On evaluating vertically merged hospitals in terms of quality and access: The Portuguese experience

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Abstract

Uncovering the optimal delivery care model to maximize value in health is one of the dominant concerns of health systems. The present study aims at contributing to the serious and contentious discussion regarding the effects of the implementation of the vertical integration model, notably by enriching the literature devoted to establishing the link between healthcare outcomes and vertically integrated healthcare providers, through an exhaustive literature review and a robust performance analysis of Portuguese healthcare providers. Using an output-oriented Data Envelopment Analysis and a Malmquist Index approach, one studied the impact of implementing vertical models (Local Health Units) on quality- and access-related performance, considering the environmental effect. From the study of 39 healthcare providers, between 2015 and 2019, one may conclude that: hospitals included in vertical models exhibit statistically significant higher partial performance than singular hospitals and hospital centers; a significant number of hospitals within vertical models are above the 75th percentile regarding partial performance; hospitals included in vertical models exhibit statistically significant lower overall performance and frontier-shift related performance than singular hospitals and hospital centers, for services availability. The overall consideration is that hospitals within vertical models exhibit slight improvements in quality and access measures when considered the environment in which these are incorporated.

Keywords: Vertical Integration; Data Envelopment Analysis; Malmquist Index approach; Environmental Effect; Quality; Access.

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1. Introduction

1.1. The health sector in Portugal: The context of the problem

Contrary to what one might think, it was only in the twentieth century that several reforms were implemented towards a better healthcare for the Portuguese population. The creation of the Portuguese National Health Service (NHS) in 1979 was the major turning point for the health sector in Portugal, by establishing a universal health system, free at the point of use. The NHS Law followed other critical moments, such as: the declaration of the first act of public health legislation, known as the Ricardo Jorge reform (1901), the creation of the Ministry of Health and Assistance (1958), the acknowledgment of the state as responsible for health policy and implementation (1971), the creation of first-generation primary care centres, through the medium of the Gonçalves Ferreira reform (1971), and the inclusion of the citizens' right to healthcare in the Portuguese Constitution (1976) (Barros et al., 2011).

From an organizational point-of-view, the Portuguese health system is, nowadays, composed of the NHS, private voluntary health insurance schemes and health subsystems associated with the labour market (Ferreira et al., 2018). More indicatively, the healthcare delivery system incorporates a diverse range of healthcare providers (primary care facilities, hospitals, long-term care (LTC) networks and pharmacies), some of which are public (not-for-profit) and others private. Each provider is coupled to the population and to the Ministry of Health and its institutions in its own way.

Regarding physical resources, Portugal had, in 2019, 238 hospitals, presenting approximately an half-and-half distribution regarding public and private hospitals, allowing a total capacity of 36,913 beds, according to *PORDATA*. Concerning primary care facilities and pharmacies, the numbers are around 1,772 (as of 2015, according to Simões et al. (2017)) and 2,924 (as of 2019, according to *PORDATA*). Geographically, the distribution of healthcare providers, and, therefore, of health professionals, is not even, giving rise to some inequalities in access to care. In fact, the Northern, Lisbon and Tagus Valley accumulate more than 70% of the health workforce (Ferreira et al., 2018). This problem is further aggravated in some more isolated interior regions of Portugal. Several facilitated recruitment processes were created in those regions to counterbalance this situation, like increases in salaries or even enhancement of conditions for participation in research (Ferreira et al., 2018), nevertheless, Portugal still struggles today with inequalities of access to care for geographic motives.

The Portuguese NHS is said to be universal, equitable and tendentiously free (co-payments are charged to some patients). The financial sustainability behind this system is derived from the implementation of the Beveridge model. In this model, the central government employs the collected funds from citizen's taxes payments into the public health sector. The allocation of financial resources for each one of the providers relies on a variety of traits, e.g., size, scope of services provided, patient's complexity, cost-efficiency, among others (Ferreira and Marques, 2018).

1.2. Defining Vertical Integration and Local Health Units

The integration of services from different levels of care (e.g. primary care, acute care, post-acute care) is designated as vertical integration, as opposed to the horizontal expansion, created, for example, when hospitals (acute care) associate between themselves (Szostak, 2015). With the assimilation of healthcare providers of different levels into a single unit, fragmentation of care is prevented.

In hospital-physician affiliations, physicians are abstractly seen as the upstream firm and hospitals as the downstream firms. Physicians have consultations with patients (primary care), making potential referrals for additional care. At the next level in the chain, hospitals appear as the downstream firms, receiving the patient - the intermediate product - and providing the next level of healthcare services (Post et al., 2017). Within the hospital-physician affiliation concept, many forms of integration may be implemented: the employment of physicians (the tightest form); comanagement; and independent affiliations (the loosest form), which happens when hospitals purchase physician administrative time through medical directorships (Sowers et al., 2013).

Regarding integration of acute care with post-acute care, hospitals may be seen as the upstream firms and post-acute care facilities as the downstream firms. In the same fashion as before, the patient is considered the intermediate product that is carried from one level of the healthcare production process to another (Post et al., 2017).

Local Health Unit (LHU) was the chosen term to designate the vertical merging between hospitals and health centers in Portugal. The first one, Matosinhos LHU, was created in 1999, through the Decree-Law No. 207/99, of 9th June. It emerged from the integration of the Pedro Hispano Hospital and the Health Centers of Matosinhos, Senhora da Hora, São Mamede and Leça da Palmeira (Lourenço et al., 2010). It was only in 2007, that the second LHU was created. Alto Alentejo PPE LHU integrated Portalegre and Elvas Hospitals and the Health Centers of Portalegre. In the following year, three additional PPE LHUs were initiated: Northern Minho, Southern Alentejo and Guarda PPE LHUs (Lourenço et al., 2010). In 2009, a LHU was established in Castelo Branco. Since then, Northeast/Bragança, in 2011, and Coastal Alentejo/Santiago do Cacém, in 2012, also greeted vertical mergers (Simões et al., 2017). It was then that Portugal reached the still present-day number of LHUs, eight.

1.3. Objectives of the thesis

Health systems around the globe have been struggling with questions regarding the optimal delivery care model to better treat patients. The current study aims at contributing for the serious discussion regarding the effects of the implementation of the vertical integration model, particularly by enriching the literature devoted to establish the link between healthcare outcomes to the vertically integrated healthcare providers, through an exhaustive systematic review and a study of the Portuguese experience.

More precisely, the systematic review aims at: a) collecting a large sample of papers that analyze vertically integrated healthcare providers, regarding prices of care, costs, efficiency, quality or access; b) obtaining statistical information regarding the studies' sample (as the most studied country, most used methodology or even the most analyzed outcomes, to name a few); c) determining how vertical integration impacts each one of the outcomes. Additionally, the Portuguese case study seeks to: d) discover the impact of the implementation of

LHUs on quality and access of the hospital-settings component, using robust methodologies and taking into account the environmental effect; e) understand the political repercussions of the results obtained.

2. Literature review

2.1. Conceptual framework

The concept of vertical integration previously described utterly involves many different strategies in practice. Nevertheless, vertical integration is most often defined within the delivery care system. In this literature review, the vertical integration assessment only includes systems integrating primary care with acute care or acute care with post-acute care, *i.e.*, hospitals exhibiting backward or forward integration.

To thoroughly analyze performance in vertical models, one might incorporate several policy-relevant outcomes in the conceptual framework: costs, prices of care, efficiency, quality of care, and access.

2.2. Summary of findings and directions for future work

Many researchers who focus their studies on vertical integration often recognize that this integration strategy mainly aims to provide financial benefits (Cuellar and Gertler, 2006; West et al., 2017). Our literature search calls into question those objectives associated with the implementation of the model. One encountered adverse effects of backward vertical integration towards the cost of care. These adverse effects were even more significant when analyzing patient-level costs. Additionally, vertical integration may also negatively influence prices of care, which may be a cause of increments in patient-level expenses.

Further, the included studies show no absolute conclusions regarding both efficiency and quality of care. A negative influence of vertical integration on these outcomes is almost out of the question, yet, a positive effect is also not absolute.

Regarding access, very little can be said. Ferreira and Marques (2018)'s study may be again highlighted in the literature since it proposes a panoply of access-related variables relevant for future research on vertical integration or even in other areas related to healthcare.

As noted in the conceptual framework, the literature in analysis focused on vertical integration within the delivery care system. From all the researches, only six examined the integration between secondary care and continuity of care. Wang et al. (2001), David et al. (2011), Liepert et al. (2014), Rahman et al. (2016), and Gupta et al. (2019) reached favorable evidence, while Konetzka et al. (2018) showed inconsistent evidence. Despite the sample being quite unbalanced (only 6 out of 64 studies examine the integration between secondary care and continuity of care), this model appears to have overall positive effects on hospitals.

Despite the fact that vertical integration did not appear routinely in the medical literature until the late 80s, since 2011 the number of studies per year regarding vertical integration in healthcare has increased, revealing a promising future on the study of this topic. Nevertheless, it is important to emphasize again that this literature review includes only quantitative research articles within the delivery care system, meaning that it only consists of a small sample of all the articles regarding vertical integration in healthcare. However, it is enough to apprehend that the medical researchers are on the pathway to fully understanding the performance of vertically integrated providers.

One additional subject that should be addressed is the methodology used to analyze vertical integration, which is a serious issue. By scrutinizing this subject, the first thing that stands out is a large number of regression analyses compared to DEA or SFA, which are substantially more robust models, by enabling the analysis of a more complete concept of efficiency, the flow of produced inputs and outputs (Wei and Wang, 2017). It is evident that both of these methods provide efficiency scores, while regressions are used more globally. However, it is never too much to clarify that these methods are complete and significant and that they allow not only to examine efficiency but also indirectly, quality of care, access or even other patient-oriented outcomes with relevance to policy-makers.

Perhaps one of the study's most significant limitations, a detail that may introduce some bias in the conclusions drawn from the study, is that only 11 out of the 64 included studies were carried outside of the US. Additionally, there was clear evidence of significant efforts from European and Asian countries to analyze healthcare providers' performance. These efforts are crucial to combat the astronomical difference between healthcare systems around the world. For example, European healthcare managers should not rely entirely on the effects of vertical integration in US healthcare providers to decide whether to implement it in their countries. Thus, it is undeniable to state a clear need for studies in countries other than the US that are gradually introducing vertical integration into their health systems.

3. Case study

3.1. Data collection and sample

This study aims at evaluating the performance of hospitals within LHUs and comparing it with traditional hospitals. Performance is computed using data relative to consumed resources and delivered services of healthcare. In view of that, key-performance indicators (KPIs) on quality and access, and environmental data were collected from the official database `https://benchmarking-acss.min-saude.pt/` and PORDATA (`https://www.pordata.pt/`), supported and developed by the (Portuguese) Central Administration of Health Systems and by the Francisco Manuel dos Santos Foundation, respectively.

The study's sample is composed of all of the existing 8 LHUs and 31 traditional hospitals, composing a total of 39 Portuguese public hospitals. The latter group includes singular hospitals (SHs), hospital centres (HCs) and PPPs. The sample is distributed over five years, from January, FY2015, to December, FY2019. Therefore, the global sample includes 2,340 observations of hospitals, of which 480 correspond to LHUs and 1,860 to traditional models.

3.2. Process and environmental variables

The choice of both process and environmental variables follows not only the data availability for all the sample but also a review of seven scientific articles that use both quality- and access-related variables to analyze Portuguese healthcare providers.

All the process variables that were used in at least one of the seven articles analyzed were included in the case study (Figures 1 and 2). In the figure, and henceforward, desirable variables are represented as g^+ and undesirable as g^-. These metrics should provide the performance on overall healthcare access and quality, by providing a robust indicator of what can and should be taken into account in an effective healthcare plan (Fullman et al., 2018).

As with process variables, all the environmental variables that were used in at least one of the seven articles analyzed were included in the case study (Figure 3), with the exception of "stillbirth rate" due to lack of data available. This set of metrics should provide enough information to take under consideration the exogenous environment in the Portuguese health sector.

Ultimately, in order to deal with gaps in the data set for certain years and variables, one designed nine distinct models. Three models analyze both quality- and access-related variables (models I-III), and only differ in the number of healthcare providers and/or number of variables. Three ad-

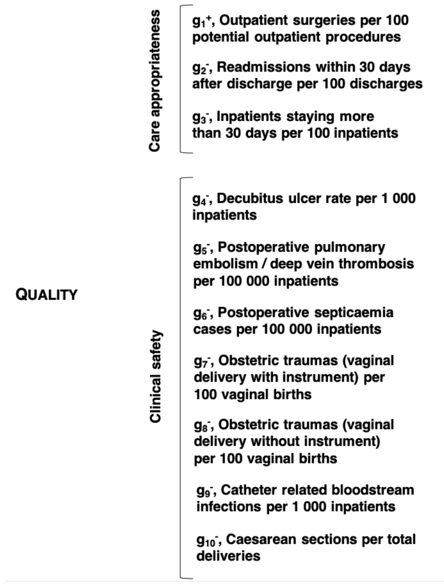

Figure 1: Quality-related variables.

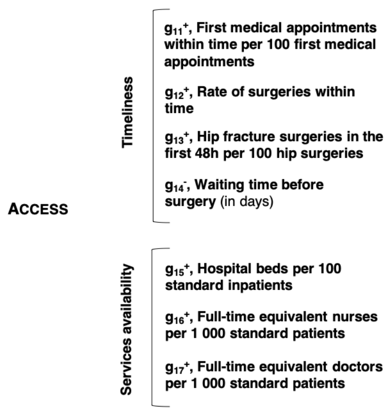

Figure 2: Access-related variables.

ditional models analyze quality-related variables, by including all the variables (model IV), or variables of a specific quality dimension (model V, care appropriateness, and model VI, clinical safety). Lastly, three models analyze access-related variables, by including all the variables (model VII), or variables of a specific access dimension (model VIII, timeliness, and model IX, services availability). For each model, missing data was replaced by the best existing value for that variable (optimistic scenario) or by the worst existing value (pessimistic scenario). Taking into account the distinct scenarios, 18 models were designed in total.

3.3. Pre-processing and consideration of environmental variables

Before replacing the models' missing values according to the scenarios, an initial search for outliers was conducted. All the values outside of the range $[\mu_i - 2\sigma_i, \mu_i + 2\sigma_i]$, which correspond to ob-

ENVIRONMENT

- z_1, **Population density**, Inhabitants per km^2
- z_2, **Population size** (in millions)
- z_3, **Purchasing power per capita**
- z_4, **Illiteracy rate**, Illiterates per 100 inhabitants
- z_5, **Childhood mortality rate**, Mortality rate under-1 per 100 live births
- z_6, **Elderly rate**, Elderlies (> 65 y.o.) per 100 inhabitants
- z_7, **Youth rate**, Youngsters (< 15 y.o.) per 100 inhabitants
- z_8, **Death rate**, Deaths per 100 inhabitants
- z_9, **Elderly rel. mortality rate**, Mortality rate over-65 per 100 deaths
- z_{10}, **Crude birth rate**, Births per 100 inhabitants
- z_{11}, **Sec./Terc. education rate**, Inhabitants with secondary or higher education per 100 inhabitants
- z_{12}, **Dependence index**, Elderlies and youngsters per 100 inhabitants at the working age
- z_{13}, **Inhabitants per doctor**
- z_{14}, **Inhabitants per pharmacist**

Figure 3: Environmental variables.

servations of variable i within the first two standard deviations, were analyzed. According to the empirical rule, 95% of the observations fall within the range used, which showed to be the best one to analyze the outliers. In fact, analyzing outliers outside the range $[\mu_i - 3\sigma_i, \mu_i + 3\sigma_i]$ appeared to be over-exclusive. After being signaled, the values that apparently looked like a typo or appeared illogical were eliminated.

Additionally, one verified if it was possible to reduce the dimensionality of each model. With this intention, one applied a principal component analysis (PCA). PCA is an orthogonal linear transformation that converts the data to a new coordinate system. By changing the basis, some principal components may be disregarded, thus reducing the dimensionality of the problem (Adler and Golany, 2007).

Ultimately, in order to deal with the environmental effect, conditional formulations were employed. In a general sense, in the DEA model, only similar DMUs were used to make up the frontier for a certain DMU. That similarity is analyzed by measuring the global bandwidth, using the dataset of environmental variables, and by applying the product kernel approach.

3.4. Data Envelopment Analysis

Data Envelopment Analysis (DEA) is a non-parametric "data-oriented" approach for evaluating the performance of a group of entities named decision-making units (DMUs), which theoretically "transform" multiple inputs into multiple outputs (Thanassoulis, 2001; Cooper et al., 2011).

Precisely, DEA directs its analysis towards frontiers rather than central tendencies. The latter is common in several methodologies, as, for example, regression models. Moreover, the present methodology stands out for uncovering relationships that would remain hidden with other methods (Cooper et al., 2011). This is a consequence of the fact that one does not require to explicitly formulate assumptions of weights or specify formal relationships between inputs and outputs, which makes DEA the most suitable methodology for the present research work.

One may recall from the literature review that, in addition to DEA, Stochastic-Frontier Analysis (SFA) is widely used in the literature. Nevertheless, although it also analyzes frontiers, it requires strong functional assumptions, and it does not allow multiple outputs to be analyzed simultaneously (Jacobs et al., 2006), which makes its use in the present study impractical. However, despite these DEA's advantages compared to SFA, it is essential to recognize that DEA also has disadvantages. Disadvantages as not enabling the distinction between efficiency variation noise, being vulnerable to outliers, and presenting endogeneity problems (Jacobs et al., 2006).

One of the most important considerations when applying a DEA model is whether to assume constant or variable returns to scale. The constant returns to scale (CRS) assumption was proposed by Charnes et al. (1978) in the original DEA paper. This framework is suitable when all units function at the optimal scale, which is difficult to assume in healthcare, for various reasons: imperfect competition, limitations on finance, mergers, to name a few (Jacobs et al., 2006). Banker et al. (1984) extended the model to be appropriate for a sub-optimal scale, which encompasses the creation of the variable returns to scale (VRS) model.

Even though one intends to analyze healthcare DMUs, the choice of CRS or VRS commonly hangs on the circumstances and the motivation of the study. One may recall that every single process variable included in the present case study incorporates a ratio. This kind of data implies the usage of the CRS model since any information regarding DMUs' proportions is neglected in the construction of a ratio (Jacobs et al., 2006).

Taking into account the previous considerations, the formulation of a DEA CRS model may be illustrated. A DMU may be denoted by k, which is characterised by a set of m inputs, $x_k = \{x_{1k}, ..., x_{ik}, ..., x_{mk}\}$ and s outputs, $y_k = \{y_{1k}, ..., y_{rk}, ..., y_{sk}\}$. A DMU may be classified as efficient, exhibiting a score of 1 (100%), if and only if no other DMU present inputs or outputs that can be improved without worsening some of its other inputs or outputs (Cooper et al., 2011). The present concept is referred to as relative efficiency. This kind of efficiency, which may also be designated as technical efficiency (TE), is formulated as presented in Equation 1, as in Huguenin (2012).

$$TE_k = \frac{\sum_{r=1}^{s} u_r y_{rk}}{\sum_{i=1}^{m} v_i x_{ik}}, \quad (1)$$

being u_r and v_i, the weights of output r and input i, respectively.

The technical efficiency of a unit k is maximized under certain constraints, requiring, for that reason, the usage of linear programming. The problem can be considered by following two different approaches: input-oriented or output-oriented. This case study follows the latter approach, in which the weighted sums of outputs are maximized, holding inputs constant (Jacobs et al., 2006). For an output-oriented model, a frontier is identified based on the DMUs achieving the highest output mix given their inputs. The efficient DMUs form a piecewise linear envelope of surfaces in multidimensional space. Then, each DMU is assigned an efficiency score by comparing its output/input ratio to that of efficient DMUs (Jacobs et al., 2006).

Using linear programming notation, one is facing the problem of optimizing a linear objective function subject to a set of constraints. The dual equations (or equations in the multiplier form) for an output-oriented DEA CRS model are presented in Equation 2, as in Huguenin (2012).

$$\begin{aligned} &\text{Minimize} \qquad \textstyle\sum_{i=1}^{m} v_i x_{ik} \\ &\text{Subject to} \\ &\textstyle\sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r y_{rj} \geq 0 \qquad j = 1, ..., n \\ &\textstyle\sum_{r=1}^{s} u_r y_{rk} = 1 \\ &u_r, v_i > 0 \qquad \forall r = 1, ..., s; i = 1, ..., m \end{aligned} \quad (2)$$

The model equations may be written in one other form, the envelopment form. This form is often recommended to solve the computation as it only involves $s+m$ constraints rather than $n+1$ constraints in the multiplier form. The equations in the envelopment form (or primal equations) are presented in Equation 3, as in Huguenin (2012).

$$\begin{aligned} &\text{Maximize} \qquad \phi_k \\ &\text{Subject to} \\ &\phi_k y_{rk} - \textstyle\sum_{j=1}^{n} \lambda_j y_{rj} \leq 0 \qquad r = 1, ..., s \\ &x_{ik} - \textstyle\sum_{j=1}^{n} \lambda_j x_{ij} \geq 0 \qquad i = 1, ..., m \\ &\lambda_j \geq 0 \qquad \forall j = 1, ..., n \end{aligned} \quad (3)$$

being $\frac{1}{\phi_k}$, the technical efficiency of unit k and λ_j, the associated weighting of outputs and inputs of unit j.

Ultimately, it is crucial to refer that this model was fitted in a Benefit of Doubt (BoD) framework. The basic BoD model is on a par with the original DEA CRS model of Charnes et al. (1978), with all KPIs considered as outputs and a dummy input equal to one for all the units. Formally, the routine way to neutralize the impact of inputs in the model is to set $m = 1$ and $x_i = 1$ for all j observations (Van Puyenbroeck, 2017). By adapting the previously defined DEA model to this framework, one constructs a version that exclusively focuses on outputs.

3.5. Malmquist Indices

In parallel to DEA, Malmquist Indices (MI) are used for comparing clusters of DMUs. MI were developed by Caves, although the construction of input quantity indices as ratios of distance functions was introduced much earlier by the Professor Sten Malmquist (Jacobs et al., 2006).

In 1994, Färe and his colleagues defined an input-oriented productivity index as the geometric mean of two MIs, one concerning the technology of production at time t and the other at time $t+1$ (Färe et al., 1994). This results in the index $M^{t,t+1}$ (Equation 4), a Malmquist-type measure of productivity, as in Camanho and Dyson (2006).

$$\mathrm{M}^{t,t+1} = \left[\frac{D^t(X^{t+1}, Y^{t+1})}{D^t(X^t, Y^t)} \cdot \frac{D^{t+1}(X^{t+1}, Y^{t+1})}{D^{t+1}(X^t, Y^t)}\right]^{1/2} \quad (4)$$

Following the rationale behind the previous Malmquist-type index, an overall measure for the comparison of performance between two groups of DMUs (group A and B) may be defined (Equation 5), as in Camanho and Dyson (2006).

$$\mathrm{I}^{AB} = \left[\frac{\left(\prod_{j=1}^{\delta_A} D^A({X_j}^A, {Y_j}^A)\right)^{1/\delta_A}}{\left(\prod_{j=1}^{\delta_B} D^A({X_j}^B, {Y_j}^B)\right)^{1/\delta_B}} \cdot \frac{\left(\prod_{j=1}^{\delta_A} D^B({X_j}^A, {Y_j}^A)\right)^{1/\delta_A}}{\left(\prod_{j=1}^{\delta_B} D^B({X_j}^B, {Y_j}^B)\right)^{1/\delta_B}}\right]^{1/2}, \quad (5)$$

being δ_A and δ_B, the number of DMUs of the groups, $X^A \in \mathbb{R}^m{}_+$ and $X^B \in \mathbb{R}^m{}_+$, the inputs of the groups, and $Y^A \in \mathbb{R}^s{}_+$ and $Y^B \in \mathbb{R}^s{}_+$, the outputs of the groups. $D^B(X_j{}^A, Y_j{}^A)$ may be read as: the input distance function for a DMU in group A with respect to the frontier of group B.

Using the index I^{AB}, one may proceed with a cross-sectional comparison of the performance of two clusters of DMUs operating in different conditions, at a certain moment in time, instead of a basic measure of productivity change between two time periods ($M^{t,t+1}$) (Camanho and Dyson, 2006). More specifically, I^{AB} evaluates the distance of the DMUs to a single reference technology. By observing the formula, it is easily confirmed that the first part of the expression estimates the ratio between the average distance of DMUs from group A to the group A frontier and the average distance of DMUs from group B to the group A frontier. The second portion of the expression expresses the same ratio but using the group B frontier. Therefore, I^{AB} is fundamentally the geometric mean of those two ratios (Camanho and Dyson, 2006).

The index I^{AB}, the overall performance measure, may be decomposed into two sub-components (which is only possible because of the usage of the geometric mean formula), as in Camanho and Dyson (2006). The decomposition expression is presented in Equation 6, and the expressions for the two sub-components, IE^{AB} and IF^{AB}, are presented in Equations 7 and 8, respectively.

$$I^{AB} = IE^{AB} \cdot IF^{AB} \tag{6}$$

$$IE^{AB} = \frac{\left[\prod_{j=1}^{\delta_A} D^A(X_j{}^A, Y_j{}^A)\right]^{1/\delta_A}}{\left[\prod_{j=1}^{\delta_B} D^B(X_j{}^B, Y_j{}^B)\right]^{1/\delta_B}} \tag{7}$$

$$\mathrm{IF}^{AB} = \left[\frac{\left(\prod_{j=1}^{\delta_A} D^B(X_j{}^A, Y_j{}^A)\right)^{1/\delta_A}}{\left(\prod_{j=1}^{\delta_A} D^A(X_j{}^A, Y_j{}^A)\right)^{1/\delta_A}} \cdot \frac{\left(\prod_{j=1}^{\delta_B} D^B(X_j{}^B, Y_j{}^B)\right)^{1/\delta_B}}{\left(\prod_{j=1}^{\delta_B} D^A(X_j{}^B, Y_j{}^B)\right)^{1/\delta_B}}\right]^{1/2} \tag{8}$$

This decomposition allows different comparisons. IE^{AB} is used to compare the within-group efficiency spreads, and IF^{AB} expresses the productivity gap between the frontiers of the two groups. This means that a good overall performance may be connected with two elements: less dispersion in the efficiency levels of the DMUs in one group compared to the other (IE^{AB}), and/or the dominance of the best practice frontier (IF^{AB}) (Camanho and Dyson, 2006).

4. Results and discussions

4.1. Partial performance

First, by designing models that include both quality- and access-related variables (models I to III), one may draw conclusions on the overall partial performance of each one of the clusters. The employed statistical tests suggest that hospitals within LHUs exhibit a slightly higher partial performance than the cluster of non-LHUs. Indeed, p-values exhibit statistical significance for all the three models.

When comparing the previous results with the literature, one may remark that from all the ten studies that describe the impact of vertical integration on technical efficiency, only one appears to include both quality- and access-related variables in its model. Leleu et al. (2017) uses a DEA model to analyze the technical efficiency of vertically integrated healthcare providers, and reaches the conclusion that backward integration appears to have positive effects in the partial performance of healthcare providers. The American researchers argue that these results were expected, as physicians control around 80% of the healthcare costs and, therefore, the majority of the process.

Second, quality-related partial performance may be analyzed independently by examining the results from models IV to VI. The employed statistical tests suggest that hospitals within LHUs exhibit slightly higher partial performance non-LHUs, when analyzing models V and VI. Nevertheless, under model IV, no significant statistical differences between clusters are encountered.

From the ten studies collected in Chapter 2 which analyze the impact of vertical integration on efficiency, none appears to be only using quality-related variables in its DEA or SFA model. Nevertheless, quality may be analyzed directly. A consensus was not reached regarding the impact of vertical models on quality of care, as twenty studies exhibit increased quality of care, four, decreased, and fourteen, unchanged. Nevertheless, it was possible to identify a positive effect of this model on process of care measures. By taking a further look at the variables presented in Figure 3.1, one may verify that one includes KPIs that consider several process of care KPIs in the clinical safety dimension. Therefore, one may state that the statistically significant results obtained from model VI (clinical safety) for quality-related partial performance appear to be consistent with the literature.

Access-related partial performance may also be analyzed. The employed statistical tests suggest that hospitals within LHUs exhibit slightly higher partial performance non-LHUs, as the p-values exhibit statistical significance for all the three models (VII to IX). Therefore, one may affirm that LHUs present better partial performance on access and on the timeliness and the services availability dimensions.

From the ten efficiency-related analysis studies collected in Chapter 2, six appear to be using services availability variables as their models' inputs. In opposition, the timeliness dimension of access does not appear to be the main focus in the literature, as no study was found to be examining this dimension. Nevertheless, by focusing on services availability, one may affirm that the present results, from model IX, are coherent with 3 studies from the previously announced body of evidence (Chu et al., 2002; Cho et al., 2014; Caballer-Tarazona and Vivas-Consuelo, 2016). The 3 remaining articles exhibit no efficiency changes upon the implementation of this strategy (Carey, 2003; Alonso et al., 2014; Comendeiro-Maaløe et al., 2019). It is important to refer that, even though these variables were considered to be access-related in the conceptual framework of the present case study, the researchers do not directly hypothesize about access. Nevertheless, scrutinizing these papers' results is still relevant.

4.2. Discriminated partial performance

It is essential to mention and describe the best performing healthcare providers from the sample. When including variables of both outcomes, Póvoa do Varzim/Vila do Conde HC exhibits the highest partial performance, followed by Guarda LHU and Braga Hospital. Regarding quality-related variables, Braga Hospital exhibits the highest partial performance, followed by Tâmega e Sousa HC and Entre Douro e Vouga HC. Ultimately, regarding access-related variables, Póvoa do Varzim/Vila do Conde HC exhibits the highest partial performance, followed by Cascais Hospital and Castelo Branco LHU.

One might observe that 4 out of the 8 LHUs in analysis incorporate the list of the 10 best performing healthcare providers referring to models I to III, and, 3 out of the 8 LHUs in analysis incorporate the remaining two lists. These results were somewhat expected after observing the cluster efficiency scores. Nevertheless, it is important to recall that the DEA model used allowed fair comparisons according to the environment on which a certain healthcare provider was inserted. In this context, the efficient frontier of a determined healthcare provider was constructed by comparing it with providers in a similar environment.

4.3. Overall performance, partial performance spread, and frontier-shift related performance

The second robust methodology, Malmquist Productivity Index Approach, provided productivity scores for each model. As previously mentioned, the overall performance measure I^{AB} may be decomposed into the partial performance spread component, IE^{AB}, and the frontier-shift related performance, IF^{AB}. One considered a result statistically significant when outside of the interval between 0.95 and 1.05.

One may emphasize that statistically significant results are only exhibited on model IX, the one that allows us to study the services availability dimension of access. More specifically, the analysis of model IX enables us to state that cluster B outperforms cluster A in the frontier-shift related performance, IF^{AB}, and in the overall performance, I^{AB}. In this sense, despite the positive from the DEA model, which suggest that hospitals within LHUs exhibit a higher partial performance, the Malmquist Productivity Index Approach adds that, at the same time, hospitals within LHUs appear to have lower frontier-shift related performance than the remaining hospitals, in terms of services availability.

5. Conclusions

The present study focused exclusively on analyzing two distinct non-parametric models: the DEA model and the non-parametric MI approach. The case study's emphasis on non-parametric models is explained by the dispensableness of a priori defining a functional form of the efficiency frontier.

Following the literature, the primal form of the output-oriented DEA CRS model was performed, in a BoD framework. When analyzing the partial performance using both quality- and access-related variables (models I to III), one may conclude that hospitals included in LHU models exhibit statistically significant higher levels of partial performance than hospitals incorporated within traditional models. A second step comprised the analysis of outcome-specific partial performances (models IV to IX). Even when analyzed independently, both outcome-specific analysis point in the same direction, exhibiting partial performance improvements in vertically integrated hospitals. Furthermore, the DEA model's use also allowed us to perform a discriminated analysis of the 39 healthcare providers. One concluded that several hospitals included in LHUs are above the 75th percentile, which complements the conclusions from the independent two-sample Student's t-test (analysis of the mean) and confirms the ones from the Kruskal-

Wallis test (analysis of the median).

A number of explanatory factors have been proposed to explain the previously announced conclusions, among which stand out a) the tighter integration of physicians within the complete delivery care process; b) improvements of prevention and management actions for certain health conditions; c) refinements in the articulation of preoperative care with the surgery environment; d) enhancements in the delivery and guarantee of healthcare, by perpetuating local access to care.

Ultimately, the non-parametric MI approach was employed. Unlike the first model, one reached significant results only for the services availability dimension of access, which corresponds to model IX. For that dimension, hospitals included in vertical models exhibit lower frontier shift-related performance levels and lower overall performance than hospitals within traditional models.

The overall consideration for the performance analysis in the current study should take into account both models. The first model presents a positive relationship between the study strategy and the hospital's performance on quality and access. The second one does not present overall significant changes when employing vertical integration. One may conclude that the Portuguese reality should be somewhere in the middle. Meaning, hospitals within the LHU models should exhibit relative improvements on quality and access measures when considered the environment in which these are incorporated.

The fundamental conclusion of this work is that the enhancements in the processes' streamlining and interoperability in vertically integrated hospitals appear to be precursors of improvements in quality and access compared to traditional hospitals.

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References

N Adler and B Golany. PCA-DEA: Reducing the curse of dimensionality. In: Modeling problem structure and data varieties using Data Envelopment Analysis: A problem-solving handbook (pp. 139-153). *Springer*, 2007.

J M Alonso, J Clifton, and D Diaz-Fuentes. The impact of new public management on efficiency: An analysis of Madrid's hospitals. *Health Policy*, 119(3):333–340, 2014.

R D Banker, A Charnes, and W W Cooper. Some models for estimating technical and scale inefficiencies in Data Envelopment Analysis. *Management Science*, 30(9):1078–1092, 1984.

P Barros, S Machado, and J Simões. Portugal: Health system review. *Health Systems in Transition*, 13(4):1–156, 2011.

M Caballer-Tarazona and D Vivas-Consuelo. A cost and performance comparison of public private partnership and public hospitals in Spain. *Health Economics Review*, 6(1):17, 2016.

A S Camanho and R G Dyson. Data Envelopment Analysis and Malmquist Indices for measuring group performance. *Journal of Productivity Analysis*, 26:35–49, 2006.

K Carey. Hospital cost efficiency and system membership. *Inquiry*, 40:25–38, 2003.

A Charnes, W W Cooper, and E Rhodes. Measuring the efficiency of decision making units. *European Journal of Operational Research*, 2:429–444, 1978.

N E Cho, J Chang, and B Atems. The effects of health information technology adoption and hospital-physician integration on hospital efficiency. *American Journal of Managed Care*, 20 (17):eSP9–eSP15, 2014.

H L Chu, S Z Liu, and J C Romeis. Does the implementation of responsibility centers, total quality management, and physician fee programs improve hospital efficiency? Evidence from Taiwan hospitals. *Medical Care*, 40(12):1223–1237, 2002.

M Comendeiro-Maaløe, M Ridao-López, S Gorgemans, and E Bernal-Delgado. A comparative performance analysis of a renowned public private partnership for health care provision in Spain between 2003 and 2015. *Health Policy*, 123(4):412–418, 2019.

W Cooper, L Seiford, and J Zhu. *Handbook* *on data envelopment analysis*. 2011. ISBN 9781441961501.

A E Cuellar and P J Gertler. Strategic integration of hospitals and physicians. *Journal of Health Economics*, 25(1):1–28, 2006.

G David, E Rawley, and D Polsky. Integration and task allocation: Evidence from patient care. *NBER Working Paper Series*, 2011. doi: 10.3386/w17419.

D C Ferreira and R C Marques. Do quality and access to hospital services impact on their technical efficiency? *Omega*, 86:218–236, 2018.

D C Ferreira, A M Nunes, and R C Marques. Doctors, nurses, and the optimal scale size in the Portuguese public hospitals. *Health Policy*, 122 (10):1093–1100, 2018.

N Fullman, J Yearwood, S M Abay, C Abbafati, F. Abd-Allah, et al. Measuring performance on the healthcare access and quality index for 195 countries and territories and selected subnational locations: A systematic analysis from the global burden of disease study 2016. *The Lancet*, 391(10136):2236–2271, 2018.

R Färe, S Grosskopf, B Lindgren, and P Roos. Productivity developments in Swedish hospitals: A malmquist output index approach. In: Data envelopment analysis: Theory, methodology, and applications (pp. 253-272). *Springer*, 1994.

S Gupta, F D Zengul, G K Davlyatov, and R Weech-Maldonado. Reduction in hospitals' readmission rates: Role of hospital-based skilled nursing facilities. *The Journal of Health Care Organization, Provision, and Financing*, 20:1–12, 2019.

J M Huguenin. *Data envelopment analysis (DEA): A pedagogical guide for decision makers in the public sector*. IDHEAP: Chair of Public Finance, 2012. ISBN 2940390541.

R Jacobs, P C Smith, and A Street. *Measuring Efficiency in Health Care: Analytic Techniques and Health Policy*. Cambridge University Press, 2006. ISBN 9780521851442.

R T Konetzka, E A Stuart, and R M Werner. The effect of integration of hospitals and post-acute care providers on Medicare payment and patient outcomes. *Journal of Health Economics*, 61: 244–258, 2018.

H Leleu, M Al-Amin, M Rosko, and V G Valdmanis. A robust analysis of hospital efficiency and factors affecting variability. *Health Services Management Research*, 31(1):33–42, 2017.

A E Liepert, J Bledsoe, M H Stevens, and A Cochran. Protecting trauma patients from duplicated computed tomography scans: The relevance of integrated care systems. *The American Journal of Surgery*, 208(4):511–516, 2014.

A Lourenço, A Dias, A Escoval, A S Ferreira, A T Paquete, et al. *30 anos do Serviço Nacional de Saúde: Um percurso comentado (Portuguese) [On the 30 years of the Portuguese National Health Service]*. Almedina, 2010. ISBN 9789724041100.

B Post, T Buchmueller, and A M Ryan. Vertical integration of hospitals and physicians: Economic theory and empirical evidence on spending and quality. *Medical Care Research and Review*, 75 (4):399–433, 2017.

M Rahman, E C Norton, and D C Grabowski. Do hospital-owned skilled nursing facilities provide better post-acute care quality? *Journal of Health Economics*, 50:36–46, 2016.

J A Simões, G F Augusto, I Fronteira, and C Hernández-Quevedo. Portugal: Health system review. *Health Systems in Transition*, 19(2): 1–184, 2017.

K W Sowers, P R Newman, and J C Langdon. Evolution of physician-hospital alignment models: A case study of comanagement. *Clinical Orthopaedics and Related Research*, 471(6): 1818–1823, 2013.

D C Szostak. Vertical integration in health care the regulatory landscape. *DePaul Journal of Health Care Law*, 17(2), 2015.

E Thanassoulis. *Introduction to the Theory and Application of Data Envelopment Analysis: A Foundation Text with Integrated Software*. Springer, 2001. ISBN 9781461355380.

T Van Puyenbroeck. On the output orientation of the Benefit-of-the-Doubt-Model. *Social Indicators Research*, 139(2):415–431, 2017.

B B Wang, T T H Wan, J Clement, and J Begun. Managed care, vertical integration strategies and hospital performance. *Health Care Management Science*, 4(3):181–191, 2001.

G Wei and J Wang. A comparative study of robust efficiency analysis and data envelopment analysis with imprecise data. *Expert Systems with Applications*, 81:28–38, 2017.

J West, G Johnson, and A K Jha. Trends in acquisitions of physician practices and subsequent clinical integration: A mixed methods study. *Journal of Evaluation in Clinical Practice*, 23(6):1444–1450, 2017.