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The Structure of Collaboration Networks: An Illustration of Indian Economics

M. Krishna* and G.D. Bino Paul**

*BITS Pilani, Pilani Campus **Tata Institute of Social Sciences Mumbai

Abstract

The main aim of this study is twofold: first, to examine the underlying structure of co-authorship in Indian economics; and second, to explore the link between the participation in scientific collaborations and academic visibility. We decipher the structure of co-authorship by presenting collaboration networks of scholars who published articles in six Indian economics journals during 1966-2005, which is split into four windows: 1966-75, 1976-85, 1986-95, and 1996-2005. In this study, the following social network measures are applied: the size of the network, the size of the main component, average degree, path length, and clustering coefficient. The study presents the following three features of Indian economics: first, a substantial proportion of Indian authors are isolated, albeit declining very slowly over a period of time; second, it appears that the structure of scholarly collaboration in Indian economics is highly fragmented, and the observed size of main components accounts for a small proportion of the total authors; third, and more importantly, the size and composition of co-authorship networks presented in the paper seldom impact the scientific visibility of authors.

Keywords: Collaboration, Structure, Networks, Degree, Indian economics
JEL Classification: A14, D85

1. Introduction

It is well documented in the realm of economics literature that knowledge[1] activity, both creation and dissemination of knowledge, is essential for enhancing a country's economic virility (Romer, 1990, Langlois, 2001). Despite the fact that the knowledge is an integral part of the production function, the structure of how different actors are connected to each other in the process of knowledge creation has been a rigorous subject for academic debate. It is observed that the process by which knowledge is being generated is inextricably connected with a concatenation of complex socioeconomic and behavioral aspects, such as institutional background, PhD origin, culture, and social identity, which have empirically been examined under the banner of social network analysis. As a scholarly theme, the application of social network analysis in deciphering the topology of structural connectedness has attracted profound intellectual curiosity, which is reflected very well in contemporary literature (Cowan et al. 2000; Langlois, 2001; Klamer and van Dalen, 2002; Cowan and Jonard, 2004). Among researchers, there is disagreement over what sort of social network configurations is imperative to enhance the knowledge activity and scientific productivity. There are two kinds of network forms that are central to the academic discussion: dense and sparse. While proponents of a densely connected structure argue that high degree of connectedness among actors has tremendous potential to generate new knowledge and innovative ideas by facilitating fast-flowing sharing of information, proponents of sparse networks, which are characterized by a low degree of links among actors, suggest that agents act strategically to form competitive advantageous in such a way that the interaction between two agents is facilitated by a third actor (Granovetter 1973, Burt 1992, Uzzi 1997).

In this context, there are two specific aspects that need to be dealt with. First, though the extant literature posits that the structure of knowledge activity wittingly or unwittingly is embedded in complex social forces, little research has been carried out in establishing a link between the degree of connectedness and visibility of actors in the structure. Second, there is hardly any attempt to extend the application of social network analysis to scholarly collaborations in developing countries, particularly India. Presumably, this deficit may have roots in the difficulty of obtaining the data on scholarly collaboration, which is mainly due to the poorly organized archive of authorship databases. In this study, we present an illustration of Indian economics in a dynamic framework under the expectation that the collaboration networks will be sparse. The following are the three research questions. First, what shapes the design of the collaboration networks? Second, does the organization of collaboration networks change over a period of time? Third, does the size of the collaboration matter in promulgating innovative ideas in the academic field? To answer these questions, we apply the framework of social network analysis to co-authorship data gleaned from six Indian economics journals, spanning from 1966 to 2005. The paper is exploratory, examining the nature of changes in scholarly collaboration in the journals using descriptive network methods - the size of the main component, average path length, average degree, and clustering coefficient.

The remainder of this study is organized into five sections. Section 2 provides a compendium of literature on social network models and the real-world networks in various disciplines, including neuroscience, physics, economics, and sociology. A detailed description of the

[1] See the introductory part of literature review for the definition of knowledge and knowledge activity

methodology, which covers sample journals, data sources, network concepts and methods with an illustration of hypothetical data is given in section 3, followed by findings in section 4. The last section provides discussion and concluding remarks.

2. Literature Survey

Before we proceed to a detailed analysis of previous studies, it is important to define knowledge and contextualize knowledge activity.

2.1 Defining Knowledge

Knowledge is defined in different contexts, which depends upon the scope of the respective subject discipline. In general, the definition of knowledge starts with data and content. When data combine with content, information is formed. The analysis and interpretation of information lead to knowledge (Contractor et al. 2000). Knowledge is essential to decipher the meaning of concepts by relating to other concepts (Carley 1986a; Carley 1986b). Put simply, the term knowledge refers to the understanding of how a particular piece of information gathered can be synthesized in the context, as well as by analyzing the relationship between various components associated with it (Prell and Lo 2016). There are two types of knowledge: migratory and embedded knowledge. While migratory knowledge can transfer from one person to another, embedded knowledge is not easy to transmit (Contractor et al. 2000). Because of this feature, as pointed out by Carley (1986a), the acquisition of knowledge by individuals, though limited, necessitates establishing a social context.

2.2 Contextualizing knowledge activity

We envisage knowledge activity, which is governed by a variety of formal and informal rules, as a historical and behavioral process (Cowan et al. 2000). Broadly, the knowledge activity refers to three distinct levels of knowledge: production, diffusion, and exchange. It is established that the formal and informal rules facilitate the knowledge activity. In this study, we consider that the academic research is one of the finest contexts of knowledge activity. The universities and the journals, which are broadly classified under institutions, constitute the base of academic research. While the universities are the source of both migratory and embedded knowledge, the journals disseminate the knowledge produced by different actors associated with the universities. The journals, therefore, are the principal channel through which more formalized and codified knowledge is disseminated. The diffusion of knowledge increases the level of knowledge in the society. In this milieu, what ignites the process of knowledge activity is a set of actions embedded in social contexts, such as collaboration, notwithstanding the formal contours that shape this activity. Presumably, measuring the nature of academic collaborations, pertinently the co-authorship, throws up useful properties and patterns of knowledge transmission.

2.3 Types of knowledge networks

The significance of knowledge is well acknowledged in the domain of economics literature. Drawing insights from economic sociology, every economic action has a social backdrop (Granovetter, 1985, 2005). Interestingly, Klamer & van Dalen (2002) adduced five forms of network models that are seemingly related to real-world cases: lone wolves, the science ideal, technology leader sets the standard, learning from neighbors, and minimal network structure with a core. Contrary to the lone wolves, in which authors would rather publish papers alone without collaboration, the science ideal represents a complete, connected system, in which authors are closely linked to each other. Setting the standard by a technology leader is one of the visible forms of networks, in which a few scholars possessing considerable preponderance over language, methods, and resources, set a certain standard by directing the dissemination of knowledge. Oftentimes, learning from neighbors is referred to as cooperative learning, in which authors collaborate with their neighbors. Minimal network structure with a core refers to one-way interaction, in which the core is the major source of generating and disseminating the fundamental knowledge. From a pragmatic point of view, the lone wolves, the science ideal, and the learning from neighbors appear to be quite quixotic. It is worth noting that the setting the standard by a technology leader and minimal network structure with a core depict the underlying structure of knowledge production in the real world; however, these two models are inadequate to explore the complexities emanating from knowledge sharing, as the knowledge activity evolves from a tangled web of structural phenomena.

2.4 Strategies explaining knowledge networks

Deviating from the structural models propounded by Klamer & van Dalen (2002), Prell and Lo (2016), to identify what drives the formation of a particular sort of network configuration, note five distinct types of strategies that explain why authors tend to collaborate: establishing brokerage, targeting knowledge experts, following socially similar others, and transitive closure, and mixed strategies. The logic of establishing brokerage is based on the idea of Burt's structural hole, which takes place when authors play the role of brokers between two authors who are otherwise disconnected, facilitating positive impacts on the knowledge front (Burt 1992; Reagans and Zuckerman, 2001). Targeting knowledge experts, though costly, suggest that authors with more knowledge and skills than others would be able to attract a range of scholars who share knowledge under the expectation of mutual benefits. The strategy of following socially similar other underlines that the configuration of networks has its strong roots in socio-demographic identities, like gender, religion, and caste (McPherson et al., 2001; Skvoretz, 2013), which not only lead to a strong and trusted collaboration (Flashman and Gambetta, 2014), but also tremendous knowledge gains (Uzzi and Lancaster, 2003). Transitivity closure, which implies that if A is a collaborator of B and B is a collaborator of C, it is likely that A tends to form a link with C. Connecting to a third actor becomes necessary when authors deal with complex and tacit knowledge. And the last is the mixed strategies, which involve the combination of the above four strategies. The degree of knowledge produced, for instance, the number of publications in various journals in the case of collaborative networks, might vary depending upon the type of strategies adopted.

2.5 Empirical evidences

In the realm of social network literature, the features of the small-world model, which has received a considerable scholarly interest for the last two decades, are observed in several fields. A small world refers to a highly affiliated group of actors, who are connected closely in such way that the average distance, also referred to as path length, appears to be very low (Watts and Strogatz, 1998; Newman, 2000). Put simply, two randomly chosen actors in the small-world model are linked with a few intermediary actors. Strictly speaking, Watts and Strogatz (1998), in a study of film actors, electrical power grid, and C.elegans[2] suggested two properties of the small world effect: first, short average path length (L); and second, high clustering coefficient, which measures the degree of the neighborhood (C). Pragmatically, the validity of the properties - short path length and high clustering coefficient- can be tested against a random graph of having the same size of actors. Interestingly, several studies on knowledge activity empirically established that the properties of the small world hold true in various disciplines. Some of the noted studies include Newman (2001), Barabási et al. (2002), Moody (2004), and Goyal et al. (2006). Appendix 1 reports the summary results of the major studies across different disciplines.

Newman (2001), using four distinct databases spanning from 1995 to 1999, showed that the size of the main component, a maximally connected substructure within the larger scientific community, comprises a substantial proportion of the population. Consistent with the Milgram's experiment, Newman adduced that a pair of randomly selected scholars within the science community could be connected with just five to six intermediaries. Barabási et al. (2002), covering authorship data spanning from 1991-98, found that the degree distribution in scholarly collaboration is characterized by a power-law distribution, commonly referred to as scale-free networks. The essence of scale-free networks is that while the majority of nodes account for only a few collaborators, a few nodes account for a considerable number of collaborators. The scale-free networks often result in the formation of 'hubs', in which actors with a large number of collaborators, like a vehicle's engine, is crucial in organizing the network structure. Though more powerful, hubs would be extremely weak if the most connected actor is cut from the network structure (Barabási and Bonabeau, 2003). Furthermore, because of dynamic forces, be it exogenous or endogenous, the structural patterns formed by hubs are subject to gradual change.

Moody (2004), using sociological abstracts from 1963 to 1999, shows that the structure of knowledge production in sociology is relatively scattered in the form of many organized sub-groups. Goyal et al. (2006), based on journals listed in the EconLit database, analyzed the evolutionary patterns of collaboration among economists by classifying the total period of study into three distinct windows: 1970-79, 1980-89, and 1990-99. The study pinpoints the following four features: first, the number of economists in the world increased from 33,770 in the 1970s to 81,217 in the 1990s; second, a quantum jump in the size of the main component, which increased from 15 per cent to 40 per cent of the population; third, the average distance between economists has decreased over the period; and fourth, the number of collaborators per author, on average, has increased. In brief, the relationship between an increase in the size of the main component and a corresponding decline in average distance shows that the world of economics is moving towards 'an emerging small world'. Therefore, exploring the structural features of collaboration networks in a dynamic frame using properties of social

[2] Caenorhabditis elegans

network analysis is crucial to understanding the topology of how scholars disseminate their knowledge.

3. Methodology

3.1 Sample and data collection

This study is based on the authorship data compiled from six Indian economics journals: the Indian Economic Review (IER), Indian Economic Journal (IEJ), The Indian Economic and Social History Review (IESHR), Artha Vijnana (AV), Journal of Quantitative Economics (JQE), and Indian Journal of Agricultural Economics S (IJAE). All the journals mentioned above are affiliated with renowned research institutions and professional associations in India. We limit our analysis to six journals owing to two reasons. First, it is found that only 19 economic journals in India have maintained publishing regularity since its inception (Mukhopadhyay, and Sarkar (2010). Since the bibliographic database for economic journals is absent in India, the manual compilation of authorship data is a laborious task. Second, the paper is an extension of the recent study by Bino *et al* (2005). As far as Indian economics is concerned, the select journals are prestigious and indexed partly in Scopus or other databases. Some of the world-renowned economists like Amartya Sen, Partha S Dasgupta, PC Mahalanobis, CN Vakil, VKRV Rao, Pranab K Bardhan, and Ashok Mitra published papers in the journals.

In this study, the unit of analysis is authors who published articles in these six journals during 1966-2005. The authorship data for all research articles and conference proceedings, except book reviews, notes, and abstracts, were manually gleaned from the journals. Following the compilation of authorship data, all the authors, according to their year of publication, were classified into four distinct windows: 1966-1975, 1976-1985, 1986-1995, and 1996-2005.

Since the compilation of authorship data from the sample journals was manual, we expected that the network dataset might include some duplicate or repeated names. In our paper, if two or more authors' names are identical, either of them was taken into consideration unless treated otherwise. A strict adherence to this rule may engender two critical errors: first, it is quite likely that two or more authors may publish papers with similar names; second, authors may also report slightly different names, probably with or without a surname, in their different publications. In fact, to minimize all the possible errors, we took extra care of poring over the datasets by collecting additional details like authors' institutional affiliation, area(s) of research, article title, year of publication, and a short biography of the co-authors.

3.2 Framing the social networks

We present a simple social network[3], called graph, delineated as *G,* which consists of a set of nodes (*N*) and a set of lines (M) between them. Taking cues from Wasserman and Faust (1994), this may be specified in the following way: $N = \{a_1, a_2, a_3, ..., a_g\}$ and $M = \{b_1, b_2, b_3, ..., b_k\}$. It shows that there are '*g*' number of nodes and '*k*' number of lines present in the graph. Thus, the graph is nothing more than nodes and lines represented as $G = \{N, M\}$. As we mentioned above, in this paper, nodes are authors, who published articles in the above mentioned journals during 1966-2005, and lines connecting authors are co-authorship. Put in a simpler way, two authors are connected by a line if they have co-authored at least one paper. Generally, the connected line can be treated as either directed or undirected. In this paper, the connected line, or co-authorship, is considered undirected[4] and dichotomous[5]. For instance, if a graph consists of two authors, that is to say, *i* and *j*, this can be delineated as $i, j \in N$. In an adjacency matrix[6], it can be presented by either 1or 0. Whilst 1 implies that *i* and *j* are co-authors, 0 represents both are single authors (Goyal *et al.* 2006).

3.3 A typical structure of collaborative networks

To exemplify the aforesaid characteristics of collaborative networks, a typical structure of authors' networks using hypothetical dataset is presented in figure 1, which consists of 25 nodes and 20 lines between them. All the nodes are labeled in English capital letters A to Y, and the dotted lines depict the collaboration. The figure shown below is a disconnected graph[7], which is usually formed by a set of distinct subgraphs called components. Strictly speaking, a component is a subgraph in which authors are connected by a reachable path, and the maximally connected subgraph is called main component (Scott, 2000). Quite clearly, the component consisting of nine authors and ten lines constitutes the main component in figure 1. It may be noted that each component in a disconnected graph is independent of the rest of the components.

It is worth noting that identifying the number of components not only provides the extent of scholarly integration in the structure, but also many intuitive insights on institutional and social stratification. A closer look at figure 1 depicts that the size of the components,

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[3] Reflexive and multiple ties are not part of a simple network. Multiple ties between two nodes exist if there is more than one line (Wasserman and Faust, 1994).

[4] Given the total number of nodes (*g*), the maximum number of undirected ties in a network is $g(g-1)/2$ (Scott, 2000). For instance, if a network consists of 10 nodes, the maximum possible ties between them are 45. A network is sparse if the number of lines present in the graph is much less than the maximum possible lines, i.e., $k \ll g(g-1)/2$ (Latora and Marchiori, 2003).

[5] By dichotomous, we mean that the link between two authors represents whether these authors have jointly published at least one paper, ignoring the frequency of joint publication between them.

[6] It is an $N \times N$ matrix of authors in which the relationship between a pair of authors is denoted by either 1 or 0

[7] Networks are of two types: connected and disconnected. A simple way of distinguishing between connected and disconnected graphs is to look at the observed number of components. For instance, if a network consists of more than one component, then the graph is disconnected, otherwise the graph is connected (Wasserman and Faust, 1994).

Figure 1
A typical structure of scientific collaboration

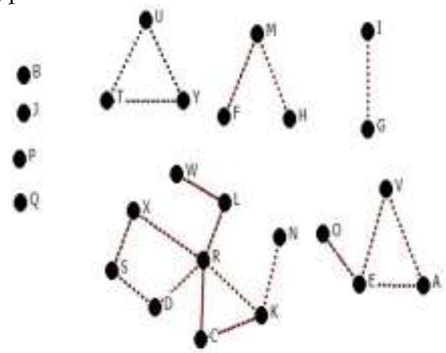

Table 1: degree distribution of figure 2

Author	*Degrees*	*Author*	*Degrees*
A	2	N	1
B	0	O	1
C	2	P	0
D	2	Q	0
E	3	R	5
F	1	S	2
G	1	T	2
H	1	U	2
I	1	V	2
J	0	W	1
K	3	X	2
L	2	Y	2
M	2	*Total=25*	*Sum=40*

measured in terms of the number of authors, varies significantly. Quite clearly, considering the extent to which authors being connected to one another in the collaboration network, it is unlikely to have a uniform degree distribution (Table 1). There are also isolated authors, B, J, P, and Q that comprise a proportion of 16 per cent of the total authors.

A widely applied network concept called the structural hole, developed by Burt (1992), is apt to explore in the context of the sparse network. Structural hole, in its simplest form, refers to a form of networks in which two actors, who are otherwise disconnected, are communicated through by a third actor who bridges the gap between these actors. For instance, the co-authorship of FMH represents an incomplete triad in which the authors F and H are not directly connected. What is interesting is that the interaction between F and H is coordinated by M, as author M is strategically positioned in the network structure (Burt, 1992). Because of this strategic positioning, M has certain competitive advantages, which includes the power to gain new knowledge. The formation of such strategic networks often facilitates innovative ideas by sharing the relevant knowledge in the field. As a social phenomenon, the implications of structural holes in various spheres have been extensively documented, particularly in social sciences (Granovetter 1973; Ahuja, 2000; Reagans and Zuckerman, 2001; Burt, 2004).

3.4 Network Measures

In order to explore the structure of scientific collaboration networks, some of the basic social networks measures are applied: network size, average degree, average distance, and clustering coefficient[8]. The network size refers to the number of nodes present in the graph. As indicated in figure 1, a disconnected graph, unlike a connected network, is composed of many sub-graphs with varying node sizes. In addition to the graph with components, scientific community often comprises lone wolves and authors without co-author(s). In social network parlance, the degree of a node refers to the number of nodes adjacent to it (Scott, 2000), and the range of degree generally varies between 0 and g-1, where *g* delineates the network size.

[8] We applied *UCINET* software to find networks measures, and to draw figures

Therefore, the mean degree of a graph denoted as $\bar{d}$ is the sum of all degrees divided by the number of nodes in the graph (Wasserman and Faust, 1994)[9].

The distance, *d*, between two nodes, *i* and *j*, refers to the length between them. If two nodes are connected by more than one path in a network, distance always implies the shortest path between the nodes, called *geodesic*[10]. In addition, the distance from *i* to *j* is equal to the distance from *j* to *i*. If there is no connection between *i* and *j*, then the distance from *i* to *j* would be infinite. In the case of a disconnected network, it is quite common that the average distance of nodes in the main component is taken as a proxy[11]. Clustering coefficient (*C*), a network measure to denote the degree of 'neighborhood', is defined as the likelihood of an author's co-authors to become collaborators of each other. The clustering coefficient of the overall network is the average clustering coefficient of all the authors in the collaboration networks (Goyal et al 2004). Generally speaking, the clustering coefficient of a graph ranges between zero and one.

4. Results

4.1 An overview of the structure of scientific collaboration

Table 2 reports the two fundamental features of Indian economics: first, the network size, which is assessed in terms of the number of authors, has recorded a sharp increase (40%); second, the presence of isolated authors in the field of Indian economics accounts for a significant share of the total authors. More specifically, a great number of the authors who published articles during 1966-1975 had not collaborated with other authors in the system, albeit the size has scaled down to just half of the population during the last window. Unlike the world economics, the field of Indian economics is in a nascent stage and yet to form a fully connected structure. Despite a substantial number of universities and research institutions[12], India accounts for just 2.6 percent of the global knowledge output (Agarwal 2005), and the participation of Indian scholars in collaborative research is limited, resulting in not only a low level of knowledge output, but also low visibility in global knowledge production (Appendix 2).

Notwithstanding the presence of a considerable number of isolated authors, the average degree of authors is slightly increasing, implying that the field of Indian economics is slowly moving towards a connected structure. For instance, the authors' average number of collaborators recorded an increase, albeit marginally, from 0.43 to 0.83 over the last four

[9] [9] It may also be presented in the following way: two multiplied by the number of observed lines (*l*) divided by the number of nodes in a graph (g). $\bar{d} = \frac{\sum_{1=i}^{g} d(n_i)}{g} = \frac{2l}{g}$

[10] It should be noted that path length is either greater than or equal to 1. Path length 1 implies the complete graph in which each node is directly connected to all other nodes.

[11] Goyal *et al.* (2004) apply the average distance of giant component as a proxy for the whole network. The study defines the average of the shortest path lengths as G, $d(G) = \frac{\sum_{i \in N} \sum_{j \in N} d(i, j; G)}{g(g-1)}$

[12] At present, India has about 718 universities and research institutions

Table 2
Descriptive statistics of collaboration networks in Indian economics, 1966-2005

Network Properties	*1966-75*	*1976-85*	*1986-95*	*1996-05*
Total authors (*N*)	889	1010	1328	1246
Isolated authors	645 (72.5)	680 (67.4)	832 (62.6)	620 (50)
Components with size two	61	84	112	137
Components with size three & above	26	43	63	75
Average Degree	0.43	0.49	0.58	0.83
(Standard deviation)	0.88	0.93	0.97	1.15
Clustering coefficient	0.47	0.45	0.46	0.48

Source: data compiled by authors from the sample journals
(Figures in parenthesis represent percentage)

decades. However, a cursory look at the way in which the authors being connected to their collaborators indicates that the degree distribution is unequal. It is apparent that while a few authors account for a large share of connections, a majority of authors account for a few connections, making more structural holes in the structure.

Unlike the structure of world economics, the field of Indian economics is not only fragmented, but also teeming with small-organized subgroups, which are growing at an alarming rate. With a view to assessing the sheer volume of sub-graphs, we classify the structure of components into two: components with size two, and components with size three and above. While the former indicates the co-authorship by two authors, the latter includes the co-authorship by more than two authors. As reported in table 2, the number of components with size two has increased from 61 in 1966-75 to 137 in 1996-2005. Unequivocally, a similar trend is conspicuous for components with size three and above. In general, the number of components, irrespective of its size, tends to increase the size of network increases. Considering authors' institutional background and PhD origin, it is ascertained that the top fifteen components are predominantly constituted by prominent scholars, who belong to universities located mainly in metropolitan cities like Mumbai and Delhi. One possible explanation for this finding is that economists in India, barring a few initiatives, are not associated with a strong indigenous school of thought. Moreover, the intellectual core of economics appears to be overwhelmingly dominated by the global north.

4.2 Pattern of Research Publications

As often as not, collaboration in an academic community takes place in several forms, be it visible or invisible. Visible ties, such as writing joint papers, collaborative research projects, organizing conferences, seminars, and workshops, are quite common. In this paper, the pattern of research papers is analyzed by using four distinct classifications: papers without co-authors, papers with single co-author, papers with two co-authors, and papers with three or more co-authors. Table 3 clearly shows, out of the total 1035 research papers published during 1966-75, that papers without co-authorship account for a considerable share and papers with three or more co-authors constitute just 0.4 per cent. Interestingly, the share of papers without co-authors has witnessed a consistent decline throughout the period, and the share of multi-authored papers –collaborators above one or more- has increased

Table 3
Pattern of authorship in Indian economics journals, 1966-2005

Journal	1966-75	1976-85	1986-95	1996-05
Total Papers	1035	1377	1457	1257
Papers without co-author	.870	.802	.759	.725
Papers with one co-author	.103	.150	.193	.212
Papers with two co-authors	.021	.040	.043	.052
Papers with three or more co-authors	.004	.006	.004	.011

Source: data compiled by authors from the sample journals

consistently[13], albeit slowly. Consistent with these findings, Guimera *et al.* (2005), based on the four disciplines[14], also showed that the teamwork in social sciences grows relatively slower than that of science disciplines, such as ecology and astronomy.

4.3 Evolution of main components

The size and growth of the main component provide an indication of whether the network is sparse or highly connected. Evidence suggests that the main component, irrespective of disciplines, comprises the majority of nodes in the graph (Newman, 2001) or records an impressive growth over a period of time (Goyal e*t al.,* 2006). In this study, as a percentage of total authors, the size of main components comprises, on average, just 3.5 percent. Although the main components grew very slowly over time, a comparison with the world economics (Goyal e*t al.,* 2006) shows that Indian economics, in terms of developing a cohesive subgraph, is yet to attain a full-fledged connected network, which is often regarded as a spur to the growth of innovative ideas. The evolution of main components presented in the paper is drawn in line with the broad theoretical propositions developed by Prell and Lo (2016).

Figure 2A consists of 31 authors comprising 3.48 per cent of the total authors. As is evident from table 4, each author has 2.34 collaborators on average. While the most connected author has 9 degrees, the least connected author accounts for just one degree. To understand how strategically an author is positioned in the network, we attempt to answer an important question: does a random removal of authors from the structure affect the design? It should be noted that, if the graph is a complete connected structure, the random removal of one or two authors does not completely change the shape of the graph. On the contrary, if a network structure is scale-free[15], the removal of the most connected author would break the structure into a number of small islands. A discernible feature emerging from figure 2A is that the removal of the most connected author -the author with nine degrees -does not completely dismantle the structure, as most of his/her collaborators are directly connected to each other. In other words, the network structure is formed by what Prell and Lo (2016) termed as the strategy of following knowledge experts and transitive closure, which is presumed to be successful in gaining knowledge.

[13] Hudson (1996) shows that multi-authored papers in leading economics journals, particularly in the American Economic Review and Journal of Political Economy, have increased significantly
[14] The four disciplines are social psychology, economics, ecology, and astronomy
[15] A structural form in which a few dominant nodes are extremely connected by many collaborators

Figure 2
The evolution of main components in Indian Economics, 1966-2005

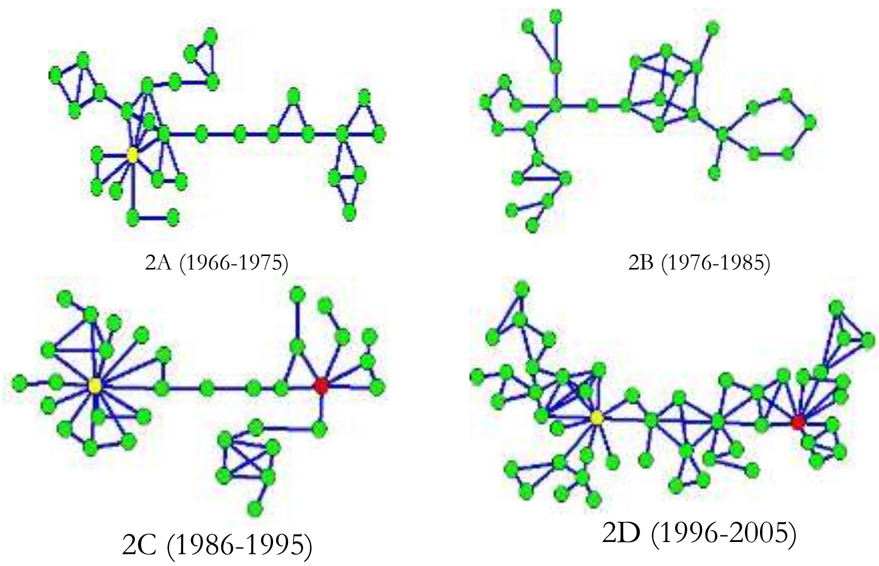

Table 4
Descriptive statistics of main components 1966-2005

Network Properties	1966-75	1976-85	1986-95	1996-05
Size of main component	31(3.48)	32 (3.16)	35 (2.63)	50 (4)
Average degree	2.90	2.43	2.62	3.20
(Standard deviation)	1.63	0.967	2.24	1.99
Maximum degree	9	4	14	10
Average Distance	4.71	5.38	4.69	4.63

Source: tabulated from the data compiled by authors from the sample journals
(Figures in parenthesis indicate percentage)

In fact, our attempt to draw a comprehensive analysis of each author in the main component, by collecting additional details like PhD origin, intuitional and professional affiliations, number of publications, nature of co-authorship, and areas of research, shows that the core author with nine degrees had been one of the well-known macroeconomists in India. Having trained at Harvard University, the author published a series of edited volumes during 1968-1975. About three-fourths of the author's collaborators were his doctoral students and colleagues in his department. According to Prell and Lo (2016), the presence of following knowledge experts and transitive closure together may give rise to a cluster of heterogeneous scholars, creating an impetus for innovative ideas in the discipline.

Figure 2B is composed of 32 authors, of which five authors constitute four degrees each. In fact, our analysis of the authors' institutional background and PhD origin shows that figure 2B is formed by two sets of authors representing two distinct schools of thought. On the one side, authors on the left-hand side of the figure primarily belong to the domain of financial economics, but include authors from other schools, such as international trade; on the other hand, authors on the right-hand side of the figure mainly focus on three areas of research:

planning, health and education. Interestingly, the author who connects these two schools of thought belongs to the domain of public policy. Seemingly, the second figure closely resembles what is termed as a brokerage-similarity model by Prell and Lo (2016).

Figure 2C consists of 35 authors comprising 2.63 per cent of the total authors. Unlike figure 2A, figure 2C is sparse, which is manifest in the measure of standard deviation. It clearly shows that one author has extensively collaborated with fourteen authors, but most of his collaborators are not connected to each other, apparently resembles the strategy of pursuing brokerage (Prell and Lo 2016). Suppose, if the author with the highest number of degrees is removed, figure 2C will be transformed into five subsets, leaving three authors isolated. In this figure, the core author, who is a well-known econometrician in India, appears to be instrumental, and indeed plays as an engine in organising this structure. Over the span of thirty years, the core author has supervised more than 30 doctoral candidates predominantly in the area of macro econometrics. This leads us to ask a pertinent question: how does a core evolve from a collaboration network? Like the metamorphosis of a butterfly, the complete metamorphosis of a core consists of various stages and undergoes a series changes over a period of time. We presume that the factors, such as institutional background, PhD origin, choice of the research methodology[16], the capability to attract research grants, and professional positions, provide the impetus for evolving a core. Nevertheless, scholars with strategic behaviour always tend to bring more structural holes to maintain their vitality in knowledge activity[17] (Prell and Lo 2016). Apart from an increase in the number of authors and pursuing transitive closure, figure 2D also shows that a pair of authors tends to be more integrated and also has a lesser number of structural holes. On the whole, from the above analysis of the evolution of main components, there are two specific features emerging: first, a marginal increase in the number of authors; second, a slight dip in average distance. Indeed, these features need to be explained in the context of recent macroeconomic changes. Since 2000, India has made great strides in several fields including higher education, science and technology, infrastructure, and information and communication technology. More specifically, a research collaboration between universities, setting up of central universities, allocation of research grants, and availability of internet facilities have paved the way for forming a cohesive group[18]. The impact of these changes is quite reflected in figure 2D. In brief, although the size of the main component reports a marginal increase, there are three aspects, which make this study stand out. First, each component is a distinct group, implying that authors of one component are not represented in any other components. Second, each component is subject to some risk, as it is vulnerable in retaining its position. Third, the relationship between the increase in the size of the graph, the main component in particular, and a corresponding decline in average distance, indicates the tendency to move towards a cohesive group, albeit moving slowly.

[16] The choice of the research methodology is significant because it affects the career progress and minimization of transaction costs, see Earl (1983)

[17] According to Earl (1983), knowledge activity, by which scholars create and disseminate their knowledge output, in economics discipline is significantly influenced by the strategic behaviour of economists. Reagans and McEvily (2003) explain what factors influence knowledge transfer and how participation in social networks is likely to be impacted by strong ties in the structure.

[18] McKnight and Cukor (2001) provide a detailed description on how the advancement in ICT affects the creation and dissemination of knowledge, and its impacts on knowledge-based activities

Table 5
Top ten cited papers in Indian Economics, 1966-2005

1966-1975				*1976-1985*				*1986-1995*				*1996-2005*			
Year	*N*	*C*	*P*	*Year*	*N*	*AC*	*P*	*Year*	*N*	*AC*	*P*	*Year*	*N*	*AC*	*P*
1970	105	2.62	1	*1983*	48	1.78	1	*1990*	48	2.40	2	*1996*	65	4.64	1
1970	72	1.76	1	*1983*	40	1.48	1	*1987*	45	1.96	4	*2004*	28	4.66	2
1966	45	1.00	1	*1976*	33	0.98	1	*1992*	30	1.67	2	*2000*	26	2.60	2
1970	42	1.02	1	*1985*	29	1.16	1	*1987*	29	1.26	1	*2003*	23	3.28	1
1974	34	0.92	1	*1980*	27	00.9	1	*1993*	24	1.41	2	*2001*	21	2.33	1
1966	32	0.71	1	*1983*	26	0.96	1	*1994*	21	1.31	1	*1997*	21	1.66	1
1969	22	0.52	1	*1976*	24	0.70	1	*1987*	18	0.78	1	*2000*	19	1.90	1
1975	21	0.58	1	*1979*	22	0.70	1	*1990*	18	1.8	1	*1997*	17	1.30	1
1967	19	0.48	2	*1980*	19	0.63	1	*1990*	18	0.90	1	*1997*	16	1.23	1
1972	18	0.46	1	*1983*	19	0.70	1	*1986*	17	0.70	1	*1998*	16	1.33	2

Source: Tabulated and compiled by authors from Hazing's Publish or Perish Database[19]

4.4 Does social network explain cues for scholarly visibility?

Against the backdrop of changes in the main component of scholarly networks in Indian economics, it would be interesting to draw the underlying link between participation in scientific collaboration and scholarly visibility. For this, first, an order of papers in terms of the number of citations, which can be an indicator of scholarly visibility of author/s, is generated. Further, we have created such order for every window, which consists of top ten cited papers. It is important to note that an order with varying level of visibility, such as top twenty, top thirty, etc., tends to generate a large proportion of papers with no citations. In fact, our search for an order, which can give meaningful insights about the linkage between participation in social networks and visibility led to the heuristics of forming an order of the top ten cited papers. Three indicators are used for the discussion: number of citations (*N*), citations per year (*C*), and the number of authors (*P*).

As shown in table 5, pooling the data across the windows, it appears that most of the highly cited papers are single-authored, clearly indicating a disconnection between participation in social networks and scholarly visibility. Presumably, this independence may have its roots in the state of economic research in Indian universities, with less emphasis given on teamwork to generate frontier knowledge. Unlike the world economics, Indian economics shares two peculiar institutional features. First, the public funded universities account for the large share of the research publications in India. Moreover, the government agencies, such as the UGC (the University Grants Commission), ICSSR (Indian Council of Social Science Research) and Union and State governments, provide a significant share of research grants. Second, until recently, the majority of the universities in India hardly had any global interface. While the universities have been creating specific scholarly niches that are pertinent to Indian economics, a fair chunk of this research tends to end up as working papers or policy documents. More importantly, India has yet to see any noteworthy mainstream schools of thought in economics emerging from Indian universities, albeit having a sizable academic community. Perhaps, this pattern is going to change once Indian universities become more resourceful in terms of creative and collaborative teams working on frontier knowledge, financial banking, and proactive social networks among scholars.

[19] Data from *Hazing's Publish or Perish Database* is based on citation figures generated by Google scholar.

5. Discussion and Conclusion

In this study, by way of presenting knowledge creation and diffusion as an activity, interwoven by a web of relations among scholars, we demonstrated that the structure of knowledge activity is likely to undergo discernible changes in a dynamic world. However, the structures that emerge as outcomes of these changes generate interesting patterns in the membership of co-authorship networks, pertinently its linkage with visibility of scholars in terms of citations. As an illustrative case, we examined the structure of scientific collaboration in Indian economics by using authorship data gleaned from six Indian economics journals. By transforming the co-authorship data into an adjacency matrix, our attempt was to present a simple network of authors who published articles from 1966 to 2005 in these journals. An interesting result of this study is that a great majority of authors in India were isolated in the early period, albeit declining during 1966-2005. Moreover, the structure of scientific collaboration in India is relatively fragmented, and most importantly, the observed size of main components account for a small proportion of the total authors. What is interesting is that the dynamics of co-authorship networks presented in this study does not provide an explicit profundity about the link between social networks and scientific visibility. The less obvious dynamism of networks, as shown in this paper, may have roots in a relatively less developed collaborative environment in Indian social sciences, particularly economics. Across four windows of the structure, the scholars, who are centrally positioned in the structure, are known for their contribution to fields, such as applied empirical research, interpreting patterns emerging from large databases, discussion of public policy issues, model building based on theories published in mainstream economics journals, which are based in Western Europe and the United States of America[20]. As shown in Appendix 3, based on origins of citation by regions for the 200 most cited journals in 2003-05, 95 per cent of citations in journals from Asia are made in articles from North America and Europe, while articles published in journals from Asia has received just 2 percent of citations. Moreover, the share of journals based in North America and Europe in citations in Asian Journals has gone up from 89 percent in 1993-95 to 95 percent in 2003-05. However, close to four-fifth of citations in the USA originate from there itself, clearly showing fundamental imbalances that exist in exchange of scholarly ideas between different regions. Moreover, this situation co-exists with an institutional oligopoly, which seems to be a fertile source of 'lock-in', which impairs the progress of innovative ideas to visible knowledge output (Hodgson and Rothman, 1999)[21].

In fact, barring a few exceptions, writings in core Indian economics journals hardly attract scholarly discourses and lead to indigenous theory development. Perhaps, this phenomenon has links with the core-periphery structure that is prevalent in the world economics; while the core exports ideas, theories, and methodologies to the periphery, the downstream structures like India tend to internalise these grand contents, leaving very little space for the indigenous development of theories, which are relevant in Indian contexts[22]. As expressed by Krishna and Krishna (2005), quality of research in social sciences, including economics, is declining in South Asia, and India, in particular. This backwardness is amply reflected in the lack of career

[2020] Our views are based on the assessment of articles published in the economics journals from 1966-2005

[21] Hodgson and Rothman (1999) pointed out, using 30 leading economics journals, that institutional[21] oligopoly prevails in knowledge output

[22] Among the five kinds of network models of Klamer & van Dalen (2002), the minimal network structure with a core explains that the core journals produce fundamental knowledge and supply to other journals.

opportunities in research, shortage of funding opportunities for research, and other critical resources, such as effective networks. The economics community in India has not attained a critical size of collaborative networks yet, which is effective in attaining knowledge output of higher visibility.

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Appendices

Appendix 1

Summary of major scientific collaboration networks

Studies	Disciplines/Data Source	Period	*N*	*k**	L_{actual}	C_{actual}
Newman (2001)	MEDLINE	1995-1999	1,520,251	18.1	4.6	0.066
	Los Alamos e-Print	1995-1999	52,909	9.7	5.9	0.43
	SPIRES	1995-1999	56,627	173	4.0	0.726
	NCSTRL	1995-1999	11,994	3.59	9.7	0.496
Barabási *et al.* (2002)	Mathematics	1991-1998	70,975	3.9	9.5	0.59
	Neuroscience	1991-1998	209293	11.5	6	0.76
Moody (2004)	Sociological abstracts	1963-1999	128,151	----	9.81	0.194
Goyal *et al.* (2006)	EconLit	1970-1979	33,770	.894	12.86	.193
		1980-1989	48,608	1.244	11.07	.182
		1990-1999	81,217	1.672	9.47	.157

Source: Compiled from the respective studies

N refers to number of nodes in the network, *k**refers to mean degree

Appendix 2

Country-wise share of knowledge output, 1994-2004

Country	*Number of Papers (% share)*	*Number of Citations (% share)*	*Citations per paper*
United States	2,698,434 (38.5)	33,212,308 (62.7)	*12.31*
China	271,032 (3.9)	799,415 (1.5)	*2.95*
Japan	722,512 (10.3)	5,264,781 (9.9)	*7.29*
India	**180,783 (2.6)**	**573,792 (1.1)**	***3.17***
Germany	666,104 (9.5)	6,102,642 (11.5)	*9.16*
United Kingdom	604,397 (8.6)	6,373,300 (12.0)	*10.54*
France	488,585 (7.0)	4,338,642 (8.2)	*8.88*
Italy	320,667 (4.6)	2,709,842 (5.1)	*8.45*
Brazil	98,747 (1.4)	433,772 (0.8)	----
Russia	282,027 (4.0)	870,485 (1.6)	*3.09*
Canada	358,176 (5.1)	3,587,966 (6.8)	*10.02*
Korea	126438 (1.8)	504,634 (1.0)	-----
The Netherlands	197,426 (2.8)	2,206,097 (4.2)	*11.17*
Switzerland	140,164 (2.0)	1,823,353 (3.4)	*13.01*
Australia	216,819 (3.1)	1,821,757 (3.4)	*8.4*
Spain	219,404 (3.1)	1,529,708 (2.9)	*6.97*
Israel	96,890 (1.4)	864,214 (1.6)	*8.92*
Finland	73,068 (1.0)	733,391 (1.4)	*10.04*
Total			

Source: Pawan Agarwal, 2005

Appendix 3

Origins of citations by region for the 200 most-cited journals

Citing regions	**Africa**		**Latin America**		**Asia**		**CIS**		**Europe**		**Oceania**		**North America**	
	1993-95	2003-05	1993-95	2003-05	1993-95	2003-05	1993-95	2003-05	1993-95	2003-05	1993-95	2003-05	1993-95	2003-05
Africa	22.0	11.7	0.4	0	0	0.2	0.2	0	0	0	0	0	0	0
Latin America	0	0	11.7	6.9	0.2	0	0	0	0	0	0	0	0	0.2
Asia	0.4	0.8	0.5	0.3	6.8	1.6	1.2	1	0.3	0.2	0	0.2	0	0
CIS	0	0	0	0	0	0	36.7	15.3	0	0	0	0	0	0
Europe	45.4	53.4	32.1	33.9	31.2	41.8	30.9	31.9	51.1	50.3	35.9	42.7	17.6	20.4
Oceania	0.3	0.2	0.4	0	0	0	0	0	0.5	0.3	12.9	7.2	0	0
North America	26.7	30.9	51.6	56.2	58.2	54.1	30.8	51.5	46.3	47.9	48.8	48.1	80.8	78.1

Source: Gingras and Mosbah-Natanson (2010: 152).