heart, and lung - is threefold the number of transplants performed, only in 2020, 12.757 new patients joined this list (ABTO, 2020). Considering the high number of patients who need organ transplants and the financial impact this procedure has on public coffers, it is imperative to ensure strategies to increase and improve the quality and access to organ transplant services across the country, as well as to ensure that resources are used as efficiently as possible.

In the literature, there have been important contributions - albeit still limited - exploring the use of DEA to assess the performance of the organ donation-transplantation process. However, a number of these studies focus only on kidney transplantation, mainly using the number of transplants performed as an output. In this paper, we have explored the potential of using DEA in order to complement the existing literature in the organ transplant area. For this purpose, we have proposed three complementary models to assess three performance dimensions and to compare the performance of Brazilian states in promoting solid organ donation and transplantation, using data from 2018 to 2020. The impact of COVID-19 on the provision of ODT services was also assessed.

Despite the exploratory nature of this study, there are some important findings that can be taken from this research. A wide variation in terms of performance was found among the states and models studied, indicating that some states have achieved considerably better results in the allocation of resources for organ transplantation than others. Consequently, there is great potential for improvement for all Brazilian states and regions, since all states have room for improvement in at least one of the proposed models. In addition, since these models assess the ODT processes as a whole, it is of paramount importance to achieve good results in the three models. On top of that, a large number of states have problems related to the scale of operation, as they get better results in the VRS model. This must be taken into account, in order to operate on a scale that allows the needs of the population to be met without wasting

resources. Based on the fact that our study, in addition to the identification of the performance of Brazilian states, allows identifying learning peers for each underperforming state, along with targets for performance improvement, we believe it can be crucial for a further assessment intended at identifying the root causes of poor performance, examining the best performers' practices; and, based on this evaluation, assist underperforming states to develop strategies for improving the ODT processes.

The formative implementation of DEA in the ODT context, with the use of data collected from a reliable and standardized source for more than a period, allows dynamic assessments to analyze possible changes in the performance of states over time. In addition, it allows obtaining consistent and robust results. However, as the data used in this study were collected by each Brazilian state, there may be some variations in this process. For example, on the waiting list for organ transplants, some states do not report having any patients on this list, as is the case of the states of Amazonas and Tocantins. Soares *et al.* (2020) believe that this is much more related to the fact that there are no authorized transplant services in those states than the fact that there are no patients with a clinical indication for transplant. Although those states are not being analysed in our study, it raises a concern that there may be an underreporting of health needs for other Brazilian states due to lower concentrations of doctors and transplant services in some regions. Furthermore, as discussed before, caution needs to be exercised in interpreting the results due to some limitations in the access to data (no information about the size of the transplant teams, about the types of transplant beds and about the number of recipients who received more than one transplant). In this respect, to promote a fairer assessment, when these data become available, the new information should be incorporated in future studies.

In conclusion, the results found in this study point to the need for integration among the different steps necessary to perform organ transplants in order to achieve better outputs and a more adequate use of public spending. The proper integration of the ODT processes and the efficient use of resources are of paramount importance in a country like Brazil due to the underfunding of public services, in general. Lower levels of performance in the studied models lead, not only to waste of public resources but also to lesser availability of transplant services for the population who need them, especially in a country with high social disparities and where over 90% of organ transplants are financed by the government. We finish this thesis claiming that DEA is an appropriate method of analysis to measure performance, which can provide very

valuable information to assist policymakers to improve the performance of the Brazilian states regarding organ donation and transplantation. Due to scarce resources and increasing needs, the health sector is particularly dependent on the efficient use of resources to achieve the results necessary to meet population needs. The DEA technique can therefore be particularly helpful in this area of study.

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APPENDIX 1 - Table 1A - Studies of organ donation-transplantation performance assessment using DEA

Study	Method	DMUs	DEA Orientation	Objectives	Inputs	Outputs
Ozcan *et al.* (1999)	DEA	64 OPOs in the United States	Output	Evaluate the technical efficiency of OPOs relative to optimal patterns of production in the population of OPOs in the United States	Hospital Development Formalization Index Hospital Development FTEs (Full Time Equivalents) Other FTEs Operating expenses excluding Hospital Development FTE salary and fringes Referrals	Extrarenal organs recovered Kidneys recovered
Marinho and Cardoso (2007)	DEA	Years from 1995 to 2003	Output	Evaluate changes in efficiency over time and identify trends in performance	Transplant expenses	Total number of transplants
Costa *et al.* (2014)	DEA MPI	Brazilian states and the Federal District in 2006 and 2011	Output	Evaluate the efficiency of the transplant service system and change in productivity in the period	Hospital services expenses Professional services expenses	Number of kidney transplants performed
Siqueira and Araujo (2018)	DEA MPI	Brazilian states from 2013 to 2015	Output	Evaluate the efficiency of the transplant service system and change in productivity in the period	Number of medical teams Number of OPOs Number of ICU beds Number of effective donors	Number of kidney transplants from deceased donors
Arteaga *et al.* (2020)	DEA	485 patients in Spain undergoing cross-over kidney transplantation from living donors	Output	Evaluate the efficiency of the procedure as well as the characteristics along which potential improvements could be introduced on a per patient basis	Age at transplant Compatibility type Days in dialysis Number of previous transplants RTX (drug) Diabetic patient Hypertensive patient Smoker Induction (type of drug used during the transplant) CNI (drug) mTORi (drug) Donor age	Rejection episode Number of rejection episodes Graft loss Death Tumor development after the transplant Number of tumor episodes in the same patient
Marinho and Araujo (2021)	DEA Bootstrap technique	Brazilian states in 2018	Output	Evaluate the efficiency of transplant services	Number of notifications of brain death (potential donors)	Number of transplanted organs

APPENDIX 2 - Table 2A - Weight restrictions included in the study

MODEL 1					
	Nº of ICU beds {I}	Nº of transplant teams {I}	Nº of family consents for OD {I}	Nº of effective donors {O}	Donors whose organs were transplanted {O}
WR1	0	-1	1	0	0
WR2	-1	0	1	0	0
WR3	-1	1	0	0	0
WR4	0	0	0	-1	1

MODEL 2						
	Transplant Service Expenses {I}	Nº of Transplant Beds {I}	Nº of transplant teams {I}	Nº of effective donors {I}	Nº of Transplant Performed (AIH) {O}	Nº of patient survivors {O}
WR1	1	-1	0	0	0	0
WR2	1	0	-1	0	0	0
WR3	0	0	0	0	-1	1
WR4	-1	0	0	1	0	0
WR5	0	-1	1	0	0	0

MODEL 3			
	Transplant waiting list {I}	Nº of Transplant Beds {O}	Nºof transplant teams {O}
WR1	0	-1	1

Note: WR = weight restriction, OD=organ donation.

APPENDIX 3 - Table 3A - Data used in the study to assess organ donation-transplantation performance using DEA

MODEL 1					
2018					
	Nº of ICU beds {I}	Nº of transplant teams {I}	Nº of family consents for OD {I}	Nº of effective donors {O}	Donors whose organs were transplanted {O}
Bahia (NE)	2092	11	334	133	133
Ceará (NE)	1149	13	400	206	194
Distrito Federal (MW)	1060	9	209	53	47
Espírito Santo (SE)	1026	5	126	36	35
Goiás (MW)	1341	4	233	89	80
Maranhão (NE)	750	2	77	14	11
Mato Grosso do Sul (MW)	488	1	132	45	43
Minas Gerais (SE)	4348	30	518	207	197
Pará (N)	974	4	71	20	20
Paraíba (NE)	625	3	88	7	6
Paraná (S)	2974	29	1000	540	428
Pernambuco (NE)	1925	10	366	183	178
Piauí (NE)	323	1	121	16	14
Rio de Janeiro (SE)	6091	23	673	261	220
Rio Grande do Norte (NE)	549	2	89	32	32
Rio Grande do Sul (S)	2308	21	488	238	186
Santa Catarina (S)	1200	10	431	287	219
São Paulo (SE)	12024	79	2268	1089	923

Note: N=North Region, NE=Northeast Region, MW=Midwest Region, SE=Southeast Region, and S=South Region. OD= organ donation.

APPENDIX 3 - Table 3A - Data used in the study to assess organ donation-transplantation performance using DEA - *Continued*

MODEL 1					
2019					
	Nº of ICU beds {I}	Nº of transplant teams {I}	Nº of family consents for OD {I}	Nº of effective donors {O}	Donors whose organs were transplanted {O}
Bahia (NE)	2100	10	365	158	158
Ceará (NE)	1229	14	435	257	237
Distrito Federal (MW)	1273	8	279	49	41
Espírito Santo (SE)	1147	4	151	45	44
Goiás (MW)	1349	4	256	75	70
Maranhão (NE)	832	2	87	10	9
Mato Grosso do Sul (MW)	515	1	155	52	51
Minas Gerais (SE)	4449	33	661	294	284
Pará (N)	991	5	76	20	17
Paraíba (NE)	698	5	118	22	22
Paraná (S)	2887	30	975	497	365
Pernambuco (NE)	1900	10	349	185	179
Piauí (NE)	296	2	60	4	4
Rio de Janeiro (SE)	5097	28	750	306	260
Rio Grande do Norte (NE)	576	3	147	52	52
Rio Grande do Sul (S)	2366	21	501	243	191
Santa Catarina (S)	1215	13	495	334	255
São Paulo (SE)	12515	73	2382	1080	885

Note: N=North Region, NE=Northeast Region, MW=Midwest Region, SE=Southeast Region and S=South Region.

APPENDIX 3 - Table 3A - Data used in the study to assess organ donation-transplantation performance using DEA - *Continued*

MODEL 1					
2020					
	Nº of ICU beds {I}	Nº of transplant teams {I}	Nº of family consents for OD {I}	Nº of effective donors {O}	Donors whose organs were transplanted {O}
Bahia (NE)	3452	10	296	131	129
Ceará (NE)	2016	14	385	193	182
Distrito Federal (MW)	2162	10	291	57	40
Espírito Santo (SE)	1754	4	145	34	33
Goiás (MW)	2233	5	227	79	75
Maranhão (NE)	1275	2	114	7	6
Mato Grosso do Sul (MW)	856	4	153	46	45
Minas Gerais (SE)	6808	30	577	245	235
Pará (N)	1578	2	44	4	4
Paraíba (NE)	992	3	111	20	20
Paraná (S)	3988	28	1003	475	324
Pernambuco (NE)	3005	10	284	121	120
Piauí (NE)	620	1	42	10	7
Rio de Janeiro (SE)	8395	25	763	272	247
Rio Grande do Norte (NE)	996	3	123	24	24
Rio Grande do Sul (S)	3461	19	426	182	142
Santa Catarina (S)	2148	11	511	283	230
São Paulo (SE)	17471	81	2478	1094	875

Note: N=North Region, NE=Northeast Region, MW=Midwest Region, SE=Southeast Region, and S=South Region. OD= organ donation

APPENDIX 3 - Table 3A - Data used in the study to assess organ donation-transplantation performance using DEA - *Continued*

MODEL 2						
2018						
	Transplant Service Expenses {I}	Nº of Transplant Beds {I}	Nº of transplant teams {I}	Nº of effective donors {I}	Nº of Transplants Performed (AIH) {O}	Nº of patient survivors {O}
Bahia (NE)	11341134.28	21	11	133	231	223
Ceará (NE)	27871515.45	82.58	13	206	423	401
Distrito Federal (MW)	12103691.54	28	9	53	162	151
Espírito Santo (SE)	5723029.33	18.92	5	36	103	100
Goiás (MW)	4751100.75	17.17	4	89	149	147
Maranhão (NE)	1208399.56	4.75	2	14	36	34
Mato Grosso do Sul (MW)	634044.85	4	1	45	17	16
Minas Gerais (SE)	37563938.79	129	30	207	716	684
Pará (N)	1638770.33	14	4	20	57	56
Paraíba (NE)	915673.51	3	3	7	28	27
Paraná (S)	60323120.54	94	29	540	986	926
Pernambuco (NE)	39763305.35	79.08	10	183	658	629
Piauí (NE)	534427.43	18	1	16	18	18
Rio de Janeiro (SE)	30589756.25	68.5	23	261	529	496
Rio Grande do Norte (NE)	1153451.44	7	2	32	39	39
Rio Grande do Sul (S)	39035808.71	78.92	21	238	640	623
Santa Catarina (S)	29041111.91	37.83	10	287	445	428
São Paulo (SE)	140532758	256.33	79	1089	2418	2301

Note: N=North Region, NE=Northeast Region, MW=Midwest Region, SE=Southeast Region, and S=South Region.

APPENDIX 3 - Table 3A - Data used in the study to assess organ donation-transplantation performance using DEA - *Continued*

MODEL 2						
2019						
	Transplant Service Expenses {I}	Nº of Transplant Beds {I}	Nº of transplant teams {I}	Nº of effective donors {I}	Nº of Transplants Performed (AIH) {O}	Nº of patient survivors {O}
Bahia (NE)	13128662.51	21	10	158	273	263
Ceará (NE)	34546256.8	83.33	14	257	502	476
Distrito Federal (MW)	10635824.75	27.17	8	49	153	147
Espírito Santo (SE)	7427226.29	17.67	4	45	136	133
Goiás (MW)	5939933.85	23	4	75	183	177
Maranhão (NE)	826240.83	19	2	10	27	26
Mato Grosso do Sul (MW)	803380.61	4	1	52	21	21
Minas Gerais (SE)	52217098.66	133	33	294	941	907
Pará (N)	1443420.85	14	5	20	51	50
Paraíba (NE)	3209794.97	4.33	5	22	61	57
Paraná (S)	52959118.44	91.75	30	497	861	815
Pernambuco (NE)	37909390.85	78.33	10	185	599	560
Piauí (NE)	239041.49	18	2	4	8	7
Rio de Janeiro (SE)	31007036.11	65.58	28	306	551	518
Rio Grande do Norte (NE)	1385106.68	7	3	52	47	47
Rio Grande do Sul (S)	40393646.59	65.75	21	243	650	638
Santa Catarina (S)	29443276.93	36.08	13	334	469	457
São Paulo (SE)	141025384.2	259.25	73	1080	2374	2278

Note: N=North Region, NE=Northeast Region, MW=Midwest Region, SE=Southeast Region, and S=South Region.

APPENDIX 3 - Table 3A - Data used in the study to assess organ donation-transplantation performance using DEA - *Continued*

MODEL 2						
2020						
	Transplant Service Expenses {I}	Nº of Transplant Beds {I}	Nº of transplant teams {I}	Nº of effective donors {I}	Nº of Transplants Performed (AIH) {O}	Nº of patient survivors {O}
Bahia (NE)	9386292.33	21	10	131	196	190
Ceará (NE)	21414972.6	77.92	14	193	296	283
Distrito Federal (MW)	8841616.56	26	10	57	131	119
Espírito Santo (SE)	5517467.76	17.5	4	34	85	81
Goiás (MW)	6048390.44	23	5	79	137	128
Maranhão (NE)	258979.54	17.83	2	7	8	8
Mato Grosso do Sul (MW)	929991.94	4	4	46	23	23
Minas Gerais (SE)	38340459.73	137.67	30	245	664	643
Pará (N)	359529.78	15.17	2	4	11	11
Paraíba (NE)	2234462.66	22	3	20	33	29
Paraná (S)	46264343.07	86	28	475	697	663
Pernambuco (NE)	17885708.01	73.5	10	121	279	260
Piauí (NE)	126204.14	18	1	10	4	4
Rio de Janeiro (SE)	29102433.27	62.58	25	272	462	442
Rio Grande do Norte (NE)	623327.32	7	3	24	21	21
Rio Grande do Sul (S)	29058395.2	59.58	19	182	446	437
Santa Catarina (S)	20276478.57	32.08	11	283	319	311
São Paulo (SE)	124236810.6	253.33	81	1094	2012	1917

Note: N=North Region, NE=Northeast Region, MW=Midwest Region, SE=Southeast Region, and S=South Region.

APPENDIX 3 - Table 3A - Data used in the study to assess organ donation-transplantation performance using DEA - *Continued*

MODEL 3			
2018			
	Transplant waiting list (December 2018) {I}	Nº of Transplant Beds {O}	Nº of transplant teams {O}
Bahia (NE)	953	21	11
Ceará (NE)	902	82.58	13
Distrito Federal (MW)	359	28	9
Espírito Santo (SE)	956	18.92	5
Goiás (MW)	216	17.17	4
Maranhão (NE)	151	4.75	2
Mato Grosso do Sul (MW)	78	4	1
Minas Gerais (SE)	2909	129	30
Pará (N)	202	14	4
Paraíba (NE)	141	3	3
Paraná (S)	1156	94	29
Pernambuco (NE)	747	79.08	10
Piauí (NE)	177	18	1
Rio de Janeiro (SE)	1069	68.5	23
Rio Grande do Norte (NE)	211	7	2
Rio Grande do Sul (S)	1207	78.92	21
Santa Catarina (S)	332	37.83	10
São Paulo (SE)	12531	256.33	79

Note: N=North Region, NE=Northeast Region, MW=Midwest Region, SE=Southeast Region, and S=South Region.

APPENDIX 3 - Table 3A - Data used in the study to assess organ donation-transplantation performance using DEA - *Continued*

MODEL 3			
2019			
	Transplant waiting list (December 2019) {I}	Nº of Transplant Beds {O}	Nº of transplant teams {O}
Bahia (NE)	1366	21	10
Ceará (NE)	976	83.33	14
Distrito Federal (MW)	644	27.17	8
Espírito Santo (SE)	1015	17.67	4
Goiás (MW)	206	23	4
Maranhão (NE)	146	19	2
Mato Grosso do Sul (MW)	135	4	1
Minas Gerais (SE)	2824	133	33
Pará (N)	278	14	5
Paraíba (NE)	162	4.33	5
Paraná (S)	1533	91.75	30
Pernambuco (NE)	979	78.33	10
Piauí (NE)	78	18	2
Rio de Janeiro (SE)	1303	65.58	28
Rio Grande do Norte (NE)	211	7	3
Rio Grande do Sul (S)	1317	65.75	21
Santa Catarina (S)	436	36.08	13
São Paulo (SE)	13258	259.25	73

Note: N=North Region, NE=Northeast Region, MW=Midwest Region, SE=Southeast Region, and S=South Region.

APPENDIX 3 - Table 3A - Data used in the study to assess organ donation-transplantation performance using DEA - *Continued*

MODEL 3			
2020			
	Transplant waiting list (December 2020) {I}	Nº of Transplant Beds {O}	Nº of transplant teams {O}
Bahia (NE)	527	21	10
Ceará (NE)	935	77.92	14
Distrito Federal (MW)	446	26	10
Espírito Santo (SE)	1086	17.5	4
Goiás (MW)	126	23	5
Maranhão (NE)	257	17.83	2
Mato Grosso do Sul (MW)	167	4	4
Minas Gerais (SE)	2837	137.67	30
Pará (N)	331	15.17	2
Paraíba (NE)	147	22	3
Paraná (S)	1356	86	28
Pernambuco (NE)	1059	73.5	10
Piauí (NE)	208	18	1
Rio de Janeiro (SE)	1382	62.58	25
Rio Grande do Norte (NE)	196	7	3
Rio Grande do Sul(S)	1269	59.58	19
Santa Catarina (S)	461	32.08	11
São Paulo (SE)	15587	253.33	81

Note: N=North Region, NE=Northeast Region, MW=Midwest Region, SE=Southeast Region, and S=South Region.

APPENDIX 4 - Table 4A - States performance score, peers and lambdas

MODEL 1															
		2018					2019					2020				
	DMUs	Technical Efficiency	Pure Technical Efficiency	Scale Efficiency	Peers and Lambdas	Return to Scale	Technical Efficiency	Pure Technical Efficiency	Scale Efficiency	Peers and Lambdas	Return to Scale	Technical Efficiency	Pure Technical Efficiency	Scale Efficiency	Peers and Lambdas	Return to Scale
1	Bahia (NE)	78.37%	80.14%	97.79%	17 (0.7749)	IRS	79.82%	81.97%	97.38%	2 (0.8352)	IRS	92.42%	94.66%	97.64%	2 (0.7669)	IRS
2	Ceará (NE)	95.45%	96.02%	99.41%	17 (0.9281)	IRS	100.00%	100.00%	100.00%	15	CRS	100.00%	100.00%	100.00%	11	CRS
3	Distrito Federal (MW)	44.26%	48.15%	91.92%	17 (0.4849)	IRS	27.75%	30.18%	91.95%	2 (0.3172) 17 (0.2846)	IRS	33.20%	34.60%	95.96%	17 (0.5695)	IRS
4	Espírito Santo (SE)	54.67%	67.01%	81.58%	17 (0.2923)	IRS	53.78%	71.85%	74.85%	2 (0.3452)	IRS	48.55%	55.83%	86.97%	2 (0.3734)	IRS
5	Goiás (MW)	67.97%	72.72%	93.47%	17 (0.5374)	IRS	51.01%	56.45%	90.36%	2 (0.5791)	IRS	70.87%	75.07%	94.41%	2 (0.5815)	IRS
6	Maranhão (NE)	28.11%	100.00%	28.11%	17 (0.1787)	IRS	19.28%	42.08%	45.81%	2 (0.1737) 17 (0.0217)	IRS	11.59%	14.24%	81.37%	2 (0.1067) 17 (0.1407)	IRS
7	Mato Grosso do Sul (MW)	65.10%	100.00%	65.10%	17 (0.3016)	IRS	61.94%	85.37%	72.55%	2 (0.3474)	IRS	62.84%	98.06%	64.08%	2 (0.3935)	IRS
8	Minas Gerais (SE)	74.85%	78.07%	95.87%	17 (1.2019)	DRS	78.86%	90.96%	86.70%	2 (1.5195)	DRS	86.16%	93.39%	92.26%	2 (1.4987)	DRS
9	Pará (N)	55.44%	100.00%	55.44%	17 (0.1647)	IRS	42.02%	100.00%	42.02%	2 (0.1010) 17 (0.0648)	IRS	19.23%	49.87%	38.56%	2 (0.1143)	IRS
10	Paraíba (NE)	13.42%	20.74%	64.68%	17 (0.2042)	IRS	34.22%	53.34%	64.15%	2 (0.2713)	IRS	38.46%	47.73%	80.58%	2 (0.2857)	IRS
11	Paraná (S)	84.23%	100.00%	84.23%	17 (2.3202)	DRS	74.30%	100.00%	74.30%	17 (1.9697)	DRS	82.86%	100.00%	82.86%	17 (1.8798)	DRS
12	Pernambuco (NE)	95.71%	97.02%	98.65%	17 (0.8492)	IRS	94.46%	97.71%	96.68%	2 (0.7996)	IRS	89.48%	92.04%	97.23%	2 (0.7368)	IRS
13	Piauí (NE)	23.57%	100.00%	23.57%	17 (0.2712)	IRS	12.24%	100.00%	12.24%	2 (0.1379)	IRS	40.32%	100.00%	40.32%	17 (0.0822)	IRS
14	Rio de Janeiro (SE)	64.33%	70.57%	91.16%	17 (1.5615)	DRS	65.13%	76.16%	85.52%	2 (0.9929) 17 (0.6426)	DRS	69.31%	79.01%	87.72%	2 (1.4885) 17 (0.3717)	DRS
15	Rio Grande do Norte (NE)	70.81%	100.00%	70.81%	17 (0.2063)	IRS	65.68%	91.00%	72.17%	2 (0.3341)	IRS	41.76%	50.21%	83.17%	2 (0.3158)	IRS
16	Rio Grande do Sul (S)	75.01%	77.23%	97.13%	17 (1.1323)	IRS	73.33%	74.22%	98.81%	2 (0.1831) 17 (0.8512)	DRS	75.76%	76.58%	98.93%	17 (0.8337)	IRS
17	Santa Catarina (S)	100.00%	100.00%	100.00%	17	CRS	100.00%	100.00%	100.00%	7	CRS	100.00%	100.00%	100.00%	7	CRS
18	São Paulo (SE)	80.09%	100.00%	80.09%	17 (5.2622)	DRS	70.56%	100.00%	70.56%	2 (2.1003) 17 (2.9664)	DRS	79.15%	100.00%	79.15%	17 (4.8493)	DRS
	Mean	65.08%	83.76%	78.83%			61.35%	80.63%	76.45%			63.44%	75.63%	83.40%		
	Standard-deviation	24.83%	22.14%	23.58%			26.29%	22.07%	23.70%			27.63%	26.97%	18.54%		
	Maximum	100.00%	100.00%	100.00%			100.00%	100.00%	100.00%			100.00%	100.00%	100.00%		
	Minimum	13.42%	20.74%	23.57%			12.24%	30.18%	12.24%			11.59%	14.24%	38.56%		

Note 1: NE = Northeast Region; MW = Midwest Region; SE = Southeast Region; N = North Region; S = South Region. Note2: IRS= increasing return to scale; CRS = constant returns to scale; DRS = decreasing returns to scale.

APPENDIX 4 - Table 4A - States performance score, peers and lambdas - *Continued*

		MODEL 2														
		2018					2019					2020				
		Technical Efficiency	Pure Technical Efficiency	Scale Efficiency	Peers and Lambdas	Return to Scale	Technical Efficiency	Pure Technical Efficiency	Scale Efficiency	Peers and Lambdas	Return to Scale	Technical Efficiency	Pure Technical Efficiency	Scale Efficiency	Peers and Lambdas	Return to Scale
1	Bahia (NE)	58.85%	87.69%	67.11%	9 (6.1965) 10 (1.2956)	DRS	63.96%	90.67%	70.54%	6 (15.7223) 8 (0.0026)	DRS	66.51%	100.00%	66.51%	9 (23.4061) 15 (1.5573)	DRS
2	Ceará (NE)	50.91%	76.73%	66.35%	10 (29.4286)	DRS	65.19%	76.42%	85.31%	6 (11.6855) 8 (0.4767)	DRS	54.55%	75.33%	72.41%	9 (48.2500)	DRS
3	Distrito Federal (MW)	75.16%	83.02%	90.53%	10 (7.5714)	DRS	97.40%	100.00%	97.40%	8 (0.1667)	IRS	79.74%	82.08%	97.16%	9 (14.2500)	DRS
4	Espírito Santo (SE)	72.02%	84.69%	85.04%	10 (5.1429)	DRS	97.84%	98.83%	99.00%	6 (0.5950) 8 (0.1328)	IRS	88.77%	91.23%	97.30%	9 (8.5000)	DRS
5	Goiás (MW)	90.54%	100.00%	90.54%	9 (2.8992)	DRS	91.99%	100.00%	91.99%	6 (5.0416) 9 (1.2292)	DRS	71.10%	100.00%	71.10%	9 (15.6326) 15 (0.6862)	DRS
6	Maranhão (NE)	85.51%	87.78%	97.41%	9 (0.6373) 10 (0.1791)	IRS	100.00%	100.00%	100.00%	10	CRS	95.36%	99.80%	95.55%	9 (0.3019) 15 (0.2414)	IRS
7	Mato Grosso do Sul (MW)	75.48%	76.84%	98.23%	9 (0.3869)	IRS	75.46%	77.35%	97.55%	9 (0.5566)	IRS	73.41%	85.03%	86.33%	15 (1.4920)	DRS
8	Minas Gerais (SE)	86.08%	100.00%	86.08%	10 (29.5714)	DRS	100.00%	100.00%	100.00%	11	CRS	96.99%	100.00%	96.99%	9 (61.2500)	DRS
9	Pará (N)	100.00%	100.00%	100.00%	10	CRS	100.00%	100.00%	100.00%	4	CRS	100.00%	100.00%	100.00%	14	CRS
10	Paraíba (NE)	100.00%	100.00%	100.00%	12	CRS	90.04%	91.56%	98.35%	6 (0.7345) 8 (0.0498)	IRS	56.36%	68.31%	82.51%	9 (5.0000)	DRS
11	Paraná (S)	50.62%	89.61%	56.49%	9 (10.5530) 10 (46.9915)	DRS	60.78%	89.56%	67.87%	6 (37.1778) 8 (0.4259)	DRS	52.06%	87.81%	59.29%	9 (118.7500)	DRS
12	Pernambuco (NE)	89.51%	100.00%	89.51%	10 (26.1429)	DRS	99.67%	99.97%	99.69%	8 (0.6293)	IRS	80.99%	86.59%	93.54%	9 (30.2500)	DRS
13	Piauí (NE)	98.56%	100.00%	98.56%	9 (0.3261)	IRS	89.68%	100.00%	89.68%	9 (0.1656)	IRS	94.07%	100.00%	94.07%	15 (0.2025)	IRS
14	Rio de Janeiro (SE)	54.22%	87.96%	61.65%	9 (3.6339) 10 (26.9031)	DRS	63.59%	91.68%	69.36%	6 (24.5742) 8 (0.2050)	DRS	60.43%	89.23%	67.72%	9 (68.0000)	DRS
15	Rio Grande do Norte (NE)	98.94%	99.24%	99.71%	9 (0.7039)	IRS	97.96%	98.08%	99.87%	9 (0.9596)	IRS	100.00%	100.00%	100.00%	6	CRS
16	Rio Grande do Sul (S)	67.86%	88.10%	77.03%	10 (34.0000)	DRS	86.74%	88.55%	97.95%	6 (2.9115) 8 (0.7275)	DRS	88.21%	91.46%	96.45%	9 (45.5000)	DRS
17	Santa Catarina (S)	46.66%	78.60%	59.36%	9 (8.6979) 10 (16.1488)	DRS	52.06%	83.43%	62.40%	6 (31.4563) 8 (0.0661)	DRS	50.25%	86.30%	58.23%	9 (50.5612) 15 (3.3648)	DRS
18	São Paulo (SE)	55.72%	100.00%	55.72%	9 (1.9648) 10 (149.9577)	DRS	74.30%	100.00%	74.30%	6 (53.4754) 8 (1.8546)	DRS	65.30%	100.00%	65.30%	9 (273.4998)	DRS
	Mean	75.37%	91.13%	82.18%			83.70%	93.67%	88.96%			76.34%	91.29%	83.36%		
	Standard-deviation	19.04%	8.87%	16.67%			16.48%	8.03%	13.56%			17.49%	9.62%	15.35%		
	Maximum	100.00%	100.00%	100.00%			100.00%	100.00%	100.00%			100.00%	100.00%	100.00%		
	Minimum	46.66%	76.73%	55.72%			52.06%	76.42%	62.40%			50.25%	68.31%	58.23%		

Note 1: NE = Northeast Region; MW = Midwest Region; SE = Southeast Region; N = North Region; S = South Region. Note2: IRS= increasing return to scale; CRS = constant returns to scale; DRS = decreasing returns to scale.

APPENDIX 4 - Table 4A - States performance score, peers and lambdas - *Continued*

		MODEL 3														
		2018					2019					2020				
		Technical Efficiency	Pure Technical Efficiency	Scale Efficiency	Peers and Lambdas	Return to Scale	Technical Efficiency	Pure Technical Efficiency	Scale Efficiency	Peers and Lambdas	Return to Scale	Technical Efficiency	Pure Technical Efficiency	Scale Efficiency	Peers and Lambdas	Return to Scale
1	Bahia (NE)	38.32%	45.23%	84.72%	17 (2.8705)	DRS	24.26%	35.03%	69.25%	10 (2.9181) 17 (2.0488)	DRS	47.82%	80.01%	59.76%	5 (4.1825)	DRS
2	Ceará (NE)	73.55%	93.77%	78.44%	17 (2.7169)	DRS	52.11%	100.00%	52.11%	13 (6.8563) 17 (1.0119)	DRS	44.24%	100.00%	44.24%	5 (7.4206)	DRS
3	Distrito Federal (MW)	83.23%	84.73%	98.24%	17 (1.0813)	DRS	42.34%	53.93%	78.51%	13 (0.9414) 17 (1.3087)	DRS	56.50%	91.04%	62.06%	5 (3.5397)	DRS
4	Espírito Santo (SE)	17.36%	22.65%	76.65%	17 (2.8795)	DRS	13.78%	22.82%	60.41%	13 (3.8252) 17 (1.6437)	DRS	9.28%	21.54%	43.10%	5 (8.6190)	DRS
5	Goiás (MW)	68.02%	74.87%	90.85%	17 (0.6506)	IRS	70.19%	87.71%	80.03%	13 (1.3616) 17 (0.2289)	DRS	100.00%	100.00%	100.00%	17	CRS
6	Maranhão (NE)	43.97%	55.76%	78.86%	17 (0.4548)	IRS	56.10%	81.22%	69.07%	13 (1.8718)	DRS	34.73%	51.72%	67.15%	5 (2.0397)	DRS
7	Mato Grosso do Sul (MW)	44.49%	100.00%	44.49%	17 (0.2349)	IRS	25.64%	25.79%	99.40%	13 (0.3836) 17 (0.2410)	IRS	60.36%	69.36%	87.02%	5 (1.3254)	DRS
8	Minas Gerais (SE)	37.94%	100.00%	37.94%	17 (8.7620)	DRS	40.48%	100.00%	40.48%	13 (8.2167) 17 (5.0071)	DRS	26.65%	100.00%	26.65%	5 (22.5159)	DRS
9	Pará (N)	65.74%	74.16%	88.65%	17 (0.6084)	IRS	60.36%	60.52%	99.73%	13 (0.0162) 17 (0.6347)	IRS	23.34%	38.84%	60.09%	5 (2.6270)	DRS
10	Paraíba (NE)	70.64%	92.81%	76.11%	17 (0.4247)	IRS	100.00%	100.00%	100.00%	3	CRS	76.53%	84.29%	90.79%	5 (1.1667)	DRS
11	Paraná (S)	83.29%	100.00%	83.29%	17 (3.4819)	DRS	66.12%	100.00%	66.12%	13 (1.0304) 17 (3.3317)	DRS	52.04%	100.00%	52.04%	5 (10.7619)	DRS
12	Pernambuco (NE)	82.77%	100.00%	82.77%	17 (2.2500)	DRS	38.79%	90.63%	42.80%	13 (10.4736) 17 (0.3717)	DRS	35.48%	84.84%	41.82%	5 (8.4048)	DRS
13	Piauí (NE)	74.51%	87.58%	85.07%	17 (0.5331)	IRS	100.00%	100.00%	100.00%	12	CRS	41.11%	55.11%	74.59%	5 (1.6508)	DRS
14	Rio de Janeiro (SE)	71.43%	85.20%	83.84%	17 (3.2199)	DRS	71.52%	100.00%	71.52%	10 (1.7777) 17 (2.3280)	DRS	45.59%	88.98%	51.23%	5 (10.9683)	DRS
15	Rio Grande do Norte (NE)	31.47%	35.01%	89.89%	17 (0.6355)	IRS	47.31%	47.47%	99.66%	10 (0.2938) 17(0.3748)	IRS	38.57%	47.55%	81.11%	5 (1.5556)	DRS
16	Rio Grande do Sul (S)	57.76%	80.55%	71.71%	17 (3.6355)	DRS	53.98%	80.16%	67.33%	13 (1.1105) 17 (2.8220)	DRS	37.73%	72.64%	51.94%	5 (10.0714)	DRS
17	Santa Catarina (S)	100.00%	100.00%	100.00%	17	CRS	100.00%	100.00%	100.00%	14	CRS	60.13%	97.65%	61.57%	5 (3.6587)	DRS
18	São Paulo (SE)	20.93%	100.00%	20.93%	17 (37.7440)	DRS	18.84%	100.00%	18.84%	13 (24.1432) 17 (26.0891)	DRS	13.10%	100.00%	13.10%	5 (123.7063)	DRS
	Mean	59.19%	79.57%	76.25%			54.54%	76.96%	73.07%			44.62%	76.87%	59.35%		
	Standard-deviation	23.69%	24.29%	20.96%			26.84%	28.24%	24.25%			21.80%	24.41%	22.19%		
	Maximum	100.00%	100.00%	100.00%			100.00%	100.00%	100.00%			100.00%	100.00%	100.00%		
	Minimum	17.36%	22.65%	20.93%			13.78%	22.82%	18.84%			9.28%	21.54%	13.10%		

Note 1: NE = Northeast Region; MW = Midwest Region; SE = Southeast Region; N = North Region; S = South Region. Note2: IRS= increasing return to scale; CRS = constant returns to scale; DRS = decreasing returns to scale.

APPENDIX 5 - Table 5A - Virtual weight attributed to the variables

MODEL 1															
	2018					2019					2020				
	Nº of ICU beds {I}	Nº of transplant teams {I}	Nº of family consents for OD {I}	Nºof effective donors {O}	Donors whose organs were transplanted {O}	Nº of ICU beds {I}	Nº of transplant teams {I}	Nº of family consents for OD {I}	Nº of effective donors {O}	Donors whose organs were transplanted {O}	Nº of ICU beds {I}	Nº of transplant teams {I}	Nº of family consents for OD {I}	Nº of effective donors {O}	Donors whose organs were transplanted {O}
Bahia (NE)	0	0	1	0	1	0	0.0267	0.9733	0	1	0	0.0327	0.9673	0	1
Ceará (NE)	0	0	1	0	1	0	0	1	0	1	0	0	1	0	1
Distrito Federal (MW)	0	0	1	0	1	0	0.0279	0.9721	0.2665	0.7335	0	0	1	0.5876	0.4124
Espírito Santo (SE)	0	0	1	0	1	0	0.0258	0.9742	0	1	0	0.0268	0.9732	0	1
Goiás (MW)	0	0.0169	0.9831	0	1	0	0.0154	0.9846	0	1	0	0.0216	0.9784	0	1
Maranhão (NE)	0	0	1	0	1	0	0.0225	0.9775	0.2525	0.7475	0	0.0172	0.9828	0.2366	0.7634
Mato Grosso do Sul (MW)	0	0.0075	0.9925	0	1	0	0.0064	0.9936	0	1	0	0.0255	0.9745	0	1
Minas Gerais (SE)	0	0	1	0	1	0	0	1	0	1	0	0	1	0	1
Pará (N)	0	0	1	0	1	0	0	1	0.2937	0.7063	0	0	1	0	1
Paraíba (NE)	0	0	1	0	1	0	0	1	0	1	0	0.0263	0.9737	0	1
Paraná (S)	0	0	1	0	1	0	0	1	0.5766	0.4234	0.7946	0.0056	0.1998	0.5945	0.4055
Pernambuco (NE)	0	0	1	0	1	0	0.0279	0.9721	0	1	0	0.034	0.966	0	1
Piauí (NE)	0.7258	0.0022	0.2719	0	1	0	0	1	0	1	0	0	1	0.5882	0.4118
Rio de Janeiro (SE)	0	0	1	0	1	0	0	1	0.2938	0.7062	0	0	1	0.3218	0.6782
Rio Grande do Norte (NE)	0	0.022	0.978	0	1	0	0.02	0.98	0	1	0	0.0238	0.9762	0	1
Rio Grande do Sul (S)	0	0	1	0	1	0	0	1	0.3102	0.6898	0	0	1	0.5617	0.4383
Santa Catarina (S)	0.7313	0.0061	0.2626	0.5672	0.4328	0.7052	0.0075	0.2873	0.5671	0.4329	0.8045	0.0041	0.1914	0.4746	0.5254
São Paulo (SE)	0	0	1	0	1	0	0	1	0.3014	0.6986	0	0	1	0.5556	0.4444

Note: N=North Region, NE=Northeast Region, MW=Midwest Region, SE=Southeast Region and S=South Region.

APPENDIX 5 - Table 5A - Virtual weight attributed to the variables - *Continued*

MODEL 2																		
	2018						2019						2020					
	Transplant Service Expenses {I}	Nº of Transplant Beds {I}	Nº of transplant teams {I}	Nº of effective donors {I}	Nº of Transplants Performed {O}	Nº of patient survivors {O}	Transplant Service Expenses {I}	Nº of Transplant Beds {I}	Nº of transplant teams {I}	Nº of effective donors {I}	Nº of Transplants Performed {O}	Nº of patient survivors {O}	Transplant Service Expenses {I}	Nº of Transplant Beds {I}	Nº of transplant teams {I}	Nº of effective donors {I}	Nºof Transplants Performed {O}	Nº of patient survivors {O}
Bahia (NE)	0.6639	0	0	0.3361	0.5088	0.4912	0.163	0	0	0.837	0	1	0.949	0	0	0.051	0.5078	0.4922
Ceará (NE)	0	0	0	1	0.5133	0.4867	0.239	0	0	0.761	0.5133	0.4867	0	0	0	1	0.5112	0.4888
Distrito Federal (MW)	0	0	0	1	0.5176	0.4824	0	0	0	1	0.51	0.49	0	0	0	1	0.524	0.476
Espírito Santo (SE)	0	0	0	1	0	1	0.279	0	0	0.721	0	1	0	0	0	1	0.512	0.488
Goiás (MW)	1	0	0	0	0	1	0.363	0	0	0.637	0.5083	0.4917	0.9521	0	0	0.0479	0.517	0.483
Maranhão (NE)	0.6666	0	0	0.3334	0.5143	0.4857	0.1872	0	0	0.8128	0.5094	0.4906	0.9057	0	0	0.0943	0.2077	0.7923
Mato Grosso do Sul (MW)	0.9999	0	0	0.0001	0.5152	0.4848	0.9999	0	0	0.0001	0	1	0.9999	0	0	0	0.2678	0.7322
Minas Gerais (SE)	0	0	0	1	0.5114	0.4886	0.1069	0	0	0.8931	0	1	0	0	0	1	0.508	0.492
Pará (N)	0.9138	0	0	0.0862	0	1	0.9575	0	0	0.0424	0	1	0.6196	0	0	0.3804	0	1
Paraíba (NE)	0.2361	0	0	0.7639	0.5091	0.4909	0.2542	0	0	0.7458	0.5169	0.4831	0	0	0	1	0.5323	0.4677
Paraná (S)	0.7213	0	0	0.2787	0.5157	0.4843	0.1993	0	0	0.8007	0.5137	0.4863	0	0	0	1	0.5125	0.4875
Pernambuco (NE)	0	0	0	1	0.5113	0.4887	0	0	0	1	0.5168	0.4832	0	0	0	1	0.5176	0.4824
Piauí (NE)	1	0	0	0	0	1	1	0	0	0	0.5333	0.4667	0.9999	0	0	0.0001	0.2348	0.7652
Rio de Janeiro (SE)	0.7308	0	0	0.2692	0.5161	0.4839	0.1914	0	0	0.8086	0.5154	0.4846	0	0	0	1	0.5111	0.4889
Rio Grande do Norte (NE)	1	0	0	0	0	1	1	0	0	0	0	1	0.9809	0	0	0.019	0.1601	0.8399
Rio Grande do Sul (S)	0	0	0	1	0	1	0.2804	0	0	0.7196	0	1	0	0	0	1	0.5051	0.4949
Santa Catarina (S)	0.701	0	0	0.299	0.5097	0.4903	0.1713	0	0	0.8287	0	1	0.9489	0	0	0.051	0.5063	0.4937
São Paulo (SE)	0.7493	0	0	0.2507	0.5124	0.4876	0.2337	0	0	0.7663	0.5103	0.4897	0	0	0	1	0.5121	0.4879

Note: N=North Region, NE=Northeast Region, MW=Midwest Region, SE=Southeast Region, and S=South Region.

APPENDIX 5 - Table 5A - Virtual weight attributed to the variables - *Continued*

MODEL 3									
	2018			2019			2020		
	Transplant waiting list (December 2018) {I}	N' of Transplant Beds {O}	Nº transplant of teams {O}	Transplant waiting list (December 2019) {I}	N' of Transplant Beds {O}	Nº of transplant of teams {O}	Transplant waiting list (December 2020) {I}	N' of Transplant Beds {O}	Nº of transplant teams {O}
Bahia (NE)	1	0	1	1	0.0378	0.9622	1	0	1
Ceará (NE)	1	0.864	0.136	1	0.1438	0.8562	1	0.8477	0.1523
Distrito Federal (MW)	1	0	1	1	0.0874	0.9126	1	0	1
Espírito Santo (SE)	1	0.4153	0.5847	1	0.1108	0.8892	1	0	1
Goiás (MW)	1	0.811	0.189	1	0.1396	0.8604	1	0.1655	0.8345
Maranhão (NE)	1	0	1	1	0.9048	0.0952	1	0.8992	0.1008
Mato Grosso do Sul (MW)	1	0.8	0.2	1	0.1014	0.8986	1	0	1
Minas Gerais (SE)	1	0.8113	0.1887	1	0.1021	0.8979	1	0	1
Pará (N)	1	0	1	1	0.0732	0.9268	1	0.8835	0.1165
Paraíba (NE)	1	0	1	1	0	1	1	0.88	0.12
Paraná (S)	1	0	1	1	0.0794	0.9206	1	0	1
Pernambuco (NE)	1	0.8877	0.1123	1	0.181	0.819	1	0.8802	0.1198
Piauí (NE)	1	0.9474	0.0526	1	0.7538	0.2462	1	0.9474	0.0526
Rio de Janeiro (SE)	1	0	1	1	0.042	0.958	1	0	1
Rio Grande do Norte (NE)	1	0	1	1	0.0418	0.9582	1	0	1
Rio Grande do Sul (S)	1	0	1	1	0.0812	0.9188	1	0	1
Santa Catarina (S)	1	0.6432	0.3568	1	0.0663	0.9337	1	0	1
São Paulo (SE)	1	0	1	1	0.0911	0.9089	1	0	1

Note: N=North Region, NE=Northeast Region, MW=Midwest Region, SE=Southeast Region, and S=South Region.

APPENDIX 6 - Table 6A - Malmquist productivity index results

MODEL 1									
	2018-2019			2019-2020			2018-2020		
	C	F	MPI	C	F	MPI	C	F	MPI
Bahia (NE)	1.02	1.07	1.09	1.16	0.86	1	1.18	0.93	1.09
Ceará (NE)	1.05	1.07	1.12	1	0.73	0.73	1.05	0.78	0.82
Distrito Federal (MW)	0.63	1.05	0.66	1.2	0.85	1.02	0.75	0.88	0.66
Espírito Santo (SE)	0.98	1.07	1.05	0.9	0.86	0.78	0.89	0.93	0.82
Goiás (MW)	0.75	1.06	0.8	1.39	0.86	1.2	1.04	0.91	0.95
Maranhão (NE)	0.69	1.04	0.71	0.6	0.86	0.52	0.41	0.88	0.36
Mato Grosso do Sul (MW)	0.95	1.06	1.01	1.01	0.78	0.79	0.97	0.86	0.83
Minas Gerais (SE)	1.05	1.07	1.13	1.09	0.87	0.95	1.15	0.93	1.07
Pará (N)	0.76	1.06	0.8	0.46	0.86	0.39	0.35	0.93	0.32
Paraíba (NE)	2.55	1.06	2.71	1.12	0.87	0.97	2.87	0.91	2.61
Paraná (S)	0.88	1.02	0.9	1.12	0.72	0.8	0.98	0.74	0.73
Pernambuco (NE)	0.99	1.07	1.05	0.95	0.87	0.82	0.93	0.93	0.87
Piauí(NE)	0.52	1.07	0.56	3.29	0.85	2.8	1.71	0.74	1.27
Rio de Janeiro (SE)	1.01	1.05	1.06	1.06	0.86	0.91	1.08	0.91	0.98
Rio Grande do Norte (NE)	0.93	1.06	0.99	0.64	0.83	0.53	0.59	0.92	0.54
Rio Grande do Sul (S)	0.98	1.02	1	1.03	0.85	0.88	1.01	0.87	0.87
Santa Catarina (S)	1	1.06	1.06	1	0.7	0.7	1	0.74	0.74
São Paulo (SE)	0.88	1.04	0.92	1.12	0.86	0.96	0.99	0.89	0.88
Geometric Mean	0.92	1.06	0.98	1.03	0.83	0.85	0.95	0.87	0.82

Note: N=North Region, NE=Northeast Region, MW=Midwest Region, SE=Southeast Region, and S=South Region. C - Catch-up Effect (Efficiency change); F - Frontier Shift (Technological Change); MPI - Malmquist Productivity Index

APPENDIX 6 - Table 6A - Malmquist productivity index results - *Continued*

MODEL 2									
	2018-2019			2019-2020			2018-2020		
	C	**F**	**MPI**	**C**	**F**	**MPI**	**C**	**F**	**MPI**
Bahia (NE)	1.09	0.92	1	1.04	0.92	0.96	1.13	0.9	1.02
Ceará (NE)	1.28	0.74	0.95	0.84	0.96	0.81	1.07	0.74	0.8
Distrito Federal (MW)	1.3	0.8	1.04	0.82	0.89	0.73	1.06	0.7	0.74
Espírito Santo (SE)	1.36	0.78	1.06	0.91	0.9	0.82	1.23	0.7	0.86
Goiás (MW)	1.02	0.98	1	0.77	0.92	0.71	0.79	0.9	0.71
Maranhão (NE)	1.17	0.92	1.08	0.95	0.95	0.9	1.12	0.93	1.03
Mato Grosso do Sul (MW)	1	1.01	1.01	0.97	0.97	0.95	0.97	0.98	0.95
Minas Gerais (SE)	1.16	0.8	0.93	0.97	0.89	0.86	1.13	0.7	0.79
Pará (N)	1	0.97	0.97	1	0.96	0.96	1	0.91	0.91
Paraíba (NE)	0.9	0.75	0.67	0.63	0.95	0.6	0.56	0.74	0.42
Paraná (S)	1.2	0.81	0.97	0.86	1	0.86	1.03	0.83	0.85
Pernambuco (NE)	1.11	0.8	0.89	0.81	0.9	0.73	0.9	0.7	0.63
Piauí (NE)	0.91	1.01	0.92	1.05	0.93	0.98	0.95	0.97	0.93
Rio de Janeiro (SE)	1.17	0.81	0.95	0.95	1	0.95	1.11	0.78	0.87
Rio Grande do Norte (NE)	0.99	1.01	1	1.02	0.97	0.99	1.01	0.97	0.98
Rio Grande do Sul (S)	1.28	0.78	1	1.02	0.9	0.92	1.3	0.7	0.92
Santa Catarina (S)	1.12	0.87	0.97	0.97	0.95	0.91	1.08	0.87	0.94
São Paulo (SE)	1.33	0.74	0.99	0.88	0.96	0.85	1.17	0.74	0.87
Geometric Mean	1.12	0.86	0.96	0.91	0.94	0.85	1.02	0.81	0.83

Note: N=North Region, NE=Northeast Region, MW=Midwest Region, SE=Southeast Region and S=South Region. C - Catch-up Effect (Efficiency change); F - Frontier Shift (Technological Change); MPI - Malmquist Productivity Index.

APPENDIX 6 - Table 6A - Malmquist productivity index results - *Continued*

MODEL 3									
	2018-2019			2019-2020			2018-2020		
	C	**F**	**MPI**	**C**	**F**	**MPI**	**C**	**F**	**MPI**
Bahia (NE)	0.63	1	0.64	1.97	1.42	2.79	1.25	1.32	1.64
Ceará (NE)	0.71	1.36	0.96	0.85	1.85	1.57	0.6	1.54	0.93
Distrito Federal (MW)	0.51	0.98	0.5	1.33	1.12	1.49	0.68	1.32	0.89
Espírito Santo (SE)	0.79	1.02	0.81	0.67	0.78	0.53	0.53	1.4	0.75
Goiás (MW)	1.03	1.17	1.21	1.42	3.14	4.47	1.47	1.5	2.2
Maranhão (NE)	1.28	1.33	1.7	0.62	0.91	0.56	0.79	1.43	1.13
Mato Grosso do Sul (MW)	0.58	1	0.58	2.35	0.71	1.68	1.36	1.35	1.83
Minas Gerais (SE)	1.07	1.03	1.1	0.66	1.74	1.14	0.7	1.5	1.05
Pará (N)	0.92	0.98	0.9	0.39	1.42	0.55	0.35	1.43	0.51
Paraíba (NE)	1.42	1.02	1.45	0.77	1.49	1.14	1.08	1.43	1.54
Paraná (S)	0.79	0.98	0.78	0.79	1.07	0.84	0.62	1.32	0.82
Pernambuco (NE)	0.47	1.62	0.76	0.91	0.89	0.81	0.43	1.54	0.66
Piauí (NE)	1.34	1.78	2.39	0.41	1.46	0.6	0.55	1.54	0.85
Rio de Janeiro (SE)	1	0.99	0.99	0.64	0.91	0.58	0.64	1.32	0.84
Rio Grande do Norte (NE)	1.5	0.98	1.48	0.82	1.07	0.88	1.23	1.32	1.61
Rio Grande do Sul (S)	0.93	0.97	0.91	0.7	1.42	0.99	0.65	1.32	0.86
Santa Catarina (S)	1	0.98	0.98	0.6	1.82	1.1	0.6	1.32	0.79
São Paulo (SE)	0.9	0.97	0.88	0.7	0.58	0.4	0.63	1.32	0.82
Geometric Mean	0.89	1.1	0.98	0.82	1.22	1	0.73	1.4	1.02

Note: N=North Region, NE=Northeast Region, MW=Midwest Region, SE=Southeast Region and S=South Region. C - Catch-up Effect (Efficiency change); F - Frontier Shift (Technological Change); MPI - Malmquist Productivity Index.