Collaboration in Knowledge Production: A case study of Superconductivity Research in India

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Abstract

Studies on research collaboration indicate an increased interaction between countries, institutions, and disciplines, leading to "global research networks". Journal articles in the area of Superconductivity published between 1975-2000 having the first author with Indian affiliation are examined to study the nature and extent of research collaboration among universities, Government R&D laboratories and Industry. The principal players (collaborators) are identified and the structure and dynamics of research collaboration in the field of superconductivity in India are analyzed using quantitative techniques. The results are examined to determine the nature and magnitude of collaboration. There are clear indicators that Superconductivity research in India is shifting from 'Little Science' to 'Big Science'.

1 Introduction

Collaboration has become an inevitable and essential research component of every field. Research collaboration between authors, disciplines and institutions is not new and is very much prevalent in many areas of research, particularly in the 'hard sciences', applied sciences and engineering. Over the years a considerable body of literature has been published addressing the issue of research collaboration. Multiple-authorship in scientific articles is on the rise in most branches of science. It has even been suggested that collaboration enhances the scientific value of an article. It has also been found that multiple-authored papers involving collaboration with foreign authors are more cited, than papers with domestic authors (Narin & Whitlow, 1990).

Various institutions concerned with science policy such as OECD (Canada), SPRU (UK), NSF (USA) and the European Commission have been emphasizing the need for collaboration in scientific research to bring down the cost, avoid duplication and maximize research output. Consequently in many countries, there have been initiatives to promote 'university-industry' collaboration to improve the links between science and technology. The concept of 'university-industry interaction' has, in recent years, been extended to include another player in the knowledge production process, i.e., Government R&D laboratory. The three are together referred to as the "*Triple Helix*" (Leydesdorff, 1996).

This increasing trend in research collaboration among universities, industry and government R&D laboratories could be viewed as an indicator of growth from '*Little science'* to '*Big science*' and thus represents a new and important aspect of knowledge production. This new mode of knowledge production enforces the researchers to be more socially oriented and encourage collaboration with other organizations in their environment. As a result, cooperation between scientists has now expanded beyond sectoral, institutional and national boundaries.

2 Objectives

This study is aimed at analyzing the structure and dynamics of research collaboration in the field of Superconductivity in India with the objective of finding the nature, extent, growth, impact and institutional aspects of research collaboration. The objectives of this paper are:

- To analyze the structure and dynamics of collaboration in superconductivity research in India.
- To identify and understand the science and technology interface between the university, government and industry.
- To examine the relationship, if any, between collaboration and productivity.

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The idea of studying collaboration patterns using data drawn from published records is not new. There is a substantial body of literature in Information Science dealing with co-authorship and research networks. There are also studies on scientific fraud, bureaucracy and political aspects of collaboration, which are not discussed here. In general the studies so far published have examined various aspects of collaboration such as:

- Reasons & motives behind research collaboration (Katz & Martin);
- Factors contributing to collaboration (Stokes et al, Price, Clark, Gordon, Frame & Carpenter);
- Forms of collaboration (Price, Clark, Subramanyam);
- Sector and country-wise collaboration trends (Katz & Hicks, Liberman et al, Melin, Narin & Whitlow, Godin, Okubo et al, Braun et al, Singh & Arunachalam); and
- Productivity and impact of research collaboration (Narin & Whitlow, Pao, Gordon, Katz & Hicks, Price & Beaver, Lawani).

3 Research Collaboration

What are the major factors that may have a bearing on collaboration? Disciplines such as physics, chemistry, materials science, have always been international in their research scope, and the degree of collaboration has generally been of a high order. There has also been a widening of the scope of contemporary research with practically no boundaries between disciplines, organizations or countries. Such an approach to research appears to be gaining more institutional support. Secondly, at least in part, research collaboration is a direct result of structural changes in scientific research driven by societal and economic needs. There is a gradual change in research practices over the last few decades from a general philosophy that can be described as '*economy of scale*' in research, characterized by 'unlimited' research resources; to an '*economy of scope*' characterized by scarcity of research funds leading to selectivity, demanding research breakthroughs within an acceptable time frame. The demand for direct applicability of research results has also become stronger due to limited funds for research and has led to a stronger focus on the scope of research to be funded (Roosendaal, 1997).

Gibbons et al (1994) in their influential book "*The New Production of Knowledge*" clearly indicate that knowledge production has become heterogeneous. Knowledge is no longer produced only in universities, but also in many other locations such as government R&D laboratories, industries, consultancy agencies, 'think-tanks' and international research projects. A new 'trans-disciplinary' approach to problem solving is emerging on top of traditional academic research. This new approach to knowledge production requires the participation of different actors or agents and an interaction between industry, university and government R & D laboratories. This has given rise to the creation of formal and informal networks leading to collaborative or cooperative arrangements for the flow of information and knowledge. Traditional disciplines are breaking down and new research areas and specialties are emerging, while the role of science in society is going through a process of transformation. Studies elsewhere indicate that the publication pattern is heading towards interdisciplinary and multidisciplinary research, particularly in natural sciences (Hicks & Katz, 1996). In other words the system of knowledge production is itself undergoing structural changes due to various internal and external factors leading to collaborative multidisciplinary and interdisciplinary research across the world. Interdisciplinary collaboration has also been the principal mechanism in the formation and evolution of new disciplines such as Material Science.

4 Research Collaboration in Superconductivity

Although Materials Science is a fully matured discipline, not much is known about the interactions between the industry, academia and R & D laboratories as well as the degree and nature of international collaboration. Beginning as a research 'specialty' in the 1960s, Materials Science has grown into a major subject and acquired the status of an independent discipline with all the necessary academic and professional attributes. According to Kodama (1992) significant advances in inter-disciplinary fields are the result of integration or ‘fusion’ of many disciplines. Hence research collaboration is a crucial element for the development of many technologies including Materials Science. Due to the complexity of research problems in the area, there is need for greater collaboration across established borders between disciplines, both in academic and industrial research. In other words, Materials Science research requirements combine scientific research with engineering application of the end product. A growing proportion of research in Materials Science is being done by ‘*materials-using’* industries compared to *materials-producing* industries in the US. Strong Government support for both academic and industrial materials research has also been a major impetus for the growth and development of the field.

Superconductivity, a sub-field of Materials Science saw a great deal of research activity during the 1980's. Research in this area brought together separate communities of scientists and engineers to form distinct teams or 'research networks'. This paper examines the nature and extent of collaboration in Superconductivity research in India. The choice of the subject field has been influenced by the fact that it is a good example of a multidisciplinary field with scope for collaborative linkages among university, industry and government laboratories. An earlier study by Singh and Arunachalam (1990) had shown that in 1984 India was the only third world country to have found a place in the top ten countries conducting research in Superconductivity. Since 1986, India too has made some progress in superconductivity research. Some new materials, compounds, heavy fermion systems, thin-film superconductors, etc., have been discovered, and SQUID devices have been developed. In 1987, the University Grants Commission has recognized superconductivity as a major area of research and has identified 19 universities/ research groups to support research in specific areas.

5 Operational Definitions

There have been efforts to distinguish between co-authorship and collaboration since the two need not be synonymous. "Co-authorship is rather an imperfect or partial indicator of research collaboration between individuals. Perceptions regarding the precise location of the 'boundary' of the collaboration may vary considerably across institutions, fields, sectors and countries as well as over a period of time. What constitutes a collaboration therefore varies across institutions, fields, sectors and countries, and probably changes over time as well" (Katz and Martin, 1997). However, in the absence of any other adaptable definition of 'collaboration', co-authorship has been considered to be an indicator of collaboration for the purposes of this study. In this study every co-authored journal paper having the first author with an Indian affiliation has been considered as one unit of "collaboration".

The literature on collaboration indicates that several different measures have been employed to study collaboration. These include: Collaborative Index (mean number of authors per paper), Degree of Collaboration (proportion of single and multiple-authored papers) etc. Collaboration Coefficient (CC) is another such measure originally introduced by Ajiferuke in 1988. It is expressed as the ratio of the number of collaborative papers to the total number of papers published in a domain during a fixed period of time.

6 Materials and Methods

In this study quantitative techniques have been used to identify and describe the various aspects of collaboration. The data for the study has been extracted from *Science Citation Index* (SCI) using key words '*superconductivity*' OR '*superconductor*' and limiting the search to journal articles. The search has been further limited to papers published by Indian authors using the address field (AD=India). Only journals articles published during the period from 1975 to 2000 have been examined for analysis. Short notes, letters and reviews have not been included. The extracted data has been grouped into 5 block years 1975-80, 1981-85, 1986-90, 1991-95, 1996 -2000.

The number of collaborating authors for each paper was counted and the papers grouped into papers involving '*single author', 'two authors', 'three authors', 'four authors', 'five authors', and 'more than five authors'*. The data about the authors' country of origin, name and type of institution were also collected. The affiliating institutions were grouped into three broad categories namely, universities, government laboratories and industries. Data about the collaborating country was also obtained from the address field and the countries were ranked according to the total number of papers published by Indian authors in collaboration with foreign authors. The journals publishing co-authored papers were taken from the source data and the average impact factor of journals from the Internet site - *http://www.geocities.com/iipopescu/Jo_ranking.htm*. Analysis of data to identify the disciplinary linkages in research collaboration based on the subject background of the collaborating authors is being carried out. However, this part of the study is not presented here.

7 Data Analysis and Findings

Overall data indicate that the total Indian research output in Superconductivity is around 2,843 papers, which is roughly 3.82% of the world output of 74,376 papers during the study period. There has been a marked growth in multiple-author papers compared to single author papers over the study period. The percentage of multiple-author papers has increased from 77.08% during 1975-80 to 89.06% by 1996-2000. The average number of authors per paper has increased from 1.95 to 4.02 between 1975 and 2000. (Table-1).

Table-1: Growth and distribution of single and multiple-author papers

Block year	World Total	Indian papers	Single author (%)	Multiple authors (%)	Authors/paper
1975-80	3234	48	11 (22.91)	37 (77.08)	1.95
1981-85	3489	66	14 (21.21)	52 (78.78)	2.18
1986-90	10947	379	45 (11.87)	334 (88.12)	4.23
1991-95	28217	1243	87 (06.99)	1156 (93.00)	3.83
1996-2000	28489	1107	121(10.93)	986 (89.06)	4.02
Total	74376	2843	278 (9.77)	2565 (90.22)	

Extent of Collaboration

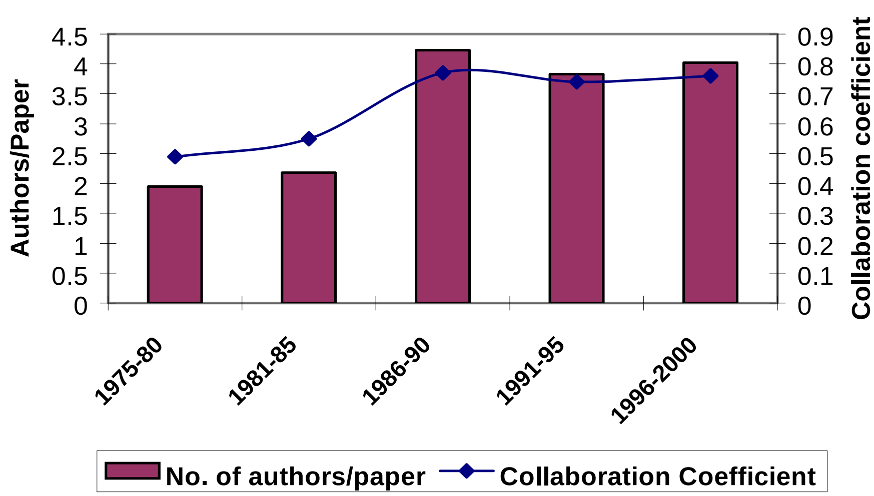
Table-2 gives the percentage distribution of single and multiple-author papers. Among collaborative papers, two-author papers and three-author papers predominate and account for almost 42%. The findings also reveal that there is a decreasing trend of single-author papers from 22.9% to 10.9% during the study period. It is interesting to note that since the mid-1980s the number of papers involving more than five authors constitutes almost 20% of the total. There is substantial increase in research collaboration during 1986-90 and since then it has stayed more or less at the same level.

Table 2 – Percentage distribution of single and multiple-author papers

No. of authors	1975-80 (%)	1981-85 (%)	1986-90 (%)	1991-95 (%)	96-2000 (%)	Total	Rank
1 author	11(22.9)	14 (21.2)	45 (11.8)	87 (6.9)	121 (10.9)	278	6
2 authors	28 (58.3)	30 (45.4)	64 (16.8)	279 (22.4)	238 (21.4)	639	1
3 authors	9 (18.7)	12 (18.1)	65 (17.1)	242 (19.4)	228 (20.5)	556	2
4 authors	0	3 (4.5)	62 (16.3)	217 (17.4)	144 (13.0)	426	4
5 authors	0	3 (4.5)	52 (13.7)	200 (16.0)	136 (12.2)	391	5
> 5 authors	0	1 (1.5)	90 (23.7)	218 (17.5)	240 (21.6)	549	3
Total	48	66	379	1243	1107	2843	

Although there are various methods to express the degree of collaboration, the Collaboration Coefficient (CC) method has been chosen because it is said to be very precise. Using the number of authors per paper, the Collaboration coefficient for Superconductivity research has been calculated to find out the extent of collaboration.

Fig 1- Collaboration Coefficient



The analysis show that the CC for Indian papers on Superconductivity has grown from 0.49 in 1975 to 0.76 in 2000 (Figure 1). This clearly indicates the growing importance of collaboration in Superconductivity research in India.

Institutional Linkages

In an attempt to examine the factors that may have a bearing on institutional linkages, the data was examined from two different angles, viz., geographical proximity of collaborating authors and the types of collaborating institutions. Table-3 indicates that there is greater collaboration among authors within a university (33.72%) followed by Government laboratories (27.17%), between Universities & Govt. laboratories (23.39%) and among universities (8.81%). Interestingly much of this growth has taken place during and after the block period 1986-90. The extent of collaboration between the university and government has been negligible before that. There has been no noticeable collaboration between university and industry. Collaboration involving all the three components of the so-called '*Triple Helix*'- the industry, Government laboratories and universities- is almost non-existent**.** It is also clear that universities still occupy a high position in collaborative research corroborating the observations made by many experts. This probably suggests that superconductivity research in India is largely 'academic' in nature but efforts are on to expand linkages between academic institutions and government laboratories and industry.

Table 3 - Distribution of papers by type of collaboration

Collaboration type	1975-80	1981-85	1986-90	1991-95	96-2000	Total	%	Rank
Within a University	18	22	123	434	268	865	33.72	1
Within a Government	12	21	118	306	240	697	27.17	2
University + Govt.	2	3	41	225	329	600	23.39	3
University + University	2	4	16	112	92	226	8.81	4
Government + Government	3	2	33	72	54	164	6.39	5
Within a Industry	0	0	0	5	1	6	0.23	6
University + Industry	0	0	3	1	2	6	0.23	6
University + Government +Industry	0	0	0	1	0	1	0.03	7
Total	37	52	334	1156	986	2565		

Table-4 presents data on the top ranking Indian institutions that are engaged in research in Superconductivity. It is seen that most of these institutions are academic institutions and Government R&D laboratories. The contribution by the industry is almost negligible (Only 2 industrial firms - BHEL and M/s Crompton-Greeves have published 5 and 1 paper each respectively).

Table 4 – Top 20 Indian institutions engaged in Superconductivity research.

Name of the Institution & place	Type of Institution	Total papers (1975-2000)	Rank
Indian Institute of Science, Bangalore	University	605	1
Tata Inst. of Fundamental Research, Bombay	R&D lab	541	2
Bhabha Atomic Res. Centre, Bombay	R&D lab	512	3
National Physical Laboratory, New Delhi	R&D lab	493	4
Regional Research Lab., Trivandrum	R&D lab	240	5
University of Hyderabad, Hyderabad	University	205	6
Osmania University, Hyderabad	University	176	7
Centre for Advanced Technology, Indore	R&D lab	168	8
Indian Association for the Cultivation of Science, Calcutta	R&D lab	160	9
University of Delhi, New Delhi	University	157	10
Shah Institute of Nuclear Physics, Calcutta	R&D lab.	150	11
IGCAR, Kalpakkam	R&D lab.	142	12
Anna University, Madras	University	140	13
Institute of Physics, Bhubaneswar	R&D lab.	116	14

Banaras Hindu University, Variance	University	99	15
Saurashtra University, Rajkot	University	86	16
University of Rajasthan, Jaipur	University	85	17
Defense Met. Research Laboratory, Hyderabad	R&D lab.	78	18
University of Poona, Poona	University	68	19
Indian Institute of Technology, Kharagpur	University	57	20

Geographical Proximity

Table-5 gives the data on the extent of domestic and foreign collaboration. It is interesting to note that during the study period, intra-institutional collaboration has gone down while domestic and foreign collaborations have substantially increased. There has been a sudden increase in foreign collaborations during 1991-95. Around 20% of the papers published so far are co-authored with foreign authors and the rest are co-authored with Indian authors.

Table 5 – Indian research collaboration by geographical proximity

Type of Collaboration	1975-80(%)	1981-85(%)	1986-90(%)	1991-95(%)	96-2000(%)	Total (%)
Intra-Institutional	30 (81.0)	36(69.2)	240(71.8)	729 (63.0)	440 (44.6)	1475(57.50)
Domestic	5 (13.5)	11(21.1)	74(22.1)	227 (19.6)	242 (24.5)	559 (21.79)
Foreign	2 (5.4)	5 (9.61)	20(5.98)	200 (17.3)	304 (30.8)	531 (20.70)
Total No of papers	37	52	334	1156	986	2565

Table-6 lists the countries with which the Indian authors collaborate most. International collaboration is comparatively a recent development as seen from the table. It is evident that this development is visible only since 1991. At present more than 30% of all the co-authored papers involve collaboration with a foreign country. From the table it is seen that USA with 192 papers is the most preferred country followed by France (99), Japan (77), UK (69), Germany (58), Italy (37), Brazil (20), Netherlands (12) and Australia (11). The share of former USSR nations and other countries together stands at 90 papers.

Table 6 – Distribution of co-authored papers by country

Country / No of papers	1975–80	1981-85	1986-90	1991-95	96-2000	Total	%
USA	0	5	11	52	124	192	28.87
FRANCE	2	0	3	51	43	99	14.88
JAPAN	0	1	1	16	59	77	11.57
GREAT BRITAIN	1	0	2	32	34	69	10.37
GERMANY	0	0	1	23	34	58	8.72
ITALY	0	0	2	12	23	37	5.56
BRAZIL	0	0	0	4	16	20	3.00
NETHERLANDS	0	0	0	4	8	12	1.80
AUSTRALIA	0	0	0	4	7	11	1.65
(Former USSR nations)	0	0	2	10	7	19	2.85
(Other Countries)	0	0	6	20	45	71	10.67
Total	3	6	28	228	400	665	100%

Journal Impact Factor and Collaboration

In order to examine the relationship, if any, between journal impact factor and collaboration, co-authored papers were counted and tabulated by the respective source journal. From the table it is seen that majority of the papers (72.92%) are published in journals having an average impact factor (AIF) of more than 1. Only 27.07 % of papers are published in journals with an AIF of less than 1. This may be an indication of the importance of research collaboration and its indirect contribution to the impact factor of journals (Table 7).

Table 7 – List of journals publishing co-authored papers and their average impact factor*

Journal title & Country of origin	1975-80	1981-85	1986-90	1991-95	1996-2000	Total	AIF*
Physica – C (NLD)	-	-	64	229	376	669	2.29
Physical Review – B (USA)	4	5	16	101	214	340	3.15
Solid state communications (USA)	7	11	73	117	120	328	1.80
Bulletin of Materials Science (IND)	-	-	7	110	66	183	0.25
Superconductor Science & Technology (UK)	-	-	5	58	98	161	1.93
Physica – B (NLD)	-	-	4	14	124	142	1.05
Journal of Superconductivity (USA)	-	-	2	22	110	134	1.07
Modern Physics Letters-B (SGP)	-	-	-	9	88	97	0.55
Pramana (IND)	2	7	16	28	34	87	0.40
Indian Journal of Pure & App. Physics (IND)	2	1	3	37	42	85	0.21
Journal of Physics - Condensed matter (UK)	-	-	2	17	51	70	1.58
Journal of Materials Science Letters (NLD)	-	-	14	20	28	62	0.49
Physics Letters – A (NLD)	7	4	7	-	40	58	1.02
Physica Status Solidi-B (GER)	4	6	6	5	33	54	0.81
Journal of Low Temperature Physics (USA)	8	10	4	-	26	48	1.35
Intl. Journal of Modern Physics (SGP)	-	-	-	11	34	45	0.92
Materials Research Bulletin (UK)	3	-	15	21	4	43	1.14
Materials Letters (NLD)	-	-	10	9	24	43	0.73
Jl. of Physics & Chemistry of Solids (UK)	-	-	-	-	40	40	1.11
Phase Transitions (UK)	-	-	26	-	6	32	0.57
Cryogenics (UK)	3	3	3	4	15	28	0.65
Applied Physics Letters (USA)	-	-	11	-	8	19	3.42
Journal of Applied Physics (USA)	-	-	2	14	-	16	1.73
Japanese Journal of Applied Physics-Part-I	-	-	8	-	6	14	0.36
Materials Science & Engineering-B (CHE)	-	-	-	11	-	11	0.66
Journal of Solid-state Chemistry (USA)	-	-	4	6	-	10	1.31
Physica - B & C (NLD)	-	5	4	-	-	9	0.96
Applied Superconductivity (UK)	-	-	-	9	-	9	0.93
Physica Status Solidi-A (GER)	-	-	-	8	-	8	0.70
Physical Review Letters (USA)	-	1	-	6	-	7	6.57
Journal of Physics-F-metal physics (UK)	2	3	2	-	-	7	2.26
Japanese Journal of Applied Physics-Part-II	-	-	3	-	3	6	0.01
Hyperfine Interactions (NLD)	-	1	4	-	-	5	0.76
Synthetic Metals (CHE)	-	-	3	-	-	3	1.44
Thin Solid Films (CHE)	1	-	2	-	-	3	1.17
Canadian Journal of Physics (CAN)	1	1	-	-	-	2	0.76

*The Average impact factor (AIF) is the arithmetic mean of annual impact factors of a journal over the period of ISI quotation.

8 Conclusions

As pointed out by many authors, this study has once again established the fact that research collaboration is a universal and growing phenomenon. Networked knowledge production through collaborative publishing has increased over the years. Scientometric analysis of co-authored papers does help us in understanding the scholarly communication system and institutional linkages in the form of research networks. Some of the major inferences that could be drawn from the study are:

- The collaboration between the university, industry and the Government in the field of Superconductivity research in India has not achieved the desired level. (Perhaps the complexity of the subject, technology, commercial interests, and research costs & delays may be responsible for the low-level of collaboration between all the three players).

- Geographical proximity does not appear to have any significant bearing on research collaboration.

- USA appears to be the most favoured country for Indian scientists for collaboration in Superconductivity.

- Knowledge production in Superconductivity in India appears to have undergone a transition and become more 'heterogeneous' in nature during 1986-90.

The outcome of the study appears to be in stark contrast to what Martin had observed that "today there is a stronger connection between academic science and industrial technology" (Martin, 2001). It will be interesting to examine whether this is a similar case with other disciplines. It will be useful to identify the environmental conditions that are conducive for greater collaboration between university, government and the industry.

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