Assessment of Quality Performance of Public R&D in India and the Strategic Role of Knowledge Management: Evidence from a Longitudinal Study

Roy, Santanu (1); Mitra, Jay (2)

1: Institute of Management Technology, Dubai, United Arab Emirates; 2: Essex Business School, University of Essex, Essex, United Kingdom

Abstract

We investigate the relationship between the structure and functioning of scientific and technical personnel and the quality R&D performance output record in laboratories functioning under the Council of Scientific and Industrial Research (CSIR), the primary umbrella for such laboratories in India. Our objective is to examine how rapid economic and social changes and the demand for better accountability are addressed by R&D institutions in a specific developing economy. We explore whether the knowledge and capabilities of knowledge workers are critical to the meeting of goals in such contexts. We draw on the role of tacit knowledge and thus organizational learning, and empirical research on managing R&D which encompasses the innovations that result from it. We use the functions performed by the scientific and technical manpower as indicators of their tacit knowledge. We use data from 27 different CSIR laboratories to analyze the specific functions carried out by these sets of knowledge workers in order to gauge the internal strengths and weaknesses of individual laboratories in different functional areas adopting the methodology of correspondence analysis, and relate this information to the quality performance output record of these laboratories over an extended period of eleven years (2003-04 to 2013-14). Our research highlights the importance of strategic management of technology practices including carrying our research and development work, supporting pilot plants, experimental field stations and engineering and design units and how tacit knowledge in these areas impact the performance of these laboratories, and the stability of such impact over time. The paper has particular implications for public R&D management leadership for innovation in a developing economy context. The paper provides critical insights into our understanding of public R&D management for innovation in an emerging economy, a relatively under researched area, in the field of innovation management. This work should be of value for planning and decision making for practitioners and policy makers engaged in global R&D based projects, innovation management and entrepreneurial outcomes.

Keywords: Scientific and technical personnel, tacit knowledge, quality R&D performance output, CSIR, India

1. Introduction

There is an urgent need to strategize and spend higher amounts of money on India's development needs which can be served by science, technology and innovation together with the alarmingly low levels of research and development (R&D) investment and activity in a country which boasts of rapid economic growth of between 6% to 8% for over a decade now. Indian science and technology development reflects the type of contradictions symptomatic of poor strategic direction and management of its resources. The relative pluses and minuses in the science and technology landscape of India raises critical questions of the management of research activities. Given the paucity of private sector investment much of the emphasis lies on the public sector's ability to drive research excellence and hence the need for ensuring effective deployment of research management capabilities.

The present study investigates into the relationship between the structure and functioning of knowledge workers and their quality R&D performance record over an extended period of eleven years, in laboratories functioning under the Council of Scientific and Industrial Research (CSIR), the primary umbrella for such laboratories in India. Such R&D performance measurement studies have assumed criticality in view of the growth in global competition (Tassey, 2010). The knowledge workers in this context are the scientific and technical (S&T) personnel working in different fields of activities like research and development, infrastructure, workshops, and engineering and design units in the CSIR laboratories. Knowledge workers add value to an organization through their ideas, analysis, judgment, synthesis and designs (Horibe, 1999, 2003). The major working tool and resource for a knowledge worker is knowledge that is intangible in character and the observer does not see and know how knowledge workers uses knowledge when creating values (Firestone and McElroy, 2005).

The rest of the paper follows a route that takes the reader through a critical review of the literature on key aspects of organisational processes that impact on R&D management, including organisational learning and especially tacit knowledge, the context of the CSIR laboratories in India providing the organisational backdrop for our empirical investigation, the methodology adopted for our research, a presentation of the findings and a discussion of the implication of those findings for both R&D management, especially in the public sector, and public policy relevant to emerging economies.

2. Literature Review

In recent times, there have been perceptible thrust on enabling knowledge creation (Von Krogh *et al*., 2000), especially in the way scientific and technical knowledge is produced and if these changes are pervasive across fields of S&T activity, they would affect R&D and innovation systems (Freeman, 2006). Multidimensional orientation of research and development activities in leading-edge research areas and indeed the process of innovation implies that in order to solve problems, generate innovative outcomes and ensure effective management of R&D, effective utilization of knowledge and skills in different areas are needed. Kimura's (2010) study on 34 technologies developed in two major projects in the area of demand-side energy efficiency conducted in the 1980s and 1990s by public R&D in Japan observes that while public R&D investments have a high risk of failure, they can bring new technologies to the market after a certain lead time. In addition, several factors resulting in the success or failure of commercialization/diffusion are identified, such as long-term R&D support by the government, a marketing strategy to respond to and influence market demand, and combination of R&D and deployment policy.

In a seminal piece of work, Nelson (1982) models the role of knowledge in R&D considering various sources of such knowledge. The model employs a 'knowledge capital stock', and also illuminates the dual private and public nature of technological knowledge. Given specific contexts and non-transferable or inimitable sets of competencies located in those contexts, the role of tacit knowledge has been identified as a key source of new knowledge production. Tacit knowledge provides much of the basis for the way we interact with people and situations. It is embodied in people, rather than in any codified form or in tangible objects. In most cases it is difficult to transfer such knowledge between people even if it can be acquired by a firm through hiring people, R&D and interpersonal networking. In most organizations, good practice is based on rich experience which cannot possibly be codified into written forms. But once it is exposed there is a possibility for testing such knowledge with a view to harnessing and developing it. However, there are difficulties with this process. If we follow Polanyi's (Polanyi, 1967, 1969) definition it may not be possible at all to carry out those tests. Tacit knowledge has been recognized as a major input to any technological innovation effort, much of it being captured in decentralized units and structures (Pitt and Clarke, 1997). Alwis and Hartmann (2008) examine the use of tacit knowledge within innovative organizations and what organizations can do to promote knowledge sharing in order to improve successful innovation. Studies of innovation, technology transfer and technology diffusion identify tacit knowledge as an important contributor of technological innovation and organizational competitiveness. Koskinen (2004, p. 15) mentions, 'Tacit knowledge presents knowledge based on the experience of individuals. It expresses itself in human actions in the form of evaluations, attitudes, points of view, commitments, motivation, etc.'. In another interesting study, Vuolle *et al*. (2009) examine the measurement of intangible aspects of research and development (R&D) projects, particularly from the funding organization's point-of-view.

Alexeis and Mitra (2007) have pointed out that contextual complexities as a result of the nature of knowledge-based resources of organizations are increasingly the bases of competitive advantage. According to Pimentel and Albino (2010), the search for competitive advantage in a global environment must consider the use of tacit and explicit knowledge circulating inside companies. The generation of tacit knowledge is an inevitable adjunct to advances in science and technology, and organizations acquire such knowledge to support innovation in a purposive manner. However, not all knowledge workers have either the capability, or the motivation, or the opportunity to transfer their experience into explicit knowledge (Gavrilova and Andreeva, 2012). It is this uniqueness of the knowledge production process that helps to achieve sustainable strategic capability for R&D leading to innovation and competitive advantage (Chen *et al*. 2010; Collins *et al*., 2010; Joia and Lemos, 2010; Mundra *et al*. 2011; Omerzel and Antoncic, 2008; Zack *et al*., 2009). Rama Mohan and Ramakrishna Rao (2005) propose a model for public R&D institute and industry partnership. Through this process, they combine tangible and intangible resources and cooperate in R&D activities. It also develops a common understanding and mutual trust and smoothens the process of adaptation of the technological innovation into a marketable product/process.

Managing strategic assets in public sector organisations has also attracted attention among researchers and decision makers not the least because of the need to carry out sharper appraisal of the value of public goods in a climate of reduced public expenditure. Yet another imperative is the need for public resource utilisation for the competitive advantage of nations. It is, however, difficult to measure how countries use their resources; more particularly, how efficiently public resources are used by R&D organizations functioning. It is difficult to measure the performance of R&D organization because the nature of these organizations and the functions these organizations perform are complex, risky, and uncertain.

The study reported in the paper attempts to bridge the gap in the knowledge space linking management practices to the innovativeness of outcomes for R&D units. Typically, the innovation practice involves managing and monetizing intellectual property which involves risk, integration and learning at the organization or entire unit level. Interestingly, it has been observed from a perusal of organizational learning literature that there is a recursive relation between performance and goals (Lant, 1982). The work reported in the paper is based on quality R&D performance output data available from 27 CSIR laboratories across a period of eleven years mapped over the structure and functioning of S&T manpower working in these laboratories.

3. India's R&D Environment

India's R&D environment is indeed a paradox. On the one hand, India is presently ranked 76th among a total of 143 economies, as per the Global Innovation Index (GII); on the other hand, India will likely get into the list of the top 25 nations in the Global Innovation Index, in the next 10 years, a view shared by Mr Francis Gurry, Director-General at the World Intellectual Property Organization (IBEF, 2017). The Government of India has proposed several measures during the last three years to increase the number of R&D professionals in the country. These include launching the: Atal Innovation Mission (AIM) in Budget 2015, which is an innovation promotion platform involving academics, entrepreneurs and researchers; Impacting Research Innovation and Technology (IMPRINT) in November, 2015, which is a PAN-IIT and IISc joint initiative to develop a road map for research; and Uchhatar Avishkar Yojana (UAY) in December, 2015, which is to promote innovation of a higher order to serve the needs of industry and promote a vibrant research echo system across Indian Institutes of Technology (IITs). According to the Research and Development Statistics, 2011-12 published by the Department of Science and Technology, India's R&D expenditure is around 0.88 per cent of GDP and number of R&D professionals per million populations are 164 (Press Information Bureau, 2017).

India's science and technology landscape is dominated by Government spending – both in R&D and in institutional development – with private sector contribution being limited in scale and scope. The national investment on R&D activities attained a level of INR 53041.30 crores in 2009-10, INR 62053.47 crores in 2010-11, and INR 72620.44 crores in 2011-12 (1 crore is equal to 10 million). A vast majority of India's R&D expenditure come from Government sources. However, private sector expenditure on R&D has been steadily increasing over the years (except a few bumps here and there) but is still way below what the Government spends. Table 1 presents the national expenditure on R&D by sector from 1970-71 to 2011-12 (DST, 2013). It may be inferred from a reading of Table 1 that the percentage share of private sector in national R&D expenditure has increased from 10.4% in 1970-71, to 15.9% in 1980-81, decreased to 13.8% 1990-91, but then increased to 19.3% in 2001-02, to 25.9% in 2005-06, to 28.9% in 2009-10, and to 30.2% in 2011-12.

India's per capita R&D expenditure had increased from US$ 5.90 in 2005-06 to US$ 9.3 in 2009-10 (DST, 2013). The split in the research and development expenditure in the institutional sector in India (excluding higher education sector) makes for an interesting reading in the context of knowledge generation in science and technology. This knowledge generation is typically carried out through a combination of multifaceted activities such as basic and applied research, research support activities, experimental field stations and engineering and design units. Data shows that in the year 2009-10, about 23.9% of the total research and development expenditure in India was spent on basic research, 33.4% was spent on applied research, 35.1% was spent on experimental development, and the rest 7.6% was spent on research support activities (DST, 2013). It may be further noted in this context that during 2010, nearly 4.41 lakhs personnel were employed in the different R&D establishments in India. Out of this total, 43.7% personnel were performing R&D activities, 28.2% personnel were performing auxiliary activities, and 28.1% of personnel were providing administrative and non-technical support (DST, 2013).

Table 1: R&D Expenditure in India (1970-71 – 2011-12)

Sector	1970-71	1975-76	1980-81	1985-86	1990-91	1995-96	2001-02	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12
Central	112.47	287.63	580.49	1654.06	3058.27	5199.79	11536.33	15079.95	17872.02	19551.80	21898.88	27513.88	31670.54	36737.25	42614.53
State	12.58	26.73	59.34	162.78	365.92	657.02	1494.33	1941.53	2334.60	2757.79	2951.80	3562.54	3865.24	4435.91	5090.84
Private	14.59	42.35	120.69	251.94	549.98	1627.07	3292.69	6038.96	8471.95	10485.58	12926.14	14365.40	15305.55	18332.88	21965.31
Higher Education							714.80	1056.80	1254.01	1443.21	1660.96	1911.56	2199.97	2547.43	2949.76
Total	**139.64**	**356.71**	**760.52**	**2068.78**	**3974.17**	**7483.88**	**17038.15**	**24117.24**	**29932.58**	**34238.39**	**39437.77**	**47353.38**	**53041.30**	**62053.47**	**72620.44**

Source: DST (2013)

In today's world, the level of complexity in management practices that is required to be adopted by organizations in emerging economies such as India has increased manifold. Shukla (1997) has looked at the Indian scenario since the economic reforms of early 1990's. According to him, the knowledge-based organization aims at creating a new paradigm encompassing competencies and capabilities. In a similar vein, Nilakant and Ramnarayan (1998) opine that organizations need to be more organic in a global environment fraught with increasing tendencies toward deregulation, increased competition and technological changes. Indigenous technology capability building could be an effective way to enable countries to compete in the international market. And this requires leveraging internal R&D capabilities with external resources to deliver long-term as well as short-term value, to facilitate rapid learning, and to focus on speed in the commercialization of new technology.

4. The Objective: Research Context

As mentioned earlier, in India, scientific and technological research is concentrated in industrial and government funded institutions such as the CSIR. The CSIR is an autonomous society under the Societies' Registration Act, 1860 with the Prime Minister of India as its ex-officio President. The Governing Body is the highest policy decision-making body of CSIR. The Director-General (DG) is its ex-officio chairman. The CSIR Headquarters at New Delhi coordinates the activities of the laboratories. In a climate of competitive advantage and the necessary evaluation of public goods, an organization such as CSIR cannot escape scrutiny in terms of efficient management processes which generate entrepreneurial outcomes through the proper organization of its strategic assets and the laboratories functioning under CSIR (Banerjee and Roy, 1999). In the opinion of former CSIR DG, R.A. Mashelkar, there are four broad categories under which CSIR laboratories are expected to deliver: private goods and services, public goods and services, social goods and services, and strategic goods and services (Mashelkar, 2007). Tacit knowledge has been particularly linked to the resource-based view of the firm focusing on 'non-purchasable, intangible, firm-specific and embedded types of resources' (Von Krogh and Roos, 1995, p. 60). The scientific personnel, the knowledge workers, are strategic assets for CSIR, more so because of the *tacit knowledge* they possess as a result of actively pursuing R&D activities in different functional areas over a long period of time. The functions being performed by the scientific manpower have been considered as indicators of their tacit knowledge in the present study. In managing R&D in changing, resource constrained and competitive scenarios it is imperative to appreciate the paradigmatic shift towards strategy innovation for survival, maintenance and growth of CSIR.

We ask the following questions. How has the CSIR managed its resources, its intellectual property and the imperatives of innovation for economic development? How have the knowledge workers of the various CSIR laboratories been organized to best offer and use their competencies? Given the new commitments to improved science and technology-based activity what can we expect from the CSIR in terms of their capabilities in managing change? How the intellectual capital deployment in CSIR laboratories along different functional dimensions impacted the quality performance of these laboratories? To best answer the questions above we probe how tacit knowledge potential of different CSIR laboratories impact the quality performance of these laboratories considering an extended period of eleven years, from the year 2003-04 to the year 2013-14. Through such critical enquiry we are able to assess the effectiveness of R&D management in the CSIR laboratories.

5. Methods

The quality performance record was analysed based on the following dimensions: number of Indian patents filed, number of Indian patents granted, number of foreign patents filed, number of foreign patents granted and the number of published papers figuring among the top 50 CSIR publications in the areas of biological sciences, chemical sciences, engineering sciences, physical sciences and information sciences.

Functional Scheme for Scientific and Technical (S&T) Personnel

Based on our understanding of the various scientific activities being carried out in CSIR laboratories, the different functions carried out by the scientific and technical personnel were grouped into six categories, as defined in Table 2.

Table 2: Functional Scheme for Science and Technology (S&T) Personnel in CSIR

Function	Specific S&T Activities
Function 1	Research and development work.
Function 2	S&T services including testing, survey, data processing, field work, liaison, planning and co- ordination.
Function 3	Infrastructure including workshop, animal house, instrumentation, equipment maintenance, special functions such as glass blowing, printing and reprography, etc.
Function 4	Pilot plants, experimental field stations and demonstration units.
Function 5	Engineering and design units.
Function 6	Research support functions.

The methodology of correspondence analysis was adopted to explore the structure of multivariate relationships among the different CSIR laboratories in terms of the functions performed by the S&T personnel in these laboratories. Correspondence analysis is an exploratory statistical methodology that displays the rows and columns of a rectangular data matrix as points in a scatter-plot, often called a 'map'. It is a powerful graphical tool in many situations involving categorical data (Lebart *et al*., 1984; Greenacre, 1984; Greenacre, 1990, 1991, 1993; Greenacre and Blasius, 1994). Correspondence analysis looks at the association, or interaction, between two categorical variables. The maps of correspondence analysis provide a view of a data table in a continuous framework, in terms of new dimensions on continuous scales.

6. Findings

A total of 27 CSIR laboratories have been analyzed in this study with reference to their quality output record. The data have been accessed from the CSIR Annual Reports of the respective years.

Table 3 presents the list of CSIR laboratories covered in the study. There are two symbols in the Table (the second column), the one outside the parenthesis refers to how these laboratories have been displayed in the CA maps and the one within the parenthesis refers to the full name abbreviation of the respective laboratories.

Table 3: List of CSIR Laboratories in the Study

S. No.	Symbol	Name of the Laboratory
1.	CF (CIMFR)	Central Institute of Mining and Fuel Research, Dhanbad
2.	CP (CIMAP)	Central Institute of Medicinal and Aromatic Plants, Lucknow
3.	NC (NCL)	National Chemical Laboratory, Pune
4.	CI (CECRI)	Central Electrochemical Research Institute, Karaikudi
5.	NA (NAL)	National Aerospace Laboratories, Bengaluru
6.	CT (CFTRI)	Central Food Technological Research Institute, Mysore
7.	CM (CMERI)	Central Mechanical Engineering Research Institute, Durgapur
8.	NM (NML)	National Metallurgical Laboratory, Jamshedpur
9.	CB (CBRI)	Central Building Research Institute, Roorkee
10.	IM (IMTECH)	Institute of Microbial Technology, Chandigarh
11.	CL (CLRI)	Central Leather Research Institute, Chennai
12.	CD (CDRI)	Central Drug Research Institute, Lucknow
13.	CC (CCMB)	Centre for Cellular and Molecular Biology, Hyderabad
14.	IT (IICT))	Indian Institute of Chemical Technology, Hyderabad
15.	NG (NGRI)	National Geophysical Research Institute, Hyderabad
16.	IB (IICB)	Indian Institute of Chemical Biology, Kolkata
17.	NE (NEERI)	National Environmental Engineering Research Institute, Nagpur
18.	RT (NEIST)	North-East Institute of Science and Technology, Jorhat
19.	SE (SERC)	Structural Engineering Research Centre, Chennai
20.	IR (IITR)	Indian Institute of Toxicology Research, Lucknow
21.	IP (IIP)	Indian Institute of Petroleum, Dehradun
22.	CE (CEERI)	Central Electronics Engineering Research Institute, Pilani
23.	NB (NBRI)	National Botanical Research Institute, Lucknow
24.	RJ (IIIM)	Indian Institute of Integrative Medicine, Jammu
25.	CR (CSMCRI)	Central Salt and Marine Chemical Research Institute, Bhavnagar

26.	PL (IHBT)	Institute of Himalayan Bioresource Technology, Palampur
27.	NO (NIO)	National Institute of Oceanography, Goa

Two correspondence analysis (CA) maps are presented here. Figure 1 presents the two-dimensional map constituted by factor 1 (¢$_1$) and factor 2 (¢$_2$) axes for the CSIR laboratory points and Figure 2 presents the same for the various function points that should be read and interpreted simultaneously. The representation of functions and laboratories in different maps has been done to avoid cluttering of the points in the same map. However, it is possible to superimpose these two maps.

Explanation

On the cloud of functions, the first factorial axis represents a polarity (bi-polar) between Function 4 - pilot plants, experimental field stations, etc. and Function 1 - R&D work. Function 1 is projected on this axis with negative coordinate, whereas Function 4 is projected on this axis with positive coordinate. This implies that most of the laboratories which emphasize R&D work for their scientific personnel and deploy their scientific manpower in this area tend to de-emphasize their work related to pilot plants, etc., and vice-versa.

The laboratories projected on this axis can be classified into two clusters, depending upon whether they are projected with positive coordinates (correlated with Function 4) or negative coordinates (correlated with Function 1).

Figure 1: CA Map – Laboratory Points

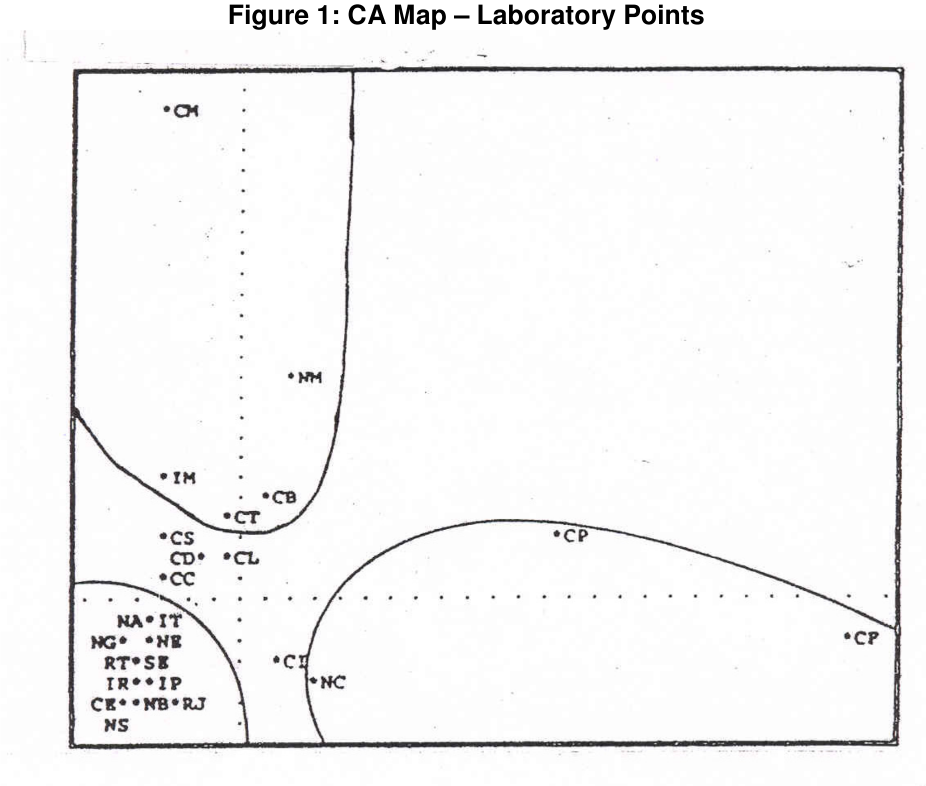
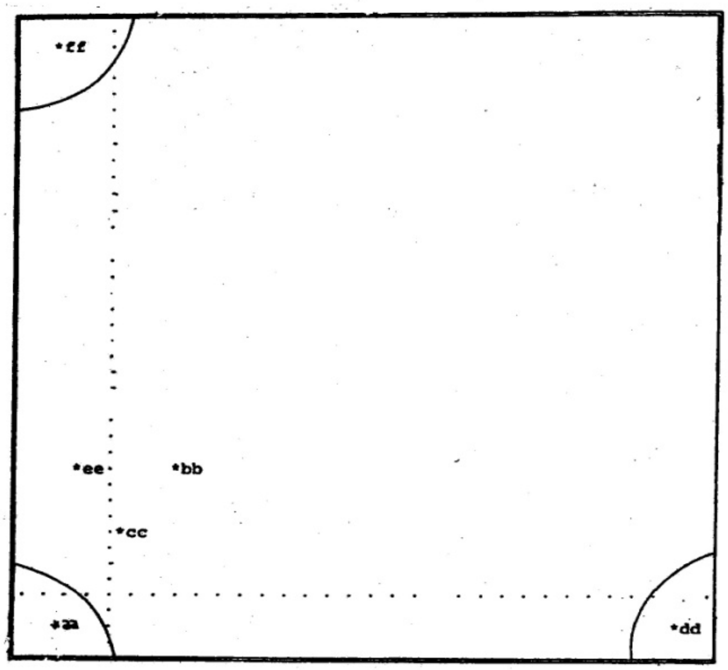


Figure 2: CA Map – Function Points



Cluster 1 (positive coordinates): CP, CF and NC

Cluster 2 (negative coordinates): RT, NG, IP, CE, CR, NB, IB, NE, SE, NI, PL, NO, NS, NA, IR.

On the cloud of functions, the second factorial axis is unipolar - both Function 2 and Function 6 are projected on the axis with positive coordinates. This implies that most of the laboratories which are projected on this axis with positive coordinates emphasize the function of working in the areas of S&T services and research support functions and deploy S&T manpower in these areas; whereas laboratories, which are projected with negative coordinates on this axis, de-emphasize both these roles for their S&T manpower.

The laboratories projected on the second factorial axis can be classified into two clusters, depending upon whether they are projected on this axis with positive coordinates (correlated with both Function 2 and Function 6) or negative coordinates (anti-correlated with both Function 2 and Function 6).

Cluster 1 (positive coordinates): CM, NM, CT, IM, CB.

Cluster 2 (negative coordinates): CI; CE, SC, NI, RJ, NC, NO, IR, NS.

Quality Performance of R&D Laboratories

Publication Record

Table 4 presents the first set of quality performance record (*publications*) of our sample of 27 CSIR laboratories for the period 2003-04 to 2009-10, and Table 5 presents the second set of these records for the period 2010-11 to 2013-14. It may be noted that consolidated publication data was not available for the year 2011-12, and thus the same is not reflected in Table 5. All data are sourced from CSIR Annual Reports of the respective years.

Table 4: Quality R&D Performance (Publication Record) of Select CSIR Laboratories (2003-04 to 2009-10)

S. No.	Symbol	2003-04 Number of Papers among Top CSIR Papers with High Impact Factor	2004-05 Number of Papers among Top CSIR Papers with High Impact Factor	2005-06 Number of Papers among Top CSIR Papers with High Impact Factor	2006-07 Number of Papers among Top 50 CSIR Papers in Specific Areas	2007-08 Number of Papers among Top 50 CSIR Papers in Specific Areas	2008-09 Number of Papers among Top 50 CSIR Papers in Specific Areas	2009-10 Number of Papers among Top 50 CSIR Papers in Specific Areas
1.	CF		1		1: Engineering			
2.	CP					1: Biological	1: Chemical	
3.	NC	4	10	8	3: Biological 21: Chemical 10: Physical 13: Engineering	8: Physical 2: Biological 7: Chemical 2: Engineering	7: Physical 1: Biological 28: Chemical 2: Engineering	5: Physical 3: Biological 13: Chemical 2: Engineering
4.	CI			1	1: Engineering	6: Engineering 2: Chemical	12: Engineering 1: Physical	7: Engineering
5.	NA				2: Physical	1: Physical	2: Engineering 2: Physical	3: Engineering 2: Physical
6.	CT	2	2		2: Biological 1: Engineering	1: Engineering 1: Biological		1: Engineering 2: Physical
7.	CM					1: Engineering	1: Chemical	
8.	NM				8: Engineering	7: Engineering	1: Engineering 2: Physical	1: Engineering

9.	CB				1: Engineering	1: Engineering		2: Engineering
10.	IM	4	11	13	7: Biological	6: Biological 1: Engineering	3: Biological 1: Chemical	1: Biological 2: Chemical 1: Physical
11.	CL	3	3	3	1: Biological 6: Engineering	6: Engineering 1: Biological 1: Physical	1: Chemical 5: Engineering 1: Physical	2: Chemical 1: Engineering
12.	CD	4	8	10	6: Biological 2: Chemical 3: Physical 7: Engineering	7: Biological 5: Chemical	8: Biological 3: Chemical	4: Biological 3: Chemical
13.	CC	8	18	26	16: Biological	8: Biological	18: Biological 1: Chemical	14: Biological
14.	IT	2	12	14	2: Biological 5: Chemical 10: Physical 2: Engineering	6: Physical 19: Chemical 9: Engineering 1: Biological	1: Physical 4: Chemical 7: Engineering	2: Physical 13: Chemical 4: Engineering 4: Biological
15.	NG				6: Physical 1: Engineering	15: Physical	10: Physical	9: Physical 1: Chemical
16.	IB	8	6	12	9: Biological 1: Engineering	14: Biological 2: Chemical	9: Biological 2: Engineering 2: Physical	3: Biological 3: Chemical 1: Physical
17.	NE				1: Biological 2: Engineering	3: Engineering	2: Engineering 1: Physical	2: Biological 7: Engineering
18.	RT						1: Engineering	1: Biological 1: Engineering 1: Physical
19.	SE							
20.	IR	2			5: Engineering	5: Engineering	1: Engineering	1; Biological

							1: Physical	1: Engineering 3: Physical 1: Chemical
21.	IP						2: Engineering 1: Chemical	1: Physical
22.	CE					1: Physical		
23.	NB	1	1		1: Biological	2: Biological 2: Engineering		2: Biological
24.	RJ		1				1: Biological	1: Chemical 1: Biological
25.	CR		1	3	7: Chemical	4: Chemical 2: Engineering	6: Chemical 1: Engineering	4: Chemical 7: Engineering
26.	PL			1		1: Chemical		2: Chemical
27.	NO			1	1: Physical	**1: Biological** 6: Physical	3: Biological 5: Physical	1: Biological 1: Chemical 4: Physical

Table 5: Quality R&D Performance (Publication Record) of Select CSIR Laboratories (2010-11 to 2013-14)

S. No.	Symbol	2010-11 Number of Papers among Top 50 CSIR Papers in Specific Areas	2012-13 Number of Papers among Top 50 CSIR Papers in Specific Areas	2013-14 Number of Papers among Top 50 CSIR Papers in Specific Areas
1.	CF	1: Engineering	2: Biological	
2.	CP	2: Biological 1: Physical	1: Biological 26: Chemical	
3.	NC	3: Physical 3: Biological 9: Chemical 10: Engineering	2: Chemical	26: Chemical
4.	CI	2: Engineering 1: Chemical	7: Engineering 1: Information	6: Chemical

5.	NA			5: Engineering
6.	CT	1: Biological 1: Chemical 3: Physical	1: Engineering	
7.	CM	2: Engineering	4: Engineering	7: Engineering
8.	NM	2: Engineering		5: Engineering
9.	CB		7: Biological	
10.	IM	2: Biological 1: Engineering 3: Physical	2: Chemical	2: Biological
11.	CL	4: Chemical 5: Physical	3: Biological	
12.	CD	6: Biological 2: Chemical 1: Engineering	10: Biological	5: Biological
13.	CC	7: Biological 1: Chemical 1: Engineering 1: Physical	9: Chemical 1: Information	13: Biological 1: Chemical
14.	IT	2: Biological 19: Chemical 5: Engineering 2: Info Science	13: Physical	1: Biological 10: Chemical
15.	NG	8: Physical	8: Biological	8: Physical
16.	IB	4: Biological	9: Engineering	13: Biological
17.	NE		3: Chemical	6: Engineering
18.	RT	1: Chemical	1: Engineering	
19.	SE		6: Biological	
20.	IR	1; Biological 1: Engineering 1: Physical	3: Chemical	1: Biological

21.	IP	2: Chemical	1: Physical	
22.	CE	1: Physical		
23.	NB	3: Biological	3: Biological	1: Biological
24.	RJ	1: Chemical 1: Engineering	2: Chemical 1: Engineering	2: Biological
25.	CR	8: Chemical 2: Engineering	2: Biological	3: Chemical 1: Engineering
26.	PL	1: Biological 2: Chemical	5: Physical	
27.	NO	1: Engineering 15: Physical		3: Physical

Patent Record

Table 6 presents the first set of quality R&D performance record (*patents*) of the select set of CSIR laboratories for the period 2003-04 to 2006-07, Table 7 presents the second set of these records for the period 2007-08 to 2009-10, and Table 8 presents the third set of these records for the period 2010-11 to 2013-14. All data are sourced from CSIR Annual Reports of the respective years.

Table 6: Quality R&D Performance (Patent Record) of Select CSIR Laboratories (2003-04 to 2006-07)

. No.	*Symbol*	*2003-04*				*2004-05*				*2005-06*				*2006-07*			
		IPF	*IPG*	*FPF*	*FPG*	*IPF*	*IPG*	*FPF*	*FPG*	*IPF*	*IPG*	*FPF*	*FPG*	*IPF*	*IPG*	*FPF*	*FPG*
1.	CF	2	3	18	4	4	1	6	4	0	3	43	5	0	3	16	5
2.	CP	11	7	10	29	18	13	29	28	12	16	39	10	2	4	22	25
3.	NC	59	53	111	19	61	35	44	32	38	59	49	26	17	57	81	28
4.	CI	12	16	0	0	10	0	5	2	5	7	2	2	5	9	3	1
5.	NA	4	1	1	0	1	1	1	1	5	1	2	0	1	5	4	2
6.	CT	104	29	66	13	59	31	44	19	52	47	54	10	21	40	86	35
7.	CM	4	2	0	0	1	0	7	0	9	0	0	0	4	0	6	1
8.	NM	12	6	2	2	7	3	12	5	15	3	5	1	1	11	16	6
9.	CB	0	1	0	0	0	1	0	0					0	2	0	0
10.	IM	4	2	7	4	3	2	0	2	4	2	5	0	2	3	10	6

11.	CL	20	7	12	3	8	3	19	4	14	8	21	2	9	8	13	8
12.	CD	15	7	14	5	21	15	29	6	20	11	9	8	5	6	21	16
13.	CC	3	1	6	1	2	0	2	2	2	1	3	2	0	1	4	5
14.	IT	17	24	58	39	26	15	39	48	29	31	78	31	13	18	45	43
15.	NG	0	0	0	1	2	1	1	0	6	0	1	1	7	0	5	2
16.	IB	6	4	11	5	4	9	6	9	8	1	5	6	5	0	18	10
17.	NE	1	9	2	0	2	1	1	0	17	0	0	1	6	3	5	1
18.	RT	4	24	1	0	14	16	44	8	7	14	25	8	7	7	3	1
19.	SE	0	1	0	0												
20.	IR	1	2	0	0	2	0	0	0	1	0	0	0	1	0	0	0
21.	IP	11	20	2	3	6	7	3	11	15	4	22	0	5	8	12	2
22.	CE	0	2	0	0					1	1	0	0	0	5	0	0
23.	NB	7	0	20	3	23	0	32	4	10	2	16	5	6	0	50	11
24.	RJ	10	3	8	12	9	2	7	13	13	12	0	1	3	10	8	19
25.	CR	15	4	25	2	19	4	48	13	14	3	68	9	4	2	89	22
26.	PL	4	0	8	21	10	0	28	17	11	0	12	8	1	1	15	10
27.	NO	9	0	34	12	14	3	21	13	6	2	20	7	1	5	10	16

Legend:
IPF = Indian Patents Filed; IPG: Indian Patents Granted; FPF = Foreign Patents Filed; FPG = Foreign Patents Granted

Table 7: Quality R&D Performance (Patent Record) of Select CSIR Laboratories (2007-08 to 2009-10)

S. No.	***Symbol***	***2007-08***				***2008-09***				***2009-10***			
		IPF	***IPG***	***FPF***	***FPG***	***IPF***	***IPG***	***FPF***	***FPG***	***IPF***	***IPG***	***FPF***	***FPG***
1.	CF	11	22	1	10	4	23	1	14	3	3	1	11
2.	CP	1	7	4	20	3	17	11	15	1	11	1	16
3.	NC	10	79	29	28	13	102	39	26	24	15	16	23
4.	CI	5	9	11	1	2	28	6	1	0	1	9	0
5.	NA	6	16	0	0	6	6	0	1	3	1	1	1
6.	CT	24	28	5	37	18	86	9	43	16	40	1	38
7.	CM	3	8	5	3	3	8	0	1	2	1	2	2

8.	NM	7	16	0	4	11	12	9	5	6	0	11	1
9.	CB	0	5	0	0	3	6	0	0	1	1	0	0
10.	IM	1	1	12	5	1	4	18	5	4	3	8	7
11.	CL	6	16	12	11	5	17	3	6	8	3	0	13
12.	CD	13	5	15	10	5	12	12	16	7	5	6	15
13.	CC	2	0	1	4	1	2	25	1	3	1	1	6
14.	IT	22	26	28	37	18	76	62	42	10	11	28	33
15.	NG	3	0	6	3	1	1	8	2	2	0	15	0
16.	IB	7	1	5	6	5	5	9	6				
17.	NE	2	8	4	3	2	9	4	1	1	0	0	3
18.	RT	5	11	1	1	5	14	3	1	9	2	1	0
19.	SE					0	1	0	0	0	0	15	0
20.	IR	1	6	0	0s	0	3	1	0	3	0	0	1
21.	IP	6	10	7	0	3	24	15	2	2	1	4	3
22.	CE	1	7	0	0	1	3	0	0	2	0	0	0
23.	NB	5	0	1	22	3	11	0	21	4	5	1	21
24.	RJ	11	10	7	11	3	20	5	14	7	3	3	9
25.	CR	7	3	40	26	16	20	56	34	9	7	18	28
26.	PL	1	2	11	10	7	13	17	8	2	2	6	
27.	NO	2	11	8	14	0	9	7	3	0	1	0	4

Legend:
IPF = Indian Patents Filed; IPG: Indian Patents Granted; FPF = Foreign Patents Filed; FPG = Foreign Patents Granted

Table 8: Quality R&D Performance (Patent Record) of Select CSIR Laboratories (2011-12 to 2013-14)

S. No.	***Symbol***	***2010-11***				***2011-12***				***2012-13***				***2013-14***			
		IPF	***IPG***	***FPF***	***FPG***	***IPF***	***IPG***	***FPF***	***FPG***	***IPF***	***IPG***	***FPF***	***FPG***	***IPF***	***IPG***	***FPF***	***FPG***
1.	CF	3	7	3	11	2	0	3	3	0	3	5	4	3	6	0	6
2.	CP	0	5	0	15	2	5	8	8	0	1	4	11	1	1	2	6

3.	NC	31	39	41	45	11	80	17	17	73	20	159	31	122	10	115	65
4.	CI	5	7	9	1	4	0	2	2	0	1	3	0	4	2	13	6
5.	NA	3	5	0	0	0	3	0	0	4	3	1	0	1	2	2	1
6.	CT	11	44	0	41	27	0	22	22	3	12	0	8	3	13	0	7
7.	CM	2	3	0	4	0	0	1	1	0	1	0	0	2	2	0	1
8.	NM	4	15	0	2	4	0	3	3	7	7	0	0	14	2	0	0
9.	CB	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.	IM	3	3	8	3	1	18	16	16	1	2	28	9	6	1	5	9
11.	CL	11	15	0	1	5	4	0	0	6	5	1	1	13	6	2	0
12.	CD	8	12	21	8	1	11	10	10	6	6	6	3	9	5	14	12
13.	CC	1	2	3	4	2	2	2	2	0	0	3	3	1	0	4	10
14.	IT	19	16	48	43	7	36	45	45	15	11	26	43	9	7	27	55
15.	NG	1	0	1	0	0	0	5	5	0	0	2	5	0	0	0	8
16.	IB	5	1	6	3	0	17	7	7	0	0	3	6	1	1	11	5
17.	NE	4	1	1	1	0	3	0	0	1	1	3	1	1	2	11	1
18.	RT	8	6	8	1	3	4	0	0	6	4	24	4	4	2	4	4
19.	SE	1	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0
20.	IR	0	0	2	0	0	0	0	0	0	1	0	0	1	0	0	2
21.	IP	8	7	2	9	3	4	6	6	22	4	9	14	11	5	7	18
22.	CE	0	0	0	0	4	0	2	2	2	0	1	0	4	0	2	0
23.	NB	4	5	0	12	2	5	3	3	1	2	3	4	2	0	3	7
24.	RJ	4	5	5	18	0	4	2	2	1	0	9	0	7	0	3	13
25.	CR	9	8	22	49	3	49	53	53	17	6	43	41	10	1	60	70
26.	PL	2	1	5	15	1	4	3	3	3	1	8	5	1	2	15	7
27.	NO	2	2	0	7	2	0	11	11	0	0	0	2	1	2	0	7

Legend:

IPF = Indian Patents Filed; IPG: Indian Patents Granted; FPF = Foreign Patents Filed; FPG = Foreign Patents Granted

Analysis of Quality Output of CSIR Laboratories

In line with the results of the correspondence analysis and the discussion on tacit knowledge above, we now focus our attention on a micro-level analysis of the quality research outputs of selected CSIR laboratories to ascertain how much the presence or the absence of tacit knowledge in specific areas affect the quality output of a research laboratory in terms of top research publications or of patents filed in India or abroad. The results of such an analysis over this extended period of eleven years would help provide validity to the analysis and interpretation of the results.

Results

What we observe from a perusal of the Table 4 through Table 8 is that the pattern of results depicting the quality R&D output of the 27 different CSIR laboratories largely follow a similar pattern over the eleven-year period (2003-04 to 2013-14) of our study. Thus, the results seem to be generally valid across different years over our study period providing confidence to the interpretation of these results and the conclusions drawn therefrom.

First we look at the broad categories of results of our analysis.

Let us first focus our attention to the *clear outliers* in the correspondence analysis study referenced. The Central Institute of Mining and Fuel Research, Dhanbad, CIMFR (CF) with profile points strongly overlapping function dd (pilot plants and experimental field stations) is an outlier in this category. The laboratory has displayed only a moderate technology development output in terms of patents but basic research output in terms of publication is poor. Another outlier is the Central Institute of Medicinal and Aromatic Plants, Lucknow, CIMAP (CP) with profile points related to dd (pilot plants) but also to function cc (infrastructure) and more closely to function bb (S&T services). The output profile of the laboratory correlates very well with this technology development knowledge base in terms of patents but it is observed from a reading of the Tables that the laboratory has been upgrading its publication record over the years (16 paper among top 5- CSIR publications in the field of chemical sciences in the year 2012-13).

The Central Mechanical Engineering Research Institute, Durgapur, CMERI (CM) with profile points strongly overlapping with function ff (research support functions) and to a much lesser extent with function bb (S&T services), and, function ee (engineering and design units) is an outlier in this category. Reference to the Tables indicate that the laboratory, however, displays only a moderate external technology outreach in terms of patents. Its knowledge base in infrastructure and S&T support activities cannot guarantee quality R&D performance unless there is integration with basic R&D activities. The laboratory has been putting a greater emphasis on R&D publication output over the years as evidenced from the eleven-year data, but the general pattern holds. Another strongly focused laboratory, though not exactly an outlier, is the National Metallurgical Laboratory, Jamshedpur, NML (NM) conveys a different story. It's profile points overlap function bb (S&T services such as testing, survey, field work, etc.) and to some extent, function cc (infrastructure). A perusal of its output over the eleven-year period reveals that its quality R&D performance record has its focus firmly on applied research output.

Let us now focus our attention to the *non-outliers* in the correspondence analysis maps. One such non-outlier is the Central Building Research Institute, Roorkee, CBRI (CB) whose profile points overlap the function bb (S&T services) and to a lesser extent cc (infrastructure). Its poor performance record over the entire period under study (except the year 2012-13) makes an important point that a mere possession of tacit knowledge in these support functions might not be sufficient to sustain performance in research and technology development. Considering the other non-outliers, we observe that the Central Food Technological Research Institute, Mysore, CFTRI (CT) and the Central Leather Research Institute, Chennai, CLRI (CL) are both are located very close to the vertical axis and to the barycentre having profile points aligned with the function ee (engineering and design units). Both these laboratories are found to display a strong quality R&D performance output record, the former with a more profound technology outreach in terms of patents and the latter with a more rounded performance both in terms of patents and publications.

The Institute of Microbial Technology, Chandigarh, IMTECH (IM) is another institute with profile points closely matching the function ee (engineering and design units). This laboratory has a very good and rounded R&D quality performance output record, both in terms of patents and publications, over the entire eleven-year period. Thus, the functional knowledge in any particular field needs to be harnessed strategically by exploiting the complementary potential in different domains for ensuring quality research performance.

The focus now shifts to the *non-aligned laboratories* in the correspondence analysis maps. The Centre for Cellular and Molecular Biology, Hyderabad, CCMB (CC) and the Central Electrochemical Research Institute, Karaikudi, CECRI (CI) are two such examples. Both display a decent volume of quality R&D output record for the period of study. A reading of the Tables indicate that CCMB has a more pronounced publication than patent record that has literally stood the test of time and CECRI has very rounded quality R&D performance record.

Let us now look at *specific laboratory clusters*. A perusal of Figure 1 and 2 reveals that there is a cluster of laboratories aligned with function aa (R&D). Does it automatically mean that all these laboratories have a strong publication record? This assumption does not seem to hold water if one considers laboratories such as the National Aerospace Laboratories, Bengaluru, NAL (NA), the National Environment Engineering Research Institute, Nagpur, NEERI (NE), and the Indian Institute of Toxicology Research, Lucknow, IITR (IR), the institutes that have displayed only a moderate publication and patent record over the years. Further, there are laboratories in this category that have literally nothing to show as quality R&D output performance such as the Central Electronics Engineering Research Institute, Pilani, CEERI (CE) and the Structural Engineering Research Centre, Chennai, SERC (SE).

On the other hand, the National Geophysical Research Institute, Hyderabad NGRI (NG) has to its credit a consistently good publication output during this period along with a moderate patent outreach. A deeper reading of the Tables further reveals that there are four laboratories that belong to this cluster who have a decent quality R&D performance record but more in the technology outreach domains in terms of patents than in terms of publications. These are the North East Institute of Science and Technology, Jorhat, NEIST (RT), the Indian Institute of Petroleum, Dehradun, IIP (IP), the National Botanical Research Institute, Lucknow, NBRI (NB), and the

Indian Institute of Integrative Medicine Jammu, IIIM (RJ). A knowledge base in core R&D could prove vital in developing business transferable technologies if properly nurtured.

How do laboratories with *exactly similar profiles* relate to one another in terms of quality R&D output? The Indian Institute of Chemical Biology, Kolkata, IICB (IB), IITR, Lucknow (IR) and the Central Salt and Marine Chemical Research Institute, Bhavnagar, CSMCRI (CR) have exactly the similar profile aligned with the function aa (R&D). IITR has only a moderate publication and patent record to show as discussed above, IICB is better placed both in terms of publications and patents, and CSMCRI is among the top quality R&D performing laboratories of CSIR. Thus, exactly similar profiles do not necessarily translate into similar quality R&D performance.

Finally, let us focus our attention to *the top performers* in terms of quality R&D output. Of interest would be an examination whether their profile points match in the CA maps. At the very top we have the Indian Institute of Chemical Technology, Hyderabad, IICT (IT) lying close to the barycentre with its profile points aligning somewhat with the function aa (R&D) that has displayed the best performance record all throughout the eleven-year period. The National Chemical Laboratory, Pune, NCL (NC) follows next, its alignment in the CA map indicating functional knowledge in running pilot plants and experimental field stations. CFTRI, Mysore follows thereafter with profile points aligning with the function ee (engineering and design units). Next in line is CSMCRI, Bhavnagar with profile points overlapping IICB and IITR as mentioned above. And finally we have with its profile positioned close to the barycentre, aligned somewhat with the function ee (engineering and design units). The profile points of all the five top performing CSIR laboratories are differently located yet there is one common thread that runs through all these laboratories. *All these top performers are strong in both the areas of publications and patents* – proving once again that innovation is one complete whole, and an inherent strength in basic research helps in the process of application of that knowledge.

7. Discussion and Conclusions

What are the key learnings from the above analysis? It is clear that there is no readymade formula that would indicate quality performance by a research laboratory given a particular set of S&T worker profile in terms of the six functions defined in the study. The aspect of tacit knowledge has been explored vis-à-vis the quality performance indicators of the laboratories, and what do we infer from the results?

Let us look at some of the key takeaways from our analysis. First, the standalone laboratories that are clear outliers in the CA map - CIMFR, Dhanbad (pilot plants and experimental field stations), CMERI, Durgapur (research support functions and engineering units), NML Jamshedpur (S&T services and infrastructure), and CIMAP, Lucknow (pilot plants/S&T services/infrastructure) are not the units that can claim to be the top performers (the latter two having a better performance record than the first two). Second, what about the non-outliers that are aligned with specific functional specializations? There is clearly a mixed response here. Laboratories with poor to moderate quality R&D performance record include CBRI, Roorkee (S&T services and infrastructure), CEERI, Pilani, SERC, Chennai, NAL, Bengaluru, NEERI, Nagpur and IITR, Lucknow (all R&D) – in that order. On the other hand, laboratories such as CLRI, Chennai and

CFTRI, Mysore (both engineering and design units) display very good quality R&D performance with CFTRI being one of the top five performing laboratories as mentioned above. Third, it is noteworthy that four laboratories - with profiles matching the R&D function – NEIST, Jorhat; NBRI, Lucknow; IIP, Dehradun and IIIM, Jammu - have their patent output much more pronounced than their publication output, again proving the point that innovation is one complete whole with success depending upon strategically mapping the different components. Finally, as highlighted above, the top CSIR performers excel in different functional knowledge base - NCL, Pune (pilot plants), CFTRI, Mysore and CDRI, Lucknow (both engineering and design units), IICT, Hyderabad (the best performer of all) and CSMCRI, Bhavnagar (both R&D), yet all of these laboratory have excellent patent as well as publication record.

The above discussion brings us right back to the original thinkers on this subject, Nonaka and Tekeuchi (1995), according to whom the social interaction between tacit and explicit knowledge helps create and expand human knowledge terming the process 'knowledge conversion'. And it is a matter of strategy, not operation. This is the crucial point that has been emphasized in the current study. Far from being involved in the operational and tactical aspects of managing R&D and innovation, CSIR as a corporate should recognize that exploiting tacit knowledge is a key component of innovation strategy. Koskinen (2004) recognizes that research and development projects often require people to act on the basis of their tacit knowledge. The organizational capability to acquire, create, accumulate and exploit knowledge forms the cornerstone of an organization's knowledge strategy (Nonaka, 1994; Nonaka and Tekeuchi, 1995; Nonaka *et al*. 2000). This includes establishing a culture and an environment that help knowledge evolve (Davenport and Prusak, 1998). What is critical is to focus on CSIR's knowledge assets comprising of human capital, patents, publications, technology transfer and other forms of intellectual capital, 'the brand CSIR', and organizational routines (Birkinshaw *et al*., 2002)**.**

The results of the correspondence analysis presented above illustrate critical points about organizational performance and the effective management of R&D knowledge workers. Quite often it is found that the laboratories that emphasize R&D work for their scientific human resources pay little emphasis on the distinctive and overlapping functions of pilot plants, experimental field stations and in the engineering and design units. But these are exactly the factors critical for technology development in CSIR laboratories and their subsequent transfer. Of equal importance is a strategy of networking among partners in technological innovation (Roy, 2006; Roy and Banerjee, 2007; and Roy, 2009). What is perhaps lacking is the consciousness and realization that there is perhaps a dialectic relationship between tacit and explicit knowledge. In Tsoukas's (1996, p. 14) words, 'Tacit and explicit knowledge are mutually constituted – they should not be viewed as separate types of knowledge…/explicit knowledge is always grounded on a tacit component…Tacit knowledge is the necessary component of all knowledge'. *Thus, we cannot manage tacit knowledge as a distinct entity from explicit knowledge.* Thus, CSIR, viewing itself as a corporate body, should, therefore, realize its core competencies, and evaluate its strengths and weaknesses in different R&D and allied areas and functions necessary for initiating technological innovation.

The present study considered the quality R&D performance output record of these laboratories over a period of eleven years and related these output records with the functional profiles of these laboratories as displayed in the CA maps. We find here that the findings of the study over this long eleven-year period seem to largely hold true providing critical validity to the results and their implications. The significance of such ingrained tacit knowledge as enunciated above cannot be underestimated. As Koskinen (2004, p. 14) points out, '…knowledge can only be produced not imported. This is to say *the only way to acquire knowledge is to utilize existing knowledge'* (emphasis added). For CSIR, viewing itself as a multi-organizational conglomerate operating globally in a select few areas of strength and competence through a network mode of consortia of laboratories and other actors in the innovative effort, such an analysis could prove extremely useful and timely. The study results and the correspondence analysis maps are a guide to forge such alliances by identifying strategic groupings of laboratories as also identifying the stand-alone ones.

8. Policy Implications

Given CSIR's dominant upstream and downstream roles there are some critical policy implications emanating from our research. The first such implication for government policy is to help develop strategic capability in the management of R&D and the innovation chain within its own departments and the R&D laboratories that drive the research agenda, Such a strategic capability needs to be built round a proper understanding of the innovation process, and especially the value of tacit and explicit knowledge, rather than on traditional research which is less concerned with practical outcomes or indeed with questions of competitive advantage. Second, developing strategic capability is inevitably linked with the enhancement of skills of highly qualified research personnel. A relevant compendium of skills needs to be centered around the more effective management of innovation in CSIR laboratories as a dynamic process covering R&D, service development and pilot plant or prototyping and marketing activities.

9. References

1. Alexeis, G.P. and Mitra, A. (2007), "Tacit knowledge elicitation and measurement in research organizations", *Electronic Journal of Knowledge Management*, Vol. 5, No. 4, pp. 373-385.
2. Alwis, R.S. and Hartmann, E. (2008), "The use of tacit knowledge within innovative companies: knowledge management in innovative enterprises", *Journal of Knowledge Management*, Vol. 12, No. 1, pp. 133-147.
3. Banerjee, P. and Roy, S. (1999), "Social partnership and network: CSIR in business", in Bagchi, A. K. (Ed.), *Economy and Organization: Indian Institutions under the Neo-Liberal Regime*, pp. 350-397, Sage Publications, New Delhi.
4. Birkinshaw, J., Nobel, R. and Ridderstrale, J. (2002), "Knowledge as a contingency variable: do the characteristics of knowledge predict organization structure?", *Organization Science*, Vol. 13, No. 3, pp. 274-289.
5. Chen, N.D., Liang, P.T. and Lin, B. (2010), "An ecological model for organizational knowledge management", Journal of Computer Information Systems, Vol. 50, No. 3, pp. 11-22.
6. Collins, D.J. Worthington, J.W., Reyes, M.P. and Romero, M. (2010), "Knowledge management, supply chain technologies, and firm performance", Management Research Review, Vol. 33, No. 10, pp. 947-960.

7. Davenport, T.H. and Prusak, L. (1998), *Working Knowledge: How Organizations Manage What They Know,* Harvard Business School Press, Boston, MA.
8. DST (2013), *Research and Development Statistics 2011-12*, Department of Science and Technology, Ministry of Science and Technology, Government of India, December.
9. Firestone, J.M. and McElroy, M.W. (2005), “Defining knowledge management: knowledge management or not knowledge management? That is the question”, *Strategic Direction,* Vol. 21, No. 10, pp. 22-24.
10. Freeman, R.B. (2006), “Does globalization of the scientific/engineering workforce threaten economic leadership?”, *Innovation Policy and the Economy Vol.* 6, pp. 123–58.
11. Gavrilova, T. and Andreeva, T. (2012), “Knowledge elicitation techniques in a knowledge management context”, Journal of Knowledge Management, Vol. 16, No. 4, pp. 523-537.
12. Greenacre, M. and Blasius, J. (Eds.) (1994), *Correspondence Analysis in the Social Sciences: Recent Developments and Applications*, Academic Press, London.
13. Greenacre, M.J. (1984), *Theory and Applications of Correspondence Analysis*, Academic Press, London.
14. Greenacre, M.J. (1990), *SIMCA-2: Program and Manual,* Department of Statistics, University of South Africa, Pretoria, South Africa.
15. Greenacre, M.J. (1991), “Interpreting multiple correspondence analysis”, *Applied Stochastic Models and Data Analysis*, Vol. 7, pp. 195-210.
16. Greenacre, M.J. (1993), *Correspondence Analysis in Practice*, Academic Press, London.
17. Horibe, F. (1999), *Managing Knowledge Workers: New Skills and Attitudes to Unlock the Intellectual Capital in your Organization*, John Wiley & Sons, New Delhi.
18. Horibe, F. (2003), “The KM grid: implementing knowledge management’, *Performance Improvement*, Vol. 9, No. 2/3, pp. 235-261.
19. IBEF (2017), *Research and Development in India*, India Brand Equity Foundation, March (https://www.ibef.org/industry/research-development-india.aspx) – accessed April 11, 2017.
20. Joia, L.A. and Lemos, B. (2010), “Relevant factors for tacit knowledge transfer within organizations”, Journal of Knowledge Management, Vol. 14, No. 3, pp. 410-427.
21. Kimura, O. (2010), “Public R&D and commercialization of energy-efficient technology: a case study of Japanese projects”, *Energy Policy*, Vol. 38, No. 11, pp. 7358-7369.
22. Koskinen, K.U. (2004), “Knowledge management to project communication and implementation”, *Project Management Journal*, Vol. 35, No. 2, pp. 13-19.
23. Lant, T.K. (1992), “Aspiration level adaptation: an empirical exploration”, *Management Science*, Vol. 38, pp. 623-644.
24. Lebart, L., Morineau, A. and Warwick, K.M. (1984), *Multivariate Descriptive Statistical Techniques*, John Wiley and Sons, New York.
25. Mashelkar, R.A. (2007), “Renewing the national laboratories”, in Wessner, C.W and S.J. Shivakumar (Eds), *India’s Changing Innovation System: Achievements, Challenges and Opportunities for Cooperation- Report of a Symposium*, National Research Council of the National Academies, Washington D.C. The National Academies Press.

26. Mundra, N., Gulati, K. and Vashisth, R. (2011), "Achieving competitive advantage through knowledge management and innovation: empirical evidences from the Indian IT sector", The IUP Journal of Management, Vo. IX, No. 2, pp. 7-25.
27. Nelson, R.R. (1982), "The role of knowledge in R&D efficiency", *Quarterly Journal of Economics*, Vol. 97, No. 3, pp. 453-470.
28. Nilakant, V. and Ramnarayan, S. (1998), *Managing Organisational Change*, Response Books, New Delhi.
29. Nonaka, I. (1994), "A dynamic theory of organizational knowledge creation", *Organization Science*, Vol. 5, No. 1, pp. 14-37.
30. Nonaka, I. and Takeuchi, H. (1995), *The Knowledge Creating Company: How Japanese Companies Create the Dynamics of Innovation*, Oxford University Press, New York.
31. Nonaka, I., Toyoma, R. and Konno, N. (2000), "SECI, Ba and leadership: a unified model of dynamic knowledge creation", *Long Range Planning*, Vol. 33, pp. 4-34.
32. Omerzel, D.G. and Antoncic, B. (2008), "Critical entrepreneurial knowledge dimensions for the SME performance", Industrial Management and Data Systems, Vol. 108, No. 9, pp. 1182-1199.
33. Pimentel, A.C.M. and Albino, J.P. (2010), "An approach for implementing knowledge management in small and medium enterprise in Brazil", in *Proceedings of the European Conference on Knowledge Management*, pp. 647-652.
34. Pitt, M. and Clarke, K. (1997), "Frames of significance: technological agenda forming for strategic advantage", *Technology Analysis and Strategic Management*, Vol. 9, No. 3, pp. 251-269.
35. Polanyi, M. (1967), *The Tacit Dimension*, Anchor Books, New York.
36. Polanyi, M. (1969), "The logic of tacit inference", in Greene, M. (Ed.), *Knowing and Being,* Routledge & Keagan Paul, London.
37. Press Information Bureau (2017), *Low Expenditure on Research and Development*, Press Information Bureau, Government of India, Ministry of Science and Technology, March 30, 2017 (http://pib.nic.in/newsite/PrintRelease.aspx?relid=160228) – accessed April 11, 2017.
38. Rama Mohan, S. and Ramakrishna Rao, A. (2005), "Strategy for technology development in public R&D institutes by partnering with the industry", *Technovation*, Vol. 25, No. 12, pp. 1484-1489.
39. Roy, S. (2006), "Networking as a strategy for technology transfer and commercialization from R&D laboratories", *Industry and Higher Education*, Vol. 20, No. 2, pp. 123-133.
40. Roy, S. (2009), "Technology transfer from R&D centres in India and development of industrial clusters", in Manimala, M.J., Mitra, J. and Singh, V. (Eds.), *Enterprise Support Systems: An International Perspective*, pp. 217-227, Sage, New Delhi.
41. Roy, S. and Banerjee, P. (2007), "Developing regional clusters in India: the role of national laboratories", *International Journal of Technology Management and Sustainable Development*, Vol. 6, No. 3, pp. 193-210.
42. Shukla, M. (1997), *Competing through Knowledge: Building a Learning Organization*, Response Books, New Delhi.
43. Tassey, G. (2000), "Rationales and mechanisms for revitalizing US manufacturing R&D strategies", Journal of Technology Transfer, National Institute of Standards and

Technology, Retrieved on 29 January 2010 (http://www.nist.gov/customcf/get_pdf.cfm?pub_id912234).

44. Tsoukas, H. (1996), "The firm as a distributed knowledge system: a constructionist approach", *Strategic Management Journal*, Vol. 17, No. S2, pp. 11-25.
45. Von Krogh, G. and Roos, J. (1995), "A perspective on knowledge: competence and strategy", *Personnel Review*, Vol. 24, No. 3, pp. 56-76.
46. Von Krogh, G., Ichijo, K. and Nonaka, I. (2000), *Enabling Knowledge Creation*, Oxford University Press, Oxford.
47. Voulle, M., Lonnqvist, A. and van der Meer, J. (2009), "Measuring the intangible aspects of an R&D project", *Measuring Business Excellence*, Vol. 13, No. 2, pp. 25-33.
48. Zack, M., McKeen, J. and Singh, S. (2009), "Knowledge management and organizational performance: an exploratory analysis", Journal of Knowledge Management, Vol. 30, No. 6, pp. 392-409.