Embrapa

Brazilian Corporation for Agricultural Research

EMBRAPA´S EVALUATION AND AWARDS SYSTEM: SELECTED PAPERS

Workshop
PRODETAB and Embrapa´s Planning, Evaluation and Management Systems

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Brazilian Corporation for Agricultural Research

Embrapa's Evaluation and Awards System Based on Results

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ABSTRACT

This paper presents basic conceptsw and operational aspects of Performance Evaluation system and Premiums fos outstanding resuilts implemented by Embrapa in 1996. This system aims to increase performance of research units, research teams and employess in gerenal, rewarding the more productive members of the institution. This system procedure for research units; c) team and individual empoyee evaluation; and, d) team and individual reward procedure.

Research units are evaluated according to: (i) the achievement of goals, (ii) relative efficiency of research activities; (iii) quality auditing of R&D; (iv) socioeconomic impact of technologies; and, (v) public image. Na index based on the combined evaluation of these factores is used to measure Institutional performance of each unit and to allocate a monetary reward from a special fund.

Performance evaluation of research teams and its members envolves: (i) achievement of individual goals; (ii) individual external research fund raising; (iii) creativitiy in termsw of Research and Development; (iv) tecnical quality of research projects; and. (v) accordancy with established priorits of Embrapa set by its administrative board. Thus, the employees with best performances, individually and in groups will receive financial rewards in addition to their regular salaries.

RESUMO

O presente trabalho apresenta conceitos e aspectos operacionais do Sistema de Avaliação e Premiação por Resultados da Embrapa, implantado em 1996. O Sistema objetiva elevar o desempenho das unidades de pesquisa, das equipes e empregados da Empresa e recompensar os mais produtivos. O Sistema é constituído por 4 componentes: a) avaliação de unidades; b) premiação de unidades; c) avaliação de equipes e empregados; e, d) premiação de equipes e empregados.

As unidades são avaliadas em conformidade a: (i) cumprimento de metas; (ii) eficiência relativa; (iii) auditoria de qualidade de projetos de P&D; (iv) impacto socioeconômico de tecnologias. E, (v) auditoria de imagem. A conjugação desses fatores constitui o Índice de Desempenho Institucional de uma unidade, base para o cálculo de sua premiação por um fundo criado com essa finalidade.

A avaliação de equipes e empregados de cada unidade compreende o respectivo desempenho em: (i) cumprimento de metas individuais; (ii) captação de recursos; (iii) criatividade em P&D; (iv) qualidade técnico das projetos de pesquisa; e, (v) cumprimento de priorides especiais da Empresa. Os empregados com melhor desempenho, individualmente e por equipes de trabalho, são premiados com um bônus financeiro.

RESUMEN

El presente trabajo eporta los conceptos y los aspectos operacionales del Sistema de Evaluacón y Premiación por Resultados en Embrapa, ya implantado em 1996. El Sistema tiene por objetivo elevar el desempeño de las unidades de investigación, de los equipos de trabajo y de los empleados, individualmente por intermedio de la compensación de los más productivos. El Sistema consta de 4 componentes: a) evaluación de las unidades, b) premiación de las unidades, c) evaluación de los equipos de trabajo y de los empleados individualmente y d) premiación de los equipos de trabalho y de los empleados individualmente.

Las unidades de investigación son evaluadas de conformidad co n: i) el cumplimiento de las metas, ii) eficiencia relativa, iii) auditoria de calidad, iv) impactos socioeconómico y, v) auditoria de la imagen. El conjunto de esos factores constituye el Indice de Desempeño Institucional de una unidad de investigación, conformando la base de cálculo para la premiación proveniente de un fondo especial creado co n esta finalidad.

La evaluación de los equipos de trabajo y de los empleados consta del desempeño respectivo en: i) cumplimiento de las metas individuales, ii) obtención de recursos, iii) creatividad en investigación y desarrollo (I&D), iv) calidad técnica de los proyectos de investigación, y) las prioridades especiales de la Empresa. Los empleados com los mejores desempños, individualmente y por equipos de trabalho, seán premiados com un bonus financeiro.

Embrapa's Evaluation and Awards System Based on Results[1]

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1. Introduction

Why should the Brazilian Corporation for Agricultural Research - Embrapa - create an Evaluation and Awards System based on Results? What is the justification for such an initiative? An evaluation of research centers and of individuals is a difficult process because it may invoke many reactions not always stimulating and foreseeable. To evaluate means to judge someone else's behavior. Even indicators considered to be objective do not eliminate the subjectivity in the process. Both the awards process, which also implies in judgment values, **and** the actual benefits unevenly distributed among people, are not always understood and accepted by the majority of public government employees.

Since its foundation, EMBRAPA has adopted several different methodologies to evaluate its employees, and not much has been done to reward them. Besides the traditional annual promotion with financial gains, the Corporation has limited itself to individual recognition, based on medals and honor lists, such as the Frederico de Menezes Veiga prize. On the other hand, at the institutional level, the experiences on the evaluation of research centers have been sporadic (specifically in the late 70's and 80's), based on external evaluation missions, utilizing processes known to be subjective, multiperiodic, and unrelated to individual evaluations.

The evaluation and awards system, already implemented by the Corporation, is innovative by integrating the institutional, team and individual levels. It sets, as evaluation targets, the evaluation of results obtained by research centers, by project teams, and by employees, in the period of one year. Another feature is the clear distinction between the awards resulting from promotions (permanent increases in wages) and the awards by results, given every year, as a function of target accomplishment, and other previously negotiated efficiency indicators.

This evaluation and awards process, guided and implemented by the Corporation's top administration, is an explicit signal that any underperformance incompatible with existing quantity and quality available resources, will no longer be tolerated, at individual, team and institutional (research center) levels.

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[1] Paper presented at the Directive Committee of PROCISUR, December 11-12 1996, in Vina del Mar, Chile.
In October 1996, this document was awarded a prize in the First National Contest of Innovative Management Experiences of the Federal Public Administration, promoted by the Administration Ministry of the Federal Republic of Brazil.

[2] President of Embrapa.

[3] Researchers of Embrapa.

From the institutional viewpoint, this model represents the management response to society's demand, in the sense of promoting efficiency and efficacy of a government institution. This does not imply that Embrapa produces little, given the fact that the Corporation is highly regarded in the public image. However it could produce a lot more, given the highly specialized human resources, the good existing physical infrastructure, including equipment, and the competitive wages presently paid. More important yet, the productive sector demands for agricultural and agroindustrial technologies are enormous, in the presence of a highly globalized competitive market, and the existence of quality requirements of agricultural products, on the side of consumers.

Embrapa is very conscious about these changes, and it is seeking to incorporate new concepts of management science. In the beginning of the present decade, the Corporation redefined its mission and objectives, utilizing strategic planning. Moreover, it revised its institutional model and implemented a new planning, monitoring, and technical & managerial evaluation system.

In 1995, Embrapa established a set of strategic managerial projects aiming at the leverage of new initiatives towards the improvement of efficiency and quality of its products. One such a case in point, is the new process to select the administrators of research centers, based in open contests, which take into account technical and managerial competence. Thus, it minimizes the external and corporative interference, which are harmful to the selection process of technical and managerially qualified professionals. The constitution of an Administration Board for the Corporation is, at present, in an advanced stage of negotiation. This new board aims at a more comprehensive participation of society in the decision making process, for the directioning of themes and strategic areas in science and technology. At the same time, the board will provide more institutional sustainability.

It is in this framework of changing environment and managerial modernization that the new system fits in, with the integration of the institutional (research centers), team work (research projects of Embrapa's Planning System) and individual levels. With the implementation of the System, a higher step in the management performance is expected to be achieved, thereby inducing an enhanced motivation among centers, work teams, and staff, so as to produce more and better quality results. The evaluation is for all units, teams and employees. The rewards will depend on the performance levels. Those with better results will receive higher benefits.

2. - Purposes of the System

2.1. Objectives

The adoption of the Evaluation and Awards System has the basic objective to increase the productivity of the Corporation research centers, in the fulfillment of its institutional mission of generating and spreading technologies for the Brazilian agribusiness. At the same time, it rewards the centers, work teams, and the staff that outperform in the accomplishment of their goals and in the Corporation growth. The System also motivates them to face new challenges.[4].

The specific objectives of the System are:
- to stimulate the Corporation centers for the accomplishment of their mission and objectives, as well as to motivate their work teams and the staff to increase their productivity and efficiency;
- to promote the conception and the development of innovative Research & Development projects, from the methodological standpoint, in the definition and solution of real and potential problems of the Brazilian agribusiness;
- to stimulate the continuous improvement of the research projects quality, and of the products generated by the Corporation, so as to better satisfy the clients needs; and,
- to increase the volume of alternative sources of funding, in addition to the revenues of the National Treasury, particularly those directed to the operating expenses.

2.2. Basic principles

The system integrates new management actions, with fully functioning systems, such as the Embrapa`s Planning System (SEP), and the Planning, Monitoring, and Individual Results Evaluation System (SAAD-RH). The new system is based on the same mechanisms, such as the Internal Technical Committees (CTIs) of the research units, and the Programs Technical Committees (CTPs), to evaluate projects. It also incorporates the individual evaluation results (SAAD-RH) in order to reward the employees.

The focus of the System is to reward (through wages add ins, advantages in the allocation and availability of funding, and by non-monetary prizes) the units, workteams and employees that most contributed for the accomplishment of the mission and the objectives of the Corporation. The awards process will be selective, in such a way that it does not become worthless. On the other hand, it cannot be too restrictive, so as not to hinder the motivation of people to participate in the process.

It is hoped that the evaluation and the awards process will stimulate a healthy competition and cooperation among units, teams and individuals, in such a way to become them more efficient. It will also emphasize the award-winning act (the ceremony), in order to highlight "good examples" and to promote the winners. According to this strategy, the winner, as a team member or individually, will obtain additional points to run in the contests for promotion and for wage increases by merit.

The Corporation strategy contemplates the periodic improvement of the system, incorporating, in a learning process, acquired experiences, as well as the success stories observed in other public and private, national and international organizations. It will

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[4] For the Corporation central units (secretariats, advisory units and departments) a specific evaluation and awards system was developed.

also stimulate partnership between research centers, and the cooperation among individuals and work teams.

3. Institutional Evaluation

The system comprises the following basic components: (i) accomplishment of institutional goals (efficacy); (ii) relative efficiency; (iii) quality auditing; (iv) socioeconomic impacts of technologies; and, (v) image assessment (Figure 1).

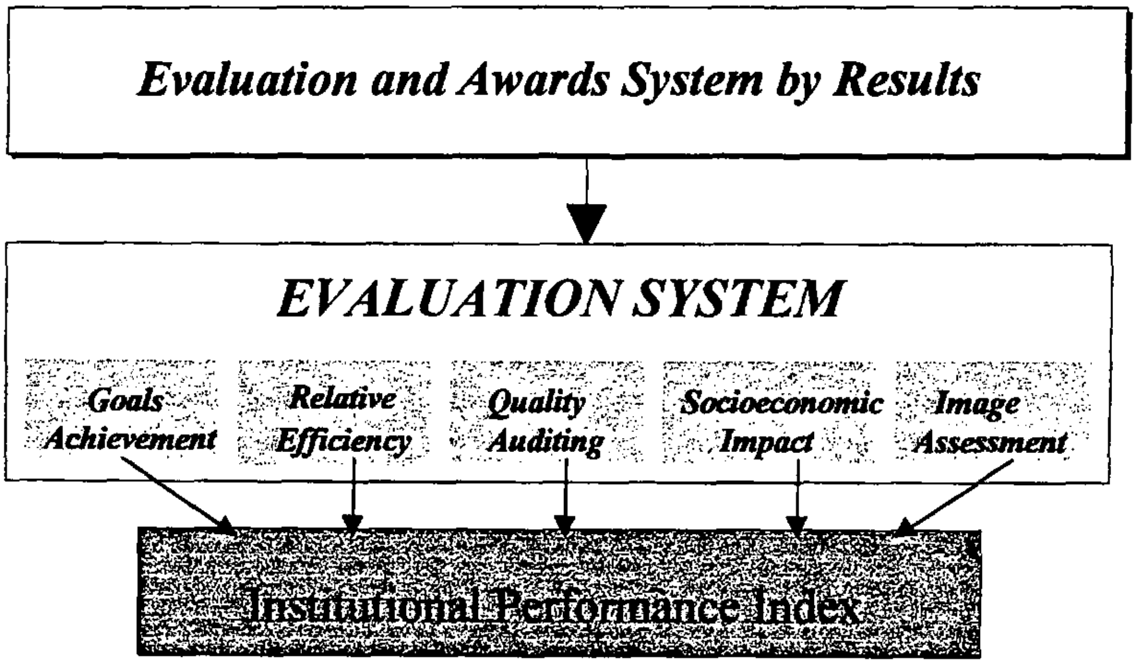

Figure 1 - Institutional Evaluation

The efficacy evaluation for the accomplishment of goals, and the relative efficiency constitute the basis of the evaluation system, and they will be performed on an annual basis. The others (quality, socioeconomic impact and image) are complementary, and their results should be progressively incorporated to the System. The weighted results of such evaluations will be used to construct the Institutional Performance Index (IDI) of each research unit.

3.1. Achievement of institutional goals (Efficacy)

a) Conceptualization

This component is based in the accomplishment of qualitative goals, defined as institutional commitments of the centers, presented in descriptive form, and of quantitative goals, relative to selected indicators. Such goals are previously negotiated between the centers and the top administration, for the period of a year.

Such goals are linked to management and research projects, set out by the Executive Board of Directors. ***Examples:*** completion of the **i th** research project, implementation of the Cost System, and reduction of **x%** of paid overtime. These goals are classified as **technical-programmatic, managerial and institutional or administrative or technical support.**

The quantitative goals are measured through a set of performance indicators. They are classified in **end goals (products) and intermediate goals (efforts).** ***Examples***: **End goals:** development of a plant variety (rice, maize, beans, etc.), development of a technology against pests and diseases in plants or livestock, development of one new software. **Intermediate goals** are: realization of five training courses, publication of four articles in a national journal, realization of two seminars, production of two technical videotapes, production of four technical bulletins, etc. These goals will be also used as output indicators in the evaluation of relative efficiency (item 3.2, below).

b) Measurement

The scale for the evaluation of centers, in terms of goal accomplishment, varies from: 0 (zero) = **planned goal not accomplished**, to 10 (ten) = **goal accomplished above target**, according to the intensity of accomplishment of each negotiated goal.

Mathematically, the efficacy index (IFA) of each center, in the accomplishment of goals, will be computed according to the following formula:

$$IFAu = \Sigma i \ ICMi \times Pi$$

where,

IFAu = Efficacy index of each unit (center) "u"
ICMi = Degree of accomplishment of each goal "i" (values from 0 to 10)
Pi = Relative weight of each goal "i"
ΣiPi = 1
i = goals from 1 to n

3.2. Relative efficiency

a) Conceptualization

The relative efficiency of each research center, will be the result of the quotient between a set of output indicators over their corresponding inputs.

The output indicators are selected as proxies to measure the annual production of the centers, in the context of the relative efficiency model. They are classified in four groups:

Publication of scientific articles in refereed journals and book chapters - measured by the following indicators: publication of articles in national and/or foreign refereed journals, publication of chapters in national and/or foreign books, and publications of summaries or articles in the proceedings of congresses.

Generation of technologies and knowledge - measured in terms of production of technical publications: technical newsletters, technical bulletins, technical communiqués, technical instructions / recommendations and periodicals (Document series of the Corporation).

Development of technologies, products and processes - quantification of the output of the centers, measured in terms of plant varieties / cultivars, livestock race, agricultural practice/process, agricultural input, agroindustrial process, scientific methodology, software, stirps, hybrids/clones, monitoring/zoning or mapping (soils, for example), methodological or technical / managerial norms developed by the Corporation.

Diffusion of technology and image - measures the efforts based on the following indicators: installation of field days, demonstration or observation units, organization of congresses and seminars, seminar presentations (conferences and talks), organization of training courses and seminars participation in expositions and fairs, concession of college level training programs to technicians and students, production of technical videotapes or folders, and publication of reports about ongoing research.

The input indicators represent the set of current and capital expenditures spent in the productive process of the research centers, in a given year. In the evaluation system the following inputs are considered:

Personnel - expenditures with salaries and social charges on labor costs, of each research center;

Other Expenditures - with running expenses, third party services, bus and air tickets, hotels, consulting services, etc., and,

Depreciation - value of the annual depreciation of the capital assets at the disposition of the center, with the exception of land.

b) Measurement

The annual performance evaluation of the research units, in terms of relative efficiency, will be performed in two stages. The first consists in the productivity computation. For each one of the output categories a partial production indicator is calculated, as a weighted average, using the output (of each center) of each category component, in relation to the Embrapa's average. Furthermore, each research unit has a coefficient of specialization attached to its productive process, that reflects its research objectives vis-à-vis the four partial output categories (publication of articles in refereed journals, generation of technologies and knowledge, development of technologies, products and processes, and diffusion of technologies and image.

The overall output of a research unit is the weighted average (coefficients of specialization as weights) of the partial production indicators. The value of the productivity is the quotient of the weighted average of relative output (production of the unit in relation to Embrapa's average) over the average input expenditures (expenses of the unit in relation to Embrapa's average) relative to year under evaluation.

The second stage measures the relative efficiency using a mathematical model. A linear programming model determines whether it is possible to a research unit to obtain the same output level, utilizing a smaller input quantity. The efficiency scale varies from **zero** to **one**, with the value of **one** being set to any efficient unit. An efficiency level of 30% means that there is a possibility of obtaining the same product with 70% less inputs. The same productivity indicators are utilized, but this time with different weightings for each unit, according to its corresponding mission and objectives.

The relative efficiency of each unit (IEFu), in terms of goal accomplishment, will be calculated according to the following formula:

$$\mathbf{IEFu} = \max_{\mathbf{w,v}} \frac{\mathbf{wYu}}{v1D1u + v2D2u + v3D3u}$$

subject to the linear constraints:

$$wYj <= v1D1j + v2Dj + v3D3j \qquad j = 1...37$$

$$v1D1u + v2D2u + v3D3u = 1$$

$$w,v => 0$$

where,

IEFu = Efficiency index of each **"u" th** research unit subject to evaluation:
Yu = Annual output indicator of unit "u", considering the four production categories (Y1 = technical scientific production, Y2 = generation of technologies and knowledge, Y3 = development of technologies, products and processes, Y4 = diffusion of technology and image) and the respective specialization coefficients of unit "u";
D1u= annual personnel expenditures of unit "u";
D2u= annual other current expenses of unit "u";
D3u= annual depreciation of capital assets of unit "u";
v = input shadow prices;
w = optimal product price;
j = Embrapa's unit (j=1...37).

3.3. Quality auditing

The quality auditing will evaluate the research units, from the quality point of view, defined in terms of the technical-scientific program and of the results generated. It will be carried out by a high level Technical Committee, with the participation of internal and external experts, in order to provide greater transparency and superiority to the process. Besides the qualitative information, it will generate an evaluation in a scale from **zero** (0) (lowest in the ranking) to **ten** 10 (top in the ranking).

3.4. Socio-economic impact evaluation

The socio-economic impact evaluation will measure the effects of the Embrapa's units research results on the agroindustrial complex, and on the consumer's welfare. For this purpose, the system establishes a data collection mechanism of the benefits generated by the Corporation to society. A specific methodology will define the products to be included, the rate of adoption, participation of other institutions, period of benefits and other relevant criteria. This evaluation will also generate an index that will vary from **zero** (no impact) to **ten** (exceedingly high impacts).

3.5. Image assessment

The evaluation of the institutional image consists in the vision that the main clients, users and partners have about Emprapa´s units. As the products and clients of each unit are not clearly identified yet, a complete survey of the more relevant products is being carried out, as well as the preparation of a list with the main clients. With a statistically significant sample, a field survey will cover information using a questionnaire, with questions about the image that the unit has with the society it serves. At the end of this process, an index will be obtained, that allows the comparison and classification of units, with regard to the degree of satisfaction of its clients. This evaluation will also product an index which will vary from **zero** (no impact) to **ten** (exceedingly high impact).

3.6. Institutional performance index

The partial evaluation indices are aggregated in a single weighted index, which will allow the classification of each unit in relation to the others. The Institutional Performance Index (IDI) represents the numeric result by unit, corresponding to the weighted average of the indices utilized in the several types of performance measurement stipulated by SAPRE (evaluation of the efficacy in the accomplishment of institutional goals, evaluation of the relative efficiency, quality auditing, evaluation of socio-economic impact and image assessment).

In the case of the thematic, products and ecoregional centers, the idea is that the relative weights to be utilized for the IDI composition are the following: a) Efficacy = 20%); b) Relative efficiency = 20%; c) Technical quality = 20%; d) Socio-economic impact = 20%, and, e) Image = 20%. These weights can be adjusted during the implementation process of the system.

The evaluation components of efficacy and relative efficiency will be calculated annually. The remaining evaluation types will be periodically assessed, every three to five years, according to a schedule yet to be defined. In the absence of any of the evaluation indices (technical quality, socio-economic impact or image), the weights will be proportionally redistributed to the remaining components so as to always add up to 100%.

In the case of the special services (SPI - Information Production Service, and SPSB - Basic Seeds Production Service) the weights of each one of the indices will correspond to: a) Efficacy = 25%); b) Technical quality = 25%; c) Socio-economic impact = 25%, and, d) Image = 25%.

Likewise the research centers, in the absence of any of the evaluation indices (technical quality, socio-economic impact or image), the weights will be proportionally redistributed to the remaining components so as to always add up to 100%.

From an operational point of view, every December of each year, the quantitative and qualitative goals will be negotiated between the Executive Board of Directors and the Head of each research unit, to be followed next year, taking into account the Units Master Plan, the demands of different society groups, and other directives of the Executive Board of Directors. In February each year, the Institutional Performance Index will be calculated for each unit, relative to the previous year, based on indicators of efficacy, relative efficiency, technical quality, socio-economic impacts and image, when applicable.

3.7. Preliminary results

With the results of the Evaluation and Awards system implementation in early 1996, it was already possible to identify substantial improvements in the results achieved during the year of 1996, when compared to the results attained by the same centers in the period 1992/95.

As an example, Figure 2 presents the evolution of scientific production of the Corporation for the period 1992/96. These data show, despite their preliminary stage, that an evaluation system, such as outlined here, tends to stimulate the research centers to increase their output.

In Table 1 the results of the Embrapa's output are presented for the period 1992-96, and the expected goals for the year 1997. The goals refer to the selected indicators for the four large groups (i) technical scientific production, (ii) generation of technologies and knowledge, (iii) development of technologies, products and processes, (iv) diffusion of technology and image.

For 1996, the expected and the realized goals were compared, in percentage terms. The resulting values, in many indicators, were above expectations. This fact can be explained by the efforts of some research units in order to surpass the targets initially set, or in a smaller amount, by the lack of experience in programming. This can

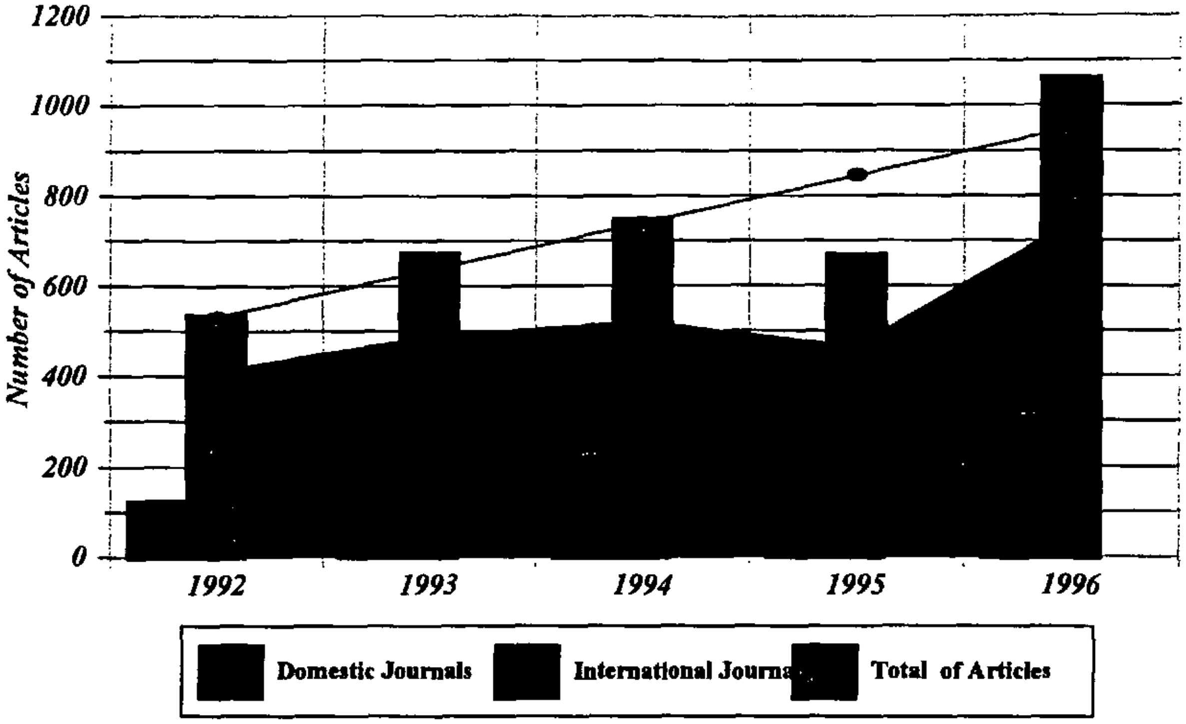

Figure 2 - Evolution of the Technical-Scientific Production of Embrapa. 1992/96.

be considered as normal. For the next few years, more consistent goal programming can be expected.

Still in a provisional fashion, Table 1 contains the output goals of Embrapa's units for the year 1997. In many of them, some growth is still observed, and in others, some small reductions. This is due to the new priorities set out, and to the reduction of the "slack capacity". Doubtless, the increases in output, as times goes by, will tend to smaller relative to the initial years. The desirable feature is that the Corporation's performance increases yearly, even if at smaller rates.

In the case of the development of technologies, products and processes, it should be borne in mind that they are about products generated by Embrapa's research centers, already duly tested at client and users level, in the form of prototypes, or through demonstration units, or are already patented, or in commercialization stages.

4. Institutional awards

4.1. Model Conceptualization

The awards by results is made of: a) financial resources of the Awards by Results Fund - **FPR** to be distributed among research units, with the aim of awarding an additional remuneration for the teams and employees; b) prizes for outstanding performance, in the form of non monetary advantages and benefits to be awarded to research units, and, c) advantages in the allocation and availability of funding by center (Figure 3).

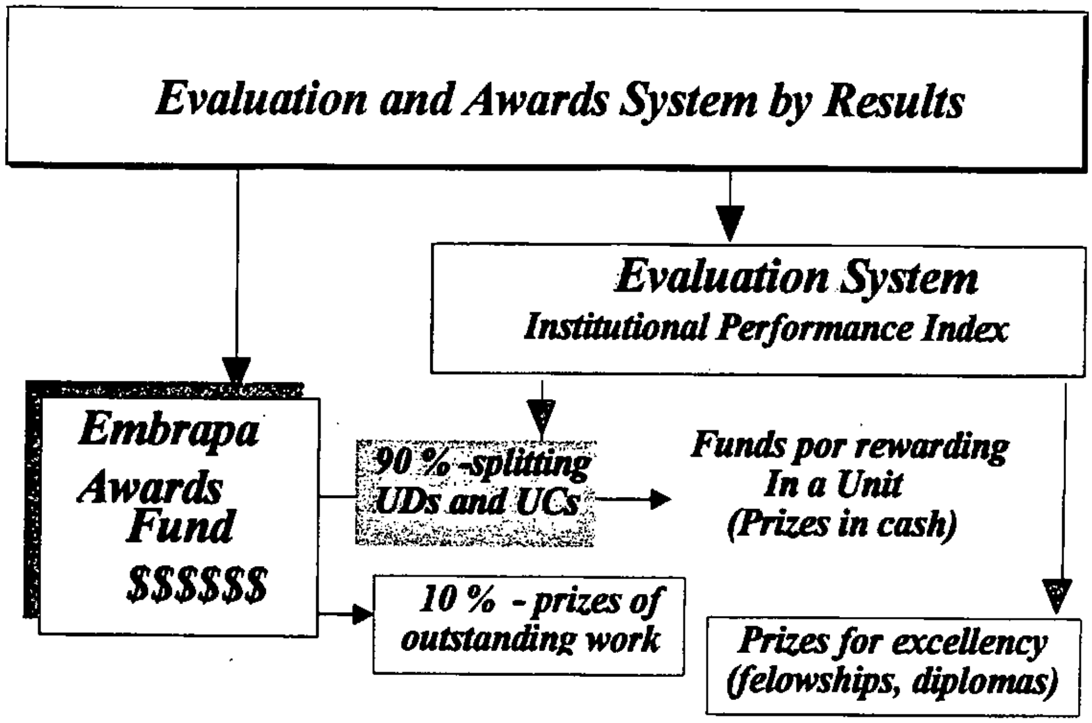

Figure3 - Institutional Awards

FPR represents the annual amount of financial resources allocated to employees by Embrapa, for the bonuses by results payments. The FPR funds will be shared among all units of the Corporation, including those located in the headquarters, proportionally to the IDI of each of them, and to the relative share of wages in relation to the Corporation as a whole.

FPR will be constructed by: a) 1.5% (one point five percent) of the Corporation payroll; and, b) funds originated from non-government revenues and / or from reduction of Corporation costs. Besides the financial resources for the bonuses payments to the employees, the units with higher IDI will be eligible to other benefits, such as:

- higher priority and extra funds for operating and investment expenditures;
- awarding of a merit certificate for **Center for Excellency** (one per year);
- establishment of a differentiated percentage for merit promotions;
- budget increases for undergraduate and graduate fellowships;
- priority in the allocation and availability of budget funds.

Table 1 - Performance indicators and output goals of Embrapa: 1992/97

Performance indicators	Accomplished goals				1996 goals			Proposed goals
	1992	1993	1994	1995	Planned (a)	Done (b)	Plan/done (%)	1997 (*)
1. Technical-scientific production								
Articles in domestic journals	412	487	520	464	1158	777	67,10	1203
Articles in foreign journals	126	187	231	208	310	313	100,97	316
Chapters in domestic books	42	81	204	149	233	236	101,29	364
Chapters in foreign books	28	21	39	37	57	57	100,00	43
Congress proceedings summaries	1102	1326	1629	1470	1571	2091	133,10	1430
Papers in congresses proceedings	297	292	359	506	497	751	151,11	405
2. Production of Technical Publications								
Technical circular	68	48	60	69	177	81	45,76	189
Research bulletin	70	43	61	47	212	82	38,68	207
Technical communiqué	110	80	80	64	313	154	49,20	305
Document series	143	98	168	126	264	287	108,71	299
Recommendations/technical newsletters	54	136	110	169	705	408	57,87	436
3. Technology diffusion and Image								
Field days	397	358	405	384	559	612	109,48	612
Org. congresses and seminars	601	569	615	466	326	274	84,05	387
Seminar presentations	1544	1890	2434	2609	2667	4353	163,22	3137
Part. Expositions and fairs	211	206	264	324	266	325	122,18	270
Courses offered	293	332	380	399	624	843	135,10	504
Trainees	1698	1178	1174	1389	1384	1921	138,80	1452
Advisory in fellowships	665	617	510	646	758	923	121,77	824
Folders Printed	88	123	139	210	308	236	76,62	216
Videotape production	104	109	153	121	263	145	55,13	155
Ongoing research	129	47	52	66	363	153	42,15	385
Demonstration units	741	634	1186	1968	1647	1658	100,67	1393
Observation units	217	274	472	953	748	1927	257,62	1170
4. Development of technologies, products and processes								
Variety/Cult./Hybrids/Clones	26	46	25	69	98	73	74,49	94
Races/types	0	0	0	1	3	3	100,00	1
Practice/Agricultural process	41	83	16	62	191	209	109,42	249
Agricultural inputs	2	12	0	23	36	31	86,11	25
Agroindustrial processes	5	12	2	16	30	20	66,67	34
Scientific methodology	42	50	43	87	299	260	86,96	210
Machinery/equipment	3	5	5	8	32	34	106,25	23
Software	10	14	15	28	70	94	134,29	60
Stirp/species	9	6	6	6	60	42	70,00	34
Monitor./Zoning/Mappings	11	9	13	34	206	274	133,01	200

(*) Initial goals negotiated by the heads of research centers with the Board of Executive Directors
Source: Avila (1997).

4.2. Operational aspects

As pointed out earlier, awarding process is based on quantitative and qualitative goals that are negotiated between the Executive Board of Directors and the Head of each research unit. These goals are valid for a period of a year (January to December), with prizes being awarded in April of the following year, as part of the Embrapa anniversary celebrations.

FPR funds will be distributed in two parts: a) 90% to directly reward the units, in proportion to their respective performance indices (IDI) and to the corresponding payroll share, and b) 10% to reward employees with outstanding performance at national level, to be awarded by the Executive Board of Directors (FPRE).

The funds to reward the units (FPRU) will be split among the central units (FPRUc) e decentralized ones (FPRUd), proportionally to the basic salaries of the two types of units.

The distribution of funds among each decentralized unit (FPRUd) will be performed according to the following formula:

$$\mathbf{FPRUdu} = \mathbf{FPRUd} \times \frac{\mathbf{IDIu\ (FSu)}}{\mathbf{\Sigma\ jIDIj\ (FSj)}}$$

where,

FPRUd = Total Award Fund value allocated to decentralized unit "u";
IDIu = Performance index of each unit "u";
FSu = Payroll amount of unit "u";
FS = Embrapa's payroll amount;
Σj IDIj (FSj) = Sum of the IDI of each unit, multiplied by its respective payroll amount (FS);
u = decentralized unit subject of the evaluation;
j = 1 ... 37 units.

5. Teams and employees evaluation.

5.1. The model

The evaluation of teams and employees, comprises two stages: a) in the unit itself; and, b) national outstanding performance.

In each unit, the employees will be evaluated in terms of the accomplishment of individual targets, based in the Accomplished Results Index (IRA), relative to the corresponding evaluation periods. Such an index is computed by the Planning System, Monitoring and Results of Individual Performance Evaluation (SAAD-RH), already implemented by the Corporation.

Still at the unit level, the technical scientific teamwork, and their members will be evaluated, as they exceed in the performance of research and development subprojects. The main evaluation indicators are related to: (i) creativity in R&D; ii) technical quality of the R & D projects/subprojects; (iii) fund raising, and iv) fulfillment of special Corporation assignments (Figure 4).

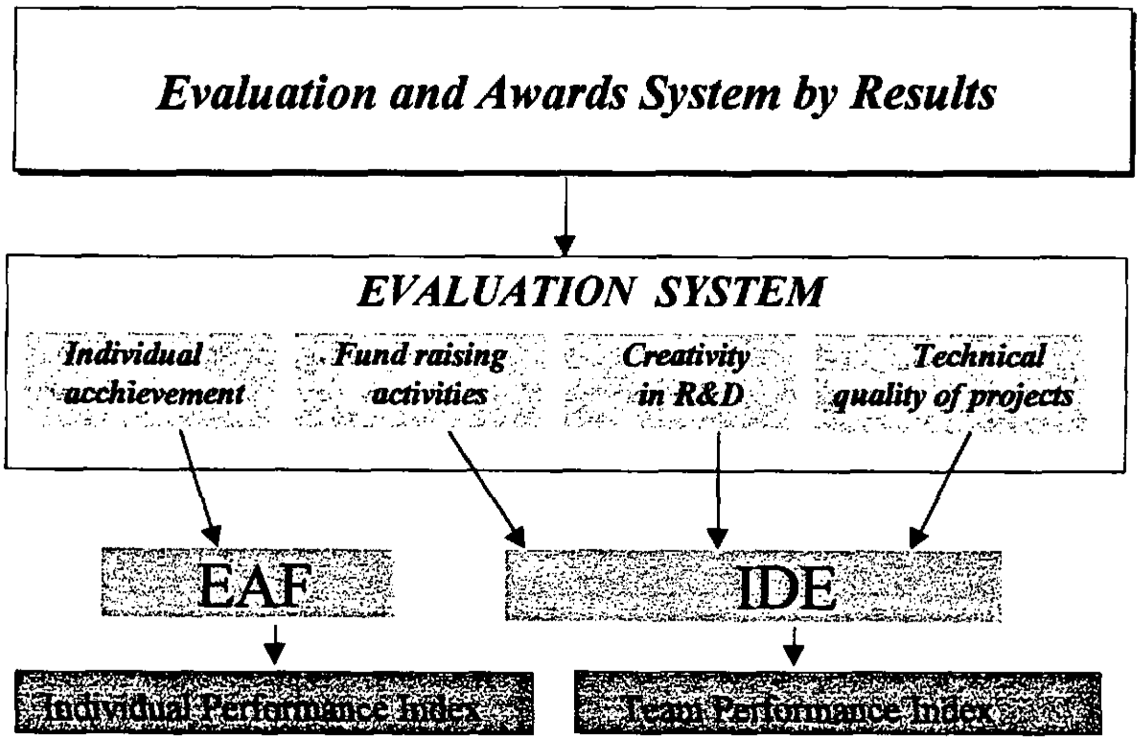

Figure 4 - Team and Individual Evaluation

The team evaluation, focused in R & D creativity, consists in the analyses of merit of the research subprojects proposals, in terms of new ideas, new methodologies, their relevance, their capacity to face challenging problems, real or potential, of the Brazilian agribusiness. Tentatively, some proposal evaluation indicators are presented in Table 2:

The team evaluation, by the participation in fund raising activities, will be made according to the contribution of employees in the non governmental budget funds that are effectively raised, aiming at the financing of research and development projects, or through the raising of revenues from technology sales (royalties), products (patents, authorship rights, research subproducts, among others), and services (consultancies, franchising, etc.)

The production projects and the sales of research subproducts will only be eligible when the balance between the cash receipts are greater than the present value of the costs incurred for the generation of that revenue, including labor costs, and capital depreciation, if positive.

Table 2 - Analyses Criteria for Innovative R&D Proposals.

Analyses criteria	**Weights**
a) originality in the methodological approach adopted in the project;	35%
b) originality and/or potential of the central idea of the project, and,	45%
c) relevance of the projects central idea, from the social, economic and environmental point of view.	20%

The team evaluations, in terms of technical quality of R&D proposals, will be based on their merit analyses. In Table 3 the following criteria are suggested: problem definition, methodology and proposed action strategy. Expected results are also considered.

Table 3 - Evaluation Criteria for Technical Quality of R & D Proposals

Analyses criteria	**Weights**
a) problem definition;	30%
b) proposed methodology;	25%
b) proposed action strategy, and,	20%
c) expected results.	25%

Another evaluation criteria refer to the accomplishment of special assignments, to be set out by the Corporation Board of Executive Directors, in order to stimulate the teams in the attainment of such directives. The evaluation will be base in the importance of the participation of them in the fulfillment of such special assignments.

Finally, the teams and the decentralized units' employees, who are engaged in R&D projects and in other relevant activities, they can submit them to the national contest. Five best project / activities will be selected with regard to: (i) creativity in R&D; ii) technical quality of the R & D projects; (iii) fund raising; and, (v) fulfillment of the special assignments. It is up to the project leader to establish the participation of the team members (Figure 4).

5.2. Operational aspects

Two indices will be generated from the evaluation process of teams and employees. With regard to the **accomplishment of individual targets**, it is based on the Index of Accomplished Results (IRA), relative to the evaluation periods corresponding to each employee of the unit. IRA is obtained from the SAAD system, mentioned earlier.

With the objective to stimulate **teamwork**, for the group of researchers and their assistants, it will be evaluated inside each unit, as a function of creativity, technical quality, fund raising, and the fulfillment of the Corporation special assignments. Each subproject will receive a special scoring. In the case of creativity and technical quality, fund raising subproject/action, and fulfillment of special assignments, they will receive a score for each one of the four indicators, when applicable. The weighted sum of the four indices will result in the IDE of the subproject, according to the formula:

$$\mathbf{IDL = (0{,}33 \times ICR) + (0{,}33 \times ICC) + (0{,}3 \times IQT)}$$

where,

IDL = Performance index of each subproject in terms of unit's performance;
ICR = Fund raising index;
ICC = Creativity index;
IQT = Technical quality index.

At the discretion of the research units, other evaluation indicators can be added. In this case, the weights inside each group will be redefined, so as to keep the balance among them, and to add up to one.

In order to identify the team work contribution for the conception and execution of subprojects/actions of the unit of the national projects, a Corporation will utilize the existing committees, such as the Internal Technical Committee - CTI of each

UD, and the Technical Program Commission (CTP) and the work groups. The evaluation scale will vary between **0** (zero contribution) to **10** (maximum contribution).

6. Employee awards in the form of bonuses by results

6.1. Model conception

The employee awards process will consist in bonuses in cash to employees that: a) according to the minimum IRA, will have contributed to the accomplishment of goals (efficacy); b) are acclaimed nationally, in team work, as top innovators in project conception, in the formulation of projects of renowned technical quality, in fund raising and in the accomplishment of the Corporation special assignments; and c) to outperform in the unit, in the fulfillment of the same indicators above (letter b) in relation do research subprojects or management actions and other indicators defined by the unit itself. (Figure5)

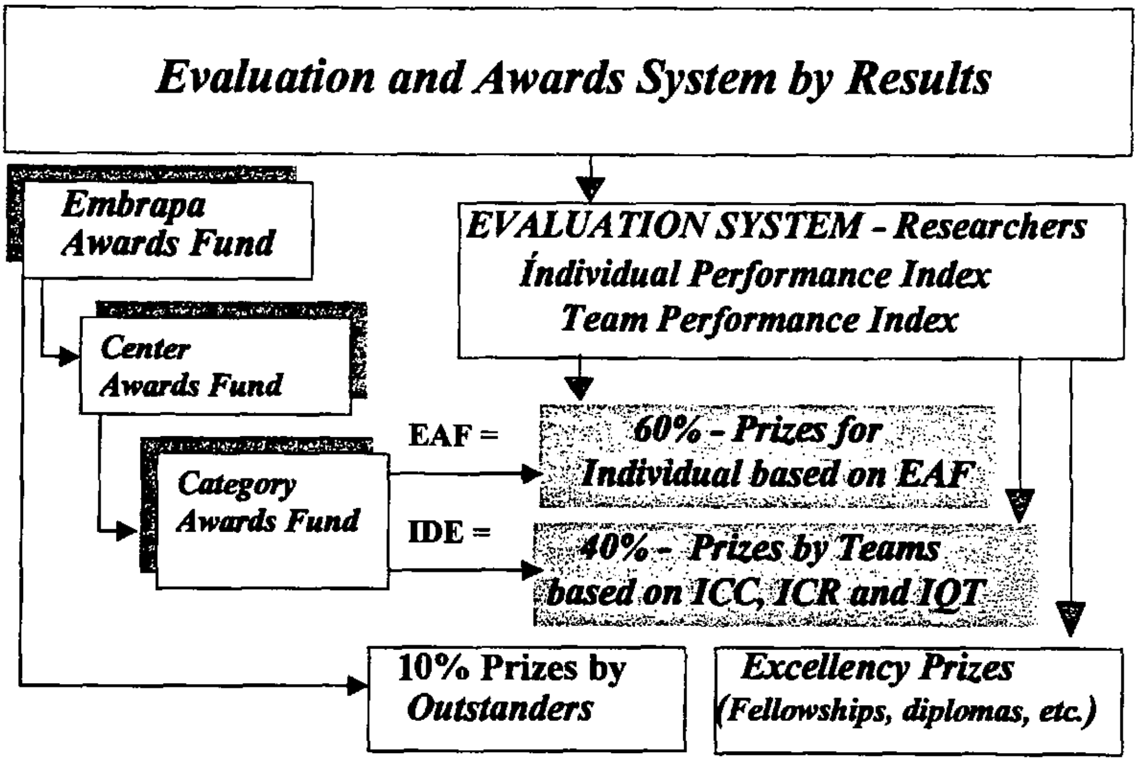

Figure 5 – Team and Individual Awards

The budget of the Awards by Results Fund (FPRUd) of each unit "u", for bonuses payment to employees, will be divided into two parts a) funds for the rewards to the technical scientific group; and, b) funds for the rewards to the research support group. This division will be proportional to the payroll of the two respective groups.

The distribution of the funds among the technical scientific groups will obey the following criteria: a) 60% of the budget to be split among all employees which contributed to the attainment of goals (proportionally to IRA of SAAD-RH); and, b) 40% of the funds to be split among the members of the team work which better performed in the subprojects / management actions, by creativity, technical quality,

fund raising, and attainment of special assignments. For the research support group, the criterion of goal accomplishment will take the value of 100%.

6.2. Operational aspects

The awards periodicity will be annual, and the prizes will be awarded during April the following year. The Bonuses by Results total cannot exceed the amount equivalent to 25% (twenty five percent) of the employee base salary, subject to the FPR budget ceiling.

The calculation of Bonuses by Results for the goals accomplishment (efficacy) will be based on the IRA of each individual (IRA minimum=1), multiplied by the base salary of the employee, in relation to the unit's total payroll.

The formula for these calculations is:

$$BRE1i = \text{"a"} \times FPRUu \times \frac{IRAi\,(SALi)}{\Sigma j\, IRAj\,(SALj)}$$

for one IRA => 1

where,

BRE1i =	Value of bonuses by results corresponding to IRA
FPRUu =	Bonuses Awards by Results Fund of Unit "u"
IRAi =	Individual performance in goal accomplishment of employee "i"
SALi =	Base salary of employee "i"

ΣjIRAj (SALj) = Sum of IRAs of all unit's employees, multiplied by the base salary, plus traditional (unconditional) annual bonuses, plus salary addition for academic tiles.

"a" = parameter taking the value of 0.6 for the technical scientific group, and of 1,0 for the research support.

The part of funds of FPRUd that are assigned for the awards of teams, will be split among the awarded subprojects, with differentiated shares according to the positioning of each of them in the four quartiles. The subprojects classified inside the top quartile (0.75 to 1.0) will be multiplied by the weight 2.0, while those located between the first and the third quartiles, will be multiplied by 1,25. The teams below the first quartile will not be rewarded. Once the funds FPRUd are distributed among the subprojects in each unit, it is up to their leader to define the participation to each team member. In mathematical terms, the budget share allocated to a team will be:

$$RECy = \text{“b”} \times FPRUdu \times \frac{IDLpy}{\Sigma yIDLpy}$$

where,

RECy = Budget share allocated to team y
“b” = Parameter set equal to 0.4 for the technical scientific group
IDLpy= IDL weighted by the quartiles of team y
ΣjIDLpj = Weighted IDL sum of all teams of a unit.

The IDL of each team will be weighted according to its relative position in the quartiles, under the following formula:

$$IDLpy = (IDly) \times (py)$$

where,
IDLpy = weighted IDL by quartiles by team y;
p = quartile weight
y = team

Each employee of the technical scientific group will receive a value corresponding to the percentage participation of the teams of each subproject or management action. The Bonuses by Results of each researcher corresponding to its individual participation in the team IDL, will be the sum of the values of each team participation, calculated according to the following formula:

$$BRE2i = \Sigma yEMPiy$$

where,

BRE2i = Bonuses value to be paid to employee i, as function of his participation in each team y;
ΣyEMPiy = Sum of financial values corresponding to the participation of employee i in y teams.
y = work teams from 1 to n.

In a given year, the total value of Bonuses by Results of each employee is limited to the amount of 25% (twenty five percent) of the employee base salary, plus the first quartile will not be rewarded. Once the funds FPRUd are distributed among the subprojects in each unit, it is up to their leader to define the participation to each team member. In mathematical terms, the budget share allocated to a team will be:

$$RECy = \text{“b”} \times FPRUdu \times \frac{IDLpy}{\Sigma yIDLpy}$$

where,

RECy = Budget share allocated to team y
“b” = Parameter set equal to 0.4 for the technical scientific group
IDLpy= IDL weighted by the quartiles of team y
ΣjIDLpj = Weighted IDL sum of all teams of a unit.

The IDL of each team will be weighted according to its relative position in the quartiles, under the following formula:

IDLpy = (IDly)x (py)

where,
IDLpy = weighted IDL by quartiles by team y;
p = quartile weight
y = team

Each employee of the technical scientific group will receive a value corresponding to the percentage participation of the teams of each subproject or management action. The Bonuses by Results of each researcher corresponding to its individual participation in the team IDL, will be the sum of the values of each team participation, calculated according to the following formula:

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BRE2i = Bonuses value to be paid to employee i, as function of his participation in each team y;
ΣyEMPiy = Sum of financial values corresponding to the participation of employee i in y teams.
y = work teams from 1 to n.

In a given year, the total value of Bonuses by Results of each employee is limited to the amount of 25% (twenty five percent) of the employee base salary, plus traditional (unconditional) annual bonuses, plus salary addition for academic tiles, subject to the FPR budget ceiling.

The units that do no implement the team evaluation system with regard to creativity, technical quality, fund raising and attainment of special assignments, will not have the right to utilize such funds for the awards of its employees. Their funds will be frozen by the Corporation Executive Board of Directors.

6.3. National contest participants

Finally, the awards for the national contest winner (FPRE) will be awarded to employees who have their projects been selected as the top national five for each of its components: (i) creativity; (ii) technical quality; (iii) fund raising; e, (iv) attainment of special assignments.

The awards funds, at national level, will be distributed among the winning projects, and from them, among the participating employees. The limit for each employee will be of up to one base salary for each prizes, subject to the general condition that the total sum of prizes received by one employee does not exceed 25% of his annual base salary.

7. Recognition by excellency

Recognition by excellency is the way that Embrapa acknowledges the relevancy of the contribution made by employees to technical scientific and management work processes made available to the Corporation.

The analysis of the awards by excellency proposals, will be based in the following criteria of innovations and or improvements introduced in a work process or activity, and in relevant contribution to the solutions of problems of the Brazilian agribusiness complex:

- conception and execution of creative R&D projects or of management innovation;
- improvement of technical quality of projects, technologies, products or services;
- highly positive influence of technology generation, knowledge, products, methodologies, processes and services in Embrapa's business;
- quality improvement to meet internal or external customers needs;
- significant contribution in fund raising for the research unit;
- improvement in the process of the unit management, with respect to waste reduction, improvement in the time spent in the execution of work processes or activities, without loss of quality in results, repercussion in the contribution in other work processes or activities.

The excellency prizes to be awarded by the Corporation to its employees, are the following:

- nomination for the Frederico Menezes Veiga prize;
- medal award and recognition diploma for excellency for one employee of the technical scientific group, and one employee of the research support group, per unit, per year;
- technical memory documentation for up to ten professionals who have significantly contributed for the agricultural research development, per year;
- scoring for promotion and salary progression by merit, for those employees who have obtained excellency recognition; and,
- nomination for prizes awarded by other organizations.

A **technical memory** consists in written, verbal and visual records, about personal information and R&D results, which have contributed in a significant way for the development of agricultural research, to be kept in the Corporation library.

The awarding of excellency prizes will be performed in a formal event scheduled by the Corporation, during the celebration of its anniversary. The Corporation will promote, internal and externally, the relevant contributions that originated awards to the work teams and employees.

8. - Final remarks

According to an old saying, a great walk starts with the first step. The recent measures taken by Embrapa, and the proposals in this document, are part of a management agenda, aiming at its modernization, to become it effective by the attainment of its goals, and highly efficient at the same, from the point of view of output/cost relation. To produce more output with less inputs, is a goal in perfect harmony with the objectives do the State reform proposed by the Federal Government. This feature is also an aspiration of the Brazilian society as a whole.

The managerial improvement will create conditions for Embrapa to meet the demands of clients and of society as a whole. These measures are instruments to increase the institutional commitment of units, work teams and employees, with regard to the attainment of bigger and better results.

Given the current advances, the new experiences successfully tested in leading private corporations impose new challenges that will allow even better improvements of the institutional performance. The Corporation follows closely the advances of management science, and evaluates its benefits and possible problems in their implementation. With firmness, deep studies, and perseverance, it is hoped that soon other ideas will be implemented in order to ensure the continuation of the improvement process.

Among the recent ongoing changes in leading private corporations, the following deserve attention: a) the implementation of organic structures, aligned with the product to be generated, with the results and the value added; b) change in the focus from the organizational post to knowledge and skills that the specialized professional can handle, with the labor division in self-managed times and professional development as the critical factor; c) remuneration by results, based on targets and comprehensive performance indicators for the business (profitability, productivity, quality, consumer satisfaction), and d) strategic remuneration for people who deserve special treatment, by their importance to the corporation, in terms of advanced knowledge, with the resulting difficulties in replacement and transferability in the labor market. Thus their remuneration is the result of the effective application of knowledge as function of personal traits.

Summing up, the new management conception reinforces the principle that the end activities are the reasons for the existence of the organization. The creativity and innovation replace the control and the conformity. In and open fashion, the management focuses on the motivation of the collaborators for the attainment of bigger and better results.

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Embrapa

Brazilian Corporation for Agricultural Research

Technical Efficiency of Production in Agricultiural Research: A Case Study

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Brasília, May 1998

Technical Efficiency of Production in Agricultural Research: A Case Study

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SUMMARY

We define and model research production at Embrapa, the major Brazilian institution responsible for applied agricultural research in the country. The main theoretical framework we use is data envelopment analysis. We explore the economic interpretation of these models to assess cost and technical efficiencies for the production of agricultural research in Brazil. Efficiency results are then compared with alternative measures defined via a stochastic frontier.

1. INTRODUCTION

It is of importance to the administrators of research institutions to have at their disposal measures and procedures that make feasible an evaluation of the quantum of productivity as well as the technical efficiency of the production process of their institutions. In times of competition and budget constraints a research institution needs to know how much it may increase its production with quality without absorbing additional resources. The quantitative monitoring of the production process allows for an effective administration of the resources available and the observation of predefined research patterns and goals. In this context we developed for Embrapa a production model based on the input-output data of its research units. The model serves the purpose of quantitative productivity evaluations at relative and absolute levels. The theoretical framework of this model is the analysis of production frontiers. We make intensive use of the DEA (Data Envelopment Analysis) models described in Seiford and Thrall (1990), Färe, Grosskpof and Lovell (1994), Charnes, Lewin and Seiford (1995), Sengupta (1995), and Färe and Grosskopf (1996). The DEA models are linear programming models that essentially generalize the notion of productivity. The dual problems of these models provide a rich economic framework relative to which it is possible to assess scale of production and input congestion. Our discussion of the subject is as follows. In Section 2 we detail the data envelopment models exploring the approach of Färe, Grosskpof and Lovell (1994). We use the notion of radial measure of technical efficiency to define production frontier and the concept of dominance to define efficient production frontier for a set of decision making units. The complementary slackness theorem has a crucial role in the discussion of these two concepts. In Section 3 we introduce the input and output measures of Embrapa's production process . In Section 4 we present our empirical findings.

The period covered in the analysis is 1996. The analysis is carried out for cost and quantity data. In Section 5 we compare our results with the econometric fit of stochastic frontiers. Finally in Section 6 we conclude our discussion and indicate directions for further studies.

2. DATA ENVELOPMENT PRODUCTION MODELS

Consider a production process composed of n decision making units (DMUs). Each DMU uses varying quantities of m different inputs to produce varying quantities of s different outputs. Denote by

$$Y = (y_1, y_2, \ldots, y_n)$$

the sxn production matrix of the n DMUs. The rth column of Y is the output vector of DMU r. Denote by

$$X = (x_1, x_2, \ldots, x_n)$$

the mxn input matrix. The rth column of X is the input vector of DMU r. The matrices $Y=(y_{ij})$ and $X=(x_{ij})$ must satisfy: $p_{ij} \geq 0$, $\sum_i p_{ij} > 0$ and $\sum_j p_{ij} > 0$ where p is x or y.

Definition 2.1 *The measure of technical efficiency of production (under constant returns to scale) for DMU* $o \in \{1, 2, \ldots, n\}$, *denoted* $\mathrm{E}^{\mathrm{CR}}(o)$, *is the solution of the linear programming problem*

$$\mathrm{E}^{\mathbf{CR}}(o) = \max_{u,v} \frac{y_o' u}{x_o' v}$$

subject to i) $x_o' v = 1$, *ii)* $y_j' u - x_j' v \leq 0,\ j = 1, 2, \ldots, n$ *e iii)* $u \geq 0,\ v \geq 0$.

If we look at the coefficients u and v as input and output prices, we see that the measure of technical efficiency of production is very close to the notion of productivity (output income /input expenditure). Technical efficiency, in this context, basically, is looking for the price system (u,v) for which DMU o achieves the best relative productivity ratio.

An interesting motivation for the concept of technical efficiency obtains from the case s=m=1. In this instance condition (ii) implies that

$$v = \frac{1}{x_o}$$

Let

$$R = \max_{j=1,\dots,n} \frac{y_j}{x_j}$$

be the largest output to input ratio (largest productivity) in the set of the n DMUs. Constraints (ii) e (iii) imply that

$$0 \leq u \leq \frac{1}{x_o R}$$

Hence,

$$E^{CR}(o) = \frac{y_o}{x_o R}$$

and the maximum is achieved when

$$u = \frac{1}{x_o R}$$

Thus we see that in the simple case of one input and one output the measure of technical efficiency is simply a normalization procedure. In other words, the DMU with best productivity ratio has unit technical efficiency. Any other DMU has its efficiency evaluated dividing its productivity ratio by the best productivity ratio. It is interesting to observe that the quantity $E^{CR}(o)$, in this simple context, represents the proportional reduction one should apply to input quantity x_o in order to induce o to achieve the best productivity ratio R. Equivalently the reciprocal of technical efficiency define the proportional increase in output production necessary to obtain R. This is the essence of DEA models.

The dual problem of the linear programming problem of Definition 2.1 has an important economic interpretation which we will explore. The features of the case s=m=1 will be more evident in the context of the dual problem. Before introducing this interpretation we find convenient to present some theoretical aspects of linear programming problems.

Table 1 shows the non symmetric formulations of the primal and dual problems which will be of concern in our subsequent discussions. The following theorem establishes the relationship existing between the solutions of the two problems. See Mas-Collel, Whinston and Green (1995) and Gass (1969) for more details.

Theorem 2.1 *(Dual Theorem) There is an optimum solution for the primal if and only if there is an optimum solution for the dual problem. The optimum values of both problems when they exist coincide.*

An equivalent formulation of the dual problem of importance for DEA models is Theorem 2.2.

Theorem 2.2 *(Complementary Slackness Theorem) In regard to the optimum solutions of the pair primal-dual we may say the following. If strict inequality occurs in the jth constraint of one of the dual problems the value of the jth variable in the optimum solution of the corresponding primal problem will be zero. If the value of the jth variable in the optimum solution of one of the primal problems is positive then the jth restriction of the corresponding dual problem will be an equality.*

Proof Consider the first pair of problems in Table 1. The result is analogous for the second pair. Let A=(a_{ij}) be mxn, c nx1, x nx1, b mx1 and w is mx1. Denote by f(x) and g(w) the objective functions of the primal and dual respectively. Let w_{m+j} be nonnegative slack variables such that

$$a_{1j}w_1 + a_{2j}w_2 + \ldots + a_{mj}w_m - w_{m+j} = c_j \quad j = 1, \ldots, n.$$

Multiply this equation by x_j, sum in j, and subtract g(w) from the result to obtain

$$\begin{aligned} f(x) - g(w) &= (b_1 - \sum_{j=1}^{n} a_{1j}x_j)w_1 + \ldots + (b_m - \sum_{j=1}^{n} a_{1j}x_j)w_m + \sum_{j=1}^{n} x_j w_{m+j} \\ &= \sum_{j=1}^{n} x_j w_{m+j} \end{aligned}$$

Then if $\hat{x}$ and $\hat{w}$ are the optimal solutions of the primal and dual, respectively, we have $\sum_{j=1}^{n} \hat{x}_j \hat{w}_{m+j} = 0$. Since variables x_j e w_{m+j} are restricted to be nonnegative, $\hat{x}_j \hat{w}_{m+j} = 0$ for every j. Result then follows.

□

In matrix terms we may write the linear programming problem of Definition 2.1 as

$$\max_{u,v,\delta}(y_o', 0, 0) \begin{pmatrix} u \\ v \\ \delta \end{pmatrix}$$

subject to the constraints

$$\begin{pmatrix} 0 & x_o' & 0 \\ Y' & -X' & I \end{pmatrix} \begin{pmatrix} u \\ v \\ \delta \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

where δ is a vector of slack variables and I is the identity of order n.

The corresponding dual problem is $\min_{\theta,\lambda} \theta$ subject to

$$\begin{pmatrix} 0 & Y \\ x_o & -X \\ 0 & I \end{pmatrix} \begin{pmatrix} \theta \\ \lambda \end{pmatrix} \geq \begin{pmatrix} y_o \\ 0 \\ 0 \end{pmatrix}$$

or, equivalently, $\min_{\theta,\lambda} \theta$ subject to i) $Y\lambda \geq y_o$, ii) $X\lambda \leq \theta x_o$ and iii)$\lambda \geq 0$; θ free.

The matrix products Yλ and Xλ with $\lambda \geq 0$ represent linear combinations of the columns of Y and X respectively. A sort of weighted averages of output and input vectors. In this way, for each λ, we can generate a new production relation (a new pseudo producer). Trivially the set of DMUs $1, 2, \ldots, n$ are included among those new producers. Making allowance for these newly defined production relationships the question that the dual intends to answer is: What proportional reduction of inputs θx_o it is possible to achieve for DMU o and still produce at least output vector y_o? The solution $\theta^*(x_o, y_o)$ is the smallest θ with this property. In this context the quantity $\theta^*(x_o, y_o)$ is known as a radial measure of technical efficiency. It is radial in the sense that the proportional reduction is applied uniformly to the entire input vector. The analogy with the case s=m=1 is perfect.

The two relevant notions in the study of the nonparametric measure of technical efficiency are the concepts of envelope and dominance within the envelope. The idea of envelope is inherited from the constraints of the dual problem. Formally the envelope is the set

$$\mathrm{E} = \{(x, y); \exists \lambda \geq 0, X\lambda \leq x, Y\lambda \geq y\}$$

It is clear that the envelope defines the kind of producers we allow to participate in the optimization process. We notice that the component x of a point (x,y) of E represents an input vector and the component y represents an output vector.

If (z,w) e (x,y) are distinct points of E we say that (z,w) dominates (x,y) when and only when z≤x and w≥y. In other words, when the producer (z,w) is able to produce more than (x,y) spending less.

The frontier (isoquant) for the input (reduction) oriented linear programming problem of Definition 2.1 is defined by the set

$$F = \{(x_o, y_o); \theta^*(x_o, y_o) = 1\}$$

The efficient frontier is [1]

$$EF = \{(x_o, y_o); (x_o, y_o) \text{ can not be dominated in E}\}$$

Proposition 2.1 *The efficient frontier EF is a subset of F.*

Proof Suppose EF not empty and let (x_o, y_o) be a point in EF. Consider the dual problem of Definition 2.1. The optimum $\theta^* = \theta^*(x_o, y_o)$ occurs when $\lambda = \lambda^*$. Suppose $0 < \theta^* < 1$ and let z=Xλ^* and w=Yλ^*. Clearly (z,w) ∈ E and (z,w) is distinct from (x_o, y_o). Thus (z,w) dominates (x_o, y_o). Hence (x_o, y_o) cannot be a point in EF, a contradiction.

□

Proposition 2.2 *Let the DMU o be such that $E^{CR}(o) = 1$. The necessary and sufficient condition for o to be a point in EF is that the optimum multipliers (shadow prices) u^* and v^* are strictly positive.*

Proof The condition is sufficient. Indeed, suppose the condition satisfied and that (x_o, y_o) does not belong to EF. There exists (z,w) in E dominating (x_o, y_o). Thus there exists $\bar{\lambda} \geq 0$ such that $X\bar{\lambda} \leq x_o$ and $Y\bar{\lambda} \geq y_o$. Thus $(1, \bar{\lambda})$ is feasible and therefore optimal for the dual problem. Since $X\bar{\lambda} \neq x_o$ or $Y\bar{\lambda} \neq y_o$ we have a contradiction by the complementary slackness theorem. Thus $(x_o, y_o) \in$ EF. The condition is also necessary. Indeed, suppose that (x_o, y_o) is a point in EF and that some component of the optimum price system (u^* , v^* is zero. Then there exists a pair $(\bar{x}, \bar{y})$ distinct of (x_o, y_o) such that $\bar{x} \leq x_o$, $\bar{x}'v^* = 1$, $\bar{y} \geq y_o$ and

[1] Notice that (0,0) is a point in E that cannot be dominated. Our definition of EF however does not include the zero vector. The definitions of F and EF in the present context are restricted to the DMUs being evaluated.

$\bar{y}'u^* = 1$. Consider the linear programming problem $\max_{u,v} \bar{y}'u$ subject to the constraints i) $\bar{x}'v = 1$ e ii) $y_j'u - x_j'v \leq 0$ $j = 1, \ldots, n$. This problem reaches its optimum solution in $u = u^*$ and $v = v^*$. By Theorem 2.1 its dual problem has an optimum solution. Thus we may find $\lambda^* \geq 0$ such that $X\lambda^* \leq \bar{x} \leq x_o$ and $Y\lambda^* \geq \bar{y} \geq y_o$. It follows that (x_o, y_o) is dominated in E, a contradiction.

The dual version of Proposition 2.2 requires $Y\lambda^* = y_o$ e $X\lambda^* = x_o$ for the optimum solution $(1, \lambda^*)$ of the dual problem.

An inefficient DMU can be made more efficient by projection onto the isoquant. This projection is defined by the mapping $(x_o, y_o) \longrightarrow (\theta^* x_o, y_o)$.The projection will be a point in EF when $X\lambda^* = \theta^* x_o$ and $Y\lambda^* = y_o$.

We can define the concept of technical efficiency of production in a context of fixed inputs instead of fixed outputs, i.e., in a program of output augmentation. In this environment the measure of technical efficiency of production of DMU o, under constant returns to scale, is defined by $\phi^*(x_o, y_o)) = \max_{\phi,\lambda} \phi$ subject to i) $Y\lambda \geq \phi y_o$, ii) $X\lambda \leq x_o$ e iii) $\lambda \geq 0$, ϕ free.

In the output augmentation program the question we ask is what proportional rate ϕ can be uniformly applied to augment the output vector y_o without increasing the input vector x_o. The solution ϕ^* is the largest ϕ with this property. Projection onto the frontier with fixed inputs is achieved with the mapping $(x_o, y_o) \longrightarrow (x_o, \phi^* y_o)$. We have $\phi^* = 1/\theta^*$. Again the analogy with the case s=m=1 is perfect.

Our aim now is to define a couple of DEA models that will allow us to define a new measure of technical efficiency, namely the scale measure of technical efficiency. This measure will be denoted by θ^*_{sca}. It will also varies in the interval (0,1] with values less than one meaning inefficiencies. We want to know why a production pair (x_o, y_o) is inefficient according to Definition 2.1 (technical efficiency less than one). When this happens the DMU belongs to a region of increasing returns to scale or to a region of decreasing returns to scale in the space xy. In the former case y_o is too small for (x_o, y_o) to be efficient. In the latter case x_o is too large. This kind of information is extremely relevant to the implementation of production policies. Inefficiencies in the region of increasing returns requires, possibly, projection onto the frontier via output augmentation. Inefficiencies in the region of decreasing returns requires, possibly, projections via input reduction.

The notion of scale of production can be made precise with the use of production sets. Färe, Grosskpof e Lovell (1994) explain in detail these sets. As before let y_o be the output vector of the DMU being evaluated.

. Production set under constant returns:

$$L(y_o, \mathrm{CR}, \mathrm{S}) = \{x; (x, y_o) \in \mathrm{E}\}$$

. Production set under decreasing returns:

$$L(y_o, \mathrm{DR}, \mathrm{S}) = \{x; (x, y_o) \in \mathrm{E}_1\}$$

. Production set under variable returns:

$$L(y_o, \mathrm{VR}, \mathrm{S}) = \{x; (x, y_o) \in \mathrm{E}_2\}$$

The sets E_1 and E_2 are derived from the envelope E imposing the constraints $\sum_i \lambda_i \leq 1$ and $\sum_i \lambda_i = 1$ respectively. We may also define the production set under increasing returns imposing in E the restriction $\sum_i \lambda_i \geq 1$. We will not need this definition. The three production sets show strong disposability (S) in the sense that if $x \in L$ then if $z \geq x$, $z \in L$. In other words, strong disposability occurs when with more input one can produce at least the same amount of output.

The production set $L(y_o, \mathrm{CR}, S)$ shows constant returns to scale in the sense that for any $\alpha > 0$

$$L(\alpha y_o, \mathrm{CR}, \mathrm{S}) = \alpha L(y_o, \mathrm{CR}, \mathrm{S})$$

Note that

$$\begin{aligned}
\mathrm{E}^{\mathrm{CR}}(o) &= \mathrm{E}^{\mathrm{CR,S}}(o) \\
&= \theta^*_{\mathrm{CR,S}}(x_o, y_o) \\
&= \min_{\theta \in (0,1]} \{\theta; \theta x_o \in L(y_o, \mathrm{CR}, \mathrm{S})\}
\end{aligned}$$

The production set $L(y_o, \mathrm{DR}, S)$ shows decreasing returns to scale in the sense that

$$L(\alpha y_o, \mathrm{DR}, S) \subseteq \alpha L(y_o, \mathrm{DR}, S)$$

for every $\alpha > 0$.

Let $\theta^*_{\mathrm{DR,S}}(x_o, yo)$ be the optimal solution to $\min_{\theta,\lambda} \theta$ subject to i)$\mathrm{Y}\lambda \geq \mathrm{y}_o$, ii) $\mathrm{X}\lambda \leq \theta \mathrm{x}_o$ and iii) $\sum_i \lambda_i \leq 1,\ \lambda_i \geq 0,\ \theta$ free. We have

$$\begin{aligned} \mathrm{E}^{\mathrm{DR,S}}(o) &= \theta^*_{\mathrm{DR,S}}(x_o, y_o) \\ &= \min_{\theta \in (0,1]} \{\theta; \theta x_o \in L(y_o, \mathrm{DR}, \mathrm{S})\} \end{aligned}$$

We notice that $\mathrm{E}^{\mathrm{DR}}(o)$ is the measure of technical efficiency of DMU o under the assumption of decreasing returns. In an analogous manner we define the measure of technical efficiency under the assumption of variable returns to scale.

$$\mathrm{E}^{\mathrm{VR,S}}(o) = \theta^*_{\mathrm{VR,S}}(x_o, y_o) = \min_{\theta \in (0,1]} \{\theta; \theta x_o \in L(y_o, \mathrm{VR}, \mathrm{S})\}$$

We see that $\theta^*_{\mathrm{VR,S}}(x_o, y_o)$ is the optimum of $\min_{\theta,\lambda} \theta$ subject to i) $Y\lambda \geq y_o$, ii) $X\lambda \leq \theta x_o$ and iii) $\sum_i \lambda_i = 1,\ \ \lambda_i \geq 0,\ \ \theta$ free.

Clearly,

$$\mathrm{E}^{\mathrm{CR,S}}(o) \leq \mathrm{E}^{\mathrm{DR,S}}(o) \leq \mathrm{E}^{\mathrm{VR,S}}(o)$$

The measure of scale technical efficiency is defined by the ratio of the technical efficiency under constant returns to the technical efficiency under variable returns.

$$\theta^*_{\mathrm{sca}}(x_o, y_o) = \frac{\theta^*_{\mathrm{CR,S}}(x_o, y_o)}{\theta^*_{\mathrm{VR,S}}(x_o, y_o)}$$

Suppose $\theta^*_{\mathrm{sca}}(x_o, y_o) < 1$. If $\theta^*_{\mathrm{CR,S}}(x_o, y_o) = \theta^*_{\mathrm{DR,S}}(x_o, y_o)$ DMU o operates in a region of increasing returns. If $\theta^*_{\mathrm{CR,S}}(x_o, y_o) < \theta^*_{\mathrm{DR,S}}(x_o, y_o)$ the DMU operates in a region of decreasing returns.

Now we are going to define a measure of technical efficiency that will make it possible the investigation of weather or not there exists an input component that is congestive. Congestion of the input variables means that increasing the quantity of resources used actually implies in reduction of the output level. The presence of congestive inputs destroys the property of strong disposability. The new measure of technical efficiency will be named congestion measure of technical efficiency and denoted by θ^*_{cong}. Its definition involves the comparison of the solutions of two linear programming problems. One under the assumption of strong disposability and the other under weak disposability. We use the following production set to handle weak disposability

$$L(y_o, \text{VR}, \text{W}) = \left\{x; \exists\lambda \geq 0 \text{ and } 0 < \sigma \leq 1 \text{ st } Y\lambda \geq y_o; X\lambda = \sigma x_o; \sum_i \lambda_i = 1\right\}$$

The measure of technical efficiency under the assumption of variable returns and weak disposability is

$$E^{\text{VR,W}}(o) = \theta^*_{\text{VR,W}}(x_o, y_o) = \min_{\theta\in(0,1]} \{\theta; \theta x_o \in L(y_o, \text{VR}, \text{W}\}$$

Clearly

$$\text{E}^{\text{CR,S}}(o) \leq \text{E}^{\text{DR,S}}(o) \leq \text{E}^{\text{VR,S}}(o) \leq \text{E}^{\text{VR,W}}(o)$$

Equivalently we may compute $\text{E}^{\text{VR,W}}(o)$ as the solution of the linear programming problem $\min_{\theta,\lambda} \theta$ subject to i) $Y\lambda \geq y_o$, ii) $X\lambda = \theta x_o$ e iii) $\sum_i \lambda_i = 1;\ \lambda_i \geq 0;\ \theta$ free.

We define,

$$\theta^*_{\text{cong}}(x_o, y_o) = \frac{\theta^*_{\text{VR,S}}(x_o, y_o)}{\theta^*_{\text{VR,W}}(x_o, y_o)}$$

When $\theta^*_{\text{cong}}(x_o, y_o) < 1$ it is of interest to pinpoint which inputs, or combination of inputs, are responsible for the observed congestion. This is accomplished with the use of partial measures of technical efficiency. Let B be a subset of $\{1, 2, \ldots, m\}$ with at least one element and B^c its complement. Suppose we want to investigate if the input set B^c causes congestion. Partition X e x_o according to the partition induced by B. In other words, write

$$X = \begin{pmatrix} X^B \\ X^{B^c} \end{pmatrix} \text{ e } x_o = \begin{pmatrix} x_o^B \\ x_o^{B^c} \end{pmatrix}$$

Find the solution $\theta^*_{\text{cong,B}}(x_o, y_o)$ of the linear programming problem $\min_{\theta,\lambda} \theta$ subject to i) $Y\lambda \geq y_o$, ii) $X^B\lambda \leq \theta x_o^B$, iii) $X^{B^c}\lambda = \theta x_o^{B^c}$ and iv) $\sum_i \lambda_i = 1,\ \lambda_i \geq 0\ \ ; \theta$ livre. If $\theta^*_{\text{cong,B}}(x_o, y_o) = \theta^*_{\text{VR,S}}(x_o, y_o)$ the subvector of inputs B^c congests production. Note that there is not uniqueness in the notion of congestion. The analysis has to be carried out for all possible subsets of the input list.

We thus have the following decomposition

$$\mathrm{E}^{\mathrm{CR,S}}(o) = \theta^*_{\mathrm{sca}}(x_o, y_o)\theta^*_{\mathrm{cong}}(x_o, y_o)\mathrm{E}^{\mathrm{VR,W}}(o)$$

It follows that a DMU is inefficient either due to scale problems, congestion or because it does not belong to the frontier of the production problem under the assumption of variable returns and weak disposability.

To summarize we present the four main linear programming problems involved in the decomposition of the technical efficiency under constant returns to scale in primal form. These problems are known as multipliers problems and are handy for computational purposes. In general we are looking for

$$\max_{u,v,u^*} y_o'u + u^*$$

subject to $x_o'v = 1$ and $Y'u - X'v + u^*1 \leq 0$. Imposing additional restrictions on the variables u, v and u^* we can generate all four linear programming problems:

1. constant returns, strong disposability: $u, v \geq 0$ e $u^* = 0$.
2. decreasing returns, strong disposability: $u, v \geq 0$ e $u^* \leq 0$.
3. variable returns, strong disposability: $u, v \geq 0$ e u^* free.
4. variable returns, weak disposability: $u \geq 0$ e u^*, v free.

If in addition to the quantity matrices Y and X a vector p of input prices is available for each DMU we may also compute cost measures of efficiency. Our discussion will assume constant returns to scale but obvious modifications may lead to more general cost measures. Let p_o and y_o denote prices and outputs for DMU o and let $C(p_o, y_o)$ be the solution of $\min_{\lambda,x} p_o'x$ subject to the conditions $Y\lambda \geq y_o$ and $X\lambda \leq x$, where x and λ are nonnegative. The measure of cost efficiency for DMU o is

$$\theta^*_{cost}(o) = \frac{C(p_o, y_o)}{p_o'x_o}$$

We see that the cost efficiency is given by the ratio of the minimum cost attainable to observed cost. Whenever $\theta^*_{cost}(o) < 1$ DMU o is spending more on inputs than is necessary to produce y_o. As in Färe, Grosskopf and Lovell (1994) the excess is due to either or both of two factors (i) using too much of all inputs, and (ii) using inputs in the wrong mix. The first factor is measured by $\theta^*_{\mathrm{CR,S}}(o)$ and the second is measured by the allocative measure of efficiency. This is simply the the ratio $A(o)$ of $\theta^*_{cost}(o)$ to $\theta^*_{\mathrm{CR,S}}(o)$. It follows that

$$\theta^*_{cost}(o) = \theta^*_{\mathrm{CR,S}}(o) \times A_o$$

If only total input costs and output quantity data it is still possible to define a measure of technical efficiency. Let Q be the cost n vector. We now look for the minimum, in λ and x, both nonnegative, of $Q'\lambda$ subject to the conditions $X\lambda \leq x$ and $Y\lambda \geq y_o$. We will not make use of this measure in this paper.

3. EMBRAPA'S PRODUCTION SYSTEM

Embrapa's research system comprises 37 units (DMUs) or research centers. Input and output actions have been defined from a set of performance indicators known to the company since 1991. The company uses routinely some of these indicators to monitor performance through annual work plans. The system of performance indicators is detailed in Embrapa (1996a). With the active participation of the board of directors of Embrapa as well as the administration of each of its research units we selected 28 output and 3 input indicators as representative of production actions in the company. A full explanation of these items is given in Embrapa (1996b).

We begin our discussion of EMRAPA's production system with the output. The output indicators were classified into four categories. Scientific production, production of technical publications, development of technologies, products and processes and diffusion of technologies and image. By scientific production we mean the publication of articles and book chapters aimed mainly to the academic world. We require that each item be specified with complete bibliographical reference. Specifically the category of scientific production includes the following items.

1. Scientific articles published in refereed journals and book chapters - domestic publications.

2. Scientific articles published in refereed journals and book chapters - foreign publications.

3. Articles and summaries published in proceedings of congresses and technical meetings.

The category of technical publications groups publications produced by research centers aiming primarily agricultural businesses and agricultural production. Specifically,

1. Technical Circulars. Serial publications, written in technical language, listing recommendations and information based on experimental studies. The intended coverage may be the local, regional or national agriculture.

2. Research bulletins. Serial publications reporting research results.

3. Technical communiqués. Serial publications, succinct and written in technical language, intended to report recommendations and opinions of researchers in regard to matters of interest to the local, regional or national agriculture.

4. Periodicals (document series). Serial publication containing research reports, observations, technological information or other matters not classified in the previous categories. Examples are proceedings of technical meetings, reports of scientific expeditions, reports of research programs, etc.

5. Technical recommendations/instructions. Publication written in simplified language, aimed at extensionists and farmers in general, and containing technical recommendations in regard to agricultural production systems.

6. Ongoing research. Serial publication written in technical language and approaching aspects of a research problem, research methodologies or research objectives. It may convey scientific information in objective and succinct form.

The category of development of technologies, products and processes groups indicators related to the effort made by a research unit to make its production available to society in the form of a final product. We include here only new technologies, products and processes. These must be already tested at the client's level in the form of prototypes or through demonstration units or be already patented. Specifically,

1. Cultivars. Plant varieties, hybrids or clones.

2. Agricultural and livestock processes and practices.

3. Agricultural and livestock inputs. All raw material that may be used or transformed to obtain agricultural and livestock products, including stirps.

4. Agro-industrial processes. Operations carried out at commercial or industrial level envisaging economic optimization in the phases of harvest, post harvest and transformation and preservation of agricultural products.

5. Machinery (equipment). Machine or equipment developed by a research unit.

6. Scientific methodologies.

7. Software.

8. Monitoring, zoning (agroecologic or socioeconomic) and mapping.

Finally, the category of diffusion of technologies and image encompasses production actions related with Embrapa's effort to make its products known to the public and to market its image. Here we consider the following indicators.

1. Field days. These event are organized by research units aiming the diffusion of knowledge, technologies and innovations. The target public is primarily composed of farmers, extensionists, organized associations of farmers (cooperatives), and undergraduate students. The field day must involve at least 40 persons and last at least 4 hours.

2. Organization of congresses and seminars. Only events with at least 3 days of duration time are considered.

3. Seminar presentations (conferences and talks). Presentation of a scientific or technical theme within or outside the research unit. Only talks and conferences with a registered attendance of at least 20 persons and duration time of at least one hour are considered.

4. Participation in expositions and fairs. Participation is considered only in the following cases.

(a) with the construction of a stand with the purpose of showing the center's research activities by audiovisuals and distributing publications uniquely related to the event's theme.

(b) co-sponsorship of the event.

5. Courses. Courses offered by a research center. Internal registration is required specifying the course load and content. The course load should be at least 8 hours. Disciplines offered as part of university courses are not considered.

6. Trainees. Concession of college level training programs to technicians and students. Each trainee must be involved in training activities for at least 80 hours to be counted in this item.

7. Fellowship holders. Orientation of students (the fellowship holders). The fellowship duration should be at least six months and the work load at least 240 hours.

8. Folders . Only folders inspired by research results are considered. Reimpressions of the same folder and institutional folders are not counted.

9. Videos . Videos should address research results of use for Embrapa's clients. The item includes only videos of products, services and processes with a minimum duration time of 12 minutes.

10. Demonstration units. Events organized to demonstrate research results - technologies, products and processes, already in the form of a final product, in general with the co-participation of a private or government agent of technical assistance.

11. Observation units. Events organized to validate research results, in space and time, in commercial scale, before the object of research has reached its final form. Observations units are organized in cooperation with producers, cooperatives, other agencies of research or private institutions. The events may be organized within or outside the research unit.

The input side of Embrapa's production process is composed of three factors. Personnel, operational costs (consumption materials, travel and services less income from production projects), and capital measured by depreciation.

3.1 Input and ouput indexes

As indicators (inputs and outputs) of the production process we consider a system of dimensionless relative indices. These are all quantity indexes. The idea, from the output point of view, is to define a combined measure of output as a weighted average of the relative indicators (indices) in the system. The relative indices are computed for each production variable and for each research unit within a year dividing the observed production quantity by the mean per research unit. Only research units that can potentially exercise the production activity related to the production variable in question are included in the computation of the mean. We see that, within a given year, the base of our system of production indices is defined by the set of means per unit defined by the production variables. In case of inputs the means use all 37 cases. DEA assumes quantity data. We use the number or employees to represent the factor personnel. Division of money expenses by their respective means will produce a quantity index under the assumption of a common price to all research units. This is a reasonable assumption for operational and capital expenses considering the interest rate as the relevant price. The input indices are indicated by x_i^o, $i = 1, 2, 3$. These quantities represent relative indices of personnel, operational expenditures, and capital expenditures, respectively. A combined measure of inputs x_o is defined as the simple average of the three quantities x_i^o.

Output measures per category are defined as follows. The output component y_i, $i = 1, 2, 3, 4$ of each production category is a weighted average of the relative indices composing the category. If o is the DMU (research unit) being evaluated then

$$y_i^o = \sum_{j=1}^{k_i} a_{ji}^o y_{ji}^o; \quad 0 \leq a_{ji}^o; \quad \sum_{j=1}^{k_i} a_{ji}^o = 1$$

where a_{ji}^o, $j = 1, \ldots, k_i$ is the weight system for DMU o in the category of production i, k_i is the number of production indicators comprising i and y_{ji}^o is the relative index of production j. The weights in principle are supposed to be user defined and should reflect the administration perception of the relative importance of each variable to each DMU. Defining weights is a hard and questionable task. In our application in Embrapa we followed an approach based on law of categorical judgment of Thurston. See Torgerson (1958) or Souza (1988). The model is competitive with the AHP method of Saaty (1990) and is well suited when several judges are involved in the evaluation process. Basically we sent out about 500 questionnaires to researchers and administrators (on a per research center basis) and asked them to rank in importance - scale from 1 to 5, each production category and each production variable within the corresponding production category. We assume that the psycological continuum of the responses projects to a lognormal distribution. Based on the analysis of the inquiry, final weights were set interacting with the board of directors of Embrapa. Minor adjustments to Thurston's analysis were then made to better reflect the administration policies for each research unit.

DEA models implicitly assume that the DMUs are comparable. This is not strictly the case in Embrapa. To make them comparable it is necessary an effort to define an output measure adjusted for differences in operation and perceptions. At the level of the partial production categories we induced this measure allowing a distinct set of weights for each DMU. In principle one could go ahead and use DEA with multiple outputs. This would minimize the effort of defining weights leaving to DEA the task of finding these coefficients. The problem with such approach is that there is a kind of dimensionality curse in DEA models. As the number of factors (inputs and outputs) increases, the ability to discriminate between DMUs decreases, i.e., as Seifford and Thrall (1990) put it "given enough factors, all (or most) of the DMUs are rated efficient. This is not a flaw of the methodology, but rather a direct result of the dimensionality of the input/output space relative to the number of DMUs". In our case with 4 separate measures of output we found that more then 60% of the DMUs were efficient. In this context we found convenient to extend the weight system to produce a single measure of output y_o. This further established a common basis to compare research units and avoided the incidence of zero output (shadow) prices, another common occurrence in multiple output models (and also a disturbing fact for management interpretation!). A single output also allows a simple comparison of DEA results with efficiency measures generated by the fit of stochastic frontiers, as we show later.

The (combined) measure of productivity for DMU o is given by the ratio $\text{Prod}(o) = y_o/x_o$.

We call a research unit productive when its productivity measure is greater than or equal to one.

4. DATA ANALYSIS I (Envelope Problems)

We performed a DEA analysis with 34 of the 37 research centers of Embrapa for the year 1996. Three research centers were eliminated from the analysis due to the particular nature and size of their operation. These are coded as UD-07, UD-19, and UD-37. The coding in use for research centers follows the actual convention used in Embrapa to designate its units. UD-19 deals mainly with the production of software, UD-07 with agricultural machinery, and UD-37 with environmental monitoring. The research units of Embrapa's system are classified into 3 types according to their missions and research objectives. Ecoregional research units (E, total of 13 units), product oriented (simply referred as product) research centers (P, total de 15 units) and thematic research centers (T, total of 9 units). As described in Section 3 the production system comprises 28 output items and 3 inputs. The output variables are reduced to a single output measure with the use of a weight system variable per research unit. For the 4 broad categories of output weights were defined by type. Within each of this categories we allowed variation among research units only for variables classified as development of technologies, products and processes. This is the production category where one can observe the major differences in perception, among research units, of the relative importance of each individual production variable. We carried out the analysis of technical efficiency with the use of three macros SAS: (1) EFIC computes the measures of technical efficiency under the assumptions of constant returns - strong disposability, decreasing returns - strong disposability, variable returns - strong disposability, and variable returns - weak disposability, (2) CONGEST analyzes partial congestion, and (3) COSTEFIC which analyzes cost efficiency for a given set of prices[2]. All macros assume the presence of a data set with data on input and output indexes. The variables should be output (Y), inputs (X_1, X_2 and X_3) and the identification of the DMUs (ID). In COSTEFIC quantity data are represented

[2] The macros EFIC, CONGEST, and COSTEFIC are available via anonymous ftp in ftp.sede.Embrapa.br in the directory /pub/dea/paper/. In the directory the data sets with the 1996 data are DADOS.DAT and PRICES.DAT. The SAS code that generates input and output indices to be used with EFIC and CONGEST is in BASIC.SAS and includes the weights being used.

by QY, QX_1, QX_2 and QX_3, respectively. We note that the macros are crude but can be easily generalized to a greater number of inputs and outputs.

Table 2 shows the results of DEA on quantity data. Shadow prices are shown in Table 3 and partial congestion measures on Table 4. On the average thematic units are more efficient than ecoregional and product research centers. Averages for these units are 0.57, 0.66 and 0.82 respectively. Figure 1 sheds some light on the distribution of efficiencies. The evidence is for a density with two modes indicating the presence of two subpopulations. A close look at Table 3 shows that units are more efficient in the use of operational expenses than personnel and capital. The last four units in Table 3 are technical efficient but only UD-01 belongs to the efficient frontier EF. The location of operation relative to the efficient frontier is as follows. Research units UDs 06, 10, 18, 20, 22, and 23 show decreasing returns to scale. The others, with the exception of the four technical efficient, show increasing returns. Congestion measures are particularly low for UDs 10, 22, 28, 32, and 33. In all these research units the congestive component is operational expenses. UD-32 also shows capital congestive. See Table 4.

Table 5 shows cost efficiencies. Prices for capital and operational expenses factors were considered constant for all units and the price for personnel is an index computed from the average year salary of each unit. The basis is the company average salary. We see that inefficiencies come much more from spending too much on all inputs than due to a poor allocation of resources. It is interesting to note that of the four units technical efficient only one is fully cost efficient.

5. DATA ANALYSIS II (Stochastic Frontier)

A single equation stochastic frontier model, Bauer (1990), has the form

$$\log y_t = \alpha + \beta_1 \log x_{1t} + \beta_2 \log x_{2t} + \beta_3 \log x_{3t} + v_t - u_t$$

where we choose the response (true stochastic frontier) in the Cobb-Douglas family, the residuals v_t are normally distributed with mean zero and variance σ_v^2, the residuals u_t are nonnegative and distributed as a half normal, truncated normal or exponential distribution with variance σ_u^2. The errors $\epsilon_t = v_t - u_t$ are assumed independent across research units.

Let $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\lambda = \sigma_u/\sigma_v$. Assuming a half normal distribution for u_t a measure of production inefficiency is given by

$$E(u/\epsilon) = \frac{\sigma\lambda}{1+\lambda^2}\left[\frac{\phi(\epsilon\lambda/\sigma)}{1-\Phi(\epsilon\lambda/\sigma)} - \left(\frac{\epsilon\lambda}{\sigma}\right)\right]$$

Here $\phi(.)$ and $\Phi(.)$ are the density and distribution function of the standard normal, respectively. See Greene (1995) for the other forms of this quantity under the assumptions of truncated normal and exponential distributions for the component u_t. We used LIMDEP to fit the Cobb-Douglas function via maximum likelihood assuming, in turn, each of the 3 distributions above. Ordinary least squares produced a fit with $R^2 = 0,47291$ and a significant F statistic. Ordinary least squares residuals for the Cobb-Douglas fit are negatively skewed, an important property for mle estimation of stochastic production function frontiers. We tried more general forms than the Cobb-Douglas. Those alternatives did not pass the skewness condition. The parametric estimates of technical efficiencies above cannot be shown to be consistent for cross section data, but we used them anyway to access the nonparametric efficiency measures. To make the measurements comparable we inverted the stochastic frontiers estimates and normalized dividing by the maximum. Final results are shown in Table 6. The hypothesis of constant returns is not rejected in any of the 3 fits. Although individual efficiencies may differ, Spearman and Pearson correlation coefficients with CR are on the order of 90%. Between stochastic frontier fits the correlations are on the order of 99%. On the average inefficiencies are lower in the nonparametric case but in many cases we have a reasonable agreement between the two methods. It is worth to mention that, independently of the residual distributional assumption, the important variable in the stochastic frontier fit is operational expenses which has an elasticity estimate of about 0,69 with a standard error of 0.25.

6. CONCLUSION AND FUTURE PERSPECTIVES

A nonparametric approach to the analysis of production frontiers is in use in Embrapa to assist management. An important contribution in this context was the definition of input and output measures that allow the company to identify the strengths and weaknesses of its research centers inducing a more effective management of resources. A further exercise is now under way relating management practices to efficiencies in an effort to identify relevant factors for near optimum administration. An important by-product of Embrapa's study is the possibility of the establishment of production goals easier to monitor with the help of other quantitative management techniques. A typical example is the balanced scorecard. See Kaplan and Norton (1996). Embrapa is successfully implementing a pilot project with this approach. Of particular interest for managers of agricultural research institutions like Embrapa is the potential use of the production frontier approach in external comparisons. In this context we are already in touch (and gathering data) with other comparable institutions (as INTA of Argentina, INIA of Chile, and the group of research institutions under the administrative coordination of ISNAR in Holland). The international setting poses challenging problems to the definition of output and input measures.

In the near future more data will be collected and other econometric techniques can be evaluated. Of particular concern is the possibility of panel data analysis from both points of view - parametric and nonparametric. Stochastic frontiers in case of panel data will generate consistent estimates of efficiencies.

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Figure 1. Box plot and density estimation of CR.

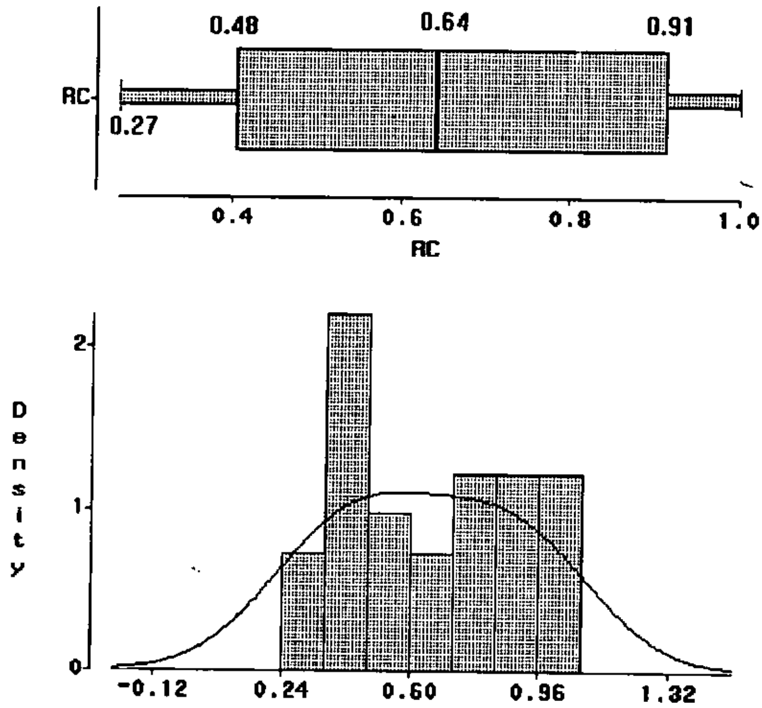

Table 1. Unsymmetric primal-dual problems.

Primal problem	Constraints (primal)	Dual problem	Constraints (dual)
$\max_x c'x$	$Ax = b,\ x \geq 0$	$\min_w b'w$	$A'w \geq c$
$\min_x c'x$	$Ax = b,\ x \geq 0$	$\max_w b'w$	$A'w \leq c$

Table 2. Productivity (Prod). Efficiencies CR(S), DR(S), VR(S), VR(W), Sca (Scale), and Cong (Congestion).

UDs	Type	Prod	CR	DR	VR	VR(W)	Sca	Cong
28	E	0.3965	0.2663	0.2663.	0.4441	0.7990	0.5997	0.5558
21	E	0.4405	0.2772	0.2772	0.3867	0.4309	0.7168	0.8973
33	E	0.6724	0.3673	0.3673	0.4018	1.0000	0.9140	0.4018
25	E	0.6639	0.3936	0.3936	1.0000	1.0000	0.3936	1.0000
31	E	0.6914	0.3964	0.3964	0.4914	0.4925	0.8067	0.9978
26	E	0.7412	0.4029	0.4029	0.5901	0.6342	0.6828	0.9305
22	E	0.6560	0.5089	0.5385	0.5385	1.0000	0.9451	0.5385
32	E	0.9839	0.5823	0.6520	0.6520	1.0000	0.8930	0.6520
27	E	1.1322	0.6944	0.6944	1.0000	1.0000	0.6944	1.0000
29	E	1.2841	0.7844	0.7844	0.9832	0.9858	0.7978	0.9975
24	E	1.3931	0.8450	0.8450	0.9215	0.9219	0.9169	0.9996
23	E	1.2449	0.9130	1.0000	1.0000	1.0000	0.9130	1.0000
30	E	1.3072	0.9706	0.9706	1.0000	1.0000	0.9706	1.0000
09	P	0.5934	0.3317	0.3317	0.4228	0.4389	0.7845	0.9632
02	P	0.7122	0.3879	0.3879	0.5099	0.5304	0.7608	0.9612
11	P	0.5632	0.4039	0.4039	0.4869	0.5416	0.8295	0.8989
10	P	0.6134	0.4090	0.4175	0.4175	1.0000	0.9797	0.4175
16	P	0.6251	0.4388	0.4388	0.5022	0.5581	0.8738	0.8998
34	P	0.7189	0.4788	0.4788	0.6668	0.7536	0.7181	0.8848
17	P	0.8701	0.5995	0.5995	0.6010	0.6795	0.9975	0.8846
08	P	1.0310	0.6533	0.6533	0.7254	0.7272	0.9005	0.9976
14	P	1.4788	0.7394	1.0000	1.0000	1.0000	0.7394	1.0000
04	P	1.1935	0.7602	0.8446	0.8446	1.0000	0.9001	0.8446
06	P	1.3678	0.7907	0.7907	0.8639	0.8654	0.9153	0.9984
20	P	1.1444	0.9232	0.9353	0.9353	1.0000	0.9871	0.9353
18	P	1.5571	0.9320	0.9930	0.9930	1.0000	0.9386	0.9930
13	P	2.0343	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
35	P	1.7933	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
15	T	0.7593	0.5003	0.5003	0.6975	0.7151	0.7172	0.9755
05	T	0.9174	0.6295	0.6295	0.7556	1.0000	0.8331	0.7556
12	T	1.0595	0.8266	0.8266	0.8779	1.0000	0.9417	0.8779
36	T	1.1819	0.9441	0.9441	0.9659	1.0000	0.9774	0.9659
01	T	1.5123	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
03	T	1.5898	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table 3. Shadow prices of production (Y), personnel (X_1), operational expenses (X_2), and capital (X_3).

UDs	Y	X_1	X_2	X_3
28	0.5935	0.0000	1.1430	0.0000
21	0.5168	0.0000	0.9953	0.0000
09	0.5068	0.3749	0.4814	0.0000
33	0.2343	0.0000	0.0000	0.7814
02	0.6391	0.4729	0.6071	0.0000
25	1.5638	1.3796	1.2879	0.0000
31	0.6914	0.5115	0.6568	0.0000
26	0.7058	0.9782	0.2393	0.0545
11	0.6506	0.0000	1.2531	0.0000
10	0.4741	0.0000	0.9132	0.0000
16	0.6167	0.4562	0.5858	0.0000
34	0.9479	0.7013	0.9004	0.0000
15	0.8256	1.2109	0.2960	0.0000
22	0.4268	0.0000	0.8219	0.0000
32	0.4067	0.0000	0.7833	0.0000
17	0.3938	0.3474	0.3243	0.0000
05	0.7272	1.2157	0.0000	0.1852
08	0.7247	0.6394	0.5969	0.0000
27	1.5138	1.1200	1.4381	0.0000
14	0.3052	0.5102	0.0000	0.0777
04	0.5115	0.0000	0.9851	0.0000
29	1.0991	1.5234	0.3726	0.0849
06	0.7490	1.0381	0.2539	0.0579
12	0.7742	1.1355	0.2775	0.0000
24	0.0217	0.7559	0.9705	0.0000
23	0.4746	0.0000	0.9140	0.0000
20	1.1299	0.0000	2.1762	0.0000
18	0.5878	0.4349	0.5584	0.0000
36	0.7828	1.1481	0.2806	0.0000
30	0.8615	1.7577	0.0000	0.0000
01	0.3790	0.5254	0.1285	0.0293
03	0.7980	0.7040	0.6572	0.0000
13	0.4979	0.3684	0.4730	0.0000
35	1.3364	0.0000	2.5739	0.0000

Table 4. Partial congestion measures: Capital (X_3), operational expenses (X_2), personnel (X_1), personnel-operational expenses (X_{12}), personnel-capital (X_{13}), and operational expenses-capital (X_{23}).

UDs	X_3	X_2	X_1	X_{12}	X_{13}	X_{23}
09	0.4228	0.4389	0.4228	0.4389	0.4228	0.4389
11	0.5383	0.4868	0.5275	0.5275	0.5416	0.5383
22	0.5516	0.5385	1.0000	1.0000	1.0000	0.5516
30	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
04	0.8446	0.8446	1.0000	1.0000	1.0000	0.8446
29	0.9833	0.9857	0.9833	0.9857	0.9833	0.9857
01	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
18	1.0000	0.9930	0.9930	0.9930	1.0000	1.0000
16	0.5581	0.5022	0.5022	0.5022	0.5581	0.5581
35	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
20	1.0000	0.9352	1.0000	1.0000	1.0000	1.0000
23	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
08	0.7273	0.7255	0.7255	0.7255	0.7273	0.7273
17	0.6795	0.6010	0.6010	0.6010	0.6795	0.6795
15	0.7150	0.7012	0.6975	0.7012	0.7150	0.7150
36	1.0000	0.9659	0.9659	0.9659	1.0000	1.0000
10	0.4206	0.4175	1.0000	1.0000	1.0000	0.4206
34	0.7536	0.6668	0.6668	0.6668	0.7536	0.7536
12	1.0000	0.8779	0.8779	0.8779	1.0000	1.0000
03	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
31	0.4914	0.4925	0.4914	0.4925	0.4914	0.4925
06	0.8639	0.8653	0.8639	0.8653	0.8639	0.8653
05	0.7556	1.0000	0.7556	1.0000	0.7556	1.0000
02	0.5098	0.5304	0.5098	0.5304	0.5098	0.5304
28	0.4605	0.4441	0.7987	0.7987	0.7987	0.4605
32	0.6520	0.6520	1.0000	1.0000	1.0000	0.6520
13	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
27	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
24	0.9220	0.9217	0.9217	0.9217	0.9220	0.9220
26	0.5901	0.6342	0.5901	0.6342	0.5901	0.6342
33	0.4018	0.4740	1.0000	1.0000	1.0000	0.4740
21	0.3975	0.3867	0.4309	0.4309	0.4309	0.3975
25	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table 5. Cost efficiency (EFCOST) and allocative efficiency (ALLOC).

UDs	EFCOST	ALLOC
28	0.1968	0.7390
21	0.2164	0.7807
09	0.2915	0.8788
33	0.3300	0.8984
02	0.3501	0.9026
25	0.3249	0.8255
31	0.3396	0.8567
26	0.3635	0.9022
11	0.2758	0.6828
10	0.3028	0.7403
16	0.2993	0.6821
34	0.3520	0.7352
15	0.3857	0.7709
22	0.3225	0.6337
32	0.4896	0.8408
17	0.4255	0.7098
05	0.4643	0.7376
08	0.5151	0.7885
27	0.5553	0.7997
14	0.7268	0.9830
04	0.5902	0.7764
29	0.6317	0.8053
06	0.6709	0.8485
12	0.5277	0.6384
24	0.6852	0.8109
23	0.6124	0.6708
20	0.5577	0.6041
18	0.7671	0.8231
36	0.6015	0.6371
30	0.6560	0.6759
01	0.7758	0.7758
03	0.7729	0.7729
13	1.0000	1.0000
35	0.8839	0.8839

Table 6. Stochastic frontier efficiency: half-normal (U), truncated normal (V), and exponential (W).

UDs	V	W	
28	0.4004	0.4090	0.3822
21	0.4207	0.4289	0.4079
09	0.4531	0.4607	0.4473
33	0.5250	0.5298	0.5305
02	0.5196	0.5249	0.5244
25	0.4378	0.4459	0.4289
31	0.5182	0.5237	0.5225
26	0.4968	0.5031	0.4985
11	0.5170	0.5228	0.5202
10	0.5618	0.5656	0.5695
16	0.5154	0.5219	0.5172
34	0.5262	0.5323	0.5297
15	0.5142	0.5209	0.5160
22	0.6341	0.6369	0.6416
32	0.7491	0.7495	0.7529
17	0.6581	0.6621	0.6628
05	0.5275	0.5334	0.5322
08	0.6630	0.6665	0.6686
27	0.6734	0.6762	0.6803
14	0.8548	0.8550	0.8522
04	0.8565	0.8562	0.8541
29	0.7153	0.7180	0.7192
06	0.7617	0.7636	0.7630
12	0.7175	0.7213	0.7187
24	0.7930	0.7946	0.7925
23	0.9285	0.9287	0.9228
20	0.8396	0.8406	0.8359
18	0.9255	0.9262	0.9200
36	0.7622	0.7657	0.7603
30	0.7120	0.7157	0.7142
01	0.8550	0.8575	0.8482
03	0.8625	0.8644	0.8568
13	1.0000	1.0000	1.0000
35	0.9463	0.9459	0.9439