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Benchmarking evaluation of performance of public research institutes using data envelopment analysis

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In this study, public research institutes (PRIs) are considered as a system with inputs and outputs. Data Envelopment Analysis is utilized to suggest a methodology to analyze and benchmark the performance of PRIs. It is applied to measure the relative performance of each institute with respect to best performing institute. The model can also suggest measures and set the targets to the institutes for improving their performance. The methods can be used as an instrument in strategic planning and can be considered for improving the performance of PRIs. The proposed methodology was applied on a set of PRIs working in the same area and evaluated their performance.

Keywords: Public research institutes, Data envelopment analysis, Performance analysis

Introduction

Public research institutes (PRIs) carry out scientific research and render technological services. They play a fundamental role in an increasingly knowledge based society in the production of inventions and innovations necessary for the development of a competitive industrial system. The study on these institutes in Italy[1], UK[2], India[3,4] and Finland[5] shows a growing interest in evaluating their performance. Government also wants to measure and evaluate their performance to manage efficiently and effectively in the light of diminishing funds[6].

In developing countries, PRIs are under tremendous pressure to improve their performance due to the globalization, resource constraints and increasing accountability. For comparing performance of PRIs, Coccia[7] proposed Relev Method, which measures the activity of each PRI by number of indices, which are combined in a simple function to evaluate knowledge scores for each institute. PRIs are ranked on the basis of their knowledge scores. Coccia[8] also applied Discriminant Analysis with direct and Wilks Method for evaluating performance of PRIs. Other models[9,10] include Principal Component Analysis and Factor Analysis.

With the liberalization of Indian economy, Indian PRIs are facing a challenge to improve their performance. In this study, PRIs are considered as a system with inputs and outputs. Data Envelopment Analysis (DEA) is utilized to suggest a methodology to analyze and benchmark the performance of PRIs. It is applied to measure the relative performance of each institute with respect to best performing institute. The model can also suggest measures and set the targets to the institutes for improving their performance. The methods can be used as an instrument in strategic planning and can be considered for improving the performance of PRIs.

Research Institute as System

PRIs systems, set up and run by men, develop a process of scientific production, mainly using public resources (Fig. 1). The elements are connected to each other and they generate an output, namely basic and applied research, which is essential for increasing wealth of nations. They are feedback systems, since they are influenced by past behaviors[11]. The resources of the system are inputs, which generate cognitive process. Scientific manpower and funds are generally the inputs of a PRI. The production process of a PRI transforms the inputs into outputs through the realization of research projects. Outputs of PRIs include publications, patents, business generated from the industry, technologies developed etc.

Research Study

Objective

The present study aims to utilize DEA for analyzing and benchmarking the performance of different PRIs. The study has been taken up with the

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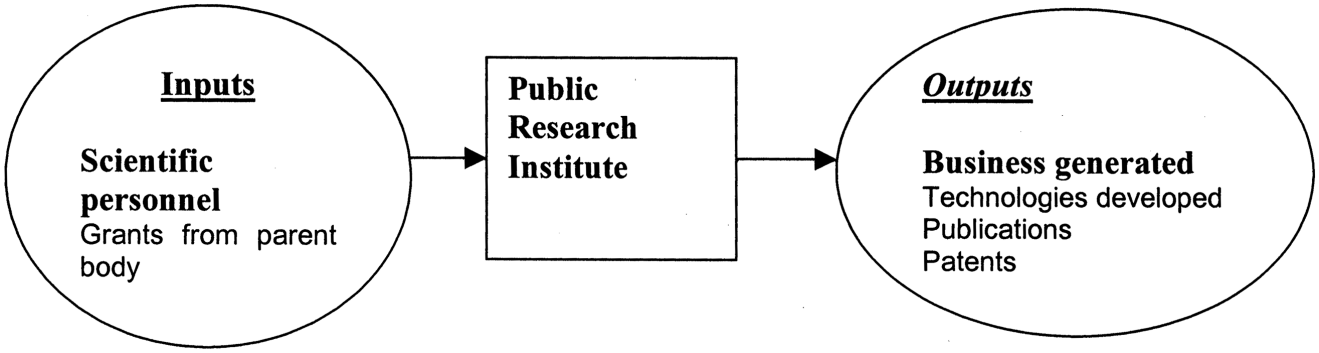

Fig. 1 — Research institute as system

following objectives: (i) To calculate the relative performance of PRIs; (ii) To benchmark the performance of PRIs with the best performing PRI; (iii) To suggest measures to PRIs for improving their performance; and (iv) To set targets for PRIs to achieve so that they can improve their performance.

Methodology

DEA (Frontier Analysis) is a performance measurement technique[12] used for evaluating relative efficiency of organizations. This model can be easily applied to non-profit making organizations. Graphical approach to this model offers an easy approach to analyze results obtained and present it to the management, though a mathematical approach to the model is available, which requires complex computer softwares[13-15].

In DEA model, organizations are viewed as utilizing inputs and converting them (with varying degrees of efficiency) into outputs. Ratios, which are calculated by taking an output dividing with input, are used to measure and compare the performance of the organizations. All the organizations will be compared with the organization that has got the highest ratio, and relative efficiency will be calculated with respect to that organization. The organizations, which do not compare well, are performing less, and they are relatively less efficient at using their given input resource to produce the desired output. The comparison can also be used to set the targets for the other organizations; a target of continuing to process the same level of output but with less input. In practice, a mix of input and output targets will be set for the organization to achieve.

Ratios are used to measure and compare the performance even if there are two output measures and a single input measure. One of the output measures will be taken and it will be divided by the input measures. The organizations that will get the highest ratios are said to be performing well and those organizations that do not compare so well are assumed to be performing less well; they are relatively less efficient at using their given input resource to produce outputs. In this method, the problem is that the different ratios can give a different picture and it is difficult to combine the entire set of ratios into a single numeric judgment. DEA helps in interpreting different ratios. For each organization, two outputs and a single input are considered at a time and ratios are calculated and plotted for each organization. The positions on the graph give the organizations having a level of performance, which is superior to all the other organizations. A straight line can be drawn from the y-axis through points of organizations with superior performance to the x-axis. This line is called the 'efficient frontier' and it envelops all the data. Mathematically, the efficient frontier is the convex hull of the data (100% efficiency). This is not to say that the performance of these organizations could not be improved. It may, or may not, be possible to do that. However, based on the data available, there is no idea of the extent to which their performance can be improved. The model only gives relative efficiencies, which are relative to the data considered. It does not give absolute efficiencies. It only presents given data on inputs and outputs in a particular way.

The relative efficiency of an organization can be calculated by comparing the current performance of the organization to the best possible performance that the organization could reasonably be expected to achieve. This can be carried out using the following equation

$$\textit{Relative efficiency of the organization} = \frac{X}{Y} \times 100$$

Table 1 — Input and output of different institutes (1997-2001)

Public research Institute	Grant from parent body Rs, in crores	Scientific Personnel Rs, in crores	Technologies developed	Publications	ECF	Patents
RI A	53.1	150	18	97	13.6	39
RI B	75.4	220	1	14	26.9	16
RI C	52.4	125	22	273	29.2	67
RI D	36.0	116	18	114	10.2	19
RI E	97.9	225	55	810	38	252
RI F	55.4	485	26	62	23.7	51
RI G	106.9	340	25	1234	77.9	436
RI H	46.8	105	4	172	8.9	45

where, X = Length of the line from the origin to the point obtained by plotting two ratios for the organization, Y = Length of the line from origin through the point obtained for the organization to efficient frontier.

The relative efficiencies of any organization would indicate that other organizations are adopting practices and procedures, which would enable it to improve its performance. The best possible performance that an organization could be expected to achieve is given by the point labeled Best, the point where the line from the origin through the point of that organization meets the efficient frontier. That point is considered to represent the best possible performance that the organization can reasonably be expected to achieve. There are a number of ways by which the organization can move towards that point. It can be achieved through one of the following options: i) Reduce input keeping output constant (an input target); ii) Increase both its outputs, retaining the current ratio whilst keeping its input constant (an output target); and iii) Do some combination of the above.

The same diagram that is used to calculate efficiency of the organization can be used for setting the targets for organizations to achieve for improving their performance. If organization is required to achieve increase (10%) in current efficiency, an organization with the same business mix but efficiency of increase (10%) can be determined on the line from the origin to the Best. Now, goal of the organization is to move from their current position to that new position.

The methodology adopted in the study can be summarized as: (i) Identification of PRIs must be engaged in a similar set of operations; (ii) Identification of inputs and outputs of those PRIs; (iii) Collection of data on inputs and outputs during a certain time period for the identified PRIs; (iv) Identification of two outputs and a single input at a time for analysis; (v) Calculation of ratios by dividing an output with the input at a time; (vi) Plotting of two ratios for each institute; (vii) Identification and drawing of efficient frontier line; (viii) Identification of institutes with hundred per cent efficiency, as per the available data; (ix) Identification of best point for each institute; (x) Determination of relative efficiency of each organization; and (xi) Setting targets and suggesting measures for each institute to improve their performance.

Results and Discussion

Indian PRIs (8) working in the same area with similar kind of operations were considered in this study and to maintain anonymity, PRIs are designated as RI A, RI B, RI C, RI D, RI E, RI F, RI G and RI H.

Inputs considered in the study were: i) Grant from parent body; and ii) Scientific personnel (SP). Outputs in the study were: (i) Business generated from the industry i.e., external cash flow (ECF) earned; (ii) Technologies developed; (iii) Publications; and (iv) Patents filed.

In some studies, ECF earned is treated as input as the money will be spent in producing the outputs. But, in this study, it was considered as output measure because the management of any institute wish to evaluate the performance of their institute regarding the business it attracts from the industry also. Nowadays, all the institutes wish to increase its self-reliance, as the public funding is squeezing. The data regarding the inputs and outputs were collected for each institute for 1997-2001 (Table 1).

ECF Generated and Technologies Developed vis a vis Scientific Personnel

The intention was to evaluate the performance of PRIs regarding the two outputs (ECF earned and the technologies developed) with respect to the input (SP). Ratios were calculated for each institute, first by dividing ECF generated with SP and then by dividing technologies developed with SP (Table 2). The two ratios were plotted for each institute (Fig. 2).

Research institutes RI E, RI C and RI G are showing superior performance (Fig. 2). Efficient frontier line can be identified by drawing a horizontal line from the y-axis to E, from E to C, from C to G, and a vertical line from G to x-axis. It represents a standard of performance that institutes, which are not on the efficient frontier, could try to achieve. It is interpreted that institutes RI E, RI C and RI G have 100 per cent efficiencies in generating cash flow and developing technologies with respect to SP.

Table 2 — ECF generated and technologies developed vis a vis scientific personnel

Public research Institute	ECF/Scientific personnel	Technologies/Scientific personnel
RI A	0.09	0.12
RI B	0.12	0.004
RI C	0.23	0.18
RI D	0.08	0.15
RI E	0.17	0.24
RI F	0.05	0.05
RI G	0.23	0.07
RI H	0.08	0.04

The best possible performance that RI A could be expected to achieve is given by the point, where the line from the origin through RI A meets the efficient frontier. Relative efficiency was calculated by 100 (length of line from origin to RI A/ length of line from origin through RI A to efficient frontier) and it was 51 per cent. Similarly, RI B, RI D, RI F, RI H relative efficiencies were as follows: RI B, 52; RI D, 62; RI F, 24; and RI H, 33 %.

The efficiencies do not automatically mean that RI A is around half as efficient as best institutes. Rather the efficiencies here would usually as indicate that other institutes are adopting practices and procedures, which if RI A were to adopt them, would enable it to improve its performance. It is suggested for these institutes to study and implement practices followed by RI C, RI E and RI G.

It was observed that RI E, RI C and RI G are best performing research institutes in generating cash flow and developing technologies with respect to SP. Next comes RI D and RI B, whereas RI F and RI H are not performing well necessitating some remedial actions.

The best point on the efficient frontier is considered to represent the best possible performance that RI A can reasonably be expected to achieve through one of the following options: (i) Reducing input (SP) keeping output constant (an input target); (ii) Increasing both its outputs, retaining the current ratio constant whilst keeping its inputs (SP) constant (output target); and iii) Do some combination above.

Since, in PRIs, it is not possible to downsize the work force easily, options 1 and 3 are out of reach and only option 2 is possible.

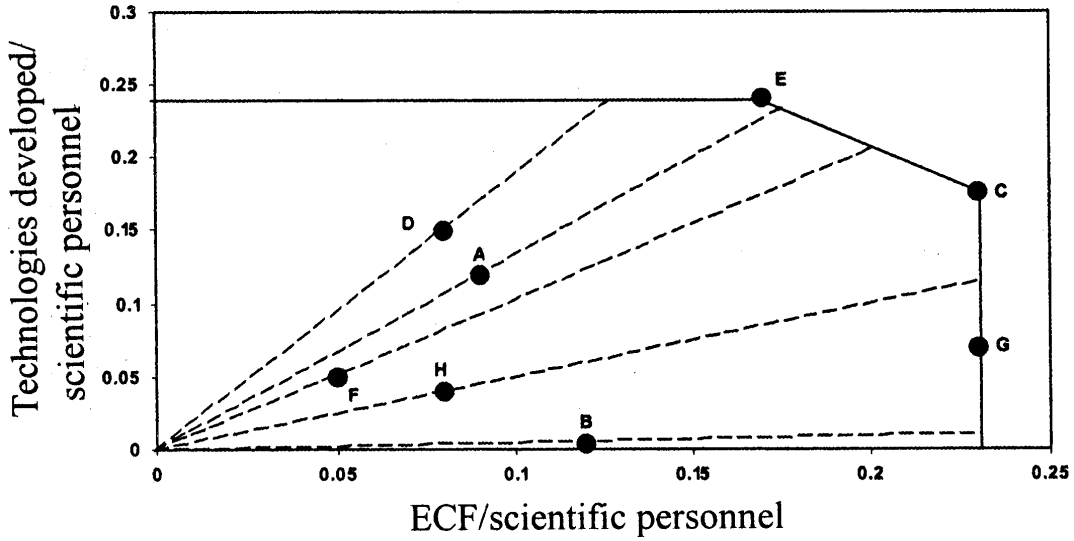

Fig. 2 — ECF generated and technologies developed vis a vis scientific personnel

Table 3 — Targets for the institute to improve their efficiency by 10 %

Research institute	ECF to earn	Technologies to develop
RI A	16.5	21
RI B	31	3
RI D	11	20
RI H	10.5	5
RI F	34	32

Table 4 — Publications and patents vis a vis scientific personnel

Public research Institute	Publications/Scientific personnel	Patents/Scientific personnel
RI A	0.65	0.26
RI B	0.06	0.07
RI C	2.20	0.54
RI D	0.98	0.16
RI E	3.60	1.12
RI F	0.13	0.10
RI G	3.63	1.28
RI H	1.64	0.43

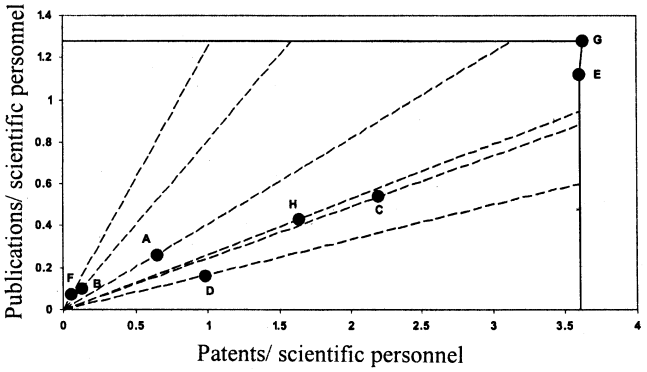

Fig. 3 — Publications and patents vis a vis scientific personnel

Assume that during the next time period, the efficiency of RI A has to be improved by 10 per cent (from present level of 51% to 61 %), the institute has to achieve ratios of 0.11 (ECF/SP) and 0.14 (Technologies/SP). Assuming SP as constant, the institute has to achieve Rs 16.5 crores ECF and to develop 21 technologies. Similarly, targets (Table 3) were calculated for other institutes (RI B, RI D, RI H & RI F) to improve their efficiency (10 %).

Publications and Patents vis a vis Scientific Personnel

To evaluate the performance of the PRIs regarding the two outputs of publications and patents with respect to SP, ratios were calculated for each institute and plotted (Table 4, Fig. 3).

Research institutes RI E and RI G show superior performance (Fig. 3). Efficient frontier line was identified by drawing a horizontal line from y-axis to RI G, from RI G to RI E, and a vertical line from RI E to x-axis. It is interpreted that RI E and RI G have 100 per cent efficiencies in publications and patents with respect to SP. The relative efficiencies, calculated for the other institutes, were as follows: RI A, 22; RI B, 9; RI C, 61; RI D, 28; RI F, 6; and RI H, 46%. It is suggested for these institutes to study and implement practices followed by RI E and RI G, which are best performing PRIs in publications and patents with respect to SP. Next comes RI C and RI H, whereas RI A, RI B, RI D and RI F are not performing well necessitating some remedial actions. These institutes can increase both outputs while keeping input constant.

Assuming that during the next time period, RI A, RI B, RI C, RI D, RI F and RI H has to improve efficiency (10%), the targets (Table 5) were calculated using the graph.

ECF Generated and Technologies Developed vis a vis Grants

It was intended to evaluate the performance of PRIs regarding the outputs of ECF earned and technologies developed with respect to grants received from the parent body. Ratios were calculated for each institute and plotted (Table 6, Fig. 4).

Research institutes RI E, RI C and RI G show superior performance (Fig. 4). Efficient frontier line was drawn. From the graph, it is interpreted that institutes RI E, RI C and RI G have 100 per cent efficiencies in generating cash flow and developing technologies with respect to grants from parent body. Relative efficiencies, calculated for the remaining institutes, were as follows: RI A, 63; RI B, 48; RI D, 89; RI F, 91; and RI H, 28%. It is suggested for these institutes to study and implement the practices followed by RI C, RI E and RI G, which are best

Table 5 — Targets for the institutes to improve their efficiency by 10 %

Research institute	Publications	Patents
RI A	150	38
RI B	44	40
RI C	312	78
RI D	145	25
RI F	97	97
RI H	200	61

Table 6 — ECF generated and technologies developed vis a vis grants from parent body

Public research Institute	ECF/Grants from parents body	Technologies/Grants from parents body
RI A	0.25	0.34
RI B	0.35	0.01
RI C	0.56	0.42
RI D	0.29	0.50
RI E	0.39	0.56
RI F	0.43	0.47
RI G	0.73	0.23
RI H	0.19	0.08

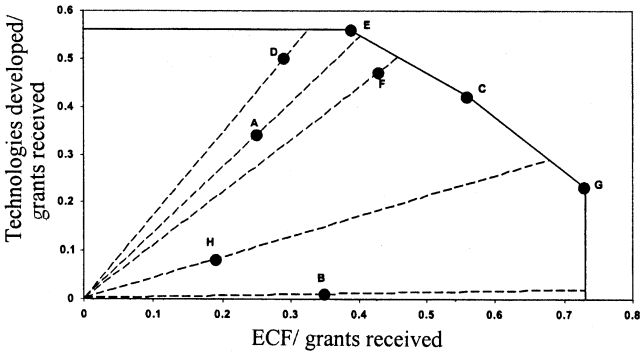

Fig. 4 — ECF generated and technologies developed vis a vis grants from parent body

performing PRIs in generating cash flow and developing technologies with respect to grants from parent body. Next comes RI D and RI F, whereas RI B and RI H are not performing well necessitating some remedial actions. These institutes can achieve best performance through one of the following options: i) Reducing input (grants from parent body) keeping output constant (an input target); ii) Increasing both its outputs, retaining the current ratio whilst keeping its inputs (grants from parent body) constant (output target); and iii) Do some combination above. Since, in PRIs, it is not that much easy to reduce the grant, it is advisable to stick to option 2. To achieve the improve in efficiency (10 %), RI B, RI D, RI H and RI F have to achieve the targets (Table 7).

Publications and Patents vis a vis Grants from Parent Body

It was intended to evaluate the performance of PRIs regarding the outputs of publications and patents with respect to grants received from the parent body. Ratios were calculated for each institute and plotted (Table 8, Fig. 5).

Research institutes RI E and RI G show superior performance (Fig. 5). Efficient frontier line was drawn. It is interpreted that institutes RI E and RI G have 100 per cent efficiencies in publications and patents with respect to grants received from the parent body. Relative efficiencies calculated for the remaining institutes were: RI A, 19; RI B, 6; RI C, 63; RI D, 38; RI F, 23; and RI H, 44 %. It was suggested for these institutes to study and implement the practices followed by RI E and RI G, which are best performing PRIs in generating cash flow and

Table 7 — Targets for the institute to improve their efficiency by 10 %

Research institute	ECF to earn	Technologies to develop
RI A	16	21
RI B	32	2
RI D	83	21
RI F	25	28
RI H	11.7	10

Table 8 — Publications and patents vis a vis grants from parent body

Public research Institute	Publications/Grants received from parent body	Patents/Grants received from parent body
RI A	1.82	0.73
RI B	0.19	0.21
RI C	5.2	1.28
RI D	3.17	0.53
RI E	8.27	2.58
RI F	1.12	0.92
RI G	11.54	4.08
RI H	3.67	0.96

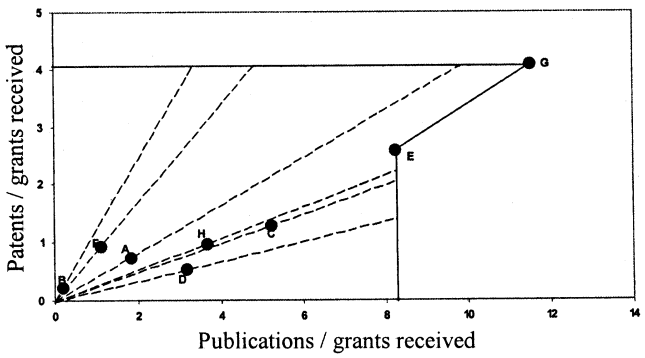

Fig. 5 — Publications and patents vis a vis grants from parent body

developing technologies with respect to grants received from the parent body. Next comes RI C, whereas remaining institutes are not performing well necessitating some remedial actions.

Institutes can improve performance by increasing both outputs, keeping input constant. To improve the efficiency (10 %), targets (Table 9) were calculated for RI A, RI B, RI C, RI D, RI F and RI H.

Conclusions

DEA is utilized to suggest a methodology to analyze and benchmark the performance of Indian PRIs. It was applied to measure the relative performance of each institute with respect to best performing institute. The model also suggested measures and set the targets to the institutes for improving their performance. The methods can be used as an instrument in strategic planning and can be considered for improving the performance of the research institutes. Methodology suggested in this study is of general nature and can be easily used for comparing performances of any set of research institutes. RI E, RI C and RI G are best performing PRIs in generating cash flow and developing technologies with respect to SP. Next comes RI D and RI B, whereas RI F and RI H are not performing well necessitating some remedial actions. It is suggested for RI B, RI D, RI F and RI H to study and implement practices followed by RI C, RI E and RI G in this aspect. RI E, and RI G are best performing PRIs in publications and patents with respect to SP. Next comes RI C and RI H, whereas RI A, RI B, RI D and RI F are not performing well necessitating some remedial actions. It is suggested for RI A, RI B, RI C, RI D, RI F and RI H to study and implement practices followed by RI E and RI G. RI E, RI C and RI H are best performing PRIs in generating cash flow and developing technologies with respect to grants from the parent body. Next comes RI D and RI F, whereas RI B and RI H are not performing well necessitating some remedial actions. It was suggested for RI A, RI B, RI D, RI F and RI H to study and implement the practices followed by RI C, RI E and RI G. RI E and RI G are best performing in generating cash flow and developing technologies with respect to grants received from the parent body. Next comes RI C, whereas remaining institutes are not performing well.

Relative efficiencies of all PRIs were summarized (Table 10). Research institutes RI E and RI G are the most performing research institutes of all. Though RI C is performing well in generating ECF and developing technologies against both SP and grants received from the parent body, it is not performing well in publications and patents. RI F is performing well in generating ECF and developing technologies against grants received from the parent body, but it is lagging behind in other aspects. There is a long way to go for RI H, whereas RI A, RI B and RI D are showing moderate performance in generating ECF

Table 9 — Targets for the institute to improve their efficiency by 10 %

Research institute	Publications	Patents
RI A	133	84
RI B	76	46
RI C	315	79
RI D	144	36
RI F	140	89
RI H	190	57

Table 10 — Relative Performance of different research institutes

Research institutes	ECF and technologies developed against scientific personnel	Publications and patents against scientific personnel	ECF and technologies developed against grants from parent body	Publications and patents against grants from parent body
RI A	51	22	63	19
RI B	52	10	48	6
RI C	100	61	100	63
RI D	62	28	89	38
RI E	100	100	100	100
RI F	24	7	91	23
RI G	100	100	100	100
RI H	33	46	28	44

and developing technologies, but they are not up to mark in publications and patents.

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