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Evaluating the performance of Brazilian university hospitals

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Abstract In order to demonstrate how DEA modeling can be helpful to aid decision making relative to the Brazilian Teaching Hospital Policy by means of hospital performance assessment, we develop a case study with 30 general hospitals linked to Brazilian Federal Universities. We consider data on medical care (Medical Model—MM), teaching and research (Teaching-Research Model—TRM) and use the software IDEAL (Interactive Data Envelopment Analysis Laboratory) as a tool for the units' efficiency evaluation. IDEAL, developed in Brazil, is unique in providing a 3-D frontiers visualization, assisting in exploratory analysis and allowing a better understanding of the DEA modeling (envelopment and multiplier). Both models are input-oriented and each hospital is categorized according to its relative efficiency in the MM and TRM. In this phase, it is very important to discuss with the decision-makers the results and patterns of the DEA models. Finally, the modelling indicates the necessary changes for the inefficient units and generates recommendations for teaching ratios and public financing.

Keywords Data envelopment analysis · Hospital performance indicators · Teaching hospitals · Hospital efficiency

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1 Introduction

In Brazil, the issue of teaching hospital productivity has received much attention in recent years. A policy debate has emerged as to the best way to reimburse teaching hospitals that will enhance their mission of education and research without sacrificing the quality of patient care.

In the United States, Medicaid funds are used to help finance medical education. While Medicaid provides direct payments, other state programs and Medicare also provide indirect funding to graduate medical education. This funding equates to 8–10% of teaching hospital inpatient expenditures (American Academy of Family Physicians (AAFP) State Government Relations, 2005). In Brazil, the funding of teaching activities inside hospitals varies according to their ownership status. For university public hospitals, the labor costs are almost entirely paid by the Ministry of Education (Marinho and Façanha 2000). For these and the other not-for-profit and for-profit teaching hospitals, the contract signed between the teaching hospital and the local health care authorities (and that passes again federal funds from the Ministry of Health) is based on medical, teaching, and research goals that are set to cover all inpatient expenditures. This type of fixed budget funding, which is based on a set of pre-established goals, typically exceeds by at least 25% the funding received by equivalent non-teaching hospitals, which hospitals are still paid using a fee-for-service model.

For Brazilian University Hospitals, there is an increasing demand to incorporate, as national policy for financing those hospitals, teaching and research as complementary goals to patient care. Until 2004, the Ministry of Health relied upon a Prospective Payment System (PPS) to pay additional reimbursements for indirect teaching expenses based on a percentage of the total medical procedures each hospital delivered. After 2004, the government shifted to a fixed budget based on productivity goals (both medical and teaching) incorporated into a contract signed by the hospital manager and the local public health authority (Marinho and Façanha 2000).

The main purpose of the change was to increase the volume of money received by the teaching hospitals (which were beneath the costs of the high complexity procedures delivered), having the quality of their medical and teaching missions enhanced by management effort.

Before signing the contracts, representatives of the Ministry of Health and the Ministry of Education visited all Brazilian teaching hospitals and certified the teaching units, based on residents training in service, undergraduate and post-graduate students, and some research activities. The fund for financing the teaching hospitals comes from both Ministries (mostly from the Ministry of Health). The distribution among the units is based on the accomplishment of the established goals and the relative efficiency of each unit.

In this paper, we propose a methodology—Data Envelopment Analysis (DEA)—that we suggest could be used to assess teaching hospital efficiencies. DEA compares each hospital's efficiency scores to a frontier of the best practices (computed by the DEA software) and thereby provides a basis for comparing the medical and teaching productivity of each hospital.

2 Background

In 1995 the Institute for Health Policy Issues (IEPS) organized a seminar on "The proper function of Teaching Hospitals within Health Systems" (WHO/SDS/DHS/96.1 1995). This discussion resulted in a definition of a teaching hospital as a centre of complex health care characterized by the important role it plays in providing tertiary care, its involvement in teaching and research related to the type of care it dispenses, and the high concentration of resources it attracts. Typically, these hospitals are costly and have important political influence. There was also a consensus that these hospitals need more integration with the other institutions in the health system in order to decrease the waste of resources and to develop new management research to improve process flow and use of new technologies that could be transferred to other health units (WHO/SDS/DHS/96.1 1995).

The situation described above applies in Brazil as well. Teaching hospitals comprise 10% of the national health systems' acute beds, 26% of the intensive care unit (ICU) beds, 12% of admissions and outpatient visits, and almost 40% of the high complexity procedures delivered by the Unified Brazilian Health System—Sistema Unificado de Saude (SUS). Despite the key role they play in the health system, few studies have been conducted that asses their efficiencies (Marinho and Façanha 2000), and none has considered teaching outputs as public goods or has assessed their contribution to medical costs.

Studies on efficiency are essential for hospital management and to assess the impact of regulatory decisions. For example, a study by Ozcan (1995) using DEA to compare hospital aggregates showed at least 3% of health care costs in the US gross domestic product (GDP) are due to inefficiencies created by the excess supply of providers.

Using non-parametric and parametric applications to measure efficiency in health care, Hollingsworth (2003) showed that teaching hospitals had a lower mean efficiency score than did their non-teaching counterparts. This study is limited, however, because it relied on a sample that was based of only two previous studies and depended on measures of central tendency to compare groups of studies, relying on non-normal distributions and comparing studies that used different input and output variables (Chilingerian and Sherman 2004). In one of these studies, Grosskopf et al. (2001a) used a DEA type approach to compare the frontiers of 236 teaching and 556 non-teaching hospitals and observed that only 10% of the teaching hospitals—the ones with lower teaching intensity (Residents/Beds) and dedication (Residents/Physicians)—performed better than the non-teaching hospitals. The same authors later studied the effects of teaching on hospital productivity based on the congestion derived from the excess use of residents as inputs, that is, 20% of the DEA inefficiency scores (Grosskopf et al. 2001b). However, as the authors have mentioned, the comparison among teaching and non-teaching hospitals considered just the technical efficiency, but not the teaching mission products as outputs.

More recently, Grosskopf et al. (2004) used DEA to study the impact of managed care competition on the performance of teaching hospitals in the USA. Using Tobit regression methodology they found that competition, measured by the number of Health Maintenance Organization (HMO) contracts, was positively correlated with efficiency, without any negative impact on the teaching mission of the hospital (measured by teaching dedication). Chen et al. (2005) also used Tobit analysis to examine overall and specific input inefficiencies. They found that a hospital's teaching function was positively associated with general and routine/special care costs, and negatively associated with ancillary costs.

Most studies in this area have defined the teaching role using the presence of residents or the affiliation with the Council of Teaching Hospitals (COTH) or with an accredited Medical School. This paper considers the IEPS definition provided above. As already mentioned, an analysis of efficiencies should consider not only clinical outputs, adjusted by case-mix and complexity, but also teaching outputs, which would include the production of residents and undergraduate and post-graduate students. In an attempt to separate clinical and teaching effects, we analyze models separately and discuss the ways by which hospitals might undertake in order to achieve high efficiency in both models.

3 Methodology

3.1 Measure of efficiency

Studies of efficiency measure the relationship among outputs and inputs. But, the assessment of multiple outputs and inputs calls for complex procedures that are able to consider the relative impacts of each. The DEA technique allows for the assessment of multiple inputs and outputs, such as would be needed to analyze teaching hospital performance (Grosskopf et al. 2001b). It calculates a non-parametric measure, based on linear programming (LP) techniques, and calculates a multi-surface efficiency frontier based on the best practices of the focal units being compared individually to others (the data envelopment model). Those that are determined in the calculations to be the most efficient within the group of all units are termed efficient decision making units (DMUs). By definition, these are the units that produce the best (most efficient) weighted sum of outputs given a weighted sum of inputs consumed (multiplier model, as a dual LP problem).

It should be noted that the units could be placed in different possible returns to scale regions and that the efficiency index is always inside a [0,1] interval. Efficient units are on the frontier surface, as vertices of the polyhedron face, and receive index equal to 1. The inefficiencies represent the degree of deviance from the frontier; the vertices of the facets where they are projected function as benchmarks for them. It is noteworthy that, to achieve an optimal LP solution of full efficiency, the efficient unit must have a hundred percent efficiency and all slacks must equal zero in every optimal solution, to satisfy the Pareto-Koopmans postulate. Otherwise stated, a DMU is fully efficient if and only if it is not possible to improve any input or output without worsening some other input or output (Cooper et al. 2000). The LP formulation of the problem can be stated as:

Data Envelopment Model:

$$
\begin{aligned}
&\min \quad \theta_o - \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+\right) \\
&\text{subject to} \\
&\theta_o x_{io} = \sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- \qquad i = 1,2,\ldots,m; \\
&y_{ro} = \sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ \qquad r = 1,2,\ldots,s; \\
&1 = \sum_{j=1}^{n} \lambda_j \\
&0 \le \lambda_j, s_i^-, s_r^+ \qquad \forall\, i, r, j.
\end{aligned}
$$

Multiplier Model:

$$\max \quad z = \sum_{r=1}^{s} u_r y_{ro} - u_o$$

subject to

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} - u_o \le 0 \qquad j = 1,\ldots,n$$

$$\sum_{i=1}^{m} v_i x_{io} = 1$$

$$v_i \ge \varepsilon, \quad u_r \ge \varepsilon, \quad u_o \textit{ free in sign}$$

3.2 Data and sources

Given the functions of teaching hospitals, we consider the evaluation in two distinct dimensions: the medical model (MM) and the teaching research model (TRM). All data are gathered from the Information System of the Federal University Hospitals—Sistema de Informações dos Hospitais Universitários (SIHUF)—of the Ministry of Education, from 2nd half of 2003. The SIHUF is filled bi-annually by all Brazilian University hospitals since 1997 and includes data on students, professors, medical residents, workforce, expenses, incomes, physical area, service production, service complexity, and administrative hospital indices (Lobo et al. 2006). In this paper, we consider all the 30 University acute general hospitals belonging to this database (each hospital is a DMU).

The choice of the variables considered the literature on DEA applications for hospitals (Chilingerian and Sherman 2004; O'Neill et al. 2008; Ozcan 2008). For the Medical Model, we use as inputs: Labor Force (Physicians—PHYSICIAN and Full Time Equivalent Non-Physicians—FTE NP); Operational Expenses (OPEx, not including payroll); Beds (BEDS) and Service-Mix (SvMIX). According to Ozcan (1993), these last two variables act satisfactorily as proxy measures to assets (accounting for 63% of the variance). The Service-Mix variable also denotes the total number of diagnostic and special services, that is, the service complexity. The same study reported that DEA-generated hospital scores were stable across a wide variety of input and output combinations. As outputs, we consider: admissions (AdjADM), surgeries (AdjSUR) and outpatient visits (AdjOUT), all of them adjusted according to the complexity index of the hospital. Note that all the medical specialties have acute beds and it is the same pool of registered patients that are accompanied as they are admitted inside the hospital, for clinical or surgery procedures, or examined at the outpatient sector after discharge.

As a proxy measure of case-mix, SIHUF includes a continuous variable called High Complexity Procedures Information System—Sistema de Informações para Procedimentos de Alta Complexidade (SIPAC)—which reveals the resources available for accomplishing high complexity procedures regulated by the Ministry of Health, such as neurological, cardiac, orthopaedic and transplantation surgeries. For adjustment, we divided each individual SIPAC hospital value by the mean SIPAC among all hospitals, creating a complexity index that was multiplied to all output variables.

For the Teaching Research Model, the input variables are: Physicians (PHYSICIAN), PhD Professors (PHDPROF), and other Professors (OTHPROF). A professor is considered a professional who signs a formal contract with the obligation to take teaching and research activities inside the University, after passing an official examination concerning skills. In contrast, a physician, although may have teaching and research activities, has no such formal obligation (instead, a physician is responsible for the medical care and joins the workforce after an official examination as well). Output variables include residents (RESIDENT), undergraduate medical students (UGMED), and Post-Graduate Students (GRADSTU). We consider that PHDPROF and GRADSTU are associated with research activities, motivating the development of another teaching hospital output, that is, new technologies to be brought to the health care system. These proxy variables were chosen as there was no information about the articles published or grant dollars received by the hospitals, although considered a better approach to research activities. Note that the resident is an output from the perspective of a teaching model and could be used as an input from the perspective of a medical model. Cook and Zhu (2007) have developed a methodology to promote a better choice for these so called flexible variables. Our option was to include the residents as outputs considering the teaching perspective.

3.3 Modeling and analysis

We evaluated the models as VRS (variable returns to scale), input-oriented, in the perspective of the regulatory side for solutions' proposals. The software used was the IDEAL (Interactive Data Envelopment Analysis Laboratory) as a tool for the units' efficiency evaluation. IDEAL, developed in Brazil at Post-Graduation and Engineering Research Institute at Federal University of Rio de Janeiro, is unique in providing a three-dimensional frontiers visualization, assisting in exploratory analysis and variables selection and allowing for a better understanding of the DEA modeling (envelopment and multiplier) by experts and decision makers.

Our analytical approach was to evaluate the relative efficiency of each DMU in both models and to generate recommendations for public financing based on quality/efficiency, considering the efficient units in both models. In this phase, it was very important to include the information regarding the perspective of the representatives of the Ministry of Education about the efficiency patterns observed inside the hospitals. This last procedure was intended to improve the face validity of the model.

4 Results

4.1 The medical model

Among the 30 hospitals (identified H1 through H30), 11 were considered efficient (35%); the mean of the inefficient peers was 0.84. It is important to note that the proportion of efficient units was greater for the hospitals with size greater than 300 beds (67% versus 24%), as we can observe in Table 1, that presents the data for the efficient and inefficient group. From Table 1, we depict a frontier with two distinctive regions according to the hospital size, that is, a region with the benchmarks above 300 beds, which consume more inputs and produce proportionally more outputs, and another region whose benchmarks are characterized by very low input usage. For the larger hospitals, the difference between efficient and inefficient units lies mainly on the output volume while for the hospitals under 300 beds the input usage is about 50% greater for almost all the inputs (Fig. 1).

This feature could be foreseen in the exploratory analysis represented in Fig. 2, with beds as inputs and adjusted surgeries and admissions as outputs. The 3D exploratory frontier

Table 1 Mean and standard deviation for input and output variables by hospital size and efficiency score (medical model)*

	Hospitals	Efficient		Not efficient	
	Size (beds)	≥ 300	< 300	≥ 300	< 300
	Number of hospitals	6	5	3	16
	Efficiency	1.00	1.00	0.81 (0.07)	0.84 (0.09)
Inputs	FTE NP	3,030 (708)	703 (235)	2,627 (657)	1,417 (444)
	PHYSICIAN	349 (91)	102 (54)	399 (95)	224 (76)
	OPEx (in 1,000,000)	3.0 (2.0)	0.5 (0.22)	2,71 (0,90)	1.06 (0.50)
	BEDS	454 (142)	132 (87)	467 (90)	227 (51)
	SvMIX	78 (30)	37 (15)	78 (12)	61 (20)
Outputs	AdjSURG	1,380 (554)	45 (37)	887 (595)	305 (219)
	AdjADM	3,085 (713)	1,066 (79)	2.011 (595)	537 (335)
	AdjOUT	41,151 (14,836)	1,853 (1,651)	31,501 (14,900)	9,849 (6,374)

*Note: two outlier hospitals were excluded from descriptive statistics

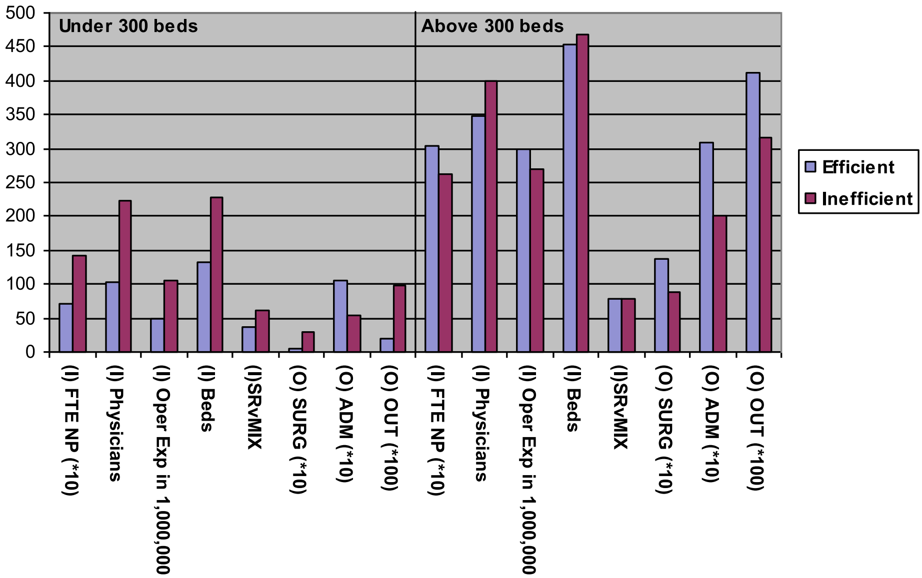

Fig. 1 Mean value of inputs (I)/outputs (O) according to hospital size and efficiency status

presented two Pareto-efficient facets and four efficient hospitals: H30, H28, H27 and H4, with H30 and H4 with the higher and lower input/output numbers and another two efficient hospitals with more then 300 beds. Naturally, all of them appeared as efficient units in the complete model thereafter, as would be expected in any model without weight restrictions. The inefficient units according to this set of variables, are spatially closer to their respective benchmarks (which could be defined by the distribution of the lambdas in the envelopment model), as we see H6, H16, H23 and H22 projecting on the frontier near H30 and H27, which have more than 300 beds. Smaller hospitals tend to project close to H4 and H28. It

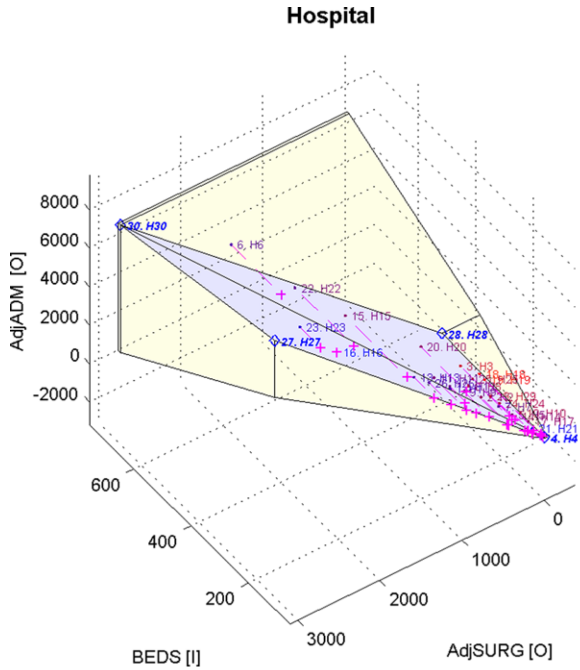

Fig. 2 Teaching hospital input (beds) and output (adjusted surgeries and admissions) relationship: exploratory analysis using IDEAL

is important to note that, if we make the exploratory analysis with different combinations of three variables, all the DMUs that appear as vertices will be efficient in the final and complete model. The full list of the Medical Model efficient units can be seen in Table 3. This practice was very important to present partial and complete findings of the model to the representatives of the Ministry of Education, who are not used to mathematical models. Finally, even with distinctive regions in the frontier, all the units appeared in the Increasing Returns to Scale geometric place, as observed by the positive u^* in the multiplier model (Lins et al. 2007).

4.2 The teaching research model

In the Teaching Research Model, 50% (15) of the teaching hospitals were considered efficient. However, four of them numbered zero research activities and were excluded from the efficient set (they had no post-graduate students and/or PhD professors, used as proxies of research activities). Among the eleven remaining efficient hospitals, six were hospitals bigger than 300 beds. The mean efficiency score for the inefficient units was 0.73. In general, the efficient hospitals had more students in all categories and a higher proportion of PhD professors (38% versus 30%). The large standard deviation for the proxy variables represents the variability of the research load in these hospitals as shown in Table 2.

As the model was input-oriented, the excess input usage was equal to 1,089 for physicians (mean = 73/hospital) and 664 for professors (mean = 44/hospital). Also, among the eleven efficient units, only two are located in the Increasing Return to Scale region, H21 and H28, which are nearer the coordinate inputs origin as shown in Fig. 4.

The exploratory 3D analysis in Figs. 3 and 4 had already showed 9 of the efficient units as vertices of the facets (H16/H6/H30/H8/H14/H17/H28/H18/H21). The facets of the full

Table 2 Mean and standard deviation of input/output variables by hospital size and efficiency score (teaching research model)*

	Efficient	Not efficient
Inputs		
PHYSICIAN	237 (115)	265 (128)
PHDPROF	47 (44)	43 (46)
OTHPROF	76 (49)	101 (50)
Outputs		
UGSTU	530 (311)	427 (163)
RESIDENT	121 (83)	84 (58)
GRADSTU	129 (146)	90 (123)

*Note: one hospital was excluded from descriptive statistics due to outlier values

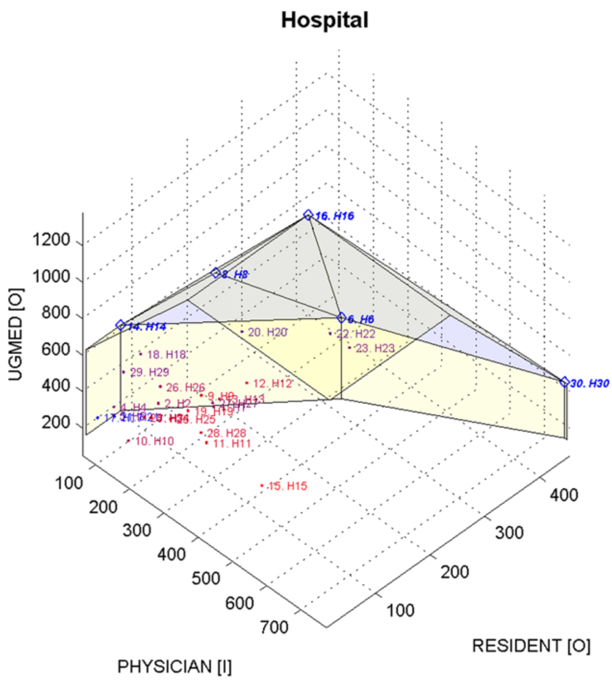

Fig. 3 Teaching hospital output (medical residents and undergraduate students) relationship

model are defined by extreme efficient DMUs that include all inputs/outputs in the efficiency calculation.

Another interesting feature observed in the 3-D presentation for the Ministry's representatives was the possibility to promote the understanding of the scale position of each unit, along with the trade-off possibilities. Figures 3 and 4 provide an insight to trade-offs presented between residents and medical students as outputs (Fig. 3) and between professors and physicians as inputs (Fig. 4), this would help to understand internal management and teaching strategies developed at the hospitals.

4.3 Unified model and individual analysis

Table 3 presents every teaching hospital according to its performance in both models: total (double) efficiency, medical model efficiency, teaching-research efficiency alone and none

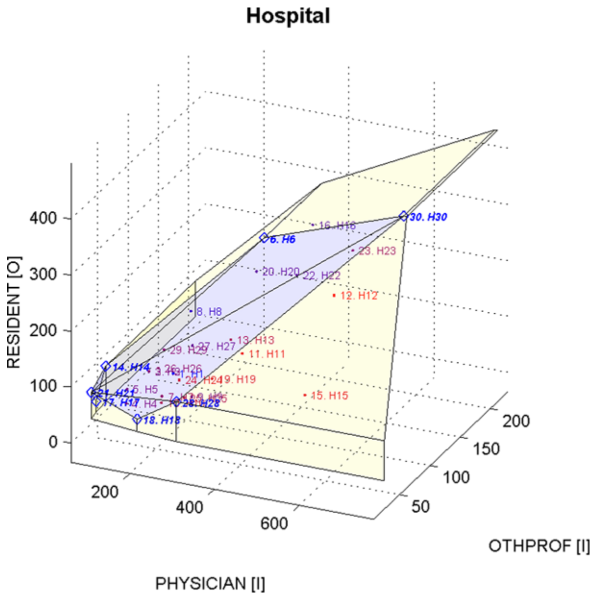

Fig. 4 Teaching hospital input (physicians and professors-others) relationship

Table 3 Teaching hospital efficiency by medical and teaching research dimension score

Total efficiency	Teaching research efficiency
H6* (1.0, 1.0)	H22* (0.90, 1.0)
H16* (1.0, 1.0)	H1 (0.87, 1.0)
H27* (1.0, 1.0)	H8 (0.83, 1.0)
H28* (1.0, 1.0)	H9 (0.80, 1.0)
H30* (1.0, 1.0)	
H14 (1.0, 1.0)	
H21 (1.0, 1.0)	
Medical model efficiency	**None**
H23* (1.0, 0.68)	H15* (0.72, 0.66)
H4 (1.0, 0.78)	H20* (0.81, 0.72)
H17 (1.0, 1.0); no research	H2 (0.88, 0.98); no research
H18 (1.0, 1.0); no research	H3 (0.68, 0.87)
	H5 (0.96, 0.68)
	H7 (0.83, 0.55)
	H10 (0.95, 1.0); no research
	H11 (0.93, 0.90)
	H12 (0.75, 0.39)
	H13 (0.80, 1.0); no research
	H19 (0.98, 0.72)
	H24 (0.85, 0.90)
	H25 (0.63, 0.67)
	H26 (0.81, 0.88)
	H29 (0.91, 0.56); no research

*Hospital size > 300 beds

efficiency. The idea is to look for behaviors and patterns inside each category that help to understand and propose new paths to reach efficiency in both models. Table 4 shows the mean and standard deviation of the variables present in both models, according to the efficient status of the hospitals, to help decision makers capture patterns for each category of efficiency. As the model is input-oriented, Table 4 also considers the physicians and teachers in excess for each inefficient category, in order to aid managerial considerations.

There were 15 efficient university hospitals in at least one of the models; seven of them were efficient in both models. It is noteworthy that five of the later had at least 300 beds, being also more complex and having a higher teaching and research load. For hospitals efficient in just one of the models, there was only one hospital with more than 300 beds in each category.

As already pointed for the Medical Model, the efficiency of H4, H17 and H18 is mostly attributed to the very low level of input usage. According to the Ministry representatives, these are mainly ambulatory care units, with no more than 20 surgeries or 50 admissions per month, located in very poor areas, with a high primary care demand. To fulfill the demand for teaching efficiency, H4 (teaching score = 0.78) needs a reduction of 26 physicians and 16 professors (or augmentation of their individual productivity). H18 and H17 are in the situation cited above of a 100% teaching efficiency, with no research activity at all. In their case, it would be interesting to motivate primary care and tropical disease research, which are associated with their day-to-day practice.

For the Medical Model efficiency result with more than 300 beds, we see H23, a large hospital that, despite the high teaching and research load, have a teaching score of only 0.67. All variables considered together, its benchmarks are in the facet that have H6, H18, H8 and H30 as vertices, with a higher proximity with the underlined hospitals (lambda = 0.47 and 0.41, respectively). To reach the frontier, H23 have to reduce at least 107 professors and 158 physicians. According to the Ministry representatives, this pattern is frequently a consequence of low number of associate professors (docent) and medical care integrative practices, with low number of professors in the admission and outpatient units, obligating the hospital manager to contract additional physicians to play their role.

The Teaching Research Model efficiency is based on a satisfactory proportion between students (any category) and preceptors (physicians and professors), given that research activity exists. All the teaching-research efficient units with more then 300 beds have considerable research, as could be seen with the high virtual share of postgraduate students inside the model, and also undergraduate teaching load. Most of them have also teaching activities outside the hospital for community health or primary care training (case of H22). On the other hand, the MM inefficiency of H22 is related to an excess of 44 physicians and 350 FTE NP. For the smaller units, most of the observed efficiency can be attributed to the high proportion of residents for a given number of preceptors. The hospitals TRM efficient, but not MM efficient have a mean MM efficiency score equal to 0.85 and have excess usage of 1,129 FTE NP, 172 physicians, 174 beds.

Finally, it is important to observe that, although all the efficient units are in the increasing returns to scale geometric place at the MM, most of them are inside the decreasing returns to scale geometric place at the TRM. This observation can guide managers when selecting between different inputs to increase.

We also have to understand the reasons and patterns that justify the fifteen MM and TRM inefficient units. Usually, small hospitals have a more intense medical care component. As they grow, they tend to sum up the other activities. Except for the huge (more than 300 beds) H15 and H20, university hospitals inside this category tend to have an intermediary size, mean 224 beds (137 to 293), intermediary complexity service and productivity, along

Table 4 Mean and standard deviation of input/output variables and excess usage of labor by medical model (MM) and teaching research model (TRM) efficiency score

Efficiency	Total efficiency		Medical model efficiency		Teaching research efficiency		None	
Size	> 300 beds	< 300 beds	> 300 beds	< 300 beds	> 300 beds	< 300 beds	> 300 beds	< 300 beds
PHYSICIAN	405 (209)	67 (5)	487 (0)	125 (61)	429 (0)	257 (43)	384 (161)	217 (84)
PHDPROF	137 (117)	15 (6)	157 (0)	12 (7)	88 (0)	45 (23)	65 (64)	27 (23)
OTHPROF	95 (66)	49 (21)	174 (0)	43 (14)	122 (0)	58 (36)	127 (57)	87 (48)
UGMED	590 (402)	385 (324)	729 (0)	421 (259)	727 (0)	600 (300)	499 (225)	369 (145)
RESIDENT	240 (143)	71 (11)	232 (0)	34 (5)	233 (0)	121 (40)	118 (75)	78 (54)
GRADSTU	850 (1.237)	21 (21)	451 (0)	17 (30)	140 (0)	142 (50)	118 (97)	37 (51)
FTE NP	3,504 (1,520)	590 (21)	3,609 (0)	779 (298)	3,438 (0)	1,586 (120)	2,221 (556)	1,410 (493)
OPEx (in 1,000,000)	4.91 (3.33)	0.63 (0.26)	2.42 (0)	0.41 (0.19)	3.6 (0)	1.31 (0.32)	2.25 (1.09)	1.01 (0.55)
BEDS	508 (193)	108 (37)	472 (0)	148 (116)	566 (0)	236 (10)	417 (98)	225 (58)
SvMIX	86 (31)	42 (18)	64 (0)	35 (16)	69 (0)	73 (19)	83 (17)	59 (21)
AdjSURG	1,626 (837)	76 (15)	1,523 (0)	10 (8)	1,255 (0)	394 (138)	702 (309)	285 (242)
AdjADM	3,853 (1,661)	168 (57)	2,723 (0)	32 (23)	2,809 (0)	680 (338)	1,612 (329)	504 (352)
AdjOUT	80,518 (89,214)	3,212 (892)	41,049 (0)	409 (150)	51,436 (0)	16,523 (3,204)	21,533 (8,363)	8,309 (6,225)
Excess PHYSICIAN (TRM)	0	0	158 (0)	9 (16)	0	0	121 (66)	51 (64)
Excess PHYSICIAN (MM)	0	0	0	0	44 (0)	43 (13)	95 (61)	43 (32)
Excess FTE NP (MM)	0	0	0	0	350 (0)	260 (37)	538 (266)	238 (200)
Excess Professor (TRM)	0	0	107 (0)	5 (9)	0	0	56 (29)	33 (50)

*Note: only one hospital has more than 300 beds in medical model and teaching research models

Table 5 Mean teaching ratios by medical model (MM) and teaching research model (TRM) efficiency score

Teaching ratios	None	MM efficiency	TRM efficiency	Total efficiency
FTE NP/Beds	6.06	6.45	6.44	6.79
Teaching Intensity	0.33	0.36	0.47	0.49
Teaching Dedication	0.34	0.39	0.50	0.62
Undergraduate Students/Professors	3.10	4.03	4.85	2.90
PhD Professors Percent	0.26	0.39	0.43	0.44

with a very low investment in research (except for H12 and H25). They have a mean excess of FTE NP and Professor equal to 238 and 33, respectively (Table 4).

It is also noteworthy that the only variable present in both models, physicians, shows similar numbers for excess usage (higher to TRM), indicating that these physicians could not just work in an alternative activity to enhance the efficiency of the other teaching hospital output. According to the Ministry representatives, physicians need to be motivated. They are paid on salary and have no extra incentive to assume teaching or research activities simultaneously. On the other hand, they are usually more concerned with quality of care as compared to non teaching hospitals. Considering all the teaching hospitals that sum up 7,805 physicians, and the formal obligation of physicians to have only medical care duties, the excess usage for physicians considered the medical model alone, and just the hospitals inefficient in both models: that summed up 690 physicians. The excess use of FTE NP in MM and professors in TRM was 5,295 (9.6%) and 664 (15.7%), respectively.

To help managers and health authorities to establish teaching goals inside the financing contracts, Table 5 shows some usual teaching ratios that can be used as estimates for the referees in the universe of Brazilian teaching hospitals. Looking forward to total efficiency in both models, we can observe a larger relationship between FTE NP and beds (above 6.0) as compared to the usual ratios pronounced by WHO for the non-teaching hospitals (about 3.0), the upward gradient toward total efficiency for teaching dedication, teaching intensity and PhD professors percent, and an ideal medical graduate students/ professors ratio about 3.0 (2.90).

5 Summary and conclusions

The paper showed the potential of DEA to help health care decision-makers with respect to the Brazilian policy for teaching hospitals. The application was also important as it modeled the policy according to the concepts underlying its construct and aggregated the opinions of the actors that participated in this endeavor, increasing its face validity.

The mission and vocation of a teaching hospital is based on three distinctive dimensions: a) medical care, b) training and preparing human resources for the health system, and c) developing and assessing new health technologies by means of research. The main objective of this paper was to assess the teaching and research dimensions of the teaching hospitals as the medical care dimension has already been extensively studied in the literature. If a model aggregates all dimensions together, it will be difficult to distinguish which of them is performing best, or otherwise, which of them could improve in one or in another way. In addition, the discriminative power of the model would be compromised if all the 13 variables were put together in the same model, as there are only 30 decision making units. In a study recently published in Brazil (Lins et al. 2007), each of the three dimensions´ respective score was treated as an output measure of a unique model, without any input variable. In the study, the correlation between medical care and teaching was 0.34 and the correlation between medical care and research was 0.49 (Spearman index). This finding suggests that it is preferable to scrutinize each dimension separately.

In this paper, we used two distinct models, medical and teaching-research, to cover the multi-input/multi-output nature of the teaching hospitals. The choice of the variables present in each model was based not only on the availability of data, but also on the concepts that tailored the Brazilian health policy for the teaching hospitals. As DEA runs the model for each DMU, in comparison to their peers, many descriptive observations of the DMU provides understanding of its position in relation to the frontier of best practices. That is, for each DMU, we can define, in conjunction with the crude data: its position according to returns of scale and the hyper plane equation for the surface were the DMU is being projected (u^* signal and weight values in the multiplier model); the benchmarks for each inefficient DMU according to the distance of the frontier (lambda in the envelopment model); the excess usage of inputs and shortage of outputs by interpreting the dynamic of the virtual share of the product variable times its weight. In the text above, we tried using all these linear programming potentials and translate the descriptive results in a managerial language that could help policy formulations. The 3-D figures of the IDEAL software were also useful in persuading managers and policy makers as to the validity of the results and recommendations. This greatly aids in translating recommendations into actions.

As previously noted, hospital managers, local and central health authorities can use DEA results as inputs in decision making processes involving resource planning, allocation and utilization (Ersoy et al. 1997). The results put in place gave useful insights to the national policy. As observed in the literature, the relative inefficiency of the teaching hospitals as compared to the nonteaching counterparts could be explained not only by the existence of multiple products not considered in the model, but also by intrinsic differences in the usual input uses and proportions. Also, the input orientation increased the value of the regulatory perspective to determine the efficient target, requiring homogeneous criteria to project the inefficient DMU onto the frontier. In the future, it may be necessary to extend the present study to integrating the perspective of the regulated unit, by the introduction of weight restrictions, allowing flexible and interactive procedures in order to contemplate particular conditions and management preferences (Lins et al. 2006).

Another question to be addressed concerns the labor policy for the universe of the public hospitals. In those hospitals, the workforce cannot be dismissed without a judicial process that prove incompetence, implying in a very low turnover and in an even greater waste of resources, as medical professionals age without necessarily becoming up to date with the new technologies and the manager needs to contract more individuals to compensate. The unique exception to this kind of contract procedure in this sample is the H6, that has more flexible criteria for contracting and dismissing the medical, teaching, and research team and has been found a hundred percent efficient in all DEA analysis made for this group of hospitals.

Moreover, physicians at teaching hospitals are expected to take on multiple roles that include teaching, research, and patient care. In practice, it is often very difficult to balance these competing roles and activities. Moreover, it is particularly difficult to measure progress or "productivity" in each of these areas, as they involve very different aspects of the hospital's mission. This issue must be treated with caution and further studies with network DEA must be developed to consider different outputs to certain inputs or the presence of multiple dimensions that deal with common resources (Färe and Grosskopf 2000; Ozcan 2008).

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