PRE-PUBLISHING VERSION

Involvement and Productivity of Research and Development Workers: A Case Study of a Publicly-funded Research Laboratory

1. Introduction

Publicly-funded research organizations are usually operated and supported by government. Such organizations are typically set up by the relevant government in the interests and wellbeing of the nation. They are meant to carry on research and development (R&D) to provide benefit to each and every citizen of the country irrespective of their social status and taxpaying capability. On the other hand, privately-funded research organizations are privately-owned and operated by a limited group of people usually for their own benefit. These organizations are generally set up as subsidiaries to provide R&D services to address specific business needs of an industry. Both types of funded organizations are important as they contribute to the economic development of the country.

This study revolves around an Indian publicly-funded research organization. Such organizations in India include the national level research laboratories set up by the government with the broad principle of doing research for the scientific and technological advancement of the nation and the benefit of the society at large. These laboratories are supported by the government and their mandate is to carry out both basic and applied research. They are different from universities as the publicly-funded research organizations are principally focused on carrying out research whereas universities have a mixed focus on teaching and research.

High R&D productivity of a publicly-funded research laboratory helps increase the overall credibility of the organization. In this era of globalization with sophisticated information and communication technologies, accessibility to "knowledge" by all has increased global competition to satisfy stakeholders. To rank highly in the global competition it is necessary that both publicly- and privately-funded research organizations conduct innovative and world class research. A continuous improvement in productivity is necessary for research organizations to remain competitive (Karlsson et al., 2004). Productivity in general can be defined as "a measure of the amount of output generated per unit of input" (Linna et al., 2010) and the productivity of a scientist or researcher can be defined as the efficiency by which they produce R&D outputs, e.g. publications, patents and copyrights. Productivity indicators like "output", "international collaborations", "normalized impact", "high quality publication" and 'leadership' are considered when ranking world class research organizations (Scimago Institutions Ranking, 2012). To increase R&D productivity of a research laboratory, it is crucial to understand and analyze the determinants of productivity of research manpower.

As indicated above, this study focuses on the productivity of researchers in a particular Indian publicly-funded research laboratory. The research projects of the laboratory relate to the areas of metals, minerals and materials. The research projects carried out are either consultancy, collaborative, sponsored; grant-in-aid or network in nature. The consultancy, collaborative and sponsored projects are funded by private organizations and grant-in-aid projects are sponsored by government organizations. The network projects involve collaboration between industry, academia and research organizations. The researchers carrying out R&D in the laboratory belong to different age groups; have different educational background and specializations. The researchers have academic qualifications, such as PhD, postgraduate, graduate and diploma, in various disciplines. The laboratory has a system of annual performance appraisal for the researchers that comprises of various key productivity indicators such as number of publications, copyrights obtained, awards received, conferences attended and training programs organized. These parameters are evaluated when considering promotion of the researcher.

A number of studies on R&D productivity have been carried out in the past which have considered demographic, social and institutional factors like age, gender and social capital. However, few studies have been found which explore the factors affecting productivity of researchers of a publicly-funded laboratory in India and, in particular none have considered the determining factor of “man-days involvement” on R&D productivity. The term “man-days” refers to the number of working-days a researcher is engaged in a research project and is used as a unit for measuring involvement of researchers irrespective of their gender.

This study provides an insight in to the factors that may affect the high productivity of the researchers of a publicly-funded laboratory in India. It also examines the extent and type of involvement of the researchers of such a laboratory and how these impact on their productivity. The objective of the study is to identify factors affecting the productivity of researchers in a publicly-funded research organization in India and to identify the effect of the determinant “man-days involvement” on productivity of the researchers. The paper is organized into the following sections: Conceptual Background, Theoretical Background, Methodology, Preliminary Study, Hypothesis, Results, and Conclusion and Limitations.

2. Conceptual Background

Self Sustainability

In the current era, with a long-lasting economic recession and a developing trend of reduced research funding, the notion of “self sustainability” and “competitive advantage” are considered crucial by leaders of government institutions (Jacob and Lefgren, 2011). Although, the vision of a publicly-funded research organization remains inclined towards research that can benefit society, e.g. CSIR 800 program[1], it has become imperative for the organization to align their research more to long-term business goals of the research organization. Implementing “Total Quality Management (TQM)” principles has become an important factor affecting the business growth of a research organization. A “facilitator” who can adapt to research and can also guide in applying TQM principles to R&D processes is required (Kiella and Golhar, 1997) to gain the necessary improvements.

Depending on organization strengths, policies and mandate there can be different categories of projects existing in a publicly-funded research organization. Basic research projects are vital for the development of science and technology in any country; hence basic research projects are an indispensible part of the R&D profile of such a research laboratory. Apart from basic research projects; sponsored, collaborative and consultancy projects have also been a part of the R&D profile of a publicly-funded research laboratory. The sponsored projects generate external cash flow which in turn improves self sustainability of the organization and reduces their dependence on government funding. In order to enhance the number of sponsored projects, an organization needs to establish its credibility amongst its existing and probable customers and also needs to deliver on schedule. A research laboratory may work in two different modes - mission mode and sharing mode. In the *mission mode* the laboratory is involved in a mission-oriented activity by putting all the resources in one project and in the *sharing mode* the laboratory works in multiple projects that can integrate core areas [2] /non-core areas [3] simultaneously i.e. sharing resources in multiple projects at a time.

Manpower in R&D

Human resource is often seen as the most important resource for an organization. Proper manpower planning and management is considered vital for the successful and timely completion of projects and deliverables. The researchers or the "knowledge workers" are the "strategic assets" of an organization (Roy, 2003). Human resource development activities and R&D process innovation (using new and advanced technologies) also play a crucial role in improving employee productivity (Brooks and Nafukho, 2006; Parisi et al., 2006). The need for creating awareness among graduate students about the challenges in taking up a research career is frequently felt by employers (Giddings, 2008). It is evident from the literature that 50% of the graduates remain in a scientific profession only for three years and then switch over to other professions because of better remuneration packages (Chevalier, 2012). Several other professional and environmental factors like "work overload", "weekly working hours", "work dissatisfaction", "work interference with family" and "family interference with work" also influence a researcher's decision for leaving R&D and joining non R&D jobs (Post et al., 2009). Participation in non R&D jobs restricts the researcher from carrying on R&D and hence, affects the researcher's R&D productivity. "Job stability" and "tenure" are other factors that positively affect productivity of researchers (Cruz-Castro and Sanz-Menéndez, 2010). Attracting and retaining suitable talent, and deriving the desired level of productivity from them is an unmet need of the hour for the publicly-funded research organization.

For a research laboratory that works in the sharing mode (resources sharing in multiple projects), it is tricky to balance the ratio of experts to projects in any specific research domain. One-to-many relationship may exist between one researcher and one's assignments which if, not managed properly may affect their productivity in several ways (Moore, 2004; James, 2011). The role of a researcher in an organization can be many fold; e.g. project leader, project team member, head of division, client interaction, project budget management, team management, resource management, student mentoring and others. The job profile of a researcher includes both R&D and R&D administration. High amounts of involvement of researchers in the administrative jobs may reduce their involvement in the core R&D activities (James, 2011). This reduced R&D involvement may become a factor affecting the R&D productivity in an adverse way. It is evident from literature that only a small percentage of the researchers create impact in science by their contribution and only some of them are "star" performers in an organization (Turner and Mairesseb, 2005; Oettl, 2012, White et al., 2012). In order to achieve "self sustainability" and "customer credibility", achieving optimum manpower utilization is essential for a research organization.

3. Theoretical Background

Literature Review:

The key concepts of R&D productivity are twofold: one is productivity measurement and the other is productivity determinants. The techniques for measuring R&D productivity are defined by Pappas and Remer (1985) as 'quantitative', 'semi quantitative' and 'qualitative'. According to the authors, although all these approaches are useful in different studies, the ‘semi quantitative’ approach is the most useful, as it involves converting qualitative judgments to numbers.

Ramírez and Nembhard (2004) reviewed the available literature on R&D productivity measurement for the last sixty years and found that no generically-applicable model on productivity measurement for “knowledge workers” had been evolved. The authors examined the different variables and their frequency of use in various productivity measurement studies. “Quality” was the most frequently used variable for productivity measurement.

Linna et al. (2010) analyzed the “mechanistic” and “functional” views about public sector productivity and found that the productivity of a public sector organization cannot be measured without considering its “effectiveness on society”. Jääskeläinen and Uusi-Rauva (2011) emphasized the importance of designing “productivity measures” for each individual service of a public sector organization and observed that the quality of the entire productivity measurement technique is dependent upon how well the individual components are designed.

The determinants of researchers’ productivity can be grouped into Individual, Institutional/Laboratory and Environmental (See Table 1). Babu and Singh (1998) observed that individual factors have a greater impact on the R&D productivity of researchers than the institutional factors. These factors were “persistence”, “initiative”, “intelligence”, “creativity”, “learning capability”, “concern for advancement” and “professional commitment”. The authors found that the institutional factors like “resource adequacy”, “access to literature”, “stimulative leadership” and “external orientation” also impact R&D productivity.

“(take in Table 1)”

The determinant ‘age’ has been discussed many times by researchers in the past. These researchers have found both positive and negative effects of the determinant ‘age’ on R&D productivity. Bonaccorsi and Daraio (2003) analyzed the determinant ‘age’ with respect to the researchers of the Italian National Research Council (CNR) and found that productivity declines with the increasing age of researchers. Skirbekk (2004) also analyzed the determinant ‘age’ and found an inverted U-shaped profile of productivity for the age group of around 50 years and pointed out that the ‘bias’ may be due to the advantage of long term loyalty and social terms enjoyed by the higher age group in the organization for being selected as members in R&D activities. Turner and Mairesseb (2005) worked upon the individual and environmental determinants of productivity like ‘age’, ‘gender’, ‘citation' and ‘promotion’ and found a positive impact of ‘age’ and ‘promotion’ on productivity. The authors found a “life cycle effect” based upon the citation of papers of retired researchers. Skirbekk (2008) again analyzed the determinant ‘age’ and found that ‘age’ had a positive impact on productivity, especially, in those jobs that required the skills and experience of elderly people. The author advocates that “flexible work arrangements” and “flexible earning systems” help the aged workforce to benefit from their experience and extending their working lives. Obembe (2012) studied productivity with respect to Nigerian scientists. The author observed that the determinant ‘age’ had no significance in explaining productivity. He found that the determinant ‘field of research’ had a significant effect on their productivity. The author also concluded that the fields of research like ‘chemistry’, “bio-chemistry”, ‘pharmacy’ and “plant science” were found to be more productive than the fields of “physics”, “mathematics” and “electronics”.

Stack (2004) explored the impact of determinants such as “gender” and “having children,” on R&D productivity and found that “gender” had a significant effect on productivity. He also observed that women in permanent positions with young children had higher productivity as compared to women in temporary positions with young children. Mauleón and Bordons (2006) conducted a gender-based comparative analysis of productivity, specific to the scientists of Spanish Council for Scientific Research (CSIC). The authors examined the productivity indicators like "number of publications", "percentage of documents in "top journals", "publication practices" and determinants viz. 'age' and "professional category". The authors observed that women were less productive than men but insignificant differences between men and women were found when the influence of "professional category" and 'age' were analyzed. Mozaffarian and Jamali (2008) investigated the determinant "gender" with respect to Iranian researchers and found that the percentage of journal papers published by female authors was only 6% while that by male authors was about 94%, but this may simply represent gender distribution. Von (2011) analyzed the determinant "gender" and observed that being in the same "age" and "position" men had a higher average score of "public outreach and engagement activities" than women.

Strauss (1966) studied the determinants "job satisfaction" and "perceptions of one's own productivity" and found that these determinants were defined by personal variables such as "supervisors", "peer ratings" and "number of promotions". Karlsson et al. (2004) advocated to keep research and development as two separate entities and defined two different sets of related variables. The authors consider the application of such a productivity measuring approach that can handle company specific determinants of productivity and external factors like "changing customer demands" and "developments in the market". Wang et al (2006) analyzed the determinants "financial resources", "human resources" and "organizational infrastructure" with respect to the German research groups. The authors found that "human resources" was the weakest factor and "decreasing education quality" and "inadequacy of researchers" were the prime reasons behind it. Carayol and Matt (2006) worked upon the individual and collective determinants of productivity. The authors observed that "size of lab" had a negative impact on productivity. The determinant "intense and quality of colleagues' research activities" had a positive impact on productivity. Jindal-Snape and Snape (2006) analyzed the factors affecting motivation for the researchers of government organizations for improving their R&D productivity. The authors found that the factor "ability to do high quality, curiosity driven research" was highly motivating for the researchers whereas factors like "lack of feedback from management", "difficulty in collaborating with colleagues" and "constant review and change" were de-motivating them. Factors like "salaries", "incentive schemes" and "prospects of promotion" were not considered to be motivators for high productivity by the researchers and the removal of 'negative factors' was more important than new 'incentives'. Ohly et al. (2006) examined the determinants "routinization", "job control", "job complexity", "time pressure" and "supervisor support" and found that "routinization" had a positive impact on the "creativity" of outputs of a researcher. Anderson et al. (2007) analyzed the effects of the determinants "competition" (for funding, positions and prestige) on the R&D productivity of researchers in science. The authors found that "competition" has a negative impact on the "conduct of a researcher" and could be "damaging to innovation". Post et al. (2009) evaluated the professional and environmental determinants like "work overload", "weekly working hours", "work dissatisfaction", "work interference with family" and "family interference with work" against the "intentions of a researcher for leaving R&D and joining non R&D". Non R&D jobs would keep the researcher away from research and would therefore affect the researcher's R&D productivity. The author found that only the determinant "work dissatisfaction" had a significant effect on the researcher's intentions for leaving R&D. Kelchtermans and Veugelers (2011) observed that the researcher groups were highly heterogeneous with respect to the "system/incentive factors" like "promotion record" and "access to research resources". The authors found that these factors incentivize the researchers to produce quality research work.

Zuckerman (2001) analyzed the determinant "network heterogeneity (demographic diversity)" and found that R&D teams having a high demographic diversity had high productivity. Abramo et al. (2009) examined the effects of the determinant "collaboration" on productivity with respect to the Italian academic research system and found that the interdisciplinary scientific disciplines were impacted by "collaboration" positively. Rotolo and Messeni Petruzzelli (2012) examined the determinants "research specialization" and "cross-community ties" with respect to the R&D productivity of researchers and found that researchers having a "central position" in the "social capital" built by them have better productivity than others who did not have "social capital".

Reagans and Oeij et al. (2011) analyzed the "Q4 - model of productivity" having variables "input quantity", "output quantity", "input quality" and "output quality" and showed that the productivity of knowledge workers could also be explained by these four variables. Ragasa (2012) explored the impacts of "quantity" and "quality" of publications on R&D productivity with respect to the researchers of Nigeria and Ghana Agricultural Research System. The author found that "quantity" and "quality" improve "organizational effectiveness" and this effectiveness could enhance productivity of researchers. Krell (2012) suggested that although high journal impact factor was an indicator of high quality publications; to measure productivity the determinants like 'discipline', 'location' and 'language-group' must also be considered, as these determinants influenced highly the number of citations.

Vinkler (2007) analyzed the "eminence of a scientist" with the determinant "h-index" (Hirsch, 2005) and suggested that the correctness of the index must be verified from as many web sources as possible. The h-index is considered as the number of citations received for the publications of a researcher. Jacso (2008) studied the "h-index" and the pros and cons of the web databases (Google Scholar, Scopus and Web of Science), e.g. "software issues" and "consistency of coverage". The author recommended that while determining the "h-index" the limitations of these databases must also be kept in view.

Shin (1999) analyzed the moderating effects of IT on the variable "coordination" and found that "investment in IT" drastically reduced the costs of "economic coordination" in firms and helped to enhance "firm performance and productivity". Ehikhamenor (2003) evaluated the determinant "access to internet" against the "productivity" in terms of journal articles published by the researchers (specific to Nigeria) and found no significance of the determinant "access to internet" in the researcher's productivity. Winkler et al. (2010) studied the influence of "IT-based internetworking (BITNET, DNS) between educational institutions", "availability of electronic journal database (JSTOR)" and the "availability of electronic library resources" on the publishing productivity of researchers. The authors found that IT-based determinants improve the "careers of the faculty" mostly in "lower-tiered" institutions. Emelo (2010) analyzed the determinant "e-mentoring" on productivity and found that "e-mentoring" enhanced around 30% of the productivity/effectiveness. The author also found that "expanding my network", "interpersonal effectiveness" and "confidence in role" were the three ways in which the productivity could be enhanced. Prathap (2013) analyzed how the use of e-resources impacted the R&D productivity of publicly-funded laboratories and found that the optimum access and use of e-resources by the best performing laboratory was based on four primary indicators (in a specific time period) "number of publications", "the total citations earned by these papers", "number of downloads" and "the number of scientists in the laboratory".

According to the literature, the determinant 'field of research' was also found to affect productivity positively. Several institutional and environmental factors were also studied in the literature and the determinants "network heterogeneity (demographic diversity)", "intense and quality of colleagues' research activities", "organizational infrastructure", "high journal impact factor", "investment in IT", "e-resources", "access to research resources", "citations "routinization" and "collaboration" were found to affect R&D productivity positively. Also, the determinants like "competition" (for funding, positions and prestige) and "work dissatisfaction" were found to affect R&D productivity negatively. Particularly, Jindal-Snape and Snape (2006) explored that in a government set up factors like "lack of feedback from management", "difficulty in collaborating with colleagues", "salaries", "incentive schemes" and "prospects of promotion" were not considered to be motivators for high productivity by the researchers.

The determinant “man-days involvement” in different roles and types of projects may also affect R&D productivity of researchers in a publicly-funded laboratory setup. The studies exploring the relationship of R&D productivity with levels of involvements, areas of specialization, roles and project types were lacking in the literature. Analyzing the aforesaid relationships may bring to light new facts and perceptions about the factors affecting R&D productivity of researchers in publicly-funded research laboratories and may help leaders and managers of such laboratories to enhance R&D productivity. This study attempts to find the factors affecting R&D productivity in an Indian publicly-funded research laboratory and to examine the combined effects of these identified factors with the determinant “man-days involvement” on the productivity of researchers.

4. Methodology

Data and Variables

The data related to the researchers in the publicly-funded laboratory considered for this study. The data were collected both from primary and secondary sources. The primary sources of data collection were various institutional databases maintained by the laboratory e.g. an employee database and manpower involvement database. The secondary resources used to identify the R&D output (i.e. the number of papers published by the researchers in the journals listed in the Science Citation Index data) were web indices “Scopus” and “Web of Science”. The institutional database “eprints” was used to extract data on the R&D output (number of conference papers published by the researchers). The data used in this study covered 117 Scientists and Technical Officers having at least four years of experience and who had at least one R&D output in the form of a paper published in journals listed in the Science Citation Index or a conference paper (published in conference proceedings). Two dependent and 18 independent variables were initially considered for the analysis (See Table 2). These variables were selected on the basis of the literature review and data availability. However, only those independent variables were used in the regression analysis which had shown high correlation with the dependent variables. The independent variable ‘Experience (experience)’ was not considered to be used in the study as the variable ‘Age (age)’ and ‘Experience (experience)’ were highly correlated and were providing redundant information. Similarly the independent variables “Man-days Involvement as Member (membermiv)” and “Total Manpower Involvement (miv)” were correlated. Hence, both these variables were not taken together as predictors in any of the regression models. The statistical software used in this study internally identifies and treats the categorical variables as “dummy variables” and assigns “dummy coding” or numerical reference values to them e.g. subject a is marked 1 and subject b is marked 2.

“(take in Table 2).

Robust Regression:

The software used for the statistical analysis includes “Systat 11” and R. The “Shapiro Wilk-Test for Normality” revealed that the p-value for all the variables is less than the default alpha value 0.5 (equivalent to confidence interval of 0.95%). Hence, none of the variables follow a normal distribution. Since the data represent a population and both dependent and independent variables have a wide range of values, the outliers are significant. An analysis was executed to examine the ways in which the independent variables affected the outliers. Since the data failed to fit the normal distribution, the normality assumption required for "Linear Regression" could not be fulfilled. Hence, the "Robust Regression (Linear)" method of analysis was used.

The Robust Regression (Least Median of Squares estimation) is much less sensitive for data with significant outliers than the Least Square Regression. Further, the Least Median of Squares estimation has the highest breakdown value compared to the other estimation techniques in "Robust Regression" e.g. Least Trimmed Squares (LTS) Estimate, M Estimate, Yohai MM Estimate, S-Estimate (Kim,2004; Alma,2011). We have used the "R" software with the package "Robust" for carrying out Robust Regression analysis. The sub-packages required to run the package "Robust" were also installed e.g. "Robust Core", "FDA", "SDE","ZOO". The Shapiro Wilk test results were tabulated (See Table 3).

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5. Preliminary Study

The scope of the study was confined to an Indian publicly-funded research laboratory whose mandate is to carry out research in the areas of metals, minerals and materials. This laboratory conducts research in multiple core and non-core area projects with shared resources and manpower. The largest number of technical manpower and projects are in the core area "Evaluation of Materials/Materials Engineering" (See Figure 1 and 2). The R&D projects of the laboratory comprise different categories of projects, out of which the grant-in-aid/network category has the maximum number of projects. Also, the maximum amount of external cash flow is generated from grant-in-aid/network category of projects (See Figure 3 and 4).

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The scientific manpower of the laboratory comprises scientists, technical officers, project assistants, technical assistants and other permanent and temporary staff to assist in the research activities. There are divisions or units that are either of R&D or R&D-Support type. The research team for carrying out any research project is formed according to the technical competence required in the projects. Also, the availability/involvement data is referred to from the database records before assigning new projects to manpower in the project approval form. The laboratory has the following policies with respect to the involvement and productivity of the scientific manpower:

i) A maximum of 80% of the total man-days in a year may be booked in R&D projects and the remaining 20% to be spent in self-development activities, extracurricular activities, committee memberships and other non-R&D activities.

ii) Any scientific manpower having an involvement of more than 80% in research projects annually is considered to be over-utilized and an involvement of less than 40% annually is considered to be underutilization of the scientific manpower,

iii) The average number of publications in SCI Journals per year, per researcher, should be at least one.

In the year 2011-12, a web-based survey was carried out in the laboratory as a part of the "Competence Mapping [4]" exercise for the researchers. This survey provided information on the percentage of man-days involvement in different competence areas, e.g. R&D projects, R&D administration, equipment handling and others. The survey inputs were compared with the actual records available in institutional databases and significant differences were noticed in the average percentage man-days involvement (See Table 4).

"(take in Table 4)"

The primary study of the records of the involvement data (direct booking of man-days in R&D projects) reflected that the average percentage utilization of manpower was 39%. Manpower utilized and underutilized were 7.69% and 63.25% respectively. The average yearly count of the outputs generated by the researchers in terms of papers published in SCI Journals and papers published in conference proceedings were 1.5 and 1 respectively. The above data indicate that besides the fact that a large part of the scientific manpower needs to be involved in more R&D activities, their respective outputs were more than the minimum threshold set by the organization. Hence, this mismatch in input and output gave rise to questions like:

- What are the factors that are responsible for under utilization/ over utilization of manpower?
- What are the factors that affect R&D productivity of manpower?
- Is there any relationship between manpower utilization and manpower productivity?
- How does man-days involvement affect R&D productivity of manpower?

In this study we have tried to find answers to questions related to man-days involvement and productivity of researchers. An analysis of the factors affecting the utilization of researchers is beyond the scope of this study.

6. Hypothesis

From the preliminary study it was observed that more than 50% of the researchers were underutilized. The researchers are supposed to be mostly involved in R&D and their annual research productivity is considered an important parameter for their performance evaluation and promotion. One of the factors which may affect the individual productivity can be high man-days involvement in R&D Projects.

It is generally assumed that if a researcher is very involved in R&D then his/her scientific output will be higher than normal. Involvement in a variety of projects provides exposure to different research areas and enhances the collaboration with inter-organizational and intra-organizational team members. These team members may have different “perspectives” and “skills” which may lead to “innovation” (Cummings et al., 2013). Different team members may also have “demographic and functional diversity” which can be advantageous to R&D productivity (Faems and Subramanien, 2012). Hence, the prospect of obtaining new results and publishing new papers or filing new patents increases.

Another factor that may affect the productivity of an individual is the role of the researcher in projects. The responsibilities of a project leader includes both R&D and project administration (project coordination, budget management and overall integration of project activities and results) and hence the man-days involvement of a project leader remains highest compared to other team members of a project. On the other hand participation in a number of projects as a team member may prove to be valuable for the researcher. The researcher may get an insight into a variety of research problems and hence may produce new scientific outputs based on the findings.

An important factor that may explain a high R&D productivity is the category of projects. The projects in grant-in-aid/network category are long term and of high value. The allocation for travel is usually available in the budget allocation of these projects. Hence attending conferences/ seminars/ workshops for knowledge updating can be funded. Therefore, the chances of conference publications from these projects are more than the other category of projects.

The preliminary study reflects that the average individual involvement in all variety of projects is 68.63 man-days annually. Out of all projects the yearly average individual involvements were 37.12 man-days in grant-in-aid/network projects, 17.43 man-days in sponsored projects and 14.08 man-days in other exploratory laboratory projects. The average individual involvement as a project leader and member were 11.93 and 59.32 man-days respectively. The average number of projects handled as a leader is much less than the number of projects in which one has participated as member i.e. 0.37 nos. and 1.68 nos. respectively. Hence, based on the above factors the first set of null (H0) and alternative (H1) hypotheses for finding out whether any relationship exists between the man-days involvement and the manpower productivity has been framed as follows:

$H0_1$: *High man-days involvement as a member leads to high scientific productivity in the form of SCI papers published.*

$H1_1$: *High man-days involvement as a member does not lead to high scientific productivity in the form of SCI papers published.*

$H0_2$: *High man-days involvement leads to high scientific productivity in the form of SCI papers published and conference publications.*

$H1_2$: *High man-days involvement does not lead to high scientific productivity in the form of SCI papers published and conference publications.*

$H0_3$: *High man-days involvement in grant-in-aid projects leads to high scientific productivity in the form of SCI papers published and conference publications.*

$H1_3$: *High man-days involvement in grant-in-aid projects does not lead to high scientific productivity in the form of SCI papers published and conference publications.*

$H0_4$: *Involvement in a large number of grant-in-aid projects leads to high scientific productivity in the form of SCI papers published and conference publications.*

$H1_4$: *Involvement in a large number of grant-in-aid projects does not lead to high scientific productivity in the form of SCI papers published and conference publications.*

The next null (**H0**) and alternative (**H1*)*** hypothesis based upon the factor "subject" which may explain manpower productivity are defined here. The maximum number of projects and the maximum manpower strength are in the laboratory's core area "Evaluation of Materials/Materials engineering" (See Figure 1 and 2). Hence, it can be expected that the productivity may be highest in the major core area of the laboratory.

$H0_5$: *High man-days involvement in the subject area "Materials Science" leads to high scientific productivity in the form of SCI papers published and conference publications.*

$H1_5$: *High man-days involvement in the subject area "Materials Science" does not lead to high scientific productivity in the form of SCI papers published and conference publications.*

The next set of null (**H0**) and alternative (**H1*)*** hypothesis are defined based upon a combination of factors like "man-days involvement" and "age group" which together may explain manpower productivity. Young researchers who are in the initial years of their service are filled with bright ideas and may utilize their R&D involvement in converting those ideas into scientific outputs (Skirbekk, 2004). On the other hand researchers gain experience and exposure in a variety of research problems with increasing age which results in more experience. Thus, they may analyze and interpret new and existing results innovatively. Hence, the chances of producing high impact output increases.

$H0_6$: *High man-days involvement in the initial years of service leads to high scientific productivity in the form of SCI papers published and conference publications.*

$H1_6$: *High man-days involvement in the initial years of service does not lead to high scientific productivity in the form of SCI papers published and conference publications.*

$H0_7$: *High man-days involvement and high level of experience leads to high scientific productivity in the form of SCI papers published and conference publications*

$H1_7$: *High man-days involvement and high level of experience does not lead to high scientific productivity in the form of SCI papers published and conference publications.*

7. Results

The robust correlation coefficients between the dependent and independent variables are tabulated (See Table 5). The robust correlation coefficients equal to or higher than 0.60, are considered to be significant for the current study. The descriptive statistics of the variables having a significant robust correlation and that have been used further for the regression model building are tabulated (See Table 6). The results of the regression models are also tabulated (See Table 7).

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Take in Table 7 about here

The first robust regression model shows that the independent variable "Man-days Involvement as Member (membermiv)" is significant in explaining the dependent variable "Papers published in SCI Journals (jpaper)". This model is able to explain the dependent variable in 74.87% of the cases in the dataset. According to this model, the manpower having high man-days involvement in R&D projects as member is also publishing highly in SCI Journals. Hence, the first null hypothesis (***$H0_1$***) was accepted. The alternate hypothesis ***($H1_1$***) is rejected.

The second model shows that the independent variable "Total Manpower Involvement (miv)" plays a significant role in explaining both the dependent variables "Papers published in SCI Journals (jpaper)" and "Papers published in conference proceedings (cpaper)". This model is able to explain the dependent variables in 74.74% of the cases in the dataset. According to this model the manpower having high man-days involvement in R&D projects is also connected to publishing significantly in SCI Journals and conference proceedings. Hence, the second null hypothesis (***$H0_2$***) is accepted. The alternate hypothesis ***($H1_2$***) is rejected.

The third model shows that the independent variable 'Man-days Involvement in the "Grant-in-aid category of projects (gapmiv)" is significant in explaining both the dependent variables "Papers published in SCI Journals (jpaper)" and "Papers published in conference proceedings (cpaper)" in 78.61% of the cases in the dataset. According to this model, a high man-days involvement in the grant-in-aid projects aids high R&D productivity. Hence, the third null hypothesis (***$H0_3$***) is accepted. The alternate hypothesis ***($H1_3$***) is rejected.

The fourth model shows that the independent variable "Number of Projects in Grant-in-aid Category of Projects (gapcount)" is significant in explaining both the dependent variables "Papers published in SCI Journals (jpaper)" and "Papers published in conference proceedings (cpaper)" in 78.78% of the cases in the dataset. According to this model, an involvement in a large number of grant-in-aid projects leads to high R&D productivity. Hence, the third null hypothesis (***$H0_4$***) is accepted. The alternate hypothesis ***($H1_4$***) is rejected.

The fifth model shows that the independent variable "Subject (subject)" is significant in explaining the dependent variables "Papers published in SCI Journals (jpaper)" and "Papers published in conference proceedings (cpaper)" in 75.47% of the cases in the dataset. The subject area "Material Science" is an indicator of the major core area of the laboratory i.e. "Materials Engineering/Evaluation of Material". It is reflected in the model that the subject "Material Science" has the highest level of significance in explaining the dependent variables. Hence, the fifth null hypothesis (***$H0_5$***) is accepted. The alternate hypothesis ***($H1_5$***) is rejected.

The last set of hypotheses try to relate man-days involvement and R&D productivity with the level of experience. The second, third and fourth models show that the independent variable

'Agegroup (agegroup)' is significant in explaining both the dependent variables 'Papers published in SCI Journals (jpaper)' and Papers published in conference proceedings (cpaper). The variable 'agegroup' has been used as a factor variable in the models. The output of the models shows significance in the age group 30-39 and 50-59. Manpower in the age group 30-39 are usually in their initial years of employment, more enthusiastic while exploring their domain of research and in the process produce high scientific output. Hence, the sixth null hypothesis ($\boldsymbol{H0_6}$) is accepted. The alternate hypothesis ($\boldsymbol{H1_6}$) is rejected.

The models also indicate that the manpower in the age group of 50-59 has high scientific output. The manpower in this age group has gained a high level of experience in their research domains. Hence, the seventh null hypothesis ($\boldsymbol{H0_7}$) is accepted. The alternate hypothesis ($\boldsymbol{H1_7}$) is rejected.

Other notable results found were: Model 1 shows that all the age groups were significant in explaining the output "Papers published in SCI Journals (jpaper)" for all the researchers having high man-days involvement as member and the subject areas "Chemistry" and "Biology" were also significant in explaining the R&D productivity of the manpower having a high amount of total "man-days involvement".

Findings and Implications:

The determinants "man-days involvement" and "role of a researcher" were rarely found to be focussed on in the literature. The current study has observed a strong relationship between these determinants and the productivity of researchers in a publicly-funded research laboratory. It implies that R&D productivity of the researchers' may be enhanced by participating in a large number of projects as members. Being a project member, the researchers need not spend time in the project management/coordination activities as compared to the project leader. They may in turn devote this time to solving research problems and bringing out the research results in the form of publications. The research organizations may encourage project participation of their researchers as members to increase their R&D productivity. This may be done by making policies which may balance the activities of researchers in different roles. On the contrary, being project leaders of numerous projects may be preferable for certain researchers as it provides opportunities like client interaction and image building by successful execution of projects. "Number of projects led" could be one of the productivity parameters in the annual performance appraisal process. Further in-depth studies may be pursued to reveal the fruitful facts about the determinant "role of a researcher" at different experience levels and in different types of projects on R&D productivity.

Other findings of the present study confirm the findings of James (2011) that a researcher must be involved in R&D more than R&D administration or R&D support services. Higher man-days involvement in R&D projects gains higher R&D outputs. It implies that research laboratories may put in effort to increase the R&D involvement of their researchers up to a minimum threshold in order to achieve a desired level of R&D productivity. This may also be considered as another productivity parameter in the performance evaluation of researchers. Another finding of the present study also points towards the previous linkage of R&D involvement with productivity. It specifies that high R&D involvement in a large number of grant-in-aid/network projects leads to high R&D productivity. Researchers involved in grant-in-aid/ network projects get the advantages like collaborating with cross-cultural team members, working in interdisciplinary research areas, getting travel grants for attending conferences and seminars and getting funds for facility creation. The studies of Zuckerman (2001), Faems and Subramanien (2012), Abramo et al. (2009), Kelchtermans and Veugelers (2011), Rotolo and Messeni Petruzzelli (2012) and Cummings et al. (2013) on “network heterogeneity (demographic diversity)”, “functional diversity”, “collaboration of interdisciplinary scientific disciplines”, “network diversity”, “cross community ties” and “collaboration with inter-organizational and intra-organizational team members” respectively also go in line with the above findings. This implies that the research laboratories may participate in a large number of network projects and facilitate their researchers to enhance their R&D productivity.

The publicly-funded laboratory considered for the present study has the largest set of researchers in its major core area of research. The results show that high “man-days involvement” of the researchers having specialization in the major core area of laboratory links to a high level of R&D productivity. Obembe (2012) also found that the determinant ‘’research area” influences R&D productivity. This implies that the research organization must keep in view its core strength area while doing business and planning manpower.

A large amount of literature is available with respect to the determinant ‘age’ and its relationship with R&D productivity. According to Skirbekk (2004), Turner and Mairesseb (2005) and Skirbekk (2008) the increasing ‘age’ of researchers has a positive effect on productivity where as Bonaccorsi and Daraio (2003) observed declining effects of ‘age’ on productivity. On the other hand, Obembe (2012) found no affects of ‘age’ on productivity. The present study has reflected that ‘age’ has a strong positive effect on the productivity of researchers. Researchers having high “man-days involvement” during their initial years of service and around 50 years of age have a high R&D productivity. This implies that the research organizations should encourage young researchers to participate in a large number of projects and gain knowledge while the experienced researchers who have already developed specialization in their respective research domains may be encouraged to increase their project participation as mentors. The results show that manpower in the 40-49 age group has a moderate level of R&D productivity. Further studies need to be taken up to find out the factors affecting the low productivity of the researchers in the age group 40-49.

8. Conclusion and Limitations

In this study “man-days involvement” has been introduced as a determinant for explaining the productivity of manpower in R&D at a publicly-funded research laboratory. The statistical analysis technique “robust regression” was applied to the data specific to this publicly-funded research laboratory and it was found that there is a significant relationship of “man-days involvement” and “manpower productivity” in this research laboratory. Different regression models indicated that the manpower productivity was dependent upon the determinants “Total Man-days Involvement”, “Man-days Involvement as Member”, “Man-days Involvement in Grant-in-aid Category of Projects”, “Number of Projects in Grant-in-aid Category” and the two factor variables ”Age group” and “Subject”.

The role and amount of involvement in R&D projects, the category of projects, the area of work and the experience level of researchers contribute towards increased R&D productivity. The amount of involvement and the productivity of the researchers were proportional for about 80% of the cases in the dataset. It was also observed in most of the cases that the researchers having a high involvement in R&D projects also had a high R&D productivity. Researchers having a high involvement in the projects belonging to the core area of the laboratory had a reasonably high productivity.

A limitation of the study is that the data and results are specific to one publicly-funded research laboratory. There is scope for extending the analysis to a larger data set to get further insight into the factors affecting the productivity of researchers and their implications. Further studies can be taken up with a further number of quantitative and qualitative factors, e.g. extent of national and international collaboration, number of students guided, number of trainings organized and extent of cooperation. Other output indicators, e.g. impact factor, patents, books published, number of projects completed as project leader, amount of software developed and copyrights, may also be taken into consideration in further studies. It was observed that the strength of female researchers (9.26%) in the laboratory under consideration in this study is lower in comparison to the male researchers. Another study could be taken up to examine the factors affecting the low strength of female researchers in the laboratory and its effect on R&D productivity of the laboratory. An attempt has been made in this study to find the relationship between "man-days involvement" and "manpower productivity". Further studies can be pursued to find the relevant factors which can increase "manpower utilization" at different positions and levels of experience.

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Notes:

[1] CSIR 800 program-A Council of Scientific and Industrial Research (CSIR), India program to improve the lives of 800 million people of India through S&T interventions.

[2] core area- Core research areas of laboratory e.g. Materials Evaluation

[3] non-core- Non core research areas of laboratory

[4] Competence Mapping- A technical competence mapping exercise for the redeployment and future manpower planning exercise.