Performance Assessment of Public-Funded R&D Organizations Working on Similar Research Streams: A Multinational Study

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Abstract

The subject of deriving a measure of efficiency of public-funded organizations (primarily not-for-profit organizations) and of ranking these efficiency measures have been major subjects of debate and discussion. In the present study, the methodology of data envelopment analysis (DEA) has been used to analyze the relative performances of public funded R&D organizations across multiple countries working in similar research streams with multiple measures of inputs and outputs. The keywords highlighting the major research areas in the field of non-metrology conducted by National Physical Laboratory (NPL) in India were utilized to select the global comparators working in similar research streams. These global comparators were three R&D organizations located in the USA and one each located in Germany and Japan. The relative efficiencies of the organizations were assessed with variables such as external cash flow (ECF) earned, technologies transferred, publications and patents as outputs and grants received from the parent body and scientific personnel as inputs. The study indicates suggested measures and a set of targets to achieve the best possible performance for NPL and other R&D organizations.

Conference Topic

Science Policy and Research Assessment

Introduction

Public funded research and development (R&D) organizations utilize public money either through government-supported research programs or other public supported activities. These organizations carry out scientific research, deliver technological services to the society and play a fundamental role in an increasingly knowledge-based society ushering in innovations necessary for the development of a competitive industrial system. Research and innovation have become strategic resources and assets to foster competitive national economies (Coccia, 2005). The ability to attract, develop and retain high quality scientific and technical manpower as well as self-sustenance by means of minimizing its dependence on state funding assume vital importance as it impacts delivery that not only addresses national needs but also ensures traction on a global scale.

Globally, public R&D organizations are currently striving to improve their performance as a result of enhanced competition due to liberalization and globalization, increasing demands on the existing resources and being accountable for optimum allocation of these resources. As the R&D process utilizes scarce resources, it becomes crucial to assess the efficiency of this process (Sharma & Thomas, 2008). In the recent past government efficiency concerns have increased, more so in the light of diminishing funds (Gupta et al., 2000). The emerging demand for evaluating the performance of R&D organizations is the result of relentless growth in global competition (Tassey, 2009). However, the provision of quality information

to decision makers through a performance measurement system assumes criticality in such a scenario (Cook et al., 1995).

One major problem in evaluating the efficiency of public institutions is the lack of a good estimate of the production function. The breakthrough came in the research work undertaken by Charnes, Cooper and Rhodes (1978), the first paper using the technique of data envelopment analysis (DEA), even though they never named it that way. The present study makes an attempt to assess the relative efficiency of the National Physical Laboratory (NPL), a constituent establishment of the Council of Scientific and Industrial Research (CSIR), India, with five selected global comparators working in the same research streams located in three countries - the USA, Japan and Germany. Finally, suggesting measures have been proposed highlighting a set of targets to achieve the best possible performance for those R&D organizations, which are less efficient.

Literature Review

It is difficult to measure the performance of an R&D organization because the nature of these organizations and the functions these organizations perform are complex, risky, and uncertain. As opined by Chiesa and Masella (1996), Bremser and Barsky (2004), Loch and Tapper (2001), Brown and Svenson (1998), and Jain and Triandis (1997), it is difficult to identify, measure and compare the performance of R&D organizations. Further, researchers have found it difficult to identify the various outputs/inputs as multiple parameters are involved in the system. As per the existing literature, there exists only a few studies that have been conducted on performance measurement of R&D organizations (Roy, Mitra & Debnath, 2013; Garg et al*.,* 2005).

R&D Output

Considering individual firms as the sample of their study, Pandit, Wasley and Zach (2011) consider R&D as an input to the innovation process and measures the productivity of a firm's innovative activities in terms of the number and the quality of patents. They argue that both of these variables are measures of innovation output or success, and proxy for the economic value of innovation. Chen, Hu and Yang (2011) suggest a multi-dimensional measurement schema including patents, royalties and licensing fees and journal articles. In their study on R&D and the national innovation system, Hu, Yang and Chen (2014) compare R&D efficiency among 24 nations during 1998-2005. In their multiple input-output framework, the input variables are R&D expenditure stock and R&D manpower and the output variables are patents, scientific journal articles, and royalty and licensing fees. Considering public research institutes, Matsumoto et al. (2010) have carried out case studies on market-impact creation outputs from the National Institute of Advanced Industrial Science and Technology, and have modelled R&D output generating economic impact along four stages – R&D output, technology transfer, commercialization, and market impact. This is in line with Roy et al.'s (2003) earlier study where a model to measure the effectiveness of research units was conceptualized. Likewise, research carried out by Laliene and Sakalas (2014) and Agostino et al. (2012) refer to the development of conceptual frameworks for R&D productivity assessment in public research organizations. Lee et al. (2011) have presented an R&D performance monitoring, evaluation and management system for national R&D to mirror not only short-term but also long-term R&D outcomes.

Methodology

Data envelopment analysis (DEA) as developed by Charnes et al. (1978) and extended by Banker et al. (BCC) (1984) has opened up new possibilities in evaluating the performances of many different kinds of entities (referred to as decision making units, DMU), engaged in

different activities and contexts (Cooper et al., 2004). DEA has been used widely to evaluate the performances of countries and regions (Rousseau and Rousseau, 1997, 1998), banks (Brockett et al., 1997), US air force wings (Charnes et al., 1985a), universities (Reichmann, 2004), Japanese manufacturing firms (Goto & Suzuki, 1989), journals (Lozano & Salmeron, 2005), R&D funding on education (Garg et al., 2005), etc. Publications and patents are used extensively to measure R&D efficiency and innovation (Pavitt, 1985). Evaluation of R&D efficiency could be advantageous to identify the better performers for benchmarking and choose better ways to improve efficiency highlighting areas of weakness (Sharma & Thomas, 2008). Charnes et al. (1985) have characterized a unit as influential if it is frequently used in the calculation of efficiency scores.

Researchers who have adopted the DEA methodology to evaluate performances of public research institutes include Rama Mohan (2005) and Roy, Mitra and Debnath (2013). Kim and Oh (2002) conducted a study on designing an R&D measurement system for Korean researchers. Wang et al. (2005) have developed extensive evaluation criteria for multidisciplinary R&D projects in China for ranking and rewarding. Roy et al. (2007) have earlier carried out a study on CSIR exploring the impact of age, research area, and rank on its scientific productivity, again using DEA as one of the methodologies.

Contextual Background of the Study

National Physical Laboratory (NPL), a premier institute of the Council of Scientific and Industrial Research (CSIR), India, has had a commendable track record of contributions and accomplishments since its inception and its scientists have received recognition for their contributions. Though maintenance and up-gradation of national standards of measurements remains the statutory responsibility of the organization, it is also involved in advanced non-metrology related research activities including engineering and electronic materials, material characterization, radio and atmospheric sciences, superconductivity and cryogenics.

A participatory workshop was conducted to diagnose NPL's R&D operations and to focus on aspects related to R&D performance. A particular research area (non-metrology) was selected for the purpose of the current analysis, and accordingly, the keywords, highlighting the organization's major research areas in this field, were utilized to shortlist global comparators. The keywords were searched in the SCOPUS database for a five-year period and global R&D organizations working on similar research streams were shortlisted. Five public R&D organizations were selected based on higher number of publications. These global comparators were the following:

1) National Institute for Materials Science, Japan (NIMS-JP, DMU-A),
2) National Renewable Energy Laboratory, USA (NREL-US, DMU-B),
3) Fritz Haber Institute of the Max Planck Society, Germany (FHI-DE, DMU-C),
4) National Centre for Atmospheric Research, USA (NCAR-US, DMU-D), and
5) Oak Ridge National Laboratory, USA (ORNL-US, DMU-E).

Data structure

The data regarding the inputs and outputs were collected for each DMU including NPL for a five-year period and are presented in Table 1. To ensure confidentiality, the exact period of the data cannot be revealed. Input variables considered in this study were: (1) grants received from the parent body, and (2) the number of scientific personnel (SP) whereas the output variables were: (1) business generated from the industry *i.e.,* external cash flow (ECF) earned, (2) technologies transferred (TT), (3) publications, and (4) number of patents filed.

The methodology to compare performance of any set of research institutes as suggested by Rama Mohan (2005) has been adopted in the present study. To illustrate the results on

efficiency assessment of public R&D organizations including NPL, one input variable and two output variables were considered at the same time.

Table 1. Input and output of different public R&D organizations (five year data).

Public R&D Organization	*Input*		*Output*			
	Grants (Million USD)	*Scientific Personnel (No.)*	*Technologies Transferred (no.)*	*Publication (No.)*	*Patents (No.)*	*ECF (Million USD)*
NIMS-JP - A	94	675	95	7480	195	20
NREL-US - B	141	307	53	2012	99	15
FHI-DE - C	72	206	1	1225	6	3
NCAR-US - D	185	310	5	2345	14	17
ORNL-US - E	107	1075	83	9144	90	23
NPL, India	47	216	3	1024	13	4

The DEAOS software was used for analysis. It analyzes relative performance of business units performing similar functions with an easy to use interface. It provides numerical and graphical output for easy interpretation and communication of results. Some of the key features of DEAOS are:

- The possibility to deal with 25 to 'unlimited' decision making units.
- Flexible facilities – importing from Excel file and direct entry of the data.
- Provides flexible input data management - possibility of addition and deletion of DMUs as well as rows and columns.
- Model input/output orientation selection.
- Provides a tabular scores report (with a variety of sorting methods) and a graphical summary.

Results

ECF generated and technologies transferred vs. scientific personnel

Ratios were calculated for each organization (Table 2) along two dimensions viz., ECF generated per scientific personnel and technologies transferred per scientific personnel. Figure 1 clearly shows that NREL-US (DMU-B) and NCAR-US (DMU-D) are the best performers exhibiting 100% relative efficiency. The efficient frontier, which envelops NIMS-JP (DMU-A), FHI-DE (DMU-C), ORNL-US (DMU-E) and NPL, represents relative efficiency of those organizations. It is observed that NIMS-JP, FHI-DE, ORNL-US and NPL exhibited relative efficiencies of 82, 28, 45 and 36 % respectively. To enhance efficiency from 36 to 46%, NPL is assumed to increase the input-output ratios from the current level of 0.86 to 1.10 (ECF/scientific personnel) and 0.014 to 0.018 (technologies transferred/scientific personnel). An improvement target of 10 %, keeping input (scientific personnel) constant, can be achieved during the next year, if NPL is in a position to increase its ECF to 1.6 M USD and transfer at least 1 technology (Table 3).

Table 2. External cash flow (ECF) and technologies transferred vs. scientific personnel.

Public R&D Organization	*ECF / Scientific Personnel*	*Technology Transferred / Scientific Personnel*
NIMS-JP - A	1.32	0.14
NREL-US - B	2.13	0.17
FHI-DE - C	0.69	0.00
NCAR-US - D	2.44	0.02
ORNL-US - E	0.94	0.08
NPL, India	0.86	0.01

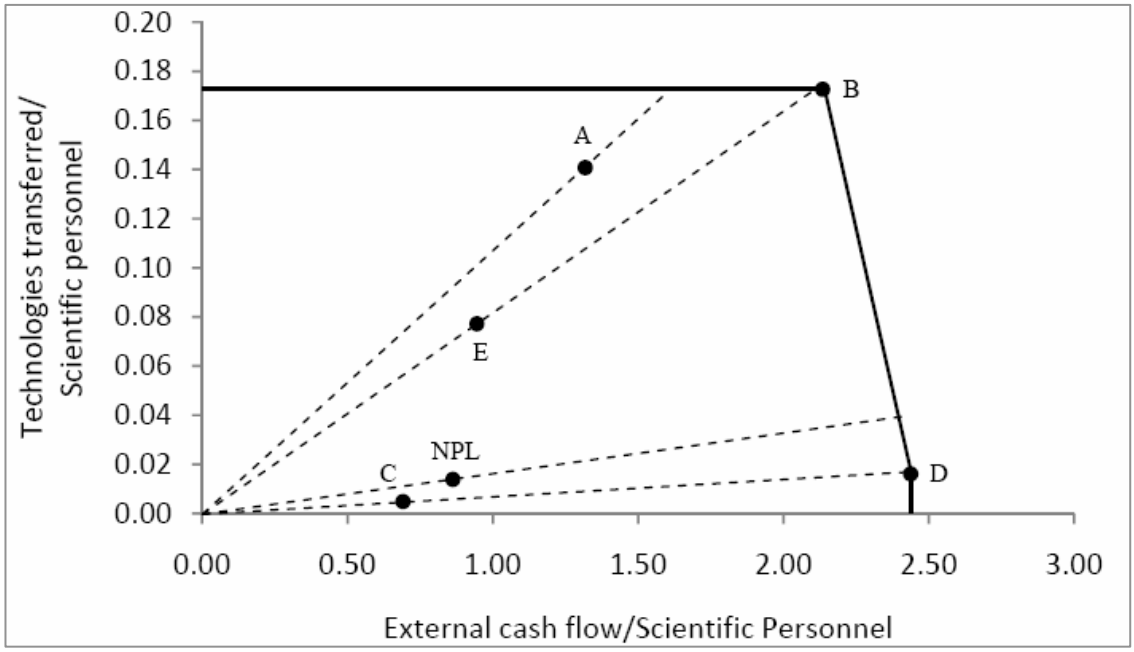

Figure 1. ECF generated and technologies transferred vs. scientific personnel.

Publications and patents vs. scientific personnel

To assess the relative performance of the R&D organizations, publications per scientific personnel and patents per scientific personnel were calculated (Table 4) and graphically represented in Figure 2. NIMS-JP (DMU-A) and NREL-US (DMU-B) show best performance exhibiting 100% efficiency in generating sufficient number of publications and patents per scientific personnel. Performance was found higher in case of ORNL-US (DMU-E) (77%) and NCAR-US (DMU-D) (67%) whereas FHI-DE (DMU-C) (54%) and NPL (43%) perform moderately. However, NIMS-JP is the reference laboratory all the organizations. To achieve improved targets by 10% during the next year, NPL and FHI-DE each would require to publish 240 and 230 papers and 9 and 12 patents respectively (Table 5).

Table 3. Targets for the R&D organizations to improve efficiency by 10%

(Scientific personnel count remaining constant)

Public R&D Organization	*ECF to earn (Million USD)*	*Technology to transfer*
NIMS-JP - A	6.8	12
FHI-DE - C	1.1	0.4
ORNL-US - E	5.1	19
NPL, India	1.6	0.8

Table 4. Pubclications and patents vs. scientific personnel

Public R&D Organization	*Publications / Scientific Personnel*	*Patents / Scientific Personnel*
NIMS-JP - A	11.08	0.29
NREL-US - B	6.55	0.32
FHI-DE - C	5.95	0.03
NCAR-US - D	7.44	0.04
ORNL-US - E	8.51	0.08
NPL, India	4.74	0.06

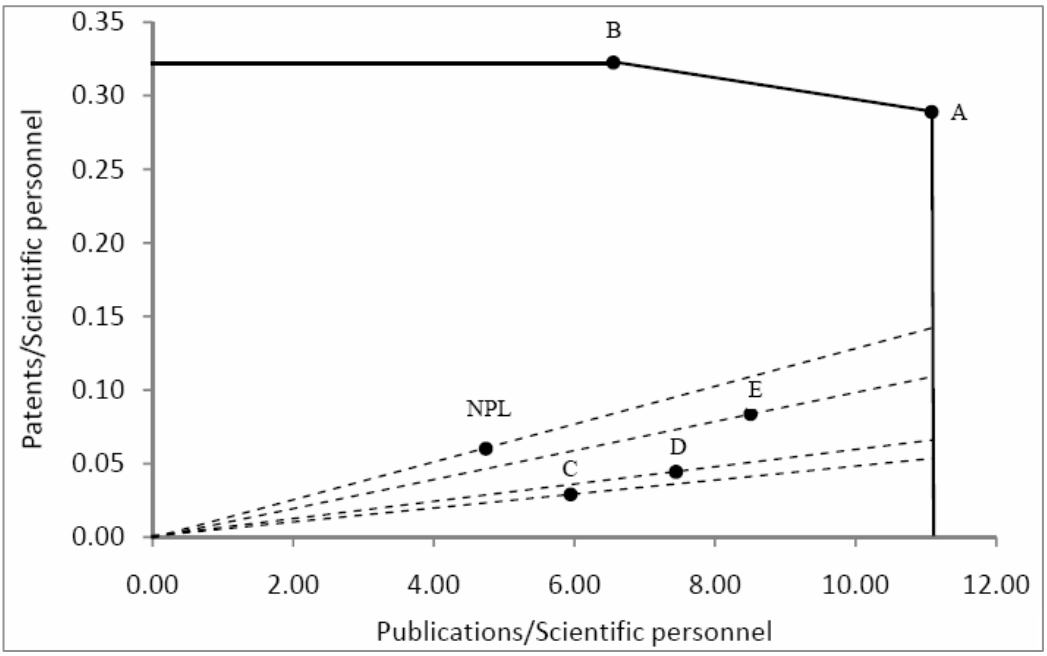

Figure 2. Publications and patents vs. scientific personnel.

Table 5. Targets for the R&D organizations to improve efficiency by 10% (Scientific personnel count remaining constant).

Public R&D Organization	*Publications*	*Patents*
FHI-DE - C	230	12
NCAR-US - D	347	23
ORNL-US - E	1204	96
NPL, India	240	9

ECF generated and technology transferred vs. grants

Next, relative efficiencies of the R&D organizations have been calculated along two outputs (ECF generated and technologies transferred) and one input (grants received from the parent body), (Table 6) and plotted in Figure 3. NIMS-JP (DMU-A) and ORNL-US (DMU-E) show best performance exhibiting 100% efficiency in generating sufficient amounts of ECF and number of technologies transferred per grants received. All the other organizations have ORNL-US in their reference set. To achieve efficiency by 10% during the next year, FHI-DE has to earn 1.5 M USD ECF and to transfer 7 technologies (Table 7).

Table 6. ECF earned and technologies transferred vs. grants received from parent body.

Public R&D Organization	*ECF / Grants*	*Technologies Transferred / Grants*
NIMS-JP - A	0.21	0.02
NREL-US - B	0.10	0.01
FHI-DE - C	0.04	0.00
NCAR-US - D	0.09	0.00
ORNL-US - E	0.21	0.02
NPL, India	0.09	0.00

Table 7. Targets for the R&D organization to improve efficiency by 10% (Grants received from the parent body remaining constant).

Public R&D Organization	*ECF to earn (Million USD)*	*Technology to transfer*
NREL-US - B	3	11
FHI-DE - C	1.5	7
NCAR-US - D	3.9	24
NPL, India	0.8	5

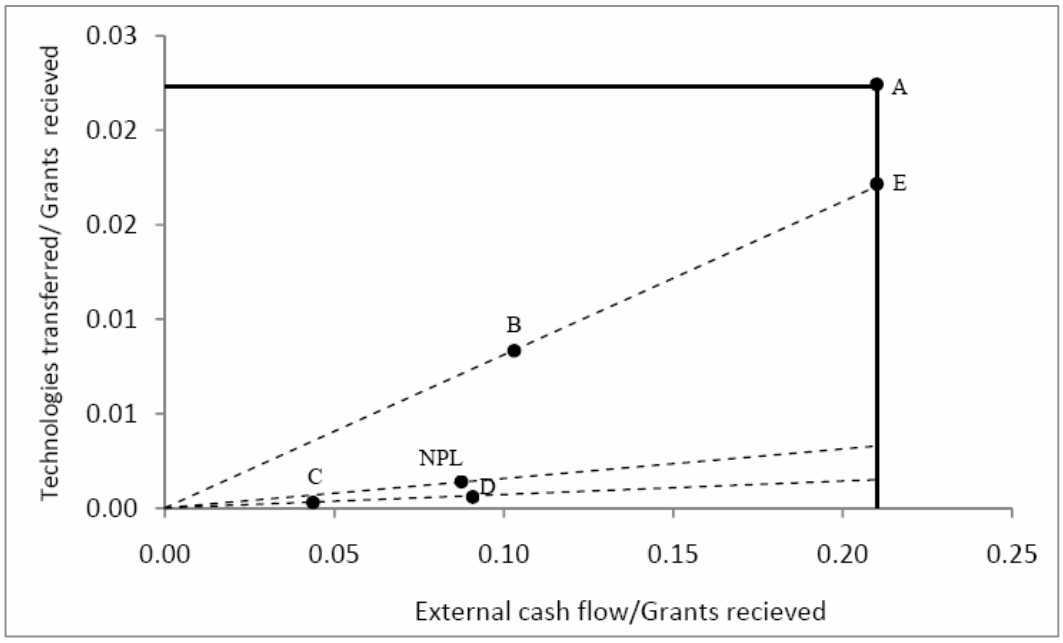

Figure 3. ECF generated and technologies transferred vs. grants received.

Publications and patents vs. grants

To assess the relative performance of the R&D organizations, ratios were calculated for publications per grants received and patents per grants received (Table 8) and graphically represented in Figure 4. NIMS-JP (DMU-A) and ORNL-US (DMU-E) show the best performance exhibiting 100% efficiency. NPL has both NIMS-JP and ORNL-US in its reference set whereas FHI-DE (DMU-C) and NCAR-US (DMU-D) relate only to ORNL-US whereas NREL-US (DMU-B) has only NIMS-JP in its reference set. To achieve efficiency by 10% during the next year, FHI-DE, NCAR-US and NPL have to increase their number of patents by a count of 7, 17 and 5 respectively from the current level (Table 9).

Table 8. Publications and patents vs. grants received from parent body.

Public R&D Organization	*Publication / Grants*	*Patent / Grants*
NIMS-JP - A	1.77	0.05
NREL-US - B	0.32	0.02
FHI-DE - C	0.38	0.00
NCAR-US - D	0.28	0.00
ORNL-US - E	1.89	0.02
NPL, India	0.48	0.01

Publication, patents, ECF generated and technology transferred vs. scientific personnel & grants

The relative efficiencies of R&D organizations on multi-input-multi-output six dimensional model keeping two inputs (*viz.,* scientific personnel & grants received) and four outputs (*viz.,* publication, patents, ECF generated and technology transferred) data have been calculated and the performance of each R&D organization under study is compared with that of every other one following the output oriented measure of efficiency at constant return to scale (CRS), variable return to scale (VRS) along with scale efficiencies (SE). The empirical analysis has been given in Table 10.

Table 9. Targets for the R&D organization to improve efficiency by 10 % (Grants received from the parent body remaining constant).

Public R&D Organization	*Publications*	*Patents*
NREL-US - B	1397	29
FHI-DE - C	617	7
NCAR-US - D	1575	17
NPL, India	399	5

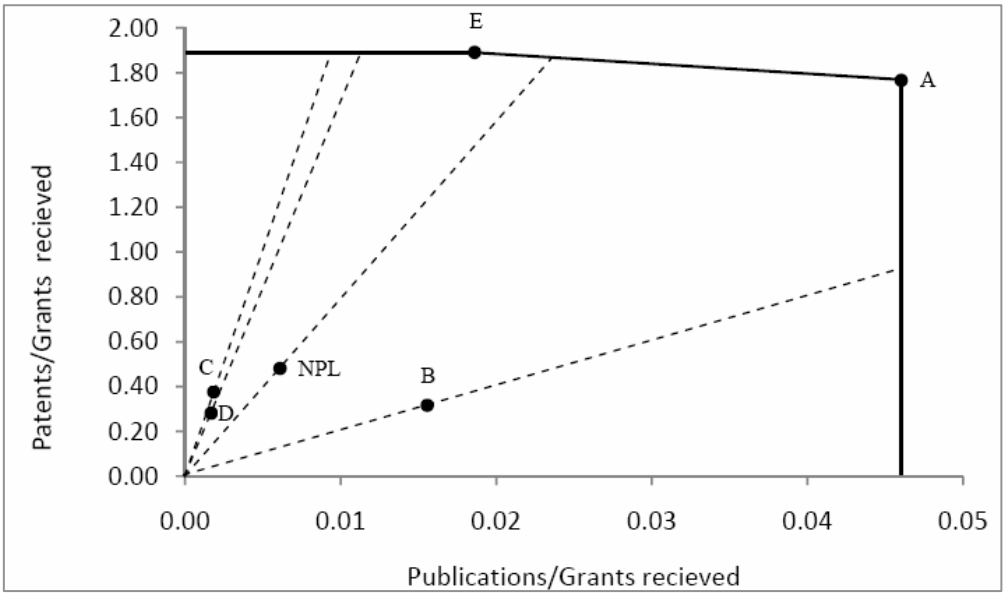

Figure 4. Publications and patents vs. grants received.

Table 10. Relative efficiency percentage of different public R&D organizations.

Public R&D Organization	*ECF & TT/SP*			*Pub. & Pat./SP*			*ECF & TT/Grants*			*Pub. & Pat./Grants*			*Pub., Pat., ECF & TT/SP & Grants*		
	CRS	*VRS*	*SE*	*CRS*	*VRS*	*SE*	*CRS*	*VRS*	*SE*	*CRS*	*VRS*	*SE*	*CRS*	*VRS*	*SE*
NIMS-JP - A	82	100	0.82	100	100	1.00	100	100	1.00	100	100	1.00	100	100	1.00
NREL-US - B	100	100	1.00	100	100	1.00	49	65	0.75	34	51	0.67	100	100	1.00
FHI-DE - C	28	100	0.28	54	100	0.54	21	25	0.84	20	27	0.74	54	100	0.54
NCAR-US- D	100	100	1.00	67	90	0.74	43	74	0.58	15	26	0.58	100	100	1.00
ORNL-US - E	45	100	0.45	77	100	0.77	100	100	1.00	100	100	1.00	100	100	1.00
NPL, India	36	94	0.38	43	85	0.51	42	100	0.42	26	100	0.26	57	100	0.57

Note: CRS: constant return to scale, VRS: variable return to scale SE: scale efficiency; (SE=CRS/VRS)

Technical efficiencies estimated under the CRS model are found to be less than the technical efficiencies coming from the more flexible VRS model. Under the CRS assumption, less average efficiency is found in case of FHI-DE (DMU-C) (54%) followed by NPL (57%) while under VRS, it was found that average technical efficiency score for all the DMUs is 100%, which implies that on an average DMUs could have used resources judicially to produce the same amount of output. However, under the scale efficiency (SE), the average score is found to be 0.54 in case of FHI-DE and 0.57 in case of NPL, which indicate that on an average the actual scale of production has diverged from the most productive scale size. In SE, the score 1 indicates that the DMU is operating at the most efficient scale or optimal size whereas SE less than 1 would be due to decreasing returns to scale (over production) or increasing returns to scale (under production).

Discussion and Conclusions

Over the past three decades, a variety of approaches, parametric and non-parametric, have been developed to investigate the failure of producers to achieve the same level of efficiency (Kalirajan and Shand, 1999). DEA which offers a non-parametric alternative to parametric frontier production function analysis has two advantages over the econometric one in measuring productivity change (Grosskopf, 1986). First, it compares the states to the 'best' practice technology rather than 'average' practice technology as is done by econometric studies. Second, it does not require the specification of an ad hoc functional form or error structure. In DEA, the less-performing units need more inputs to produce the same amount of output (Andersen & Petersen, 1993). DEA produces a piecewise empirical extreme production surface which in economic terms represents the revealed best-practice production frontier (Charnes et al., 1994).

In this study, the performance of each R&D organization (here the DMU) under study is compared with that of every other one following the output oriented measure of efficiency at constant return to scale (CRS), variable return to scale (VRS) along with scale efficiencies (SE). DEA has been used to analyze the relative efficiencies of the public funded R&D organizations keeping one input and two outputs at a time and results have been demonstrated in four possible dimensions. Secondly, the relative efficiencies of R&D organizations on multi-input-multi-output six dimensional model keeping two inputs and four outputs data have also been calculated. Comparatively less efficiency of NPL (0.57) that is a cause for concern might be due to its lower efficiency in generating sufficient amounts of external cash flow, number of technologies assumed to be transferred to the industry per scientific personnel as well as number of papers published and patents filed per grants received from the parent body.

The significance of the work presented in the paper stems from the fact that this is perhaps the first multinational study of relative performance assessment of R&D organizations, all of whom work on similar research themes. Relative performance assessment of different R&D organizations have been ascertained in the past (Roy, Mitra & Debnath, 2013) but the R&D organizations in question were working on diverse research streams. The focus of the current study, therefore, seems much more relevant as absolute comparators were first identified and thereafter assessed in terms of their performance characteristics. The present work has opened up new avenues for further research in this area.

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