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Maria Stella de Castro Lobo

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Alberto Luiz Coimbra Post-Graduation and Engineering Research Institute,

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Dear Dr. Lobo,

As a member of the scientific committee and session organizer, It is my pleasure to invite you to present a research paper (as speaker) for DEA 2013 conference that will take place in Samsun, Turkey during June 27-30, 2013. The title of the session I would like to include your research paper is "Performance Evaluation in Health Care".

The details of the conference can be found at http://deasociety.org/dea2013/, you may use this letter as an official invitation for planning to attend this conference.

With My Best Regards,

Yasar A. Ozcan

Yasar A. Ozcan, Ph.D.

Professor

Member of Scientific Committee

DEA 2013 Conference

# Use of Data Envelopment Analysis (DEA) to Assess Performance and Quality for Cardiac Procedures in the State of Rio de Janeiro, Brazil

***Abstract title sent before finishing this paper: Performance assessment and quality of cardiac procedures in Rio de Janeiro through DEA****

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## ABSTRACT

*The study develops a two-stage model, using Data Envelopment Analysis (DEA), output oriented, variable returns to scale (VRS), in order to assess performance for high complexity cardiac procedures (cardiac artery bypass graft - CABG and PTCA -* percutaneous transluminal coronary *angioplasty) in habilitated hospitals to execute them in Rio de Janeiro, Brazil, 2005. The first model evaluates production (number of procedures) according to used resources (beds and equipment). The second one considers the survival rates for these procedures as a proxy measure to quality of care. Although it would be expected a negative correlation between the number of procedures and the number of deaths, quantity and quality did not come together in the studied group of hospitals. Risk adjustment should be made to turn the results more accurate.*

***Keywords:*** *Data Envelopment Analysis, Health Services Assessment, Cardiac Procedures.*

## Introduction:

Cardiovascular diseases (CVDs) are the leading causes of death and disability in the world. In 2008, an estimated 17.3 million people died from CVDs, over 80% in low- and middle-income countries and, by 2030, almost 23.6 million people are expected to die from CVDs**.** Although a large proportion of CVDs is preventable, by means of controlling tobacco use and promoting a healthy diet and physical activity, they continue to rise mainly because preventive measures have been ineffective. Albeit prevention is cheap, treatment is costly and requires allocation of the scarce family and public resources to medical care (1).

Among the universe of cardiovascular diseases, the coronary artery disease (CAD), that generates coronary heart disease (CHD), as angina (stable or unstable) and myocardial infarction (MI), has the highest lethality rate, comprising 25 to 35% of all cardiovascular deaths. The treatment of coronary heart disease (CHD) has evolved significantly due in part to improvements in both medical therapy and

surgical and percutaneous revascularization techniques. The majority of patients with chronic stable angina are treated with medical therapy, but there are a variety of indications for high complexity interventional treatments as coronary artery bypass graft surgery (CABG) or PTCA (percutaneous transluminal coronary angioplasty). In a large sense, the subgroups that primarily benefit from CABG are those with triple vessel disease and left ventricular dysfunction, those with significant left main coronary disease and those with diabetes mellitus. Coronary angioplasty, along with intracoronary stents and atherectomy devices, has multiple indications, including unstable angina, acute myocardial infarction (AMI) and multivessel CAD, serving viable myocardium (2).

According to the "Bypass Angioplasty Revascularization Investigation" trial (BARI trial), that compared 10-year clinical outcomes in patients who were randomly assigned to PTCA versus CABG, both interventional therapies are effective in improving quality of life. Comparative cost of the two treatments shows angioplasty to be less expensive initially (about 2.5 times), but as recurrent procedures is required in the PTCA group, the cost of PTCA may approach the cost of CABG by the end of five years of follow-up. However, patients with diabetes, three-vessel disease, and advanced age (markers suggesting more favorable outcomes with coronary surgery), also have a lower cost for a CABG strategy than for PTCA. PTCA is less expensive than CABG in non-diabetic, two-vessel disease and in younger patients. These results suggest that the most efficacious treatment also tend to be the most cost-effective treatment (3).

Simultaneously, there is increasing interest in deploying and publicly reporting a risk-adjusted measure of mortality as a quality indicator of hospital system-level performance. Among these indicators, the Agency for Healthcare Research and Quality (AHRQ) has proposed, as inpatient quality indicators, the PTCA and CABG mortality rates to reflect quality of care inside hospitals. In 2002, in the United States of America, for instance, the mean rate was 3.42 per 100 discharges at risk for CABG and 1.37 per 100 discharges at risk for PTCA (4). These indicators are usually evaluated along with volume because, as noted in the literature, higher volumes of PTCA and CABG have been associated with fewer deaths (5,6).

In Brazil, CVD is the leading cause of mortality, 30% of all deaths, and it is estimated that nowadays up to 6.4 million Brazilians suffer from this group of diseases. Concerning the high complexity cardiologic procedures performed by the National Unified Health System (SUS), 81.0% comprise CABG (36.4%) and PTCA (44.6%). In a 2003 study, the Inpatient Mortality Rate for CABG was about 7%. Burden of treatment for CVD through these procedures rests on hospitals who are equipped to perform them, and there is a public policy that regulates activities and habilitates hospitals to execute interventional treatment (7).

The objective of this study is to develop a model to assess performance of the habilitated hospitals in Rio de Janeiro, Brazil, considering not only the efficiency to perform the quantity of procedures (volume of CABG and PTCA), but also the quality of care (by means of mortality rates per procedure).

**Methods:**

Many performance and benchmark reviews approach the issue of practical use of health care assessment from the efficiency perspective. Ozcan, O'Neill *et al.*, Lins *et al.*, Lobo *et al.* (8, 9, 10, 11) health care efficiency studies collectively provided comprehensive overview of the theme, pointing out the general advantages, concerns and limitations of applying these methods in hospital settings. One issue of concern was pointed by Hollingsworth (12), who argued that the pressure to be efficient can lead to low cost, low quality system, and there may be also a trade-off between these aspects and the one of equity.

The most common used technique, Data Envelopment Analysis (DEA) based on linear programming, draws a frontier of best practices, shows which health organizations are efficient, gives the magnitude of inefficiency and indicates the means of improving efficiency by giving targets/projections for each of the inputs and/or outputs individually.

The units of analysis (DMUs- Decision Making Units) in our case are hospitals in Rio de Janeiro habilitated to perform CABG and PTCA. The ones over the frontier, therefore, efficient, have an efficiency measure that equals to 1.00 or 100%, while the DMUs located under the frontier are inefficient (values between 0 and 1.00, or 100%). The production models used in this work consider variable returns to scale (VRS) and are oriented to the increase of outputs to the projection in the frontier (maximization). The VRS model allows an inefficient unit to be compared only with others efficient units of similar size or operate in similar scale and is the choice to cope with hospitals that have differing sizes. The orientation choice (output) admits the maximum success of the results (procedures and survival rates), given a fixed amount of resources. The formulae for the VRS, output oriented DEA envelope model can be seen in Chart 1. The decision variable lambda considers the distance of the unit to the frontier that literally envelops the set of DMUs. In its dual formulation, the multiplier model, the decision variables consist of the weights given to each variable so that the efficiency score is calculated by the weighted sum of outputs divided by the weighted sum of inputs consumed. Details of the technique can be seen elsewhere but the constraints inserted inside the multiplier model are the key to guarantee the inception of weight restrictions in DEA (13).

**Chart 1: Output Oriented DEA VRS Envelope Model**

$$\max \theta + \varepsilon \left( \sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \right)$$

Subject to

$$\sum_{j=1}^{n} x_{ij} \lambda_j + s_i^- = x_{io} \qquad i = 1,2,\dots,m;$$

$$\sum_{j=1}^{n} y_{rj} \lambda_j - s_r^+ = \theta y_{ro} \qquad r = 1,2,\dots,s;$$

$$1 = \sum_{j=1} \lambda_j \qquad \lambda_j \geq 0 \qquad j = 1,2,\dots,n.$$

To assess both quantity and quality, a two-stage model was designed. The first model, or the Quantitative Efficiency Model, considered efficiency as the quantity of procedures executed (as the number of CABG and PTCA are the outputs) given the resources spent to perform them. The inputs were: a) number of beds, summing up the cardiologic and the cardiac intensive care ones; b) equipment, multiplying the number of cardiologic equipment in the hospital units by the mean price for each one in Brazil´s medical market.

The outputs of the first model (number of CABG and PTCA) were then made inputs for the second Model, or the Qualitative Efficiency Model, which had the inpatient survival numbers for each procedure as outputs.

In order to enhance the models, it is noteworthy that there was a need to insert weight restrictions in both of them. In the Quantitative Model, the Assurance-Ratio Global (ARG) model was used to guarantee that all virtual inputs (outputs) would contribute at least with 10 percent relative to the total virtual inputs (outputs). In this way, no unit could allocate a zero weight to any variable. In the second Qualitative Model, aside from avoiding null weights, the inception of weight restrictions should consider the difference in the risk of dying after being submitted to each output procedure (higher for CABG). To choose the bounds the for the ratio of weights in the Assurance Region Model (AR), a graphical analysis of the frontier inclination was made, to reach the criteria that the weight for survival after CABG should be 2 to 9 times higher than the one after PTCA.

The data sources used are publicized from the Ministry of Health/ DATASUS: Hospital Information System (SIH) and National Dataset on Health Facilities (CNES), for the year 2005. The software used was the DEA-Solver PRO.

**Results & Discussion:**

In 2005, eleven hospitals were allowed to perform both procedures in Rio de Janeiro; 06 of them are located in the capital; 04 of them are public (02 are teaching hospitals/TH), 02 are private for-profit and 05 are private non-for-profit (philanthropic, 01 is TH). As can be seen in Table 1, the number of cardiologic beds varied from 07 to 131 (mean 52). The number of CABG ranged from 30 to 171 (mean 95), with mean survival rate of 92, 8 %. The number of PTCA varied from 19 to 464 (mean 171), with mean inpatient survival rate of 98, 9 %.

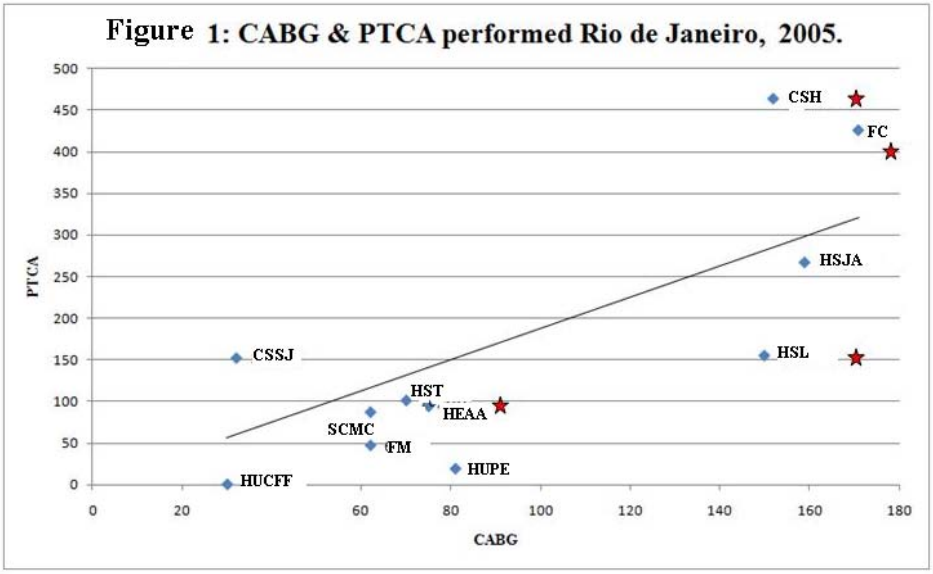
**Table 1: Inputs and Outputs of the Two-Stage Model**

| | Input Quantitative | | Output Quantitative/Input Qualitative | | Output Qualitative | |
|---|---|---|---|---|---|---|
| HOSPITALS | Cardiologic Beds (n) | Cardiologic Equipment * | CABG (n) | PTCA (n) | Inpatient Survival CABG (n) | Inpatient Survival PTCA (n) |
| CASA DE SAUDE SAO JOSE - CSSJ | 24 | 1,532 | 32 | 152 | 28 | 152 |
| CLINICA SANTA HELENA - CSH | 19 | 1,045 | 152 | 464 | 141 | 463 |
| FALMED - FM | 60 | 1,522 | 62 | 47 | 54 | 46 |
| FUNDACOR - FC | 131 | 3,259 | 171 | 426 | 158 | 383 |
| HOSPITAL ESCOLA ALVARO ALVIM - HEAA | 7 | 1,203 | 75 | 94 | 68 | 94 |
| HOSPITAL SANTA TERESA - HST | 22 | 1,857 | 70 | 101 | 68 | 97 |
| HOSPITAL SAO JOSE DO AVAI - HSJA | 54 | 2,528 | 159 | 267 | 156 | 262 |
| HOSPITAL SAO LUCAS - HSL | 16 | 0,543 | 150 | 155 | 137 | 154 |
| HOSPITAL UNIVERSITARIO PEDRO ERNESTO -HUPE | 103 | 2,971 | 81 | 19 | 73 | 19 |
| SANTA CASA DE MISERICORDIA DE CAMPOS - SCMC | 43 | 1,698 | 62 | 87 | 60 | 86 |
| HOSPITAL UNIVERSITARIO CLEMENTINO FRAGA FILHO - HUCFF | 98 | 2,176 | 30 | NP | 29 | NP |

* US$/1.000
** NP Not performed

In the Quantitative Model, 04 hospitals were considered efficient: Santa Helena Clinic (CSH - for-profit, outside the capital), FUNDACOR (FC- public and specialized, from the Ministry of Health, in the capital), São Lucas Hospital (HSL - for-profit, at the capital), Hospital Escola Alvaro Alvim (HEAA - not-for-profit, outside the capital). The first ones were considered benchmarks for 08 and 06

hospitals, respectively. The average efficiency was 59.8% and the lowest value was 0.2 % (Hospital Universitário Clementino Fraga Filho - HUCFF). Except for the Casa de Saúde São José (CSSJ), all hospitals attributed a higher (nearly 90%) virtual weight to the CABG volume. These could be foreseen in Graph 1, which plots both procedures for each hospital. To have a preview of the frontier, the efficient units are marked with a red star and. Aside from Clínica Santa Helena e Fundacor, which should stay in the frontier even with many differing equations that estimate the inclination of the frontier, the only hospital that presumably invest more on performing PTCA than on CABG (by staying above the regression line).




Finally, Table 2 presents the rank for the Quantitative Model, the benchmarks for each hospital and the projection of all the units so that each one could reach the best practice frontier. Naturally, the first 04 efficient units do not have to change their numbers (that are similar to the actual ones seen in Table 1). The least efficient hospital should have, according to the model, astonishing increase of their numbers, by 999.9%, what could not be applied in the real scenario. Except for this hospital, all the other inefficient units should raise the CABG numbers by 62.0% and the PTCA numbers by 69.7% to reach the frontier. It is noteworthy that almost all targets is above 120 procedures per year, the exactly minimum number recommended by the Brazilian Ministry of Health.

**Table 2 : Rank, Score, Benchmarks and CABG and PTCA Projections for the Hospitals, Rio de Janeiro, 2005**

| DMU | Score | Benchmarks | | Projection CABG | Projection PCTA |
|---|---|---|---|---|---|
| HOSPITAL SAO LUCAS - HSL | 100,00% | HOSPITAL SAO LUCAS | | 150 | 155 |
| HOSPITAL ESCOLA ALVARO ALVIM - HEAA | 100,00% | HOSPITAL ESCOLA ALVARO ALVIM | | 75 | 94 |
| CLINICA SANTA HELENA - HSH | 100,00% | CLINICA SANTA HELENA | | 152 | 464 |
| FUNDACOR - FC | 100,00% | FUNDACOR | | 171 | 426 |
| HOSPITAL SAO JOSE DO AVAI - HSJA | 93,91% | CLINICA SANTA HELENA | FUNDACOR | 158 | 452 |
| HOSPITAL SANTA TERESA - HST | 41,31% | CLINICA SANTA HELENA | FUNDACOR | 169 | 245 |
| SANTA CASA DE MISERICORDIA DE CAMPOS - SCMC | 35,84% | CLINICA SANTA HELENA | FUNDACOR | 173 | 243 |
| CASA DE SAUDE SAO JOSE - CSSJ | 31,03% | CLINICA SANTA HELENA | | 152 | 464 |
| FALMED - FM | 30,87% | CLINICA SANTA HELENA | FUNDACOR | 156 | 455 |
| HOSPITAL UNIVERSITARIO PEDRO ERNESTO - HUPE | 24,16% | CLINICA SANTA HELENA | FUNDACOR | 335 | 79 |
| HOSPITAL UNIVERSITARIO CLEMENTINO FRAGA FILHO - HUCFF | 0,21% | CLINICA SANTA HELENA | | 14.057 | 47 |

Going to the Qualitative Model, one important issue was already pointed in the methodology concerning the choice of the lower and upper bounds of the ratio between the weights for survival from CABG and survival from PTCA, as the risk of dying after the first is higher. To reach the bound values, a VRS output model was run with both survival rates as outputs (and no inputs), and the ratio of the respective weights of the efficient units, hence, that were on the frontier, was calculated. Given that, in DEA linear programming, the weights or multipliers are responsible for the equations that assume the inclination of the frontier, the mechanism of choice was based on geometrical representation of the frontier. In this case, four units were on the frontier, and the calculated values ranged from 1.8 to 9.7. That is why, the bounds considered for the AR Qualitative Model ranged from 2 to 9. Table 3 presents the scores for the qualitative model, along with the mortality rates encountered for these hospitals.

**Table 3: Qualitative Model Score and Mortality Rate (MR%) for PTCA and CABG**

| DMU | Score | MR PTCA | MR CABG |
|---|---|---|---|
| HOSPITAL UNIVERSITARIO CLEMENTINO FRAGA FILHO | 100,00% | NP | 3,33 |
| HOSPITAL SAO JOSE DO AVAI | 98,64% | 1,87 | 1,89 |
| SANTA CASA DE MISERICORDIA DE CAMPOS | 98,56% | 1,15 | 3,23 |
| HOSPITAL SANTA TERESA | 98,20% | 3,96 | 2,86 |
| CLINICA SANTA HELENA | 97,26% | 0,22 | 7,24 |
| CASA DE SAUDE SAO JOSE | 97,20% | 0,00 | 12,50 |
| FUNDACOR | 96,15% | 1,03 | 7,60 |
| HOSPITAL ESCOLA ALVARO ALVIM | 95,04% | 0,00 | 9,33 |
| HOSPITAL SAO LUCAS | 94,48% | 0,65 | 8,67 |
| HOSPITAL UNIVERSITARIO PEDRO ERNESTO | 92,18% | 0,00 | 9,88 |
| FALMED | 91,12% | 2,13 | 12,90 |

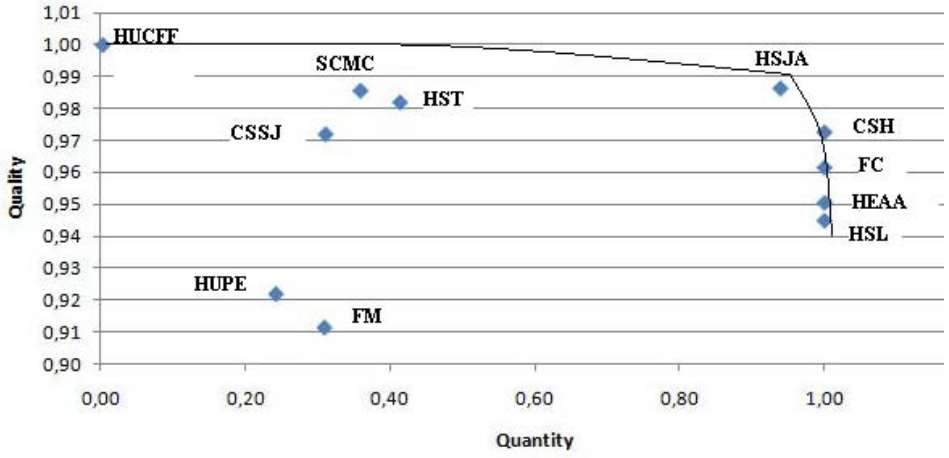
In the Qualitative Model, one hospital was considered efficient: Hospital Universitário Clementino Fraga Filho - HUCFF, a federal university hospital inside the capital, a benchmark for all others, and the hospital with the lowest score in the Quantitative Model. Just beneath, two other private hospitals (not-for-profit) that were not remarkable in the Quantitative Model, Hospital São Jose do Avaí (HSJA) and Santa Casa da Misericórdia de Campos (SCMC), appear with a 99% score. The average efficiency was 96.3% and the lowest value was 91.1 % (FALMED). In this model, there was an equitable distribution of virtual weights to both outputs. The calculus for the projections was jeopardized as no one should expect and council a manager to aim survival rates other than a hundred percent. The mean observed Mortality Rate for PTCA was 1.1%, with two hospitals surpassing the vales recommended by AHRQ (Hospital Santa Teresa and FALMED). For CABG, the average value was 7.2, compatible with the cited Brazilian study and doubling the AHRQ preconized value.

Ideally, if one wishes to compare mortality among hospitals, it is important to introduce some kind of adjustment for the different risks and severity of diseases. From the perspective of administrative databases, age, gender and co-morbidities are the most frequent used variables used for risk-adjustments (14). With this especially

little dataset, age did not alter the results; the other variables were not present in the current database.

As we can already presume, and diverging from the literature, we could not find a positive correlation between volume and survival rate (actually, it was negative in 0.04). Figure 2 compares the scores in each model, so that we can preview a frontier that considers both dimensions: quantity and quality. If no weight restrictions are added, the frontier will pass over efficient units in both models, with SJA and SCMC almost reaching it, because of the high quality score.

**Figure 2: Quality X Quantity DEA Scores**




Although it is not easy to establish a cut-off point to establish a trade-off between quantity and quality, a DEA model with both scores was run, to get a final score, given that each previous model should have a virtual weight of at least 20% (by Assurance Ratio Global). The results of all models are found in Table 4. Clinica Santa Helena is in the top of the rank, followed by Hospital São Jose do Avai, Fundacor, Hospital Escola Alvaro Alvim and Hospital São Lucas; pointing towards a balance between quantity and quality. As already mentioned, a risk adjustment for CABG survival rates should be nice here as the only hospital with rates beneath the recommended parameter by AHRQ was seen in Hospital São Jose do Avai.

**Table 4: Final Score, Quantity and Quality Models DEA Results**

| DMU | Final | Quantitative | Qualitative |
|---|---|---|---|
| CLINICA SANTA HELENA - CSH | 100,00% | 100,00% | 97,26% |
| HOSPITAL SAO JOSE DO AVAI - HSJA | 99,82% | 93,91% | 98,64% |
| FUNDACOR - FC | 99,77% | 100,00% | 96,15% |
| HOSPITAL ESCOLA ALVARO ALVIM - HEAA | 99,54% | 100,00% | 95,04% |
| HOSPITAL SAO LUCAS - HSL | 99,42% | 100,00% | 94,48% |
| HOSPITAL SANTA TERESA - HST | 78,34% | 41,31% | 98,20% |
| SANTA CASA DE MISERICORDIA DE CAMPOS - SCMC | 74,21% | 35,84% | 98,56% |
| CASA DE SAUDE SAO JOSE - CSSJ | 69,20% | 31,03% | 97,20% |
| FALMED - FM | 66,59% | 30,87% | 91,12% |
| HOSPITAL UNIVERSITARIO PEDRO ERNESTO - HUPE | 59,81% | 24,16% | 92,18% |
| HOSPITAL UNIVERSITARIO CLEMENTINO FRAGA FILHO - HUCFF | 1,06% | 0,21% | 100,00% |

**Conclusions:**

DEA model is a potential tool to assess the hospital efficiency for cardiologic procedures in both, the quantitative and qualitative perspectives, and should be explored to aid decision making in public policy. As a multi-input multi-output index, it allows the comparison of hospitals that have diverse sizes and resources and also establishes differing goals to each one, based on their real capabilities.

From a methodological point of view, it is really important to incorporate quality variables inside the production models that deal with health scenarios, and flee from the sole quantitative logic. Also, the systematic dialogue between the OR analyst and the health specialist enhances the models, as any result can be discussed according to its impact on the clinical setting and on the health system. The OR analyst needs to know what is exactly the nature, indications and risks of any procedure to be analyzed, so that he/she can understand what is the real meaning of the costs and benefits, what possible correlations are to be expected, which constraints will approach the model to the real hospital operations and what findings could be interesting to be put in practice in the real world. Here, the graphical approaches to the frontier and to other visual mathematical characteristics of the models are very useful to enhance the interdisciplinary comprehension. In this study, the graphical analysis was especially important to establish the bounds for the necessary weight restrictions, turning clinical and epidemiological facts to clear models, with very equitable distributed weights and zero slacks, that is, only Pareto-efficient frontiers (in OR language). In this study, the expected correlation between volume and survival was not observed, but the validity of this conclusion is low because there was no risk-adjustment for severity of disease. Besides this necessary correction, in the future, the Quantitative and Qualitative Models could be unified in one sole Network Dynamic Model (15), so that a quality output (survival) could be indirectly influenced by an input resource (bed or equipment), now presented in a distinctive quantitative model. After all, to increase quality, the manager would have to invest in resources already considered in the quantitative model as inputs. There is a study who states that a 1% increase in the level of quality of care delivered is estimated to increase hospital cost by an average of 1.34 % (16).

Finally, it is time to do follow what Avkiran and colleagues (17) affirmed: DEA has already passed through the development phases of problematization and gap identification, when the theory became influential and overcame the challenge of completeness and adequacy as a science. Now, as a mature science, DEA has to be put in practice and the black-box of production needs to be opened, either by using network DEA models, either by the contextualization of the clinical and epidemiological realities (sometimes congregating multiple methodologies). The only way to evaluate the long term impact of the applied recommendations relies on assuring face validity from the health professionals and turning the findings meaningful and acceptable to managers by means of credibility, theoretical foundation and pertinence to the priorities of the public health policies.

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***Abstract sent before finishing this paper:**

***Performance assessment and quality of cardiac procedures in Rio de Janeiro through DEA***

*This work resulted from research developed in the context of CT-Saúde, a project supported by the Ministry of Health, which also keeps the DATASUS, a database that provides data on procedures and death of inpatients. A two-stage modeling is proposed to assess two processes: the first aims at providing services to cardiac inpatients, the second focuses on the inpatient outcomes. The methodology uses geometrical and graphical analysis to support weight restrictions formulation. Analysis of results comprises both primal and dual variables and their contribution to build performance indices, thus allowing confrontation with experts' judgments regarding large hospitals assessment in the state of Rio de Janeiro.*