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# Visualizing Research Collaboration in Statistical Science: A Scientometric Perspective

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# Visualizing Research Collaboration in Statistical Science: A Scientometric Perspective

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## Abstract

*Using Sankhyā – The Indian Journal of Statistics as a case, present study aims to identify scholarly collaboration pattern of statistical science based on research articles appeared during 2008 to 2017. This is an attempt to visualize and quantify statistical science research collaboration in multiple dimensions by exploring the co-authorship data. It investigates chronological variations of collaboration pattern, nodes and links established among the affiliated institutions and countries of all contributing authors. The study also examines the impact of research collaboration on citation scores. Findings reveal steady influx of statistical publications with clear tendency towards collaborative ventures, of which double-authored publications dominate. Small team of 2 to 3 authors is responsible for production of majority of collaborative research, whereas mega-authored communications are quite low. Country-wise mapping of research contributions reveals that, top five countries have contributed about 66% of the total authors and about 55% of the total affiliated institutions. Indicates few numbers of countries has substantial participation to statistical science research, while large majority has nominal contributions. Of which, USA contributes the most (31%) followed by India, Canada, France and Japan. Result therefore indicates presence of 'sort of 'clique' with dominant foreign coauthors. Further analysis reveals that, unilateral collaboration dominates at the country level whereas at the institution level bilateral collaboration dominates - implies authors from two different institutions of same country are key contributors of this specialty. Indian Statistical Institute (native institute of the source journal) found to be the most productive institution. Study therefore signifies skewed distribution of co-authorship with limited evidence of cross-country collaboration. Furthermore, Google Scholar citation analysis showed that collaboration has significant positive influence on the article impact.*

**Keywords:** Bibliometrics, Research collaboration, Collaboration mapping, Collaboration Density, Statistical science research, *Sankhyā*, Indian Journal of Statistics

## 1. Introduction

Phenomenal development of ICT (especially Internet, web2.0 and social networking technology) has drastically reduced the role of spatial boundaries for accessing information. This in turn have facilitates researchers of distant locations to interact easier than before. Nowadays, researchers of distant places interact frequently to brainstorm diverse problem with greater probability of success. Countries, all over the world have developed policies to foster cross-fertilization of intellectual assets. Research policy across the globe thus has become more focused on stimulating collaborative research. Therefore, collaboration has become the norm of current research towards knowledge economy. Reportedly, research collaboration being a multi-faceted abstraction, often been defined loosely in the literature. Generally, it can be described

as a process of working together throughout a large part of the project, and collaborators are those who either initiate the project, or lead the project, or are responsible for the main part(s) of the project (Katz & Martin, 1997). Therefore, collaboration is an intense form of interaction that facilitates sharing of competence, skills and other resources. Researchers collaborate for variety of motivations and considerations like pooling of intellectual resources, sharing of overhead for expensive experiments, cross-fertilization of thoughts, increased visibility and recognition (Frame & Carpenter, 1979). Though various fields of knowledge may exhibit different affinity towards collaborative activity, increasing collaboration is the norms of current research fraternity. Numerous studies have been undertaken to visualize and analyze the features of research collaboration among the affiliated countries and institutions. However, several factors like mutuality of interest, subject specialty, data resources, geographical proximity, cultural and linguistic diversity, political interference, socio-economic conditions and foreign policy are some of the basic determinants shaping the pattern of collaboration (Harirchi et al., 2007).

Conventionally, in an academic setup research publication is regarded as perceptible output of research project, and co-authorship is used as a proxy indicator for estimation of research collaboration. Moreover, ever-increasing trend of research collaboration across discipline has raised few pertinent concerns, for which there is hardly any consensus of opinions. In fact, there has been mixed opinion among researchers of various disciplines regarding the relationship between pattern of collaboration and its impact on quality of research (Nude, 2016). Studies have reported significant positive impact of collaboration on the citation in the disciplines of Economics (Levitt and Thelwall, 2010); Biology and Biochemistry (Didegah and Thelwall, 2013); Computer Science (Ibáñez et al., 2013); Library & Information Science (Patra, 2014) and (Abt, 1984). Conversely, good number of studies in the disciplines of Ecology (Leimu and Koricheva, 2005); Chemistry (Bormann et al., 2012); Geography and Forestry (Slyder et al., 2011); Social Psychology (Haslam et al., 2008) identifies no significant correlation exists between these two variables. Therefore, there has been little consensus about the proposition that collaboration boosts or fosters citation across domains. However, in spite of numerous studies, no such effort had been ventured in the area of statistics to address the issue.

## 2. Research Collaboration in Statistical Science

There has been considerable ambiguity among world statistician viewpoints regarding precise interpretation of the term 'Statistics'. According to ASA President Marie Davidian, "Statistics is the science of learning from data, and of measuring, controlling and communicating uncertainty." (Davidian and Louis, 2012). Generally, "Statistics at its best provides methodology for dealing empirically with complicated and uncertain information, in a way that is both useful and scientifically valid" (Chambers, 1993). However, Feinberg (2014) opined that statistical methods could be used not just within their fields of interest but across the spectrum of disciplines. Therefore, statistics is a meta-discipline in the sense, as principles and methodologies are abstracted from particular experiment could be easily incorporated into innovative scaffold that facilitate them to be used in numerous problems of many other places.

Reportedly, most of the disciplines have distinctive epistemological feature which regulates its research practices. Moreover, disciplines show verity of practices towards collaboration. Statistics, being a domain of multidisciplinary nature, often intermingles expositions from both social science (soft discipline) and mathematical sciences (hard discipline). Thereby, significant contribution between the researchers from both the disciplines is quite normal affair. Moreover, Statistics is generally perceived as the universal tool of inductive inferences. Therefore, it is little surprising that statistics journal literature (say *Sankhyā*) could be candidate for study of collaboration trend. Furthermore, scientific collaboration is generally presumed to enhance quality and impact of research, as individuals with network environment have better access to larger pool of ideas and resources. While positive role of research collaboration has been confirmed across disciplines of natural and social sciences, there have been stray attempts (Stigler, 1994, & Visakhi and Srivastava 2002) to study the collaboration pattern of Statistical Science researchers. Our study intends to identify collaboration trend along with the citation scores thereof by examining the institutional and country affiliations of the authors published in one of the flagship journal of Statistical science.

### 3. Scope and Objectives

This study is confined to the scholarly articles appeared in journal *Sankhyā* (both series A and B) during the period 2008 to 2017. However, relatively lesser communications like editorial notes, biography, corrigendum, obituary, book reviews, etc. are excluded from the purview of this study. So the bibliometric analysis of peer-reviewed research articles appeared during last ten years period (vol. 70 to 79, covers twenty issues) of *Sankhyā* would certainly be an indicative of current trends of statistical research. However, present study is structured around the following specific research objectives:

- ❑ To identify the quantum of collaborative and non-collaborative publications in this specialty
- ❑ To determine the extent of research collaboration among the affiliated authors, institutions and transnational countries of statistical science research.
- ❑ To deduce collaborative metrics so as to map extent of research collaboration
- ❑ To analyze collaboration patterns at various levels of aggregations
- ❑ To enumerate prolific authors and their affiliated institutions of statistical research
- ❑ To identify the correlation between collaboration and citation impact of statistical science research

### 4. Origin and genesis of *Sankhyā* - The Indian Journal of Statistics

*Sankhyā – The Indian Journal of Statistics* has been chosen as the data source to identify the statistical science, primarily because - it is the flagship Indian journal in the field of statistics. Practically it is considered the first Indian journal in the area of statistics. (Rudra, 1996). However, dedicated publication outlet to showcase contemporary research communication in the area of statistics and related areas was aptly perceived by multifaceted Renaissance man Prof. P. C. Mahalanobis (Rao, 2006). He founded and edited *Sankhyā – The Indian Journal of Statistics*, an international scholarly journal from Indian Statistical Institute. Genetically, the journal *Sankhyā* has close bearing with Indian epic *Mahabharata* (Ghosh et al., 1999), objectively, journal *Sankhyā* has evolved to unfold twin aspects of statistics, both theoretical and applied towards his perception ‘statistics as key-technology for social welfare and national development’. In pursuance of above philosophy, the journal provides a convenient communication channel for exchanging innovative ideas in the different sub-domains of statistics, which make *Sankhyā* an effective and reliable representative of contemporary statistical research. Elsewhere, we have discussed about significant ebbs and flows undergone by the journal since its inception (Das and Pal, 2013).

### 5. Data Source and Collection

The study has been conducted in successive phases: data extraction, verification and scientometric analysis. First of all, primary data of statistical research has been extracted from MATHSCINET. Its search interface provides diverse combination of fields like - MR No, author, institutional affiliations, country code, MSC classification code, source journal and citations thereof, which could be useful to identify the publications of journal. Bibliographical data elements of individual articles having source *Sankhyā* published during 2008 to 2017 were retrieved from the MATHSCINET website by framing search query: *Journal = Sankhya AND publication type = journal AND year range = 2008 to 2017*. Searching has yielded 340 hits (as on 28 April 2018, Fig - 1), were considered as working dataset of our study. Further scrutiny of retrieved dataset (340 in numbers) has revealed that, as many as five item records were not ‘research articles’, they are actually erratum to earlier publications. So, these five records – viz. MR3575747 (erratum to MR3317478), MR3400122 (erratum to MR3061848), MR3302278 (erratum to MR3302274), MR3302277 (erratum to MR3082814) and MR3167778 (erratum to MR3010292) are excluded from the purview of our study. Again, MR2658160 [contains biography of A P Mitra (1938 – 2008)] and MR3749268 [contains obituary of J K Ghosh] also excluded for the same logic.

Further validation with the physical volumes of source journal, we found the record for last article of *Sankhyā* [Vol. 71 part B (2009), p. 264 – 289], entitle “*An application of Martingale Convergence Theorem to Analyse Company Data*” by VC Augustine & M G Nadkarni, is somehow missing in the MATHSCINET, this has been included to our study sample. Therefore, the final counting of *Sankhyā* articles during the study period (2008 to 2017) becomes  $(340 - 7 + 1) = 334$ . This has been reaffirmed by visiting the official website of the source journal. Finally, relevant scientometric techniques are applied to determine the bibliographic attributes of the research publications. So, necessary bibliographic elements of each article like year of publication, author/s name, number of authors, affiliations, collaboration types, mathematics subject classification, etc. are recorded and subsequently analyzed for making insightful interpretations.

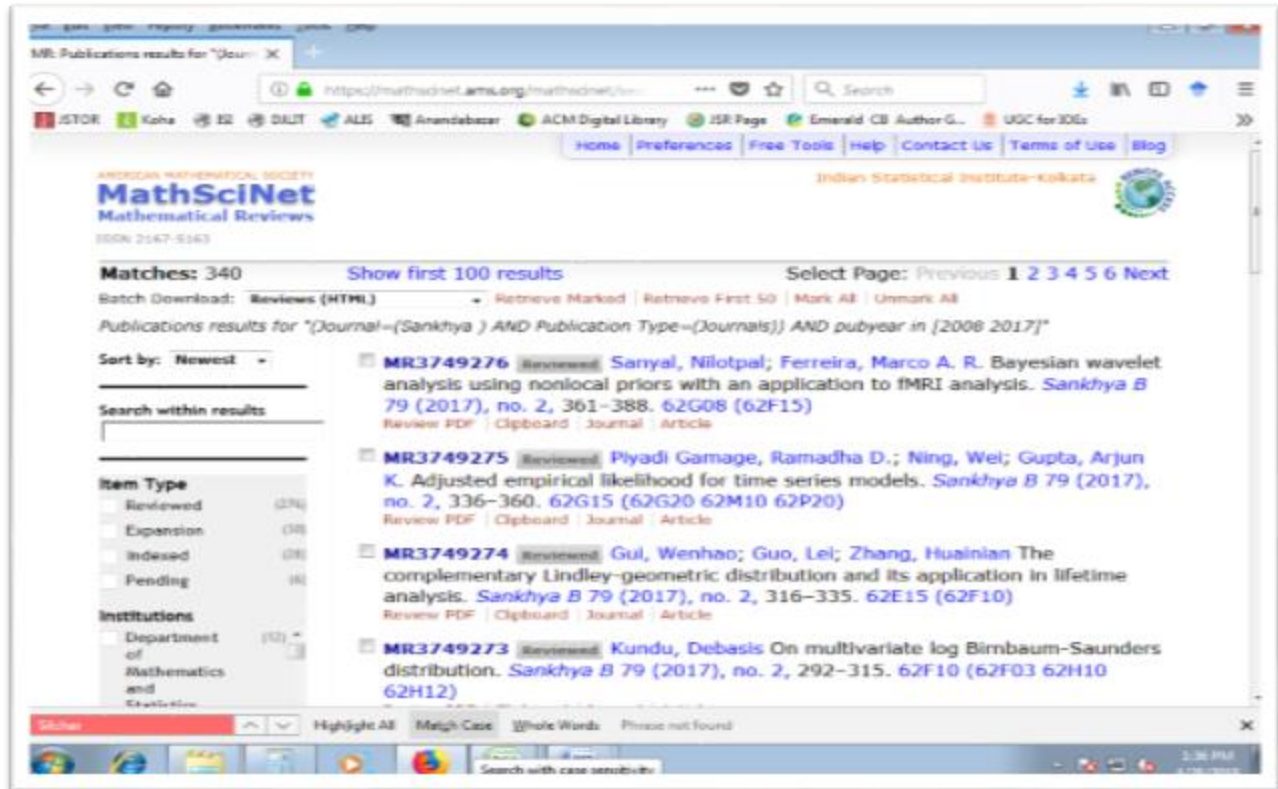


Fig – 1: Search results of MathSciNet

## 6. Methodology

To investigate the research collaboration and citation impact of the statistical publications, basically a descriptive Scientometric scrutiny was employed. Scholarly articles published in *Sankhyā* over 10 year period (2008 - 2017) has been assessed retrospectively. Collaboration has been attributed on the basis of number of authors, where single authored paper implies no-collaboration and two or more authored paper imply collaborative research. Furthermore, collaboration has been studied in two broad perspectives – viz. country-wise collaboration and institution-wise collaboration. However, collaboration typology used for this study was mostly based on the topology used by Sooryamoorthy (2009). Here, national collaboration is considered for the case in which co-authors are exclusively from different Indian institutions; at the same line - foreign collaboration is supposed to take place in case where all the co-authors are from different foreign countries (except India). Whereas International collaborations is termed - when collaborations take place between authors from foreign countries and India (at least one author). Furthermore, these has been subdivided to Intra (within same link), Inter (among links) modes. Various collaboration metrics viz ‘degree of collaboration’, ‘collaboration coefficient; and ‘collaboration index’ for the sampled data were

deduced by applying established methods (Ajiferuke, 1988; Subramanyam, 1983; Lawani, 1980). Rank list of prolific authors is enumerated using fractional counting method (Van-Hooydonk, 1997). Citation counts of all sampled articles were retrieved from Google Scholar. Individual article was searched to find the number of citation (including self citations) received up to Dec'18. All bibliographic and citation data for 334 articles were transcribed in MS Excel spreadsheet for applying various mathematical and statistical techniques. Finally, necessary data sheets were presented for perceptive interpretations.

## 7. Data Analysis and Interpretation

A detailed analysis of collected data revealed lots of information to answer various interesting questions, which are presented in the following sections.

### 7.1 Year wise distribution of contributions

Table-1 shows descriptive statistics of bibliometric attributes of *Sankhyā* over the last ten years period (2008 – 2017). Result reflects that, during this period a total of 334 articles were published by total 682 authors in the 40 issues of *Sankhyā* Series A and B. These articles totally consumed 6984 pages that collectively appended 1734 keywords and 7275 references respectively. Therefore, average authorship per article measures to slightly greater than 2 (2.04), indicates the dominance of joint authorship. Results also reflect steady influx of *Sankhyā* articles (average 33.4 articles/ year). More significantly, up to December 2018, these publications receive fairly good numbers of citation (1804) with an average of 5.4 citations per paper. Of which, 2011 received highest average citation and 2016 has received the least (2.16). (Expectedly this would increase over course of time). Result therefore reflects the visibility and popularity of the journal among the peers.

Year	Article	Author	Author / Article	Total Citations	Citation/ Article	Ref. appended	Total Page	Keyword appended
2008	30	55	1.83	282	9.40	614	661	142
2009	33	65	1.97	257	7.79	647	624	185
2010	36	75	2.08	262	7.28	653	650	180
2011	36	70	1.94	353	9.80	759	687	188
2012	31	70	2.26	154	4.97	678	605	167
2013	33	66	2.00	97	2.93	810	724	181
2014	34	79	2.32	140	4.12	773	734	177
2015	38	71	1.87	110	2.89	818	808	175
2016	31	61	1.97	67	2.16	769	728	170
2017	32	70	2.19	82	2.56	754	763	169
<b>Total</b>	<b>334</b>	<b>682</b>	<b>2.04</b>	<b>1804</b>	<b>5.40</b>	<b>7275</b>	<b>6984</b>	<b>1734</b>

### 7.2 Authorship Pattern

Table-2 represents 'pattern of authorship' of the published articles of *Sankhyā* during 2008-2017. The study identified a total of 682 occurrences of authors counted in 334 articles produced during the period, thus average authorship obtained 2.04 for each publication. It is also observed that double-authored papers are predominate (142, 20.82%), followed by single authored (98, 14.37 %) and triple-authored (82, 12 %) respectively. Whereas mega-authored papers (four, five & six-authored) are quite low (12, 1.76%). Mean co-author for collaborative articles are 2.47. Therefore, result signifies that contributors of *Sankhyā* prefer to work in collaborative fashion. Observed trend of collaborative publications have been the norms in many other disciplines as well (Bandyopadhyay, 2001). However, Visakhi and Srivastava (2002) in their study on research collaboration of statistical science also endorsed the similar trend.

Year	Number of Articles	Authorship value						Total occurrence authors	Average authorship
		Solo	Two	Three	Four	Five	Six		
2008	30	12	12	5	1			55	1.83
2009	33	10	14	9				65	1.97
2010	36	9	15	12				75	2.08
2011	36	8	22	6				70	1.94
2012	31	7	12	10	1	1		70	2.26
2013	33	11	12	9	1			66	2.00
2014	34	9	11	10	3		1	79	2.32
2015	38	14	16	7	1			71	1.87
2016	31	12	11	7		1	1	61	1.97
2017	32	6	17	7	1			70	2.19
<b>Total</b>	<b>334</b>	<b>98</b>	<b>142</b>	<b>82</b>	<b>8</b>	<b>2</b>	<b>2</b>	<b>682</b>	<b>2.04</b>

### 7.3 Ranking of Prolific Authors

Table-3 enumerates the ranking of prolific authors based on total weigh of authorship in all publications of *Sankhyā* during the study period. Total Weight of particular author has been summarized by cumulating individual weights in different authorship contributions using fractional counting method. Table reflects that 334 articles of *Sankhyā* have been contributed by 565 individual authors in different authorship positions resulting total of 682authorships. Of which, large majority of authors (453, 80.18%) have contributed nominally (having cumulative weight < 1); only 30 authors (5.1%) have cumulative weight > 1 for their entire contribution. Out of which, Brajendra C. Sutradhar (Memorial University of New Foundland, Canada) is found to be the most prolific author followed by Debasis Kundu (Indian Statistical Institute, New Delhi); Saraless Nadarajah (University of Manchester, UK); Mike Jacroux (Washington State University, USA); M. C. Bhattacharjee (New Jersey Institute of Technology, USA); Fuxia Cheng (Illinois State University, USA); Denys Pommeret (CREST-ENSAI, France); Soumendra N. Lahiri (Iowa State University, USA), etc. However to avoid long listing, names of the contributors who have received nominal cumulative weighted ( $\leq 1$ ) is not taken into account.

Rank	Author name	Authorship contribution						Weight	Total Wt.	Cu Wt.
		One	Two	Three	Four	Five	Six			
1	Sutradhar, Brajendra C.	1	5	4				4.833	4.833	4.833
2	Kundu, Debasis	2	4	2				4.667	4.667	9.500

3	Nadarajah, Saralees		5	2				3.167	3.167	12.667
4	Jacroux, Mike	2	2					3.00 x 2	6.000	18.667
	Sengupta, S.	3								
5	Kruglov, Victor M.	2	1					2.500	2.500	2.500
6	Sen, Pranab K.	2		1				2.333	2.333	4.833
7	Ghosh, Jayanta K.	1	1	2				2.167	2.167	7.000
8	Balakrishnan, N		2	3				2.00 x 8	16.000	41.667
	Withers, Christopher S.		4							
	Cassese, Gianluca	2								
	Kosorok, Michael R.	2								
	Kunita, Hiroshi	2								
	Ogawa, Shigeyoshi	2								
	Sarkar, Sanat K.	2								
Wellne, Jon A.	2									
9	Sinha, Bimal		2	1		1		1.533	1.533	43.200
10	Bhattacharya, Rabi		1	3				1.50 x 6	9	52.200
	Pradhan, Biswabrata		3							
	Nkurunziza, Sévérien	1	1							
	Patriota, Alexandre G.	1	1							
	Rajeev, B	1	1							
	Ramasubramanian, S	1	1							
11	Bhattacharya, A	1		1				1.333x4	5.332	57.532
	Bhattacharya, Sourabh	1		1						
	Chesneau, Christophe	1		1						
	Maitra, Ranjan	1		1						
12	Caro-Lopera, Francisco J.		1	2				1.167x2	2.334	59.866
	Lin, Lizhen		1	2						
13	Pardo, Leandro		1	1	1			1.083	1.083	60.949



14	82 authors having			3				1.000	82.000	142.949
15	Basu, Ayanendranath			2	1			0.917	0.917	143.866
16	10 authors each having		1	1				0.833x10	8.330	152.196
17	Klein, Martin		1			1		0.700	0.700	152.896
18	13 authors		1				1	0.667x13	8.671	161.567
19	3 authors having			1	1			0.583x3	1.749	163.316
20	Sengupta, Arindam			1		1		0.533	0.533	163.849
21	203 authors having		1					0.500	101.500	265.349
22	176 authors having			1				0.333	58.608	323.957
23	27 authors having					1		0.25 x27	6.750	330.707
24	7 authors having						1	0.2 x7	1.400	332.107
25	11 authors having						1	0.167x11	1.837	333.944
<b>Total 565 unique authors</b>		<b>98</b>	<b>284</b>	<b>246</b>	<b>32</b>	<b>10</b>	<b>12</b>			<b>334.000</b>

#### 7.4 Research Collaboration

Globally, collaborative research is becoming more pervasive across disciplines (Georghiou, 1998). Here also, it is observed (Table- 4) that, out of total 334 research papers, 98 (29.34%) papers are single authored, therefore devoid of any authorship collaboration. Of which, 32 non-collaborative articles are from India authors and 66 are contributed by foreign authors. Collected data is mapped for level of collaboration undertaken by the authors of *Sankhyā*. Affiliations of the contributing authors were scrutinized to ascertain levels of collaboration as Domestic (collaboration occurs among authors of different institutions of India); Foreign (collaboration occurs between authors of different foreign institutions outside India. International collaboration is assigned to publications in which collaboration occurs between authors from Indian and other foreign countries. It is found that, out of 236 collaborative papers, majority (186, 79%) are of 'Foreign' category, followed by national (12.71%). Noteworthy is the fact that in both for collaborative and non-collaborative publications foreign contributions are significantly dominant. Out of 236 collaborative communications, domestic collaboration constituting only 8% and foreign collaboration constituting 58%, while the share of 34% of multi-authored contributions are collaborated among statisticians across the countries. Clearly it brings out the prevalence of collaborative research (69.85%) over the solo research (30.15%), which needs to be explored to promote international collaboration.

**Table 4 – Collaboration Scenario**

Year	Non-collaborative (N <sub>s</sub> )			%	Collaborative (N <sub>m</sub> )				%
	Domestic	Foreign	Total		Domestic	Foreign	International	Total	
2008	3	9	12	12.24	1	15	2	18	7.63
2009	10	0	10	10.20	3	18	2	23	9.75
2010	4	5	9	9.18	5	21	1	27	11.44

2011	1	7	8	8.16	4	22	2	28	11.86
2012	0	7	7	7.14	3	18	3	24	10.17
2013	2	9	11	11.22	3	17	2	22	9.32
2014	2	7	9	9.18	3	20	2	25	10.59
2015	6	8	14	14.29	2	19	3	24	10.17
2016	3	9	12	12.24	2	15	2	19	8.05
2017	1	5	6	6.12	4	21	1	26	11.02
<b>Total</b>	<b>32</b>	<b>66</b>	<b>98</b>	<b>29.34</b>	<b>30</b>	<b>186</b>	<b>20</b>	<b>236</b>	<b>70.66</b>

### 7.5 Collaboration Topology

Here lateral relationship among co-authors of collaborative contributions is studied under three different levels of aggregation - viz. *unilateral*, *bilateral*, and *multilateral*. *Unilateral collaboration* is described when co-authorship of a publication occurs within a link, whereas *bilateral collaboration* implies the co-authorship occurs between two different links and *multilateral collaboration* indicates the participation of co-authors from more than two different links for producing an article. Table-5 reveals the distribution of collaborative contributions in order to map the lateral relationship among co-authors.

Year	Table 5 – Lateral relations among collaborative contributions							
	Country-wise collaboration				Institution-wise collaboration			
	Unilateral	Bilateral	Multilateral	Total	Unilateral	Bilateral	Multilateral	Total
2008	12	6	0	18	6	9	3	18
2009	17	6	0	23	6	13	4	23
2010	23	4	0	27	8	14	5	27
2011	22	4	2	28	13	12	3	28
2012	13	11	0	24	6	13	5	24
2013	17	5	0	22	11	7	4	22
2014	13	8	4	25	5	13	7	25
2015	17	7	0	24	9	13	2	24
2016	9	10	0	19	5	10	4	19
2017	21	4	1	26	9	16	1	26
<b>Total</b>	<b>164</b>	<b>65</b>	<b>7</b>	<b>236</b>	<b>78</b>	<b>120</b>	<b>38</b>	<b>236</b>

Here collaborative attributes are mapped in two levels of stratum viz. country-wise collaboration and institution-wise collaboration. Institution-wise collaboration of a publication occurs among the (co-) author/s affiliated to same institution/s (Unilateral), or two different institutions (Bilateral), or more than two different institutions (Multilateral). Similarly, country-wise Multi-lateral collaboration indicates that the authors of particular article are affiliated to the institutes located in three or more different countries. Result reflects that at the country level, unilateral collaboration dominates (164, 70%) whereas, institution level bilateral collaboration dominates. However, in both the stratum, multilateral collaboration is the least preference. Results, therefore signifies authors from two different institutions of same country predominates in statistical science research collaboration.

<b>Collaboration Type</b>	<b>Freq</b>	<b>%</b>
FORN-UNI (authors from same foreign countries)	130	55.08
FORN-BI ( authors from two different foreign countries)	46	19.49
NATL-UNI( among the Indian authors)	30	12.71
INT-BI ( Indian authors and foreign countries)	20	8.47
FORN-MULT( authors from two or more foreign countries)	8	3.39
INT-MULT(authors from India and two or more foreign countries)	2	0.85
<b>Total</b>	<b>236</b>	<b>100.00</b>

Further mapping of collaborative attribute of *Sankhyā* articles reflects that out of 236 collaborative articles majority (130, 55%) are in the form of 'FORN-UNI' (foreign unilateral) i.e. collaboration within the authors of same foreign countries. Followed by contributions of 'FORN-BI' (foreign bilateral) (46) i.e., collaboration between two foreign authors; and 8 papers are 'FORN-MULT' (foreign multilateral) i.e. collaboration among authors from more than two foreign countries. These foreign contributions (184 in total) are devoid of any domestic authors. Conversely, 30 papers are in the nature of 'NATL-UNI'(domestic unilateral) i.e., these papers are collaborated by two or more Indian authors, therefore devoid of any foreign affiliations. However, collaboration occurs among foreign countries and India occurs in the case of 22 papers. Of which in case of 20 papers ('INT-BI'), collaboration occurs between one Indian author and one foreign author (International bilateral) and rest 2 papers are 'international multilateral' type i.e. among Indian authors and two or more foreign authors. Therefore, country-wise collaboration mapping reveals clear dominance of foreign collaboration. Probably, tremendous proliferation ICT and internet with and improved research infrastructure has paved the scope for increased foreign contributions in this specialty.

## 7.8 Collaboration Indices

To deduce the extent of collaboration towards multi-authorship of given discipline, array of metrics have been proposed in the form of Collaborative Index (CI); Degree of Collaboration (DC) and Collaboration Coefficient (CC). Here, these three indices are deduced using the working data set to have an estimate of collaboration scenario.

<b>Year</b>	<b>Authorship</b>						<b>Total articles</b>	<b>Total authors</b>	<b>CI</b>	<b>CC</b>	<b>DC</b>
	<b>Single</b>	<b>Double</b>	<b>Triple</b>	<b>Four</b>	<b>Five</b>	<b>Six</b>					
2008	12	12	5	1			30	55	1.833	0.336	0.600
2009	10	14	9				33	65	1.970	0.394	0.697
2010	9	15	12				36	75	2.083	0.431	0.750
2011	8	22	6				36	70	1.944	0.417	0.778

2012	7	12	10	1	1		31	70	2.258	0.459	0.774
2013	11	12	9	1			33	66	2.000	0.386	0.667
2014	9	11	10	3		1	34	79	2.324	0.449	0.735
2015	14	16	7	1			38	71	1.868	0.353	0.632
2016	12	11	7			1	31	61	1.968	0.355	0.613
2017	6	17	7	1	1		32	70	2.188	0.460	0.813
<b>Total</b>	<b>98</b>	<b>142</b>	<b>82</b>	<b>8</b>	<b>2</b>	<b>2</b>	<b>334</b>	<b>682</b>	<b>2.042</b>	<b>0.404</b>	<b>0.707</b>

Subramanyam (1983) mathematically deduced degree of collaborative (DC) as the ratio of number of collaborative publications to total number of publications as follows:

$$DC = \frac{N_m}{N_m + N_s} = \frac{236}{236 + 98} = 0.707$$

Where  $N_m$  denotes total multi-authored contributions and  $N_s$  denotes the number of non-collaborative (single-authored) publications of the journal during study period. Thus, average degree of collaboration is found to be significant (0.707). Table shows the variations of degree of collaboration from 0.6 (in 2008) to 0.81 (in 2017) with an average of 0.707. Therefore, result indicates the prevalence of collaborative research over solo research in the specialty which is in agreement with previous studies (Das & Pal, 2012).

Another significant metric, Collaborative Index (a proxy measure for research collaboration) derived by Lawani, as the mean number of authors publications. This can be calculated by the formula:

**CI** = [(f1) 1 + (f2) 2 + (f3) 3 + ... (fk) k] / N. For, for the working dataset, it becomes, CI = [(98x1) + (124x2) + (82x3) + (8x4) + (5 x2) + (6x2)] / 334. So, here CI = (682/334) = 2.042.

Result therefore indicates reasonable value of collaboration index among the researcher of the specialty.

According to Ajiferuke (1988), Collaboration Co-efficient (CC) implies the mean number of papers per joint authored publications. For the present dataset, it is easily obtained using the formula suggested by Ajiferuke (1988) as follows:

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

Where,  $F_j$  = number of paper having j authors in the collection of k;

$N$  = total number of paper published

$K$  = highest number of authors per paper; therefore,  $N = \sum iF_j$

$CC = 1 - [f_1 + (1/2) f_2 + (1/3) f_3 + \dots + (1/k) f_k] / N$ . For the given dataset it becomes

$CC = 1 - [98 + (1/2) \times 142 + (1/3) \times 82 + (1/4) \times 8 + (1/5) \times 2 + (1/6) \times 6] / 334$

$CC = 1 - [0.599] = 0.401$ . From the deductions of three collaborative indices it is numerically evident that researchers working in this field prefer to conduct research in collaborative fashion.

## 7.9 Country Affiliations of the Contributors

Table-8 reflects country-wise distribution of articles as appeared in *Sankhyā* during the study period. Country names have been ascertained from author affiliations as reflected in their respective publications further verified from their 'institution code' data-field of MathSciNet. Tabulated data shows that all 682 contributing authors of *Sankhyā* has emanated from 51 different countries worldwide. Therefore, indication of global connectedness of the countries and authors of the source-journal is clearly observed. Rank list of affiliated countries of contributing authors has been prepared on the basis of share value of the contributions from respective countries. Analysis shows authors belong to 7 countries of Africa; 20

countries of Asia; 15 countries of Europe; 3 countries of North America; 4 countries of South America and 2 countries from the continent of Oceania. So there have been fairly vast distributions of authors across the globe. Of which, USA contributes the maximum (31%) of 211 authors from 78 institutions; followed by India (18%), Canada (8.5%), France (4.55%), Japan (3.5%) and others. It has been found that top five countries are contributing about 66% of the total authors and about 55% of the total affiliated institutions. Result indicates high concentrations of statistical research activities in this region. This indicates that author distribution is very much skewed with respect to geographical locations of contributing authors and their affiliated institutions.

<b>Table 8 - Geographical distributions of Authors</b>						
<b>Rank</b>	<b>Country</b>	<b>Continent</b>	<b>Authors</b>	<b>%</b>	<b>Institutions</b>	<b>%</b>
1	USA	North America	211	30.94	78	26.62
2	India	Asia	123	18.04	35	11.95
3	Canada	North America	58	8.50	16	5.46
4	France	Europe	31	4.55	18	6.14
5	Japan	Asia	24	3.52	15	5.12
6	Italy	Europe	23	3.37	15	5.12
7	England	Europe	19 each	2.79	6	2.05
	Germany	Europe			10	3.41
	Iran	Asia			9	3.07
8	PRC China	Asia	18	2.64	11	3.75
9	Brazil	South America	13	1.91	4	1.37
10	Australia	Oceania	10 each	1.47	6	2.05
	Greece	Europe			7	2.39
	Taiwan(R.O.C.)	Asia			5	1.71
11	Belgium	Europe	6 each	0.88	4	1.37
	Spain	Europe			3	1.02
12	Poland	Europe	5 each	0.73	2	0.68
	Sweden	Europe			2	0.68
13	Egypt	Africa	4 each	0.59	3	1.02
	New Zealand	Oceania			1	0.34
	Russia	Asia			2	0.68
	Switzerland	Europe			3	1.02
14	Algeria	Africa	3 each	0.44	2	0.68
	Argentina	South America			1	0.34
	Colombia	South America			1	0.34
	Israel	Asia			1	0.34
	Mexico	North America			2	0.68
	Singapore	Asia			1	0.34
	Thailand	Asia			2	0.68
	The Netherlands	Europe			2	0.68

	Vietnam	Asia			2	0.68
15	Cyprus	Europe	2 each	0.29	1	0.34
	Ethiopia	Africa		0.29	1	0.34
	Georgia	Europe		0.29	2	0.68
	Jordan	Asia		0.29	2	0.68
	Kuwait	Asia		0.29	1	0.34
	Nigeria	Africa		0.29	1	0.34
	Saudi Arabia	Asia		0.29	2	0.68
	UAE	Asia		0.29	2	0.68
	Ukraine	Europe		0.29	1	0.34
16	Bangladesh	Asia	1 each	0.15	1	0.34
	Botswana	Africa		0.15	1	0.34
	Denmark	Europe		0.15	1	0.34
	Ecuador	South America		0.15	1	0.34
	Gambia	Africa		0.15	1	0.34
	Iraq	Asia		0.15	1	0.34
	Malaysia	Asia		0.15	1	0.34
	Mauritius	Asia		0.15	1	0.34
	Morocco	Africa		0.15	1	0.34
	Pakistan	Asia		0.15	1	0.34
	Uzbekistan	Asia		0.15	1	0.34
<b>Total 51 countries from 6 continent</b>			<b>682</b>		<b>293</b>	

<b>Table 9: Collaborative behavior of Countries</b>						
Nature	No. of Country (Collb.)	Paper	%	Author	Citation	Cit / Paper
Collaborative	1	166	70.33	401	824	4.96
	2	63	26.69	160	336	5.33
	3	6	2.54	18	150	25.00
	4	1	0.43	5	3	3.00
	<b>Total</b>	<b>236</b>	<b>70.66</b>	<b>584</b>	<b>1313</b>	<b>5.56</b>
Non collaborative	0	98	29.34	98	491	5.01
<b>Total</b>		<b>334</b>		<b>682</b>	<b>1804</b>	<b>5.40</b>

Table - 9 represents the country of affiliated authors who have collaborated *Sankhyā* during the study period. Results shows that majority of the collaborative articles (70%) are contributed by authors from single country. Whereas, two countries participated in the authoring of 63(27%) articles and three countries participated in the authoring of 6(2.54%) articles respectively. In single case, collaboration occurs among the authors from four different countries.

### 7.10 Institution-wise distribution of Contributors

Table-10 enumerates prolific institutions of statistical science research based on the data retrieved from the 'author affiliations' of the contributing authors of *Sankhyā*. Analysis of authorship data shows that 682 contributors of *Sankhyā* are affiliated to 293 different institutions across the globe. A rank list of participating institutions has been prepared based on the frequency of institutions. It is observed from the table that Indian Statistical Institute (6-ISI) has appeared on the top; followed by Memorial University of Newfoundland, USA (3-NF), University of California, and University of Manchester, Indian Institute of Technology, Kanpur and others. It is also evident from the table, that though there has fairly large number of institutions (293) are involved in statistical science research only 15 institutions have contributed more than one author in the listing. Large majority of institutions (155) contribute minimally (1author).

<b>Table 10 - : Prolific Institutions of Statistical Research</b>				
<b>Sl no</b>	<b>Title of the Institution</b>	<b>Country</b>	<b>Freq. of authors</b>	<b>%</b>
1	Indian Statistical Institute (6-ISI)	India	41	6.01
2	Memorial University of Newfoundland (3-NF)	Canada	14	2.05
3	University of California, Dept of Statistics (1-CA-S)	USA	13	1.91
	University of Manchester, Dept of Mathematics (4-MANC)	UK	13	1.91
4	Indian Institute of Technology, Kanpur (6-IITK)	India	12	1.76
5	University of North Carolina (1-NC)	USA	10	1.47
	University of Minnesota Twin Cities (1-MN)	USA	10	1.47
	University of Manitoba (3-MB)	Canada	10	1.47
	University of São Paulo (BR-SPL)	Brazil	10	1.47
6	Iowa State University (1-IASU)	USA	8	1.17
7	Washington State University (1-WAS)	USA	7	1.03
	University of Washington, Dept. of Statistics (1-WA-S)	USA	7	1.03
	University of Maryland Baltimore County (1-MD4-MS)	USA	7	1.03
	Cornell University (1-CRNL)	USA	7	1.03
	Universität Konstanz (D-KNST-NB)	Germany	7	1.03
8	U.S. Bureau of Census, Statistical Res. Div. (1-USBC-SMT)	USA	6	0.88
	Texas A & M University (1-TXAM-S)	USA	6	0.88
	Shahid Beheshti University (IR-SHBH)	Iran	6	0.88
	University of Calcutta (6-CALC)	India	6	0.88
9	University of Rochester Medical Center (1-RCT-BCB)	USA	5	0.73
	University of Arizona (1-AZ)	USA	5	0.73
	Purdue University, Dept of Statistics (1-PURD-S)	USA	5	0.73
	Duke University, Dept of Statistics (1-DUKE-S)	USA	5	0.73
	Sri Sathya Sai University (6-SSSU-NDM)	India	5	0.73
	Indian Institute of Management, Ahmadabad (6-IIM3-QM)	India	5	0.73
	Université de Paris VI (Pierre et Marie Curie)	France	5	0.73
	University of Windsor (3-WIND-NDM)	Canada	5	0.73
McMaster University (3-MMAS-MS)	Canada	5	0.73	
10	20 Institutions having 4 each		80	11.80
11	22 Institutions having 3 each		66	9.68
12	68 Institutions having 2 each		136	19.72

13	155 Institutions each having 1 each		155	23.25
	<b>Total 293 unique institutions</b>		<b>682</b>	<b>100.00</b>

### 7.11 Research Collaboration and Impact

Relation between authorship and citation frequency of *Sankhyā* articles is shown in the Table - 11. Result indicates that, 334 articles of *Sankhyā* have received total 1804 citations in the Google Scholar (as on Dec'18). Of which as many as 77 (23%) articles haven't received any citation, whereas only two papers have got more than 50 citations. Highest citation (121) received by a triple-authored paper (MR2924199) in 2011. Year-wise distribution of citation shows that the year 2011 has received highest total citations (353) whereas the year 2017 has received the least (67) total citations. Irrespective of authorship, majority of articles (177, 46.4%) received citations within 1 to 5 ranges. As far as collaboration is concerned, 98 non-collaborated papers have received 491(27.22%) citations with an average of 5.03 per paper. Whereas 236 collaborated papers has received 1313 (72.78%) citations with the average of 5.56 citations per paper. Investigating the average number of citations received by the collaborated and non-collaborated papers of this journal, it could be concluded that collaborated papers are cited more often than the non-collaborated papers. This is probably because, while collaborating, researchers became more familiar with co-authors 'research network' that exposes the 'research' to a bigger audience that eventually enhance the chance to be cited sooner or later. Result shows resemblance with previous studies (Bordons et al. 1993; Van Raan, 1997 and Sooryamoorthy, 2009).

As found in table - 11, Statistical science researchers publish in different authorship patterns ranging from one to six authors per paper. Approximately 71% of publications were collaborative, of which double-authored publications (142, 42.5%) constitute the largest proportion followed by three-authored publications. As far as citation is concerned, it is found among the collaborative publications six –authored publications have received highest average citations, followed by three-authored publications and two-authored publications. Whereas non-collaborative papers have received comparatively lower average citations (5.40) than collaborative papers (5.56) have. However, publications having greater number of authors not necessarily received higher number of citations in this study. Therefore, no significant correlation between authorship and a average citation was found in this study.

Type	No. of Authors	Paper	%	TotalCitation	%	Cit/Paper
Collaborative	Six	2	0.6	36	2.00	18.00
	Five	2	0.6	3	0.16	1.50
	Four	8	2.4	34	1.88	4.25
	Three	82	24.55	558	30.93	6.80
	Two	142	42.51	682	37.80	4.80
	<b>Total Collb.</b>	<b>236</b>	<b>70.66</b>	<b>1313</b>	<b>72.78</b>	<b>5.56</b>
Non collaborative	Single	98	29.34	491	27.22	5.01
<b>Total</b>		<b>334</b>	<b>100</b>	<b>1804</b>	<b>100</b>	<b>5.40</b>

Authorship	Citations distributions									
	Nil	1 - 5	6 - 10	11 - 20	21 - 30	31 - 40	41 - 50	51 - 100	100 - 200	Total
Single	29	48	10	6	1	1	2	1		98



	29.60%	48.98%	10.20%	6.10%	1.02%	1.02%	2.04%	1.02%		
Double	30 21.12%	67 47.18	27 19.01%	13 9.15%	4 2.82%	1 0.07%				142
Three	15 18.29%	35 42.68%	20 24.39%	9 10.98	2 2.43%				1 1.22%	82
Four	2 25%	3 37.50%	2 25%	1 12.50%						8
Five	1 50%	1 50%								2
Six	0 0%	1 50%				1 50%				2
<b>Total</b>	<b>77</b>	<b>155</b>	<b>59</b>	<b>29</b>	<b>7</b>	<b>3</b>	<b>2</b>	<b>1</b>	<b>1</b>	<b>334</b>

## 8. Major Findings and their Implications:

Based on scientometric scrutiny, present study reflects a holistic perspective of collaborative landscape of statistical science research. These are as follows:

- Result shows consistent influx of statistical science literature (33.4 articles/year) contributed by total 682 authors, of which 565 are unique authors. Maximum contribution of any author (Brajendra C Sutradhar) is 10 papers, whereas majority (489, 56.55%) of authors contributes nominally. Of which, 'double-authored' papers dominate but mega-authored papers are significantly low.
- This study shows positive trends towards collaborative research as multi-authorship (236, 70.66%) clearly dominate over non-collaborative papers (98, 29.34%). Mean co-author for collaborative research is found to be 2.47. Furthermore, estimation of collaborative indices (DC, CC and CI) indicates clear inclination towards collaborative research with average authorship 2.04 per paper.
- Though, the source journal originates from Asian country, there have been fairly vast distributions of authors across the globe (51 countries). Of which, USA contributes the maximum (31%) followed by India (18%), Canada (8.5 %), France (4.55%), Japan (3.5%) and others. Top five countries are contributing about 66% of the total authors and about 55% of the total affiliated institutions. Indicates high concentrations of statistical research activities in this region. Therefore, wide geographic representation of author implies global acceptance of the journal without any bias towards native authors what so ever. However, author distribution is very much skewed with respect to geographical locations of contributing authors and their affiliated institutions.
- There has been fairly large number of institutions (293) involved in statistical science research, but only 15 institutions have contributed more than one author. Large majority of institutions (155) contribute minimally (one author). Of which native Institute of the journal, Indian Statistical Institute is the leading producer of authors. However, in the top five positions (containing 9 institutes), 7 are foreign institutions - indicates dominance of foreign institutions.
- Foreign unilateral collaboration (i.e. Collaboration within authors of same foreign countries) is found to be the most prominent collaboration type and accounts for 55% (130 articles) of collaborated communications, followed by Foreign unilateral (46 articles); NATL-UNI (within two or authors of India, 30articles); INT-BI (within one author form India and other foreign countries, 20 articles). However, the most diversified proposition - international multilateral collaboration (within two or more authors from foreign countries one of which if from India) is the least option practiced by the researchers.

- At the country level, unilateral collaboration dominates (70%) whereas, institute level bilateral collaboration dominates. Two different countries have participated in the authoring of 63(27%) articles and 3 different countries have participated in the authoring of 6(2.54%) articles respectively. Only single case, collaboration occurs among the authors from four different countries. However in both the stratum, multilateral collaboration is in the least preference. Results, therefore signifies authors from two different institutions of same country predominates in statistical science research collaboration.
- Moreover, there were 121 (32.01%) joint authored articles by authors from the same institution (domestic intra-institutional collaboration) and 52 (13.76%) articles produced by authors from different institutions within the same country (inter- or external institutional collaboration).The significance of this observation is the scarcity of researchers involving more than two nations. Prevalence of smaller teams (2/3 links) responsible for the publication of collaborative papers could perhaps be justified by the presence of sort of ‘clique’ in this research community.
- Study of citation performance shows that as on date, 77 (23%) articles haven’t received any citation, whereas majority of articles 262 (78.44%) received citations ranging from 1 to 121. Of which, majority (155, 46%) of articles received nominal citations (1 to 5). But, proportion of highly cited paper is very low (only 2). Average citation per paper consistently varies from 3 to 5.56, only in case of three country collaboration, it jumped unusually to 25. However, this skewed citation data influenced the average citation/paper value by the few highly cited papers. Significantly, collaborated articles are better cited as average citation per paper for collaborative publications (5.56) is slightly higher than non-collaborative publications (5.40). Therefore, research collaboration has marginal significant impact on the citation performance of the research.

## 9. Conclusion

In view of the substantial benefit of collaborative research endeavors, countries all over the world have reengineered policies and strategies to facilitate research collaboration. Present study investigates current collaboration scenario of scholarly literature of Statistical science in terms of co-authorship in various perspectives. Based on the analysis and research findings, it is apparent from the study that there has been steady influx of literature produced by the flagship journal. However, though author-base is vastly distributed across the globe, majority of individual authors contributed nominally. As the study revealed, researchers of the specialty have clear tendency towards collaborative ventures. However, both the average authorship for all publications and average co-authorship for collaborative papers are moderate (2.04 and 2.47 respectively). Moreover, though a total 51 countries had participated in statistical science research output, only few countries viz. USA, India Canada, France and Japan have contributed substantially; while majority of the rest countries have token contributions. Furthermore, majority of papers in our study sample had one or two partner countries. Only in single case, collaboration occurs among the authors from four different countries. Result indicates variable distribution of statistical science research activities across different parts of the world. Little surprisingly, Indian Statistical Institute (native institution of the source journal) is the leading producer of the statistical science researcher. About 46 % of publications were under ‘domestic’ category and 20 % of publications were as a result of international collaboration, of which ‘domestic intra-institutional’ collaboration predominates (32%). Therefore, authors from two different institutions of same country predominate in statistical science research collaboration. Results, therefore indicates the presence of ‘sort of clique’ in the statistical science research community. However, country-wise collaboration mapping reveals clear dominance of foreign collaboration. On the whole, at the country level, unilateral collaboration dominates (70%) whereas, institute level bilateral collaboration dominates.

As the result shows, research collaboration especially at the international level is low, which needs to be encouraged not only for better visibility of ‘local research’ but also to bring diversity in the research network, which eventually promotes the impact and quality of the research. Furthermore, collaborated research articles tend to have better impact (in terms of citations) than non-collaborative counterparts, probably because of aggregated efforts and synergies of ideas. Consistent with previous studies (Bordons et al, 1993; Van Raan, 1997) present study also reaffirms that collaboration boosts citation impact of research. However, our study provides useful information for policy makers seeking to intensify scientific

collaboration, particularly at the global level. Launching of ‘researcher exchange program’, ‘research forums with international institutes’; organizing conferences, symposia and research curricula with international peers are some of the possible measures that could provide congenial environment to promote international research collaboration. So, the implication of this analysis to science policy makers and stakeholders is that - collaboration among the researchers has obviously a positive influence on the research endeavors in this specialty. However, findings are based on bibliographical data limited to a single journal with focused authorship; therefore, any multi-journal study having extensive dataset could have produced different result. Hence, these might instigate further research endeavors in this direction.

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