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Efficiency of Public-Funded Crop Sciences Research in India

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Abstract

The efficiency of crop sciences research in India has been estimated and its determinants have been evaluated using stochastic frontier production function. The results have shown a considerable scope in improving the efficiency of crop sciences research as the existing efficiency is less by 33 per cent than the achievable efficiency. The research productivity measured in terms of annual number of publications per scientist is less than one. Restructuring the institutes with adequate financial (operating contingency) support, correcting the cadre strength in favour of young scientists, and better opportunities for interaction would enhance the research efficiency.

Introduction

The Indian Council of Agricultural Research (ICAR) is the apex body mandated to plan, conduct and coordinate agricultural research in the country. It has set several milestones in the past, which did pay high dividends. However, some recent reports have raised concerns over deterioration in the scientific productivity and efficiency in agriculture. Improving research efficiency is critical in maximizing benefits of research under the dwindling funding scenario and declining scientific strength.

Efficiency is the measure of performance, depicting how the available resources are being utilized for producing some pre-determined research output. It is closely linked with the scientific productivity and the allocation of research resources. A number of studies have addressed the issues of efficiency and its impact at the global level (Anderson and Dillon, 1968; Andersen and Leonardi, 1982; Echeverria, 1990; Ozediz, 1990; Andersen and Hardaker, 1992; Souza *et al.,* 1999). In India also, a few studies have attempted the estimation of scientific productivity (Lele and Gold Smith, 1989; Laharia and Singh, 1987; Garg and Rao, 1988; Basu, 1999; Basu and

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Kumar, 1999). Most of these studies have used *Science Citation Index* as a measure of scientific productivity. However, the issue of measurement of production (technical) efficiency and its determinants has not been attempted, particularly for the agricultural research. This is untenable in the context of emerging challenges of resource crunch and reforms being undertaken to address these issues (ICAR, 1997).

The measurement of scientific productivity and technical efficiency is a complex task. The most fundamental question is related to the identification of indicators of research productivity and efficiency. It includes construction of a combined research output index by assigning appropriate weights to various output indicators. Selection of weights is also critical for the construction of index for measuring the productivity and efficiency. Efficiency is a relative measure, which evaluates the performance of an individual or organization by comparing the observed values of output(s) and input(s) with their corresponding optimal values in a particular production process (Lovell, 1993). Technically efficient production assumes maximum attainable output at a given level of input. In other words, technical efficiency is achieved by producing at the production frontier.

In this study, we have applied the concept of technical efficiency to measure research efficiency of the crop research institutes of the ICAR. These institutes, 23 in number, share 15 per cent of the ICAR's expenditure. Based on the mandates and coverage, these are classified into national institutes, central institutes, national research centres (NRCs) and project directorates (PDs).

Methodology

Data

The technical efficiency of 22 research institutes[1] was assessed by developing an output index based on research publications, a widely used indicator of scientific output (Fox, 1983; Gustin, 1973). Information pertaining to the number of publications, number of scientists and age of the institutes were gathered from the *Annual Reports* of 1997, 1998 and 1999 of the selected Crop Science Research Institutes (CRIs). Data on annual expenditures of the selected institutes were compiled from the ICAR Budget Books.

[1] A newly established institute - NRC DNA Fingerprinting, was excluded from the analysis.

Selection of Weights

Since all publications do not have the same status, publications were grouped into different classes and suitable weights were assigned for arriving at a combined output index. The groups were made as per the type of publications, viz. (i) international publications, (ii) national publications, (iii) book chapters, (iv) proceedings of the workshops/ seminars, (v) technical reports/ bulletins, and (vi) popular articles. The relative weights were decided after consultations with a multidisciplinary group of scientists and peers. Following weights were assigned for developing an aggregate research productivity index (O_i).

Publication category	Weights
Research articles in international journal	5.00
Research articles in national journals/ books/ book chapter	2.50
Technical reports/ bulletins	1.25
Papers in seminars/ workshop proceedings	0.75
Popular articles	0.50

Research Productivity Index (O_i)

An index of a scientist's research productivity (O_i) was constructed as per Equation (1):

$$O_i = \sum_{i=1}^{n} PijWi / N \qquad \ldots(1)$$

where, O_i indicates per scientist output score of the *ith* institute (i = 1,2,...,22),. P_{ij} is the number of *jth* publication published by the scientists of *ith* institute (j= 1,2,..6). W_i is the weight of *jth* publication and N_i is the number of scientists in the *ith* institute.

This O_i served as the dependent variable while formulating the functional relationship for the stochastic frontier function used for estimating the technical efficiency.

Measurement of Technical Efficiency

Mainly two approaches, parametric and non-parametric, are used to measure the technical efficiency. The non-parametric approach needs not to specify a functional form to explain the technology or efficiency frontier. Souza *et al.* (1999) have developed a production model based on input - output data of research for research institutes under EMBRAPA, Brazil. The authors prepared a weighted productivity index by covering indicators like publications, varieties developed, training/ workshops/ seminars attended/ organized, etc. They applied the Data Envelopment Analysis (DEA) model to estimate the efficiency of EMBRAPA. Hartwich and Oppen (2000) have also used DEA in the performance evaluation of agricultural research in Sub-Saharan Africa. The DEA is a non-parametric method, which follows linear programming models and generalizes the notion of productivity to find out the optimum solution for efficiency maximization. Since the measurement of efficiency is based on linear programming model, DEA does not accommodate any statistical noise and therefore its estimates are deterministic. On the other hand, parametric or econometric approach to estimate technical efficiency assumes the functional relationship between output and input. A number of functional forms are being used to estimate frontier function. Based on the model specification, the parametric approach can give a deterministic or stochastic efficiency estimate. However, in real world situation, the presence of inefficiency in a system is not always due to the defined or observed factors. Many unexplained factors also have an important role in determining the performance and thus efficiency. Therefore, the parametric approach, particularly the stochastic production function, has an edge over other approaches. The stochastic model recognizes inefficiency as deviations from the production frontier and also assumes that all the deviations from the frontier are not due to the inefficiency alone. In this way, it decomposes the deviations from the production frontier in terms of technical inefficiency and random effects.

The Parametric Approach

The technical efficiency was estimated by applying the stochastic frontier function (Farrel, 1957; Aigner *et al.* 1977; Meeusen and Van den Broeck, 1977). There are evidences, which confirm the use of stochastic frontier for the estimation of technical efficiency (Dawson and Lingard, 1989; Kalirajan, 1990; Battese, 1992). The following functional form of stochastic frontier model was applied to determine the output maximizing combination of existing resources with available technology [Equation (2)]:

$$\ln O_i = \beta_0 + \beta_1 \ln (X_{1i}) + \beta_2 \ln (X_{2i}) + V_i - U_i \qquad \ldots(2)$$

where, i refers to the institutes (i= 1, 2, …., 22), X_{1i} is the per capita total annual expenditure and X_{2i} represents the number of scientists in the *ith* institute. U_i represents non-negative random variable representing the technical inefficiency; and V_i is the random error-term distributed independently and identically with zero mean and finite variance; V_i is independent of U_i; and β_0, β_1 and β_2 are the vectors of unknown parameters to be estimated.

The maximum likelihood estimates can be obtained by parameterization $\sigma_u^2 + \sigma_v^2 = \sigma^2$ and $\gamma = \sigma_u^2 / \sigma^2$ where, σ_u^2 and σ_v^2 are variance parameters representing variances in symmetric error and efficiency that occur due to technically inefficient performance of the decision-making units. The exponential of u_i after assigning the negative sign gives the technical efficiency.

Determinants of Technical Efficiency

The following semi-log function was fitted to observe the effects of various factors on the level of technical efficiencies of the institutes [Equation (3)]:

$$TE_i = \delta_0 + \delta_1 \ln X_{1i} + \delta_2 \ln X_{2i} + \delta_3 \ln X_{3i} + \delta_4 \ln X_{4i} + \delta_5 \ln X_{5i} + u_i \quad \ldots(3)$$

where TE_i is the efficiency score of the *ith* institute, X_{1i} is age of the *ith* institute (years), X_{2i} is average age of the scientists in the *ith* institute, X_{3i} is the opportunities of interaction to a scientist in the *ith* institute and is defined in terms of number of times the scientist participated in seminars, symposia and workshops; X_{4i} is the share of operational expenses in the total budget of the *ith* institute, and X_{5i} is proportion of principal scientists in the *ith* institute.

Results and Discussion

Institutes' Profile and Research Productivity

The number of scientists and their age profile in different institutes are given in Table 1. There is a considerable variation in the number of scientists across the institutes. For example, during the triennium ending 1998-99, Indian Agricultural Research Institute (IARI), a national institute, had a strength of 646 scientists, whereas the average cadre strength in the central institutes was about 77. These imbalances are due to the mandate, research focus and target domain of different institutes.

The composition of scientific positions was found to follow a pyramidical structure. About 16 per cent of the total scientists were in the cadre of principal scientists, followed by senior scientists (36 per cent) and scientists (48 per cent). The average age of the scientists was 44 years. Scientists below 35 years of age comprised only 30 per cent. About 53 per cent scientists were above 45 years of age. The proportion of young scientists was expected to decline further because of the reduction in number of positions and delay in filling up the vacant positions.

Availability of financial resources was another important determinant of scientific productivity. Seventy per cent of the budget came from non-plan source, to meet establishment costs and salaries (Table 2). The share of operational expenditure in the total funds varied between 17 and 30 per

Table 1. Cadre-wise and age-wise scientific composition of scientists, 1997-99

Institute	Per cent			Number of scientists (TE: 1997-99)	Percentage distribution			Average age (years)
	Scientists	Senior scientists	Principal scientists		Less than 35 years	35 to 45 years	45 to 55 years	
National Institutes	31	48	21	646	15.9	36.3	36.5	43.9
Central Institutes	65	24	11	77	10.2	8.2	55.1	50.1
National Research Centres (NRCs)	59	27	14	21	12.5	2.8	52.1	46.9
Project Directorates (PDs)	52	31	17	33	29.5	20.7	38.6	42.9
All Institutes	48	36	16	78	29.4	17.7	47.0	43.5

Table 2. Expenditure and per scientist publications of the institutes, 1997-99

Institute	Expenditure (Rs in lakh)			Percentage of operating expenditure in total	Number of publications per scientist					
	Non-plan	Plan	Total		International	National	Proceedings	Technical reports/ bulletin	Popular articles	Book chapters
National Institutes	4514	869	5383	17.6	0.02	0.31	0.77	0.09	0.32	0.15
Central Institutes	442	150	592	19.5	0.04	0.29	0.36	0.03	0.28	0.05
NRCs	71	98	169	29.7	0.09	0.31	0.57	0.10	0.12	0.10
PDs	137	271	408	17.7	0.08	0.42	0.58	0.14	0.18	0.21
All Institutes	456	196	652	20.8	0.06	0.32	0.48	0.08	0.14	0.11

cent. The National Research Centres were better placed in terms of operational expenses.

A researcher was found to take 11-20 years for publishing a paper in a refereed international journal, whereas a paper in a national journal came out in a period of about three years. The estimated national journal equivalent score of productivity in some CRIs was found less than one. It is a matter of concern that some scientists are unable to produce even a single paper in a refereed journal in a year. It indicated that there was either a lot of unproductive scientific manpower or lack of infrastructure support, or both. Therefore, there is a need to take measures for improving the research productivity. This could be done in two ways. First, by augmenting research resources and maintaining the quality of research infrastructure. And second, by looking into the factors affecting efficient utilization of these resources to maximize the technical efficiency. The next section deals with this issue.

Frontier Production Function

The maximum likelihood estimates of the stochastic production function alongwith OLS estimates are presented in Table 3. The results show that budget had a significant and positive effect on scientific productivity. It certainly highlighted the role of investment in agricultural research and

Table 3. Estimates of the ordinary least square and frontier production functions

Variable	OLS	Frontier
Constant	–2.5088***	–2.0517***
	(0.8603)	(0.8310)
Budget [Rs (lakh)/ scientist]	0.6834***	0.6665**
	(0.2531)	(0.151)
Size (number of scientist)	–0.1742	–0.1739**
	(0.12089)	(0.08369)
σ^2_v	-	0.10164
σ^2_u	-	0.27958
γ	-	0.7338
σ	-	0.6174
λ	-	1.6585
R^2	0.4587	-
log-likelihood	13.6645	–13.4594
Number of iterations	-	9
Number of observations	22	22

Figures within parentheses are standard errors of respective variable.
*** significant at 1% and ** significant at 5%.

Table 4. Distribution of institutes by technical efficiency

Efficiency range	Number	Per cent
< 0.50	3	13.6
0.51 - .60	3	13.6
0.61 - 0.70	7	31.8
0.71 - 0.80	5	22.8
0.81 - 1.00	4	18.2
Mean efficiency	0.67	100.0

asked for better financial assistance. However, the existing scientific strength narrated a different story. The results confirmed that the existing scientific strength was performing much below its potential. The coefficient of the institute's size was negative and significant for MLE, indicating that in the present circumstances, increasing the number of scientists beyond a certain limit would have negative impact on scientific productivity and therefore, increase in institutes' scientific strength is not advisable. However, this does not mean that change in the composition of scientific strength will not enhance scientific productivity. This issue has been analyzed in the next section.

Technical Efficiency and Its Determinants

Technical efficiency of a research institute can be defined as the ability of the institute to maximize its output with the available scientific and financial resources. The estimates of the frontier production function showed the varying levels of inefficiency in different institutes (Table 4). The ratio of variance parameters (γ) showed the presence of inefficiencies in the performance of the CRIs. Nearly 73 per cent of the variation in the productivity was found due to differences in the technical inefficiency, and the rest was attributed to the random factors beyond the control of the CRIs.

The mean technical efficiency of the selected institutes was 67 per cent. However, it varied from 36 to 84 per cent for different institutes. The efficiency was 70 per cent or less in 13 out of 22 institutes, and only 4 institutes had an efficiency level of 80 per cent or more. Obviously, there was a scope for improving the technical efficiency, but it required assessment of factors affecting the technical efficiency.

The explanatory variables explained about 64 per cent of the variation in the technical efficiency of different CRIs (Table 5). It was interesting to note that better opportunities of interaction among the scientists increased the efficiency significantly. The other factors like proportion of operating

Table 5. Determinants of technical efficiency

Variable	Coefficient	Standard error (±)
Age of the institute (X_{1i})	0.0775**	0.0327
Age of the scientists (X_{2i})	0.8659	0.5314
Opportunities for interaction (X_{3i})	0.1198***	0.0295
Proportion of operating expenses in the total budget (X_{4i})	0.1642*	0.0899
Proportion of principal scientists (X_{5i})	-0.0989*	0.0547
Constant term	-2.5999	1.9537
R-squared	0626	
F-value	3.88**	

***, ** and * indicate significance at 1, 5 and 10 per cent levels, respectively.

expenses and age of the institute also had positive and significant impact on the technical efficiency. Higher proportion of the operating expenses and younger institutes had positive effect on the scientific efficiency. Here, it was worth noting that higher proportion of principal scientists had negative and significant influence on the technical efficiency. This is in line with the life-cycle theory of productivity, which indicates that productivity of an individual decreases after a certain stage. The results indicated that there was a need for increasing operational expenses, correcting cadre strength in favour of younger scientists and enhancing opportunities of interaction among the scientists.

Conclusions

This paper has analyzed the productivity and efficiency of the crop sciences research institutes in the ICAR system. The research productivity measured in terms of number of publications per scientist per year is less than one, which is very low by any standard. This is attributed to both inadequate resources as well as inefficiencies in their use as a majority of the institutes have low level of technical efficiency, which calls for the measures to be taken for improving efficiency. Small institutes with higher proportion of young scientists and with greater proportion of operating expenses are found more efficient. Increased opportunity for scientific interactions is another important factor that adds to the efficiency and productivity.

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