# MEASUREMENT AND SOURCES OF EFFICIENCY IN ARGENTINA´S AGRICULTURAL SCIENCES RESEARCH SYSTEM: A STOCHASTIC FRONTIER ANALYSIS

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Abstract

*The focus of the present study is to evaluate the productivity of the agricultural sciences researchers , analyzing the efficiency of those scientists that participate in the agricultural research system at the National Research Council of Science and Technology of Argentina (CONICET).The data used in the study have been obtained from the researchers database of CONICET. The specific discipline of Agricultural Sciences has 102 researchers, representing 3% of a total of 3,513 individuals.The data cover the period 1996-2000. To evaluate efficiency, we use the approach proposed initially by Farrell in 1957. It consists on the estimation of a production function that allows to calculate the maximum output that can be obtained by each production unit for an input combination. The stochastic frontiers models used in the study are those proposed by Battese and Coelli (1996). The research output is measured in quantity and quality of publications, thesis advising, etc. Different input measures are considered such as project budgets, and salaries. Specific variables are included in the estimation to assess the efficiency effects: type of research institution (e.g. INTA); individual characteristics (age, gender) and environmental aspects to identify scale effects.*

**Keywords: agricultural sciences, research system, stochastic frontiers, production function**

## I) INTRODUCTION

The public budget of Science and Technology in Argentina, whose evolution is shown in Table Nº 1, reached U$S 724 million in 2001, corresponding to 0.20% of the Gross Domestic Product. This budget

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represents 1.4 % of public expenses and 19 U$S per capita. The activity of agriculture forestry and fishery participates in 10.6% of the budget.

**Table 1:**

**Science and Technology Public Budget, 1996-2001.**

| **Year** | **MILLIONS U$S** | | **%** |
|---|---|---|---|
| | **NATIONAL EXPENSES** | **SC&T** | |
| 1996 | 41,169 | 756 | 1.8 |
| 1997 | 43,936 | 794 | 1.8 |
| 1998 | 48,676 | 890 | 1.8 |
| 1999 | 49,299 | 804 | 1.6 |
| 2000 | 48,176 | 740 | 1.5 |
| 2001 | 51,802 | 724 | 1.4 |

*Source: Secretariat for Technology, Science and Productive Innovation- Ministry of Economy, 2001.*

**Table 2**

**Science and Technology Public Budget per GDP percentage**

| YEAR | % | U$S/ per capita |
|---|---|---|
| 1996 | 0.28 | 21 |
| 1997 | 0.27 | 22 |
| 1998 | 0.30 | 25 |
| 1999 | 0.28 | 22 |
| 2000 | 0.26 | 20 |
| 2001 | 0.26 | 19 |

*Source: Secretariat for Technology, Science and Productive Innovation- Ministry of Economy, 2001.*

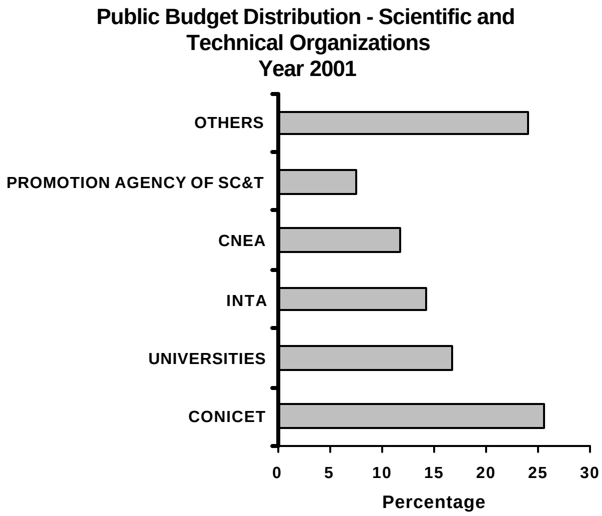
The National System of Research (SNR) of Argentina consists of two components: one, centralized, constituted by private and official agencies that participate in the definition of scientific public policies and in the assignment of resources for research, and the other, conformed by a group of agents (e.g.: businesses and private organizations and individuals) that carry out tasks of research out of the centralized structures. The nucleus of the system is a public group of institutions. In Argentina, most of these institutions were created in the decade of the 50´s, in the framework of an import substitution model. The base of this model was the development of knowledge and national technological and productive capacity, with a strong participation of the state (Ekboir et al, 1999). In this period, the main national institutions of science and technology supporting agricultural research were created: the National Research Council of Science and Technology (CONICET) and the National Institute of Agricultural Technology (INTA).

CONICET was created in 1958, to structure an academic organization that would promote science development, and execute scientific and technological activities throughout the whole country and in the different areas of knowledge. It is important to note that, for the first time in Argentina, the category of full-time scientific researchers appeared (the researchers were in the past, in general, professors at public universities ).

INTA was created in the same year. The initial mission was the development and adaptation of technology carrying out research and technological transference to the rural sector; its objective has been expanded to include the support to the agricultural industries and the sustainable management of the natural resources.

The budgets of these institutions and other organizations are presented in the next figure:

**Figure 1:**




*Source: Secretariat for Technology, Science and Productive Innovation- 2001*

*Notes: CNEA*, National Nuclear Energy Commission

## II.GENERAL BACKGROUND AND PERFORMANCE INDICATORS IN AGRICULTURAL SCIENCES

The focus of the present study is to evaluate the productivity of this sector, analyzing the efficiency of those scientists that participate in the agricultural research system at CONICET. The purpose is to obtain some conclusions about the use of public funds in this area, looking for some political recommendations to improve the efficiency level.

The promotion system implemented by CONICET includes: the careers of scientific and technological researchers and support staff, the supply of fellowships, the financing of research projects and research centers. Also, CONICET promotes the establishment of bonds with international governmental and non-governmental organizations with similar characteristics.

CONICET is one of the most important assets of the national capital as regards science and technology. The organization sustains the inter-institutional articulation as a mean to formulate concrete action plans and establish priorities. The researchers develop their tasks mostly in national universities from different regions of the country, in organizations of science and technology research and in independent units or shared with the institutions already mentioned. This institution, with other agencies and governmental programs, shares the cost of projects, and in some cases, the salaries.

The next table illustrates CONICET´s budget destined to Scientific Promotion. It reached U$S 156,792,692 in 2000.

**Table 3**

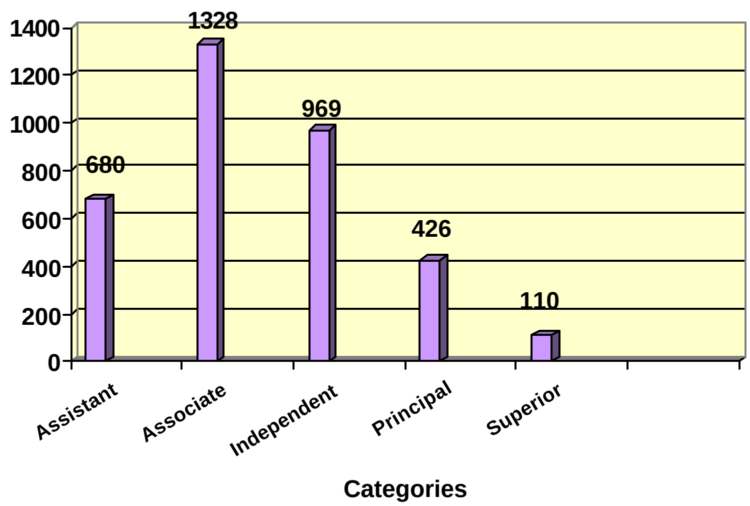
**CONICET´s Budget – 2000 Scientific Promotion (*)**

| Category | U$S (millions) |
|---|---|
| Scientific and Technological Research career | 64, 616 |
| Scholarship program | 23,373 |
| Project funding | 6,700 |
| Support Staff | 55,043 |
| International cooperation | 0,960 |
| Other (research units) | 6,100 |
| Total | 156,792 |

*Source: CONICET-2000 (*) excluding salaries of administrative staff and managerial costs*

During the last five years, CONICET has maintained a mean of 3,500 researchers, distributed in 5 categories where the career promotion is achieved through a rigorous performance evaluation. The Technicians and Support Staff consist of approximately 2,600 individuals. Figure Nº 2 and Table Nº 4 present the researchers distribution by categories and type of workplace.

**Figure 2 Distribution of Researchers by categories (2001)**




*Source: CONICET- 2001*

**Table 4**

**Distribution of Researchers by Type of Workplace**

| WORK PLACE | (%) |
|---|---|
| Research Units *(CONICET´s centres) | 40 |
| National Universities | 48 |
| Science and technology Public Institutions (INTI, INTA, CONEA, Provincial Governments) | 8 |
| Private Organizations | 4 |
| **Total** | **100** |

* CONICET Research Units: 12%, administrated jointly with: Universities 23%, with Public Bodies 3% with other research and technology Bodies and Prov. Governments 2% - *Source: CONICET- 2001.*

The following table shows the distribution by discipline of the CONICET Researchers

**Table 5**

| **DISCIPLINE** | **Number of researchers** | **(%)** |
|---|---|---|
| Medicine | 477 | 14 |
| Biology | 481 | 14 |
| Veterinary Sc. | 34 | 1 |
| Biochemistry | 217 | 6 |
| Law, Political Sc. and International Relationships | 61 | 2 |
| Philology, Linguistics and Literature | 69 | 2 |
| Philosophy, Psychology, and Educational Sc. | 142 | 4 |
| History, Anthropology and Geography | 287 | 8 |
| Sociology and Demography | 88 | 3 |
| Economy, Management and Public Administration Sc. | 47 | 1 |
| Earth, Water and Atmosphere Sc. | 352 | 10 |
| Mathematics | 101 | 2 |
| Physics and Astronomy | 409 | 11 |
| Chemistry | 218 | 7 |
| Agricultural Sc. | 102 | 3 |
| Engineering | 368 | 10 |
| Architecture | 55 | 2 |
| Others | 5 | |
| **Total** | **3,513** | **100** |

*Source: CONICET- 2001*

CONICET has a participative and rigorous evaluation system, that contemplates and ponders, by contest, the quality of the submitted research projects, the productivity derived from them, the background of individuals and research groups.

The evaluation system is based upon the assessment of scientific boards and peer review.

The CONICET researchers'efficiency, as generators of knowledge, is reflected by their participation in 68 % of the 17,000 scientific articles written by Argentines who live in the country (Caicyt-CONICET, 2000). These articles were cited in several international databases in the last 5 years. The efficiency of CONICET members, measured in number of articles indexed by year/researcher is 0.52.This performance is specially outstanding when the organization relies on only 25.6 % of the Science and Technological National Budget (Figure Nº 1)

The specific discipline of Agricultural Sciences has 102 researchers, representing 3% of a total of 3,513 individuals. Currently, there are relevant number of researchers, not included in this study, that belong to other disciplines but with research competencies in agricultural subjects.

The number of fellowships in this discipline is 136 (doctoral and post doctoral ones), that represents 7 % of the total quantity. In the period 1997-2001, 71 projects (5.7 %) have been assigned by CONICET to Agricultural sciences.

## III. METHODOLOGY AND EMPIRICAL ANALYSIS

### III.1. Stochastic Frontier Models

In his original work, Farrel (1957) proposed a measure of the efficiency of a production unit that consists of the estimation of a production function that allows to calculate the maximum output that can be obtained by each production unit for an input combination. The level of technical efficiency (TE) of each production unit can be defined as the relationship observed between the actual product (y) and the potential maximum (y*) : $0 \leq TE = y/y^* \leq 1$

Aigner and Chu (1968) proposed the estimation of a Cobb-Douglas production function using cross section data. The proposed model is:

$$(1) \qquad \ln(y_i) = x_i \beta - u_i \ , \qquad i = 1,2,.....,N$$

where

$\ln(y_i)$ is the logarithm of the output for the i-th firm

$x_i$ is a (K+1) vector of the logarithms of the K input quantities used by the i-th firm (the first element is 1)

$\beta$ is a (k+1) vector of unknown parameters to be estimated, and

$u_i$ is a non-negative random variable, associated with technical efficiency

The ratio of the observed output for the i-th firm, relative to the potential output, is used to define the technical efficiency of the i-th firm. This measurement takes a value between zero and one, and represents the magnitude of the output of the i-th firm relative to the output that could be produced by a fully efficient firm using the same input vector. The TE ratio can be estimated by the ratio of the observed output, $y_i$, to the estimated value of the frontier output, $\exp(x_i\beta)$, obtained by estimation of $\beta$ using linear programming. In this deterministic frontier methodology no account is taken of the influence of measurement errors and other possible noise effects. All deviations are assumed to be the result of technical inefficiency.

An alternative approach is the method of stochastic frontier. The stochastic frontier production function model was proposed by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977). The original specification involved a production function specified for cross-sectional data which had an error term which had two components, one to account for random effects and another to account for technical inefficiency.

We follow the general model proposed by Battese and Coelli (1992), described by:

(2) $y_i = \exp(x_i\beta + V_i - U_i)$ $i=1,...,N$,

where $y_i$ is the output of the i-th firm;

$x_i$ is a k×1 vector of input quantities and other explanatory variables for the i-th firm;

$\beta$ is a vector of unknown parameters to be estimated;

the $V_i$ are random errors which are assumed to be i.i.d. $N(0,\sigma_V^2)$,

the $U_i$ are non-negative unobservable random variables which is associated with the technical inefficiency of production (for a given technology and levels of inputs is a measurement of the gap between the observed and potential output)

The Battese and Coelli model is a stochastic frontier production that has firm effects which are assumed to be distributed as truncated normal random variables, and also permitted to vary systematically with time (if panel data are available). The $U_{it}$ term is defined by:

(3) $U_{it} = (U_i \exp(-\eta(t-T)))$,

where the $U_i$ are i.i.d. non negative random variables obtained by truncation (at zero) of the normal distribution with unknown mean ($\mu$), and unknown variance ($\sigma_U^2$ ). $\eta$ is a parameter to be estimated (the case of the half normal distribution for the technical inefficiency effects is the most frequently assumed).

Battese and Corra (1977), suggested the parametrisation of the likelihood function in terms of (4)

$$\sigma^2=\sigma_V^2+\sigma_U^2 \text{ and } \gamma=\sigma_U^2/(\sigma_V^2+\sigma_U^2).$$

The log likelihood function, in terms of this parametrisation, is equal to (Battese and Coelli 1992):

(5)

$$Ln(L) = \frac{-N}{2}\ln(\frac{\boldsymbol{p}}{2}) - \frac{-N}{2}\log(\boldsymbol{s}_s^2) + \sum_{i=1}^{N}\ln[1-\Phi(z_i)] - \frac{1}{2\boldsymbol{s}_s^2}\sum_{i=1}^{N}(\ln y_i - x_i\boldsymbol{b})^2$$

Where

(6)

$$z_i = \frac{(\ln y_i - x_i \beta)}{\sigma_s}\left(\frac{\gamma}{1-\gamma}\right)^{1/2}$$

and $\Phi(.)$ is the distribution function of the standard normal random variable.

Imposing the restrictions $\eta$=0, $\mu$=0 and T=1 the Battese and Coelli model returns to the original cross-sectional, half-normal formulation of Aigner, Lovell and Schmidt (1977). Given these specifications there is particular interest in testing the null hypothesis that the technical inefficiency effects are not present in the model. This is expressed by $H_0$: $\gamma$=0. If the null hypothesis, where $\gamma$ equals zero is accepted, this would indicate that $\sigma_U^2$ is zero and hence that the $U_t$ term should be removed from the model, leaving a specification with parameters that can be consistently estimated using ordinary least squares.

We use the software FRONTIER 4.1, setting $\eta$=0 (time invariance), $\mu$=0 (half normal) and T=1 (cross section data) to obtain the maximum likelihood estimates for the parameters of the stochastic frontier model. The computer program calculates predictions of individual firm technical efficiencies from estimated stochastic production frontiers by replacing the unknown parameters with their Maximum Likelihood (ML) estimators in the following equation (Coelli et.al.1998):

$$E[\exp(u_i)] = \frac{1-\Phi(\sigma_A + \gamma e_i / \sigma_A)}{1-\Phi(\gamma e_i / \sigma_A)} \exp(\gamma e_i + \sigma_A^2 / 2)$$

(7)

where $\sigma_A = \sqrt{\gamma(1-\gamma)\sigma_s^2}$ ; $e_i = \ln(y_i) - x_i\beta$ and $\Phi(.)$ is the density function of a standard normal random variable.

III.2. Empirical Application - Data and Variables

In this section we shall examine the estimation of a knowledge production function frontier using cross-sectional data and assuming a half-normal distribution.

We consider data on agricultural sciences researchers from CONICET for the period 1996-2000. Ideally a panel data set should be used to estimate individual-level efficiency. However, the available information does not allow us to separate the scientific production and use of resources in a year to year basis. Consequently, the information was processed as a one period cross sectional data.

Data used for empirical analysis correspond to 91 agricultural sciences researchers from CONICET. From a total number of 102 researchers, 11 observations were discarded due to incomplete information.

A set of indicators of scientific production are detailed in the periodic reports that each researcher presents to CONICET. We have collected the information from these reports and

we selected five output indicators as representative of knowledge production activities in CONICET:

- Articles published in journals cited in the Science Citation Index (SCI) Data Base
- Articles published in journals not cited in the SCI and book chapters
- Articles published in proceedings of congress or scientific meetings
- Masters or Doctorates thesis advising
- Fellowship advising.

A set of quantitative and qualitative variables were selected as a proxies for the input side of the production function and to reflect the specific characteristics of each individual:

- Salaries (gross monthly average )
- Project funding (total of research grants or subsidies received)
- Age
- Gender
- Number of CONICET researchers that work in the same workplace unit

A summary of the values of the variables selected is presented in the table below:

**Table 6: Summary statistics for variables**

| | RPI | Salaries (u$s) | Grants (u$s) | Age | N | DI |
|---|---|---|---|---|---|---|
| **Mean** | 1.00 | 1,841 | 96,734 | 48 | 3.37 | 0.42 |
| **Max** | 2.58 | 5,432 | 666,950 | 70 | 12 | 0.85 |
| **Min** | 0.23 | 787 | 0 | 36 | 1 | 0.21 |
| **St. Deviation** | 0.54 | 856 | 141,636 | 8.53 | 3.66 | 0.12 |
| **Median** | 0.90 | 1,756 | 36,700 | 46 | 2 | 0.40 |

Notes:
RPI: Relative Production Index
N: Number of researchers in the same workplace
DI: Diversification Index

From the total sample, 29 observations are females, and 62 males. 55 cases work in large units[3], and 36 in small units. The salaries of 21 researchers are paid by CONICET or shared with universities; 58 cases paid by universities, and 12 by INTA.

For the purpose of estimation we define a dimensionless relative index as an output indicator. The relative index is computed as a weighted average of the five production activities previously mentioned. The weights reflect the institutional perception of the relative importance of each activity. The weights were defined from the opinion of qualified agents and researchers involved in the evaluation system of CONICET. There are five different categories of researchers in CONICET: assistant, associate, independent, principal and superior, and each one has a different set of weights. The set of weights applied in the formulation of the output index is presented in the following table.

**Table 7: Set of weights**

| Category | Articles SCI | Articles non SCI | Proceedings of Congress | Thesis advising | Fellowships | Total |
|---|---|---|---|---|---|---|
| Assistant | 0.56 | 0.24 | 0.10 | 0.05 | 0.05 | 1 |
| Associate | 0.49 | 0.21 | 0.10 | 0.10 | 0.10 | 1 |
| Independent | 0.455 | 0.195 | 0.10 | 0.125 | 0.125 | 1 |
| Principal / Superior | 0.42 | 0.18 | 0.10 | 0.15 | 0.15 | 1 |

III.3. Functional Form

A conventional Cobb-Douglas form is used here to model the stochastic frontier production function. Using lower case to denote natural logarithms, the function to be estimated is:

$$(8) \qquad y_i = \beta_0 + \Sigma_{j=1,\,5}\, \beta_j\, x_{ij} + \Sigma_{j=1,\,5}\, \alpha_j\, D_{ij} + V_i - U_i$$

where for the i-th observation, i=1,..91

y = output index

$x_1$ = salaries (in U$S)

[3] Large workplace: more than 40 researchers (CONICET and Others)

$x_2$ = grant or subsidy (in U$S). This variable is the log of the amount of grant if a grant was received by the researcher, and zero otherwise.

$x_3$ = number of CONICET researchers in the same workplace

$x_4$ = age

$x_5$ = diversification index. For each individual a "Herfindahl" production diversification index is computed using the shares of each activity.[4]

$D_1$= dummy variable for grants, which has value one if the individual received a grant, zero otherwise[5].

$D_2$ = dummy variable for INTA researchers, which has a value one if the researcher receives a salary entirely from INTA, zero otherwise.

$D_3$ = dummy variable for gender which has a value one if the researcher is female, zero otherwise.

$D_4$= dummy variable for large workplaces which has a value one if the researcher works in a large unit, zero otherwise.

$D_5$ = dummy variable for advising assistant researchers which has a value of one if the i-th individual has a CONICET assistant researcher, zero otherwise. (assistant researchers have to be monitored by a senior researcher).

$U_i$ and $V_i$ are the error components previously defined.

III.4 Estimation Results

Table Nº 8 reports the maximum likelihood estimates of the parameters in the Cobb-Douglas stochastic frontier production function. The log likelihood function for the full stochastic frontier model is –62.912

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[4] Variable $x_5$ is calculated as $\sum_{i=1,5} (s_i)^2$ where $s_i$ represents the share of the i-th activity in total output index. For i=5 this variable is bounded in the interval [0.2 , 1].

[5] If the dummy variable $D_1$ is not included to account for an intercept change, then the estimator for $\beta_2$ is biased. (Battese 1997)

and the value for the OLS fit (results not reported) of the production function is -65.40. The generalized likelihood ratio (LR) test for testing for the absence of technical inefficiency effects from the frontier is 4.975. This statistic has a mixed chi-square distribution and the critical value is 2.706 ($\alpha$=0.05 and 1 degree of freedom) obtained from Table 1 of Kodde and Palm (1986). Hence, the null hypothesis of absence of technical inefficiency effects is rejected. Note that the ML estimation for $\gamma$ is relatively close to one (0.86) and with an standard error of 0.10. These results suggest that the most important part of residual variation is due to the inefficiency effect $U_i$, and that the random error $V_i$, has a minor participation.

Consequently, it appears that the traditional average response function is not an adequate representation of the data. However, the stochastic frontier model is not significantly different from the deterministic frontier model with has no random error included.

**Table 8: Maximum Likelihood Estimates for Parameters of the Stochastic Frontier Model**

| Variable | Parameter | Coefficient | Standard Error |
|---|---|---|---|
| Constant | $\beta_0$ | 2.260 | 1.370 |
| Salaries | $\beta_1$ | 0.184 | 0.210 |
| Grants | $\beta_2$ | 0.057 | 0.039 |
| Number of CONICET Researchers | $\beta_3$ | 0.092 | 0.069 |
| Age | $\beta_4$ | -0.782 | 0.447 |
| Diversification Index | $\beta_5$ | 0.337 | 0.209 |
| Grants Dummy | $\alpha_1$ | -0.668 | 0.435 |
| INTA Dummy | $\alpha_2$ | -0.022 | 0.162 |
| Gender Dummy | $\alpha_3$ | -0.154 | 0.124 |
| Workplace Size Dummy | $\alpha_4$ | 0.220 | 0.109 |
| Assistant Researcher Dummy | $\alpha_5$ | -0.030 | 0.154 |
| Sigma-squared | $\sigma^2$ | 0.551 | 0.145 |

| | | | |
|---|---|---|---|
| Gamma | $\gamma$ | 0.863 | 0.107 |
| Log likelihood function | | -62.912 | |

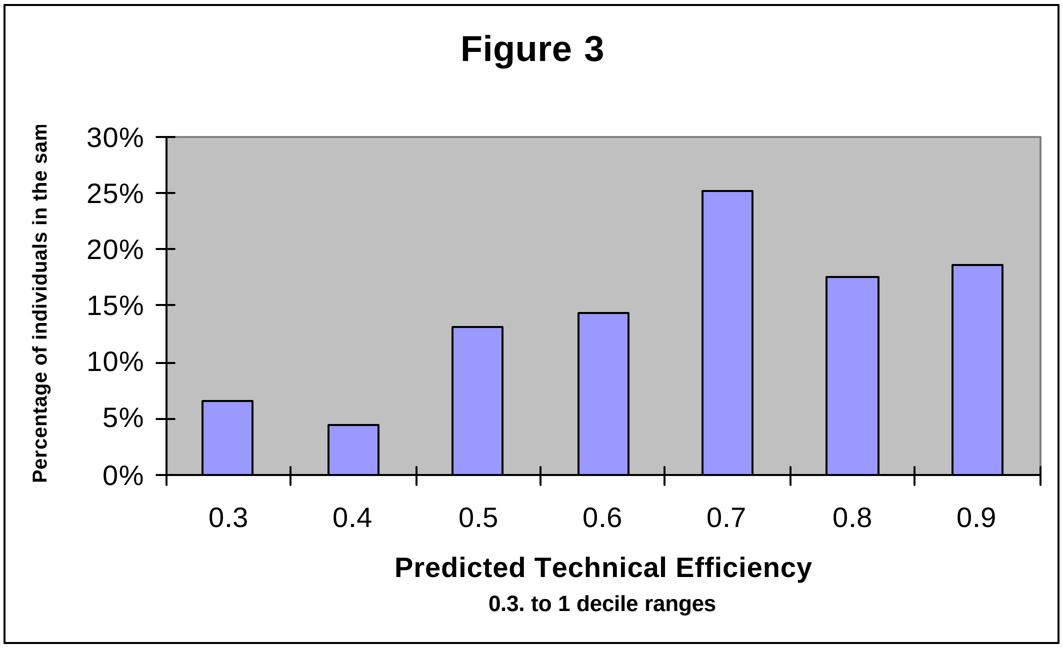
LR test of the one-sided error = 4.9750677
with number of restrictions = 1

We note that the estimated coefficient for salaries is positive but small, relative to the standard error suggesting that its true value is zero. This result could reflect the fact that in the system there is not an incentive structure that relates salary and performance.

The estimated $\beta$ for the grants variable in the model is positive , indicating that individuals with higher grants in the sample tend to have more scientific production. On the other hand, the coefficient shows a low partial elasticity (0.057). Age is a significant variable associated negatively with production, suggesting that the younger researchers have more scientific production than older ones. The value of the estimated coefficient for $\beta_5$ suggests that the production index decreases with an increase in the degree of diversification. The size of workplace appears to have a positive effect, since the estimated coefficient of $\alpha_4$ is positive and presents a low standard error. There is no clear evidence that the dummy variables controlling gender, INTA full salary and assistant researcher have effects over the production level.

III.5.Technical Efficiency

The technical inefficiencies effects were predicted using FRONTIER 4.1.The estimated mean efficiency value was 0.62. Percentages of the sample individuals with predicted technical efficiencies in the decile ranges from 0.3 to 1.0 are graphed in Figure 3. The graph illustrates that approximately 19% of the researchers have predicted technical efficiencies greater than 0.9 and approximately 18% in the range 0.8-0.9. The rest of the sample (63%) has efficiencies in the range 0.3-0.8 suggesting that important improvements could be made through policies focused on the relevant variables considered in this analysis. Yet, the results should be considered as preliminary indicators because the model specifications and variable definitions could have a significant bearing on the predicted technical efficiencies (Figure Nº 3).




## IV. FINAL REMARKS

This study presents a systematization of the information available from the evaluation process of an important public agency in the promotion of scientific activities in Argentina. The area of agricultural sciences was analyzed, gathering information from the annual or biennial reports presented by the 102 researchers of the discipline in the period 1996-2000. From these reports a series of indicators of scientific production, use of resources, individual and environmental characteristics were constructed.

A production index was defined including different products (articles) or activities (thesis advising) selected according to the category of the researcher. The decision of the weights assigned to each activity was made on the basis of the opinion of qualified agents and researchers at CONICET. Defining these weights is a complex task and that can be, to a certain extent, arbitrary or subjective. Although CONICET has normative rules that define the duties for each class of researcher, the different scientific activities are not explicitly valued.

The estimation of a production function using the methodology of stochastic frontier shows that some of the selected variables are relevant in the determination of the level of scientific production: the amount of grants received by each researcher, the age, the degree of diversification and the size of the workplace. The received grants affect the production level positively, although the results show a relatively low marginal effect. The younger the researcher, the greater the level of production is, indicating that the incorporation of young researchers to the system could improve the productivity levels. A high dispersion of activities seems to affect the production negatively, indicating that the researchers who have a greater concentration of tasks, have higher productivity levels. The scale of the research unit has a clearly positive effect on the scientific production, showing the importance of a critical mass and a suitable environmental structure that could imply effects of scale and knowledge spillovers.

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