UNIVERSIDADE FEDERAL
DO RIO DE JANEIRO

INSTITUTO DE ECONOMIA

BRAZILIAN FEDERAL UNIVERSITIES:
Relative Efficiency Evaluation and Data Envelopment Analysis

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Textos para Discussão

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May 1997

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Ficha catalográfica

MARINHO, Alexandre

Brazilian Federal Universities: relative efficiency evaluation and data envelopment analysis. /Alexandre Marinho; Marcelo Rezende; Luís Otávio Façanha. -- Rio de janeiro: UFRJ/IE, 1997.

24 p.; 21 cm. -- (Texto para Discussão. IE/UFRJ; n. 389)

1. Universidades e Faculdades - Avaliação - Brasil. I. Resende, Marcelo. II. FAÇANHA, Luís Otávio. III. Título. IV. Série.

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SUMÁRIO

1. Introduction

The study of multioutput non-profit organizations is being object of increasing interest in the empirical literature. The main difficulty associated with the assessment of those entities, has to do with a precise characterization of their technology. In this sense, several recent studies addressed such organizations by means of flexible empirical approaches.

Universities and professional hierarchies constitute an influential example of the aforementioned issue, since its technology is characterized by multiple inputs and outputs and "strict profit maximization" is not the main organazing principal of conduct. Secondly, their operations are guided by multiple missions/general objectives. Consequently, efficiency cannot be trivially defined and measurements of efficiency become a central research and management challenge as have been discussed by Façanha et ali. (1996) among others. Examples of efficiency measurement in the context of universities include Davies and Verry (1976), Beasley and Wong (1990), Beasley (1990, 1995). Gamerman et ali. (1992), Johnes (1992) and Johnes and Johnes (1993).

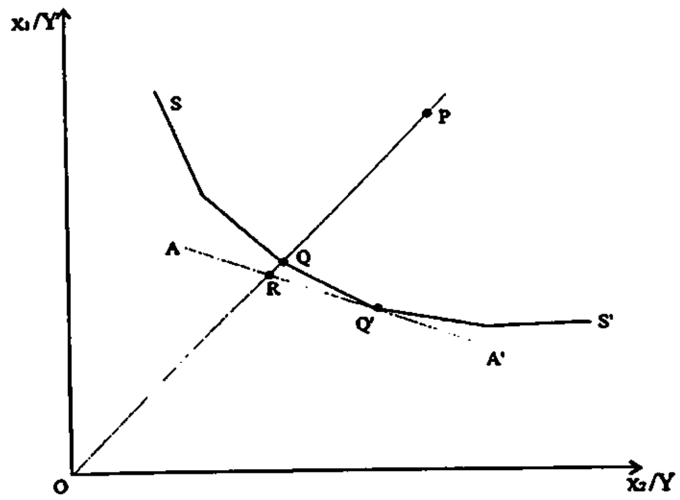
A leading flexible empirical approach for comparative efficiency measurement is the nonparametric method of Data Envelopment Analysis (DEA). The yardstick for efficiency is not a theoretical concept or an ideal but rather the achievement of other (comparable) organizations or decision making units (DMUs). "Efficiency is measured relative to the observed best practice" (Felder, 1995). Moreover, the methodology also handles difficulties brought in by unavailability/non-observability of market prices, of inputs, of outputs, of inputs and outputs. Universities are well-known conspicuous examples of such complex managerial problems.

The present paper intends to pursue a DEA approach in the context of the Brazilian Federal Universities. DEA can provide useful insights into critical resource allocation and management problems that constrain the DMU's considered in this paper. Federal Universities are essential parts of the Brazilian Federal System of Higher Education, where those problems are certainly part of a much broader agenda that envisages reform and institutional consolidation, and calls for better evaluation, guidance and motitoring instruments as mandatory ingredients. The paper is organized as follows. The second section provides a brief digression on DEA. The third section presents a description of the information and variables used in the exercise, and an application of Factor Analysis for data preparation, which allowed us to obtain the basic result of DEA, the "efficient frontier" for the DMU's. Section IV presents final comments.

2. Data Envelopment Analysis: a Brief Digression

The study of empirically determined efficiency frontiers have their roots on the seminal paper by Farrell (1957), who considered a data derived approximation to a representative unit isoquant with respect to which, deviations would characterize inefficiency. Consider a firm that produces a single output upon two inputs x_1 and x_2 according to a production function f (x_1, x_2); the next graphic illustrates the main ideas:

Figure 1



At a general conceptual level, Farrell distinguishes two components of the productive inefficiency: the technical inefficiency given by the ratio OQ/OP and the allocative inefficiency provided by OR/OQ. Finally, OR/OP indicates the total efficiency; it should be noted that the unit isoquant representation above relies on the potentially restrictive assumption of constant returns to scale. In the previous example the DMUs Q and Q' are technically efficient, and P is inefficient at both the technical and allocative criteria; Q' represents the unique point at which both forms of efficiency are attained. A feasible empirical counterpart for a theoretical smooth isoquant will display the piece-wise linearity as above, and consists on the consideration of the free disposal convex hull of the observed input-output ratios that would be obtained by linear programming procedures. The **Data Envelopment Analysis (DEA)** literature may be thought as inspired on Farrel's concepts, and considers multi-output multi-input, as well as variable returns to scale extensions. It is worth mentioning that DEA differs from the econometric methods in two fundamental aspects:

i) The production efficiency frontier is obtained in a nonparametric fashion, as the solution to a fractional linear programming problem;

ii) The focus is on relative efficiencies, in contrast with the econometric approach that considers central tendencies or average planes that would be adjusted and assumed to hold for each decision making unit (DMU) [See eg. Seiford and Thrall (1990)].

Leibenstein (1966) advanced the possibility of non-allocative forms of inefficiency, the x-inefficiency, that may arise among other factors, due to sub-optimal effort levels within a principal-agent relationship. Frantz (1988, 1992) and Leibenstein and Maital (1992) defend the properness of DEA to assess the degree of x-inefficiency of a given DMU. In addition, such technique imposes no functional forms restrictions on the underlying technology, the basic structure imposed refers to the convexity and piece-wise linearity of the technology.

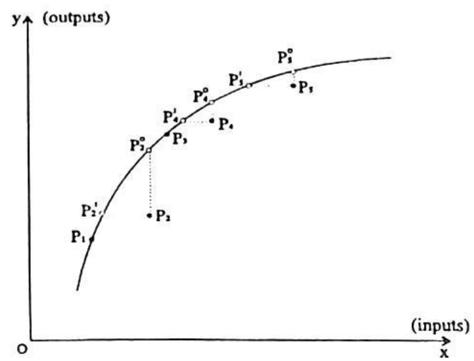
DEA has been object of increasing popularity, with a wide range of applications in different areas [See Seiford (1994) for an extensive bibliography], and its consolidation as an influential approach can be illustrated by the publication of a comprehensive textbook in the matter by Charnes et al. (1994); some general introductions to that approach appear in Seiford and Thrall (1990) and Boussofiane et ali. (1991).

There are two classes of DEA models that are most commonly applied, and for which a brief description will follow. It should be noted that the general idea underlying DEA models, is the comparison of a virtual output measure

(that aggregates output measures) with a virtual input measure (that aggregates input measures), such that the corresponding weights are chosen in a way to represent a given DMU in the most efficient characterization consistent with the data and with the restriction that no DMU can be beyond the efficiency envelopment surface.

The DEA models admit two orientations: output augmentation (output orientation) or input conservation (input orientation). In the former, efficiency refers to obtaining the maximum output level given a fixed utilization of inputs, whereas in the latter efficiency alludes to securing the minimum employment of inputs given the output level.[1] In the case of constant returns to scale the efficiency frontier hyperplane would be linear and pass through the origin; in this case the two orientations would produce the same efficiency scores. In the case of variable returns to scale, this is no longer the case; however, empirical practice seems to show that the choice of inputs and outputs to be used in the analysis is the crucial choice rather than the orientation choice [See eg. Charnes et ali. (1994)].The next figure illustrates some basic ideas.

Figure 2



Once the efficient frontier is defined, one can project an inneficient DMU (such as indicated by points P_2, P_4 and P_5) to the frontier in the sense of making salient the gap between the actual and the best practice. For example consider DMU 2; according to an output orientation, one would compare P_2 with P_2^o by definining a constant level of input use. One could, on the other hand, consider an input orientation and define a constant level of output, in this case DMU 2 could have saved inputs for this given level of production given the gap between P_2 and P_2^1. For the DMUs 1 and 3, no further output augmentation or input conservation would have been possible as they are situated on the efficiency frontier. The seminal contribution in DEA was advanced by Charnes, Cooper and Rhodes [1978-CCR] and addressed the constant returns to scale case. The basic set-up considers m inputs (indexed by subscript i), s outputs (indexed by subscript r) and n DMUs (indexed by subscript j); additionally it is assumed that $x_{ij} > 0$ and $y_{rj} > 0$, which refer to strictly positive values of inputs and outputs from the j-th DMU, respectively. CCR consider the following fractional linear programming problem:

$$\max_{u,v} h_k = \sum_{r=1}^{s} u_r y_{rk} \Big/ \sum_{i=1}^{m} v_i x_{ik} \qquad (1)$$

subject to:

$$\sum_{r=1}^{s} u_r y_{rj} \Big/ \sum_{i=1}^{m} v_i x_{ij} \text{ £ } 1 \quad (for\ j = 1,2,\ldots,k,\ldots n) \qquad (2)$$

$$u_r > 0 \quad (for\ r = 1,\ldots,s) \qquad v_i > 0 \quad (for\ i = 1,\ldots m) \qquad (3)$$

The problem above is to be solved for each DMU taken as reference, such that there would be n mathematical programming problems to be solved, and the solution would

generate optimal inputs and outputs weights given the constraints that no DMU can operate beyond the efficiency frontier (constraint 2) and that the referred weights should be non negative (constraint 3). As it stands, the above problem is complex, however CCR have shown that it can be transformed into an equivalent linear programming problem.

A potentially limiting assumption of the CCR model concerns the constant returns to scale. Banker (1984) and Banker, Charnes and Cooper [BCC - 1984] extended the CCR model by incorporating the possibility of variable returns. The notion of variable returns is defined as follows, let the production possibility set be given by T = {(X, Y): the output vector Y ³ 0 can be produced from the input vector X ³ 0}. Then, returns to scale at a point (X, Y) on the efficient surface of T, can be expressed in terms of as below:

$$\rho = \lim_{\beta \to 1} \frac{\alpha(\beta) - 1}{\beta - 1} \qquad (4)$$

where $\alpha(\beta) = \max \{\alpha: (\beta X, \alpha Y) \in T\}$, $\beta > 0$.

The idea is to observe how proportionate changes in the input vector reflect in terms of changes in the output vector. Specifically, if $\rho > 1$ one would have a situation of increasing returns to scale, as a change in the inputs (maintaining the input mix fixed) leads to a more than proportionate change in the outputs (keeping the output mix constant). Similarly, one can characterize a situation of decreasing and constant returns to scale when $\rho < 1$ and $\rho = 1$, respectively. Furthermore, one can define the notion of a most productive scale size (mpss), that would indicate the most efficient scale for given inputs and outputs mixes. The main result obtained by the aforementioned author is that aggregate efficiency can be factored in terms of technical efficiency and scale efficiency, where the latter would capture deviations of the actual scale from the mpss. In other words, the efficiency score obtained from the CCR model (that assumes constant returns to scale) is equal to the product of the technical efficiency score obtained from the BCC model (that contemplates variable returns to scale) multipled by the scale efficiency score.

The BCC model extends the previous DEA analyses by imposing more structure in the production possibility set, so as to capture scale effects. Most importantly, a convexity restriction is added to the CCR model. More precisely, convexity requires that if $(X_j, Y_j) \in T$ for $j=1,\dots, n$, and $\lambda_j \geq 0$ are non-negative scalars such that $\sum \lambda_j = 1$, then $(\Sigma\lambda_j X_j, \Sigma\lambda_j Y_j) \in T$. The basic modification of the CCR model accounts for introducing the constraint $\sum \lambda_j = 1$ into the mathematical programming problem.

The intuition underlying the usefulness of convexity, is that it would secure that any composite unit extrapolated is similar in size to the reference unit and not merely an extrapolation of another composite unit operating at a different scale size, therefore the restriction ensures that all DMUs are evaluated taking the convex combination of inputs and utputs as reference [Sawkins and Accam (1994)].

3. Applications

3.1. Data Description

The present paper makes use of a new data set concerning Federal Universities in Brazil for the year of 1994. Most of the data was obtained from MEC/ANDIFES (1995), which covers 52 Federal Institutions of Higher Education (*instituições Federais de Ensino Superior* – IFES). The informations was carefully collected and auditted by a Special Commission during 1995, as part of a promising

follow-up activity ushered by the Ministry of Education–MEC and Higher Education Federal Institutions Managers' Association – ANDIFES. The IFES will each be treated as an individual DMU. The data also includes information about Current Expenses (OCC), obtained from a public report released by ANDIFES. As a reference, it should be mentioned that OCC is the initial budget, allocated to each IFES/DMU according to a "model" that privileges "historical OCC" (with a weight of 90%), "input" data (with around 9% weight), and "output" data.

The exercise will take full advantage of all the information available, avoiding the risky consequences of delimitting the data set with *a priori* criteria and/or making use of popular (however useful and/or convenient) measures of performance, like professors/students, total expenses / students, and others. Stronger reasons to adopt the more exploratory procedure can be found in Marinho (1996), and are related to the nature of returns of scale of the (implicit, unobservable) "technology" that prevails in such cases. Moreover, the main objective of the Special Commission was to provide good information for better management, and to improve the "model" of initial budget allocation that is currently being used among the IFES. This objectives pressuposes that the organizations have better control over all the range of resources/inputs and results/outputs that have to be managed and transformed of course, averages are poor/very parcial substitutes for those knowledege/ control requirements. In any case, the reader can assess some of these comments by examining the list of variables that is presented next.

Input Variables

1. Area of buildings - AREA;
2. Area of hospitals - ARHOSP
3. Area of laboratories - ARLAB;
4. Total number of students - ALU;

5. Professors with doctoral degree - DD;
6. Professors with master degree - DM;
7. Professors with specialization degree - DE;
8. Professors with undergraduate degree - DG;
9. Professors of second and first degree teaching - DSG;
10. Administrative personnel at support level - TECADAP;
11. Administrative personnel with high school degree background - TECAMED;
12. Administrative personnel with undergraduate degree or higher - TECADS;
13. Budget for current expenses - OCC;
14. Incoming students at undergraduate level - ING;
15. Incoming medical residents - MATRMED.

Output Variables

1. Number of undergraduate courses - NGRAD;
2. Number of graduate courses-master degree level - NCMEST;
3. Number of graduate courses - doctoral degree level - NCDOUT;
4. Certificates issued: undergraduate degree - NDI;
5. Certificates issued: medical schools residence - DIPRMED;
6. Number of master' thesis approved - NTM;
7. Number of doctoral dissertations approved - NTD;
8. Weighted average of MEC' evaluation: master degree courses - CAPESM;
9. Weighted average of MEC' evaluation : doctoral degree courses - CAPESD.

The last two variables were conventionally defined. The rank of each course, A,B,C,D, or E was transformed into 10, 8, 6, 4, or 2, respectivelly, and the weights were defined by the number of courses in each category of evaluation.

Before performing the application of DEA, a close examination of the data recommended that some observations/DMU's should be suppressed on grounds of notorious specialization. Moreover, for the IFES whose graduate courses were not evaluated, we attributed the average grades from the remaining sample. This procedure can be justified on assumption that new courses are expected to possess at least average quality, otherwise it wouldn't obtain official support. The IFES for which graduate courses weren't available, received grades of zero. After taking into account the previous remarks, we ended with 38 DMU's to be compared.

But this procedure has a cost; the final number of DMU's resulted small vis-à-vis the number of variables selected. This fact complicates the application of DEA as a discriminant and ranking technique. The intuitive reason is that with too much dimensions all DMU's tend to become special. Comparability results impaired. A possible approach is then to treat DMU's in different years as distinct DMU's [See eg. Marinho (1996)]. In the present situation, while the updated information (for 1995) is not yet officially available, the resort to Multivariate Statistical Analysis is a natural device, that to the best of our knowledge hasn't been applied in the context of DEA. Factor Analysis was then used to explore the presence of common dimensions in the data set, so as to allow a reduction on the number of variables considered. Next we describe such application.

In the factor model – see Manly (1994), as a good introductory reference –, a random vector X of observed characteristics, with p components, mean u and covariance matrix E, is linearly related to some non-observed random variables, F_1 ... F_m, (m<p), called "common factors", as well as to errors or "specific factors", e_1 ... e_p , as follows:

$$\underline{X} - \underline{u} = \underline{L}\ \underline{F} + \underline{e}.$$

The generic coefficient l_{ij} of matrix L is the "factor load" of variable i over factor j, (the method of principal components was used to obtain the loads) and the variance explained by Factor $_j$ is given by $l^2_{1j} + ... + l^2_{pj}$ / p. Factor analysis was applied first to reduce the dimension of "input variables", and then to reduce the dimension of the "output variables", with the results displayed in the next sub-section.

3.2. Empirical Results

Table 1
Factor Matrix for Input Variables

	Factor 1	Factor 2	Factor 3
ALU	.94	.13	-.01
AREA	-.06	.20	-.59
ARHOSP	.82	-.32	-.13
ARLAB	.48	-.32	.21
DD	.90	-.32	.06
DE	.57	.77	-.03
DG	.81	.47	-.04
DM	.94	.22	-.01
DSG	.05	.30	.76
ING	.91	.14	.02
MATRMED	.66	-.19	.24
OCC	.97	-.07	-.01
TECADAP	.68	-.01	-.22
TECADMED	.96	-.14	.00
TECADS	.87	-.27	-.11
Variance Explained	59,0%	9.7%	7.5%

Table 2
Factor Matrix for Output Variables

	Factor 1	Factor 2	Factor 3
CAPESD	.72	.34	.40
CAPESM	.51	.57	.50
DIPRMED	.44	-.43	.30
NCDOUT	.93	-.31	.05
NCMEST	.97	.01	-.03
NDI	.73	.40	-.43
NGRAD	.67	.11	-.61
NTD	.84	-.43	.08
NTM	.94	-.09	-.02
Variance Explained	59.5%	12,1%	11.9%

The exercise will turn now to the application of DEA, using only the factors that now represent inputs and outputs of the DMU's. It should be pointed out that the "problem" of negative loads among variables and factors was bypassed by using affine transformations on the original loads values. This procedure does not alter the "efficient frontier" of DEA, cf. Ali & Seiford (1990), thus justifiying the use of factor analysis as an intermediate stage in DEA applications.

The results from the DEA approach are presented next.

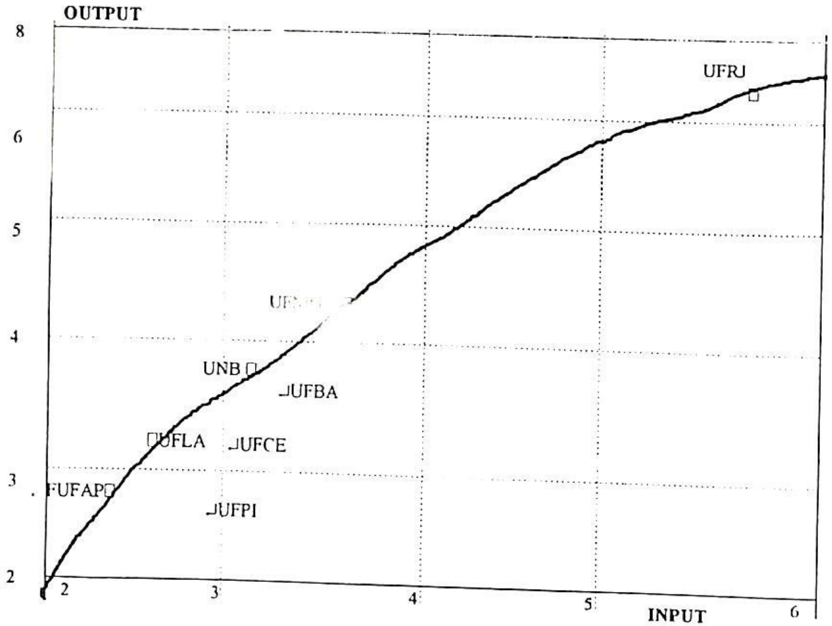
Table 3 presents the final ranking of the DMU's obtained from the BCC formulation. Those DMU's with 100 % efficiency scores constitute the "efficient frontier". It is worth mentioning that the exploration of common dimensions in the data set, by means of factor analysis, was instrumental to enable a proper discrimination of the DMU's. In fact, most of the previous DEA applications made use of a very restricted number of variables.

Table 3

UNIVERSITIES	Efficiency Value
FUFAC - Fundação Universidade Federal do Acre	77.08
FUFRO - Fundação Universidade Federal de Rondônia	78.18
FUFRR - Fundação Universidade Federal de Roraima	79.22
UFPI - Fundação Universidade Federal do Piauí	79.24
UFJF - Universidade Federal de Juiz de Fora	82.06
FUAM - Fundação Universidade do Amazonas	82.64
FUNREI - Fundação de Ensino Superior de São João del Rei	82.71
FUFMS - Fundação Universidade Federal de Mato Grosso do Sul	84.07
FUOP - Fundação Universidade Federal de Ouro Preto	84.69
UNIRIO - Fundação Universidade do Rio de Janeiro	87.75
UFRN - Universidade Federal do Rio Grande do Norte	88.03
UFSE - Fundação Universidade Federal de Sergipe	88.81
UFRPE - Universidade Federal Rural de Pernambuco	88.96
FUFUB - Fundação Universidade Federal de Uberlândia	89.18
UFGO - Universidade Federal de Goiás	89.29
UFES - Universidade Federal do Espírito Santo	91.33
FUFPEL - Fundação Universidade Federal de Pelotas	93.79
UFBA - Universidade Federal da Bahia	96.03
UFCE - Universidade Federal do Ceará	96.10
UFPE - Universidade Federal de Pernambuco	97.46
UFSM - Universidade Federal de Santa Maria	97.51
UFF - Universidade Federal Fluminense	99.61
UFRJ -Universidade Federal do Rio de Janeiro	100.00
UFPA - Universidade Federal do Pará	100.00
UNB - Fundação Universidade de Brasília	100.00
FURG - Fundação Universidade do Rio Grande	100.00
FPB - Universidade Federal da Paraíba	100.00
UFAL - Universidade Federal de Alagoas	100.00
UFMG - Universidade Federal de Minas Gerais	100.00
UNIFESP - Escola Paulista de Medicina	100.00
FUSCAR - Fundação Universidade Federal de São Carlos	100.00
UFRGS - Universidade Federal do Rio Grande do Sul	100.00
FUFUV - Fundação Universidade Federal de Viçosa	100.00
UFRRJ - Universidade Federal Rural do Rio de Janeiro	100.00
UFPR - Universidade Federal do Paraná	100.00
FUFAP - Fundação Universidade Federal do Amapá	100.00
UFSC - Universidade Federal de Santa Catarina	100.00
UFLA - Escola Superior de Agricultura de Lavras	100.00

The ranking of DMUs according to efficiency scores is one of DEA's most remarkable and well-known accomplishments. Nonetheless, there are useful extensions to be explored, and one of them will be selected to illustrate another dimension of the model's potentialities. The next picture synthesize the motivation, and it was drawn up with a particular choice of variables. Input values are actual values of factor 1, defined by the correlations and loadings of the original input variables, and output values were taken from the scores of factor 1 defined by the original output variables. The high percentage of variance explained by factor 1 (in either case) turns the choice made a non-arbitrary device to portray the DMU's, as well as the inner meaning of this common factor. Factor 1 combines variables related to human resources, physical assets and budget, teaching and research policies, suggesting the complementary [in the sense of , eg., Milgrom & Roberts (1992), chap. 4] dimensions, and the importance of Universities' management activities.

Some of the efficient DMU's were then plotted, and some of the efficient cases. The important point to stress is that the frontier can be taken as a reference and orientation to the inefficient DMU's [and to the efficient ones], as shown by Marinho, op.cit. In fact, DEA provides targets for each input and each output, and the menu can serve as a support information to DMU's planning and monitoring activities. It should not be assumed that the targets are rigid goals and/ or will be self-imposed as a standard of performance. They are simply and indication of how the bundle of inputs and how the bundle of outputs could be more efficiently adjusted as a whole. To sum up, as a comparative evaluation instrument DEA can be used as a helpful "partial equilibrium" and "general equilibrium" management purpose.



4. Final Comments:

This paper had two initial objectives. The first one was to develop a preliminary application of Data Envelopment Analysis-DEA to new data about Brazilian Federal Universities. The authors are undertaking an experiment using DEA in UFRJ, as part of its budgeting and institutional evaluation activities, and the exercise had both challenging and positive motivations. In fact, the exercise could manage a broad and comprehensive data set, overcoming difficulties associated to the definition of variables as emphasized before. A ranking for the DMU's could be generated without arbitrary selection of the informations available. Additionally, the most prominent feature of the methodology could also be exemplified. DEA explores diversity, instead of trying to "adjust" the DMU's observations to pre-specified parametric

constructions. A remarkable result is that most of the prominent well-known IFES were assessed as efficientorganizitions.

These more "technical" achievements reinforced the second thrust of the paper; to motivate the systematic application of DEA as a subsidiary policy instrument. This objective was not completely attended – new information and inventories [cf. described in Façanha et ali. (1996)] will certainly improve the results of DEA applications – , but the authors think that the pioneering job done by the Special Comission (see Section I) will merit the readers' consideration.

Notes

1 For a generic discussion of such distinction, outside the realms of DEA, see Färe and Lovell (1978).

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