Annals of Library and Information Studies
Vol. 61, March 2014, pp. 65-73

Scientometrics of collaboration pattern in solar cell research in India

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Received: 16 January 2014; revised and accepted: 20 February 2014

The paper looks into collaboration in solar cell research in India as reflected by the publications indexed in Web of Science for a period of 20 years from 1991-2010. Almost half of the total output emerged out of domestic and international collaboration. Academic institutions had almost equal proportion of output emerging from domestic as well international collaboration. Among the prolific institutions National Physical Laboratory-Delhi of the Council of Scientific and Industrial Research had the highest publications emerging out of collaborative research. Indian researchers collaborated with their counterparts in 31 countries; however, South Korea, Japan, USA, Germany, England, France and Greece were dominant collaborating research partners. Various bibilometric indicators have been used to examine collaborative research activity. Research collaboration gained momentum during the later decade. International collaborative output had more impact compared to domestic collaboration in terms of citations per paper.

Keywords: Scientometrics; Collaboration; Solar cell research; Photovoltaic; India

Introduction

Solar cell research is characterized by a blend of basic and applied research as well as technology[1]. Solar cell technology draws on knowledge from several established fields including physics, chemistry, electrochemistry, physical chemistry and material science. This requires an enhanced understanding pertaining to knowledge interactions in science-based innovation progression, particularly those seeking sustainable energy solutions. Studies on research collaboration in the renewable energy technology field are scarce[2]. This is more so in case of solar cell research in India. A few studies are reported in literature that have dealt with solar cell research in India but touched upon the research collaboration aspect only peripherally. However, a few studies dealing with scientific research collaboration are available in literature. These studies deal with the research collaboration in the entire gamut of science in India[3-7] and specific fields in science[8-14]. However, there is no study on collaboration on solar cell research in India. This study aims to fill that gap.

A comprehensive research performance evaluation study on solar cell research in India has already been carried out by the authors[15]. The present study is, therefore, in a way an extension of the earlier study on solar cell research in India carried out by the authors.

Research collaboration

Sociologists of science and others have shown that science is a social institution where advances depend crucially on interactions with other scientists[16]. At the most basic level, it is people who collaborate, not institutions. Direct co-operation between two or more researchers is the fundamental unit of collaboration[17]. Modern research is increasingly complex and demands an ever widening range of skills. Collaboration is one way of transferring knowledge, especially tacit knowledge. According to Beaver and Rosen[18-20] professionalization and increased knowledge in science gave rise to the need for collaboration.

Initially, Smith suggested that multi-authored or multi-address papers could be used as a proxy to measure collaboration[21]. These include domestic as well as international collaboration. To decipher collaboration, bibliometric data in scientific publications is used as a unit of analysis. Various collaborative aspects could be unraveled through analysis of co-authorship[22]. Katz and Martin[17] have

made rigorous articulation of a plethora of aspects and reasons of fostering collaboration in their seminal work on collaboration. Beaver[23] too has enumerated the purposes for which people collaborate.

Collaborative papers attract more citations than those without any collaboration. Also articles written in international collaboration receive more citations than articles written in domestic collaboration, which in turn receive more citations than articles written in local collaboration. This, in turn, suggests that internationally co-authored articles represent a more important segment of the world science[24].

International research collaboration may not always be seen from the point view of research excellence or creating impact but also for forging strategic partnerships and gaining knowledge[25]. International scientific collaboration is particularly advantageous for less advanced countries but also beneficial for highly industrialized countries, is generally accepted[26].

Objectives of the study

The paper aims to study the collaborative pattern in solar cells research in India for a period of 20 years from 1991-2010 as reflected by the publication indexed in Thomson Reuters' *Web of Science (WoS)* with the following objectives:

- To study the growth of collaborative research during the 20 years period;
- To examine the collaboration trends in solar cell research in two different ways:

  (a) Change in the pattern of co-authorship during the four blocks of five years each, i.e. 1991-1995, 1996-2000, 2001-2005 and 2006-2010;

  (b) Change in the pattern of nature of collaboration during the four blocks mentioned above;
- To identify the countries that have collaborated with India;
- To examine the collaborative research output of performing sectors and prolific institutions;
- To examine domestic and international collaboration and its impact in terms of citations per paper.

Methodology

Author affiliation was the basic unit of analysis of the study. Data was downloaded on 28th November 2011 for a period of 20 years (1991 to 2010) from the Web of Science (WoS) of the Thomson Reuters, Philadelphia, USA. Detailed strategy for downloading, cleaning and standardization of the data has been given in our earlier paper[15].

The data was enriched with various parameters, like, number of authors, nature of collaboration, research performing sectors, etc. Citations to the data were updated in November 2013 to allow for maximum possible citation window.

Collaboration was categorized on an institutional basis. A large number of papers were observed having several addresses within India and those from outside. Based on this, collaboration has been classified as domestic and international. Bordons[27] *et al* have defined forms of collaboration in a similar manner.

Domestic collaboration (DC): This type of collaboration is formed between different institutions within a country. Thus publications with different addresses within India were categorized as DC.

International collaboration (IC): Papers having at least one foreign address. The papers that had at least one foreign address were classified as IC.

The database was made in Fox Pro for carrying out various analytical dimensions.

Indicators used

1. Volume of collaboration

The volume of collaboration was measured by the quantum of publications P (no fractional count was used)

Co-authorship Index (CAI)

To study the shift in the pattern of co-authorship during 1991-2010 CAI suggested by Garg and Padhi[13] was used. CAI is computed as follows

$CAI = \{(N_{ij} / N_{io}) / (N_{oj} / N_{oo})\} \times 100$ where

N_{ij} : numbers of papers having j authors in block i;

N_{io} : total output of block i;

N_{oj} : number of papers having j authors for all blocks;

N_{oo} : total number of papers for all authors and all blocks.

J = 1, 2, (3 or 4), >= 5.

Collaboration Co-efficient (CC)

Ajiferuke[28] suggested a single measure to measure collaborative research and termed it as collaborative coefficient. The method is based on fractional productivity defined by Price and Beaver[29]. The

following formula denotes CC. The symbols used have been explained as under:

$$CC = 1 - \frac{\sum_{j=1}^{k} (1/j) f_j}{N}$$

Where fj is the number of j authored papers;

N is the total number of research papers published and

k is the greatest number of authors per paper

According to Ajiferuke, CC tends to zero as single authored papers dominate and to 1-1/j as j-authored papers dominate. This implies that higher the value of CC, higher the probability of papers with multi or mega authors. Here multi authors imply papers with 3 or 4 authors and mega authors with more than 4 authors. However, inclusion of authors as multi or mega can be changed according to data to be analyzed.

Domestic Collaborative Index (DCI)

To examine the shift in pattern of collaboration Domestic Collaborative Index (DCI) and International Collaborative Index (ICI) suggested by Garg and Padhi[13] and used by Dutt, Garg and Bali[30] were used.

$DCI = \{(D_i / D_{io}) / D_o / D_{oo})\}$ X 100 where

D_i = number of domestically co-authored papers for block i;

D_{io} = total output of block i

D_o = total number of domestically co-authored papers

Doo = total output

Likewise

International Collaborative Index (ICI)

$ICI = \{(I / I_{io}) / I_o / I_{oo})\}$ X 100 where

I_i = number of internationally co-authored papers for block i

I_{io} = total output of block i

I_o = number of internationally co-authored papers for all the blocks

I_{oo} = total output

The value of DCI or ICI = 100 suggests that a country's collaborative effort corresponds to world average. DCI or ICI > 100 indicates collaboration higher than the world average and DCI or ICI < 100 reflects less than average collaboration

Impact of collaboration

The influence / impact of collaboration as usually measured in bibliometric studies on the basis of total number of citations and the average citation rate (or citedness) the number of Citations Per Paper (CPP).

Analysis

The analysis suggests that of all the publications (2024) pertaining to solar cell research in India during 1991-2010, more than half was collaborative research output emerging out of domestic and international collaboration. The proportion of both the forms of collaborative research output was almost the same (Fig. 1). During the first decade from 1991-2000 only about 11 per cent papers were published as a result of collaborative research, subsequently in the later decade there was a remarkable rise in collaborative research output, both domestic as well as international collaboration (Fig. 2).

Collaboration pattern

Pattern of co-authorship

To examine the pattern of co-authorship the entire data was divided into four blocks of five years in single author, two authors, multi authors (3 or 4 authors) and mega authors (>=5 authors). CAI was calculated as suggested by Garg and Padhi[13]. The results of CAI are presented in parentheses in Table 1.

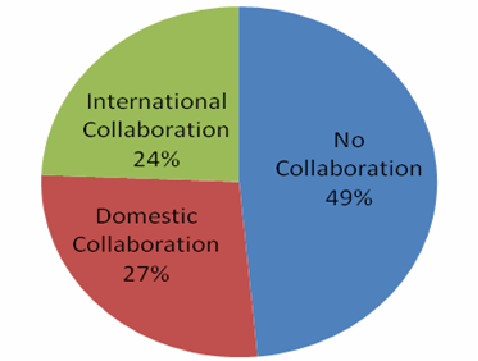

Fig. 1—Distribution of solar cell research output in India

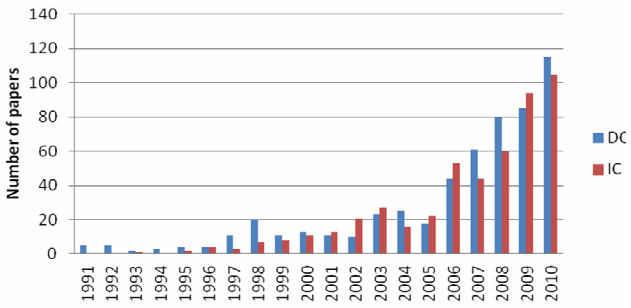

Fig. 2—Year-wise distribution of domestic and international collaborative output

Table 1—Distribution of output according to number of authors

5-Year Block	Number of authors				Total	CC
	Single	Two	Multi*	Mega*		
1991-1995	21 (224)	75 (138)	108 (99)	36 (54)	240	0.593
1996-2000	18 (154)	88 (130)	152 (112)	41 (49)	299	0.614
2001-2005	10 (71)	92 (112)	162 (98)	99 (97)	363	0.665
2006-2010	30 (68)	204 (80)	499 (97)	389 (124)	1122	0.693
Total	79	459	921	565	2024	

*Multi = 3 or 4 authors, Mega > 4 authors

Table 2—Distribution of output according to nature of collaboration

5 - Year Block	Nature of collaboration		Total Papers
	DC (DCI)	IC (ICI)	
1991-1995	19 (29)	3 (5)	240
1996-2000	59 (73)	33 (45)	299
2001-2005	88 (89)	99 (112)	363
2006-2010	383 (126)	358 (131)	1122
	549	493	2024

The value of CAI in the first block of 1991-1995 and the second block of 1996-2000 was the highest for single authored papers which gradually declined in respect of two, multi and mega authored papers. This implied that during the first decade single authored papers dominated the scenario. The third and fourth block indicated that the values of CAI gradually increased from the single authored papers to mega authored papers suggesting the trend in the later decade was marked with more research papers with larger team sizes. This trend was almost a reversal of the co-authorship trend in the first decade. The gradually increasing values of CC suggest that over the period increasingly more emphasis is given to collaborative research.

Domestic and international collaboration

Table 2 suggests that during the first decade ~80 per cent research papers were produced without any kind of collaboration. Among the remaining, domestic collaboration dominated followed by international collaboration, however, the values of indices indicated above average collaborative activity in both the types of collaboration. During the later decade only ~37% papers emerged without any collaboration which was a significant change. The values of DCI and ICI suggest predominance of international collaborative research activity over domestic collaboration during the period 2001-2005 whereas during the later period i.e., 2006-2010 the domestic as well as international collaborative activity was almost at par with each other as there was no substantial variation in the values of DCI and ICI.

Table 3—Collaborative research in performing sectors

Sl. No.	Performing sector	DC (DCI)	IC (ICI)	Collaborative papers (%)*	Total Papers
1	AI	299 (102)	300 (114)	599 (55.8)	1072
2	CSIR	78 (136)	55 (107)	133 (62.7)	212
3	IITs	68 (92)	46 (69)	114 (42.0)	272
4	EC	47 (158)	25 (93)	72 (65.4)	110
5	DST	16 (30)	41 (179)	57 (29.3)	194
6	DRDO	14 (82)	4 (26)	18 (28.5)	63
7	DAE	9 (92)	7 (80)	16 (44.4)	36
8	DSIR & M	9 (138)	5 (90)	14 (58.3)	24
9	PVT	3 (53)	10 (196)	13 (76.1)	21
10	Others	6 (110)	0 (0)	6 (30.0)	20
	Total	549	493	1042 (51.4)	2024

* Table arranged in the descending order of collaborative papers.

Collaborative activity in research performing sectors

Among the major research performing sectors, academic institutions (AI) contributed almost equal research output resulting out of domestic as well as international collaboration. Department of Science & Technology (DST) of the Government of India and Private Organizations (PVT) had more research output emerging out of international collaboration (Table 3). Also the values of ICI in respect of these sectors were considerably higher than their respective DCIs as well as any other sector. Defence Research & Development Organization (DRDO) followed by Department of Atomic Energy (DAE) had the least collaborative research output whereas private institutions followed by Engineering Colleges (EC) and Council of Scientific and Industrial Research (CSIR) had the higher proportion of collaborative output. CSIR, EC and Department of Scientific and Industrial Research & other Ministries (DSIR & M)

Table 4—Collaborative research output of prolific institutions

Sl. No.	Institution*	DC (DCI)	IC (ICI)	Total Collaborative papers (%)**	Total Papers
1	CSIR- NPL	41 (168)	6 (27)	47 (52.2)	90
2	JNVU	33 (217)	9 (66)	42 (75.0)	56
3	AU	19 ((180)	18 (190)	37 (94.8)	39
4	IITD	24 (87)	5 (20)	29 (28.4)	102
5	SU	19 (83)	8 (39)	27 (32.1)	84
6	IISc	23 (149)	4 (29)	27 (47.3)	57
7	JU	16 (118)	9 (74)	25 (50.0)	50
8	CUSAT	6 (61)	17 (194)	23 (63.8)	36
9	CSIR-CECRI	22 (239)	1 (12)	23 (67.6)	34
10	IACS	9 (22)	13 (38)	22 (15.6)	141
11	IITK	15 (231)	7 (120)	22 (91.6)	24
12	SVU	3 (15)	16 (89)	19 (25.6)	74
13	CSIR-IICT	7 (99)	11 (174)	18 (69.2)	26
14	IITB	8 (65)	8 (73)	16 (35.5)	45
15	DU	7 (63)	6 (60)	13 (31.7)	41
16	BU	7 (129)	5 (102)	12 (60.0)	20
17	BHU	9 (75)	2 (19)	11 (25.0)	44
18	KASC	4 (64)	7 (125)	11 (47.8)	23
19	IITM	7 (74)	1 (12)	8 (22.8)	35
20	DRDO-DL	8 (148)	0 (0)	8 (40.0)	20
21	DRDO- SSPL	3 (44)	0 (0)	3 (12.0)	25
22	IITKH	2 (33)	1 (19)	3 (13.6)	22
	Sub-total	292	174	466 (42.0)	1108
	Others (313 institutions)	257 (103)	319 (143)	576 (62.8)	916
	Total	549	493	1042(51.4)	2024

*Full name of institutions provided in Appendix 1

** Table arranged in the descending order of collaborative papers

had relatively higher values of DCI establishing that these sectors had more domestic research collaborative output. Relatively lower collaborative research output in respect of DRDO and DAE might be due to their research culture coupled with embedded strategic reasons in these organizations.

Collaborative research activity in prolific institutions

National Physical Laboratory-Delhi (CSIR-NPL) followed by Jai Narain Vyas University-Jodhpur (JNVU), Alagappa University-Karaikudi (AU) and Indian institute of Technology-Delhi (IITD) were the top four institutions having more collaborative output (Table 4). Indian Institute of Technology-Kanpur (IITK), CSIR-NPL and Central Electrochemical Research Institute-Karaikudi (CSIR-CECRI), Indian Institute of Science-Bangalore (IISc), JNVU and Jadavpur University-Kolkata (JU) had relatively more domestic research collaboration output compared to international collaborative output as revealed by the values of DCI and ICI. Whereas the values of ICI suggests that some other institutions like CSIR-Indian Institute of Chemical Technology-Hyderabad (CSIR-IICT), Cochin University of Science and Technology-Cochin (CUSAT) and Kongunadu Arts and Science College-Coimbatore (KASC) had predominantly more research output emerging out of international collaboration compared to domestic research collaboration. Institutions under DRDO had no international collaboration whereas IIT Kharagpur (IITKH) and DRDO-Solid State Physics Laboratory-Delhi (DRDO-SSPL) had the least proportion of collaborative output. Alagappa University (AU) had almost equal proportion of papers emerging out of domestic and international collaboration. Relatively more collaborative work was undertaken in AU followed by IITK, and CSIR-IICT while the least collaborative research was carried out in DRDO-SSPL, IITKH and the Indian Association for the Cultivation of Science-Kolkata (IACS).

International research collaboration

Collaborating countries

Indian researchers collaborated with 31 countries from almost all regions of the world. However, the dominant research collaborating countries among them included South Korea, USA, Japan, Greece, Germany, France, England, Italy, Canada, Switzerland and Taiwan, etc. as is seen in Figure 3 which presents a bird's eye view of collaborating countries and the strength of the collaborating linkages in terms of research output. The numbers in the parentheses have not been given in respect of those countries that had a feeble collaborative link in terms of collaborative research output. The most prominent linkage is with South Korea followed by USA, Japan and Germany, etc. To map this network of collaborating countries the data was downloaded in the text form which was further processed using Bibexcel[34] software to extract the name of countries from the institutional address details. The network files were then constructed using the same and imported to the Pajek[35] (visualization software) for the linkage analysis.

Impact of collaboration

As reflected in Fig. 4, Citations per paper (CPP) in respect of domestic collaboration (DC) was lower than that of internationally collaborative output. Katz and Hicks have also demonstrated that the impact

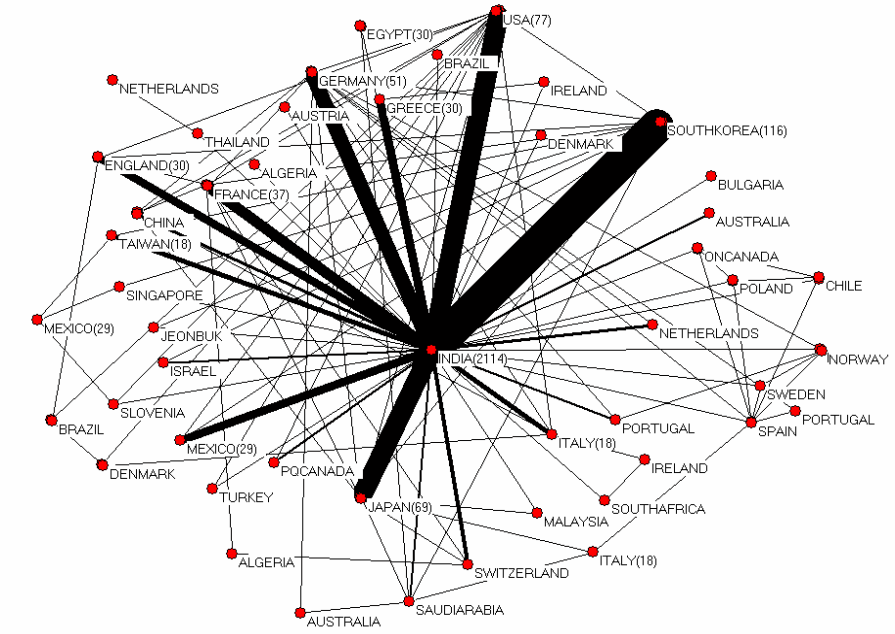

Fig. 3—Bird's eye view of collaborating countries in solar cell research in India

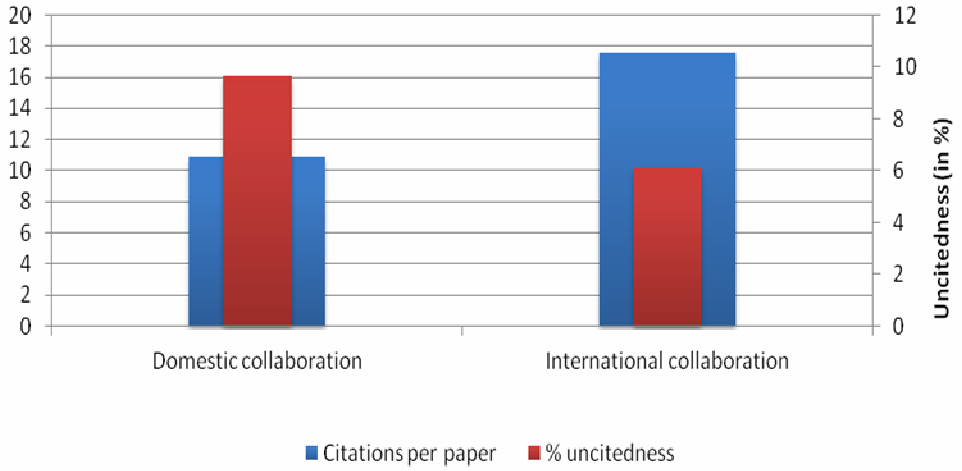

Fig. 4—Citations per paper and uncitedness Vs nature of collaboration in solar cell research in India

varies with different types of collaboration[31]. Moed[32] too has shown that international scientific collaboration does pay in terms of impact measured in citation per paper received. On the other hand, the percentage of uncited papers declined from DC to IC. It is obvious that IC has more impact as compared to DC in terms of CPP.

Conclusions

The study revealed that during a period of 20 years from 1991-2010 almost half of the total output (2024) in solar cell research in India emerged out of collaborative research activity. Of the collaborative output, almost half originated out of domestic collaboration and the other half out of international collaboration. Research collaboration gained momentum during the last decade and especially in the last quarter, i.e. 2006-2010 which was revealed and established by the Co-authorship Index (CAI) and Collaboration Co-efficient (CC).

Collaboration in the research performing sectors suggest that Academic Institutions (AI) had almost equal output emerging out of domestic as well as international collaboration. Institutions under Department of Science and Technology (DST) of Government of India and Private Organizations (PVT) had more output emerging out of international collaboration whereas Defence Research & Development Organization (DRDO) and Department of Atomic Energy (DAE) had the least proportion of collaborative output and total absence of internationally collaborative output which may be ascribed to cultural norms and strategic reasons of these organizations. Council of Scientific and Industrial Research (CSIR) and Engineering Colleges (EC) had higher proportion of collaborative output.

National Physical Laboratory-Delhi (CSIR-NPL) followed by Jai Narain Vyas University-Jodhpur (JNVU), Alagappa University-Karaikudi (AU) and Indian institute of Technology-Delhi (IITD) were the top four institutions that had more collaborative output. Some institutions had relatively more domestic research collaboration output compared to international collaborative output whereas certain others had more publications emerging out of international research collaboration. Institutions under DRDO had no international collaborative research output. Alagappa University (AU) had almost equal proportion of publications emerging out of domestic and international collaboration.

Indian researchers collaborated with their counterparts in 31 countries; however, the most dominant linkage was with South Korea, which was followed by USA, Japan, Germany, France and Greece. The most prominent linkage of Indian researchers with South Korea may be ascribed to its strong leadership in various S&T disciplines and high technology areas as reflected in their publication output and patents owned in USPTO[33]. Impact of research emerging out of collaborative work in terms of CPP tends to increase from domestic collaboration to international collaboration. On the other hand the proportion of uncited papers decreased from domestic collaborative work to international collaborative research output.

It appears that policy initiatives by the Ministry of New and Renewable Energy of the Government of India must have had a bearing on the impetus in the research collaboration which has witnessed a remarkable rise in the last quarter of the period under study.

References

1 Tijssen R J W, A Quantitative assessment of interdisciplinary structures in science and technology co-classification analysis of energy research, *Research Policy,* 21 (1991) 27-44.

2 Larsen K, Knowledge network hubs and measures of research impact, science structures, and publication output in nanostructured solar cell research, *Scientometrics*, 74(1) (2008) 123-142.

3 Basu A and Vinu Kumar B S, International collaboration in Indian scientific papers, *Scientometrics*, 48(3) (2000) 381-402.

4 Arunachalam S R, Srinivasan R and Raman V, International collaboration in science: Participation by the Asian giants, *Scientometrics*, 30(1) (1994) 7-22.

5 Basu A and Aggarwal R, International Collaboration in Science in India and its Impact on Institutional Performance, *Scientometrics*, 52(3) (2001) 379-394.

6 Gupta B M and Dhawan S M, India's collaboration with People's Republic of China in Science and Technology: A scientometric analysis of coauthored papers during 1994-1999, *Scientometrics*, 57(1) (2003) 59-74.

7 Anuradha K T and Urs S R, Bibliometric indicators of Indian research collaboration patterns: A correspondence analysis, *Scientometrics*, 71(2) (2007) 179-189.

8 Raina D, Gupta B M and Kandhari R, Collaboration in Indian physics: A case study of the macro and micro parametrization of sub-disciplines (1800–1950), *Scientometrics*, 33(3) (1995) 295-314.

9 Kundra R, Investigation of collaborative research trends in Indian medical sciences: 1900–1945, *Scientometrics*, 36(1) (1996) 69-80.

10 Gupta B M, Kumar S and Karisiddappa C R, Collaboration profile of theoretical population genetics speciality, *Scientometrics*, 39(3) (1997) 293-314.

11 Gupta B M and Karisiddappa C R, Collaboration in theoretical population genetics speciality, Scientometrics, 42(3) (1998), 349-376.

12 Kundra R and Kretschmer H, A new model of scientific collaboration part 2, Collaboration patterns in Indian medicine, Scientometrics, 46(3) (1999) 519-528.

13 Garg K C and Padhi P, A study of collaboration in laser science and technology, Scientometrics, 51(2) (06-2001) 415-427.

14 Kundra R and Tomov D, Collaboration Patterns in Indian and Bulgarian Epidemiology of Neoplasms in *Medline* for 1966–1999, Scientometrics, 52(3) (11-2001) 519-523.

15 Dutt B and Nikam K, Solar cell research in India: A scientometric profile, *Annals of Library and Information Studies*, 60(2) (2013) 115-127.

16 Kuhn T S, The structure of scientific revolution, (University of Chicago Press; Chicago), 1970.

17 Katz J S and Martin B R, What is research collaboration? *Research Policy*, 26 (1997) 1-18.

18 Beaver De D B and Rosen, R, Studies in scientific collaboration I: The professional origin of scientific co-authorship, *Scientometrics*, 1 (1) (1978) 65-84.

19 Beaver De D B and Rosen R, Scientific co-authorship, research productivity and visibility in the French scientific elite, *Scientometrics*, 1(2) (1979) 133-149.

20 Beaver De D B and Rosen R, Professionalization and the natural history of modern scientific co-authorship, *Scientometrics*, 1(3) (1979) 231-245.

21 Smith M, The trend toward multiple authorship in psychology, *American Psychologist*, (13) (1958) 596-599.

22 G. Melin G and Persson O, Studying research collaboration using co-authorships, *Scientometrics*, 36(3) (1996) 363-377.

23 Beaver D D, Reflections on scientific collaboration (and its study): past, present and future, *Scientometrics*, 52(3) (2001) 365-377.

24 Whitlow E S and Narin F, Measurement of scientific cooperation and co-authorship in CEC related areas of science, Vol 1, Commission of the European Communities, (EUR 12900 EN), 1990.

25 Gorraiz J, Reimann R and Gumpenberger C, Key factors and considerations in the assessment of international collaboration: a case study for Austria and six countries, *Scientometrics*, 91(2) (2012) 417-433.

26 Glanzel W, Schubert A, and Czerwon H J, A bibliometrtic analysis of international scientific cooperation of the European Union (1985-1995), *Scientometrics*, 45(2) (1999) 185-202.

27 Bordons M, Gomez I, Fernandez M T, Zulueta M A and Mendez A, Local, domestic and international scientific collaboration in biomedical research, Scientometrics, 37(2) (1996) 279-295.

28 Ajiferuke I, Burrel Q and Tague J, Collaborative coefficient: A single measure of the degree of collaboration in research, *Scientometrics,* 14(5-6) (1988) 421-433.

29 Price De Solla, Beaver De D B, Collaboration in an invisible college, *American Psychologist,* 21(11) (1966) 1011-1018.

30 Dutt B, Garg K C and Bali A, Scientometrics of the international journal Scientometrics, *Scientometrics*, 56 (1) (2003) 81-93.

31 Katz J S and Hicks D, How much is a collaboration worth? A calibrated bibliometric model, Scientometrics, 40 (3) (1997) 541-554.

32 Moed H F, Does international scientific collaboration pay? In Citation Analysis in Research Evaluation (Springer), 2005, p.285-290.

33 CSIR-NISTADS, A comparative study on S&T, innovation & development strategies of China & South Korea vis-à-vis India, June 2012, p.206.

34 Bibexcel is software which assists in analyzing the textual data and format the data files which can be imported to the visualization software's like pajek. For details of the bibexcel refer web link http.//www8.umu.se/inforsk/Bibexcel/(Accessed on Nov. 2013).

35 Pajek is used for analysis and visualization of large networks. For details of Pajek refer web link http://vlado.fmf.uni-lj.si/pub/networks/pajek/(Accessed on Nov. 2013).

Appendix I – Full names of institutions

IACS - Indian Association for Cultivation of Science, Kolkata
IITD - Indian Institute of Technology, Delhi
NPL - National Physical Laboratory, Delhi
SU - Shivaji University, Kolhapur
SVU - Sri Venkateswara University, Tirupati
IISc - Indian Institute of Science, Bangalore
JNVU - Jai Narain Vyas University, Jodhpur
JU - Jadavpur University, Kolkata
IITB - Indian Institute of Technology, Bombay
BHU - Banaras Hindu University, Banaras
DU - Delhi University, Delhi
AU - Alagappa University, Karaikudi
CUSAT - Cochin University of Science And Technology, Cochin
IITM - Indian Institute of Technology, Madras
CECRI - Central Electrochemical Research Institute, Karaikudi
IICT - Indian Institute of Chemical Technology, Hyderabad
SSPL - Solid State Physics Laboratory, Delhi
IITK - Indian Institute of Technology, Kanpur
KASC - Kongunadu Arts & Science College, Coimbatore
IITKH - Indian Institute of Technology, Kharagpur
DL - Defence Laboratory, Jodhpur
BU- Bharathidasan University, Tiruchirapalli
CSIR - Council of Scientific and Industrial Research
DRDO - Defence Research and Development Organisation
AI - Academic Institutions
EC - Engineering College
DST - Department of Science and Technology
IIT - Indian Institute of Technology
DAE - Department of Atomic Energy
PVT - Private Organizations
DSIR&M - Department of Scientific and Industrial Research & other Ministries