Co-authorship network of scientometrics research collaboration

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ABSTRACT

This paper examines the co-authorship network in the field of scientometrics using social network analysis techniques with the aim of developing an understanding of research collaboration in this scientific community. Using co-authorship data from 3125 articles published in the journal Scientometrics *with a time span of more than three decades (1980-2012), we construct an evolving co-authorship network and calculate three centrality measures (closeness, betweenness, and degree) for 3024 authors, 1207 institutions, 68 countries and 22 academic fields in this network. This paper also discusses the usability of centrality measures in author ranking, and suggests that centrality measures can be useful indicators for impact analysis. Findings revealed that scientometrics was not dominated by a couple of key researchers as quite a significant number of popular researchers were identified. The United States occupies the topmost position in all measures except for degree centrality. The most active, central and collaborative academic discipline in scientometrics is Information & Library Science.*

Keywords: Social Network Analysis; Co-authorship collaborative network; Centrality measures; Degree centrality; Closeness centrality; Betweenness centrality.

INTRODUCTION

The term scientometrics was first introduced by Vassily V. Nalimov in 1969. The term was mainly used to address all studies related to the literature of science and technology, and it is now often defined as the quantitative study of science and technology. Hood and Wilson (2001) noted practices of scientists, structures of organisations, research policy and management, the impact of science and technology in the economy among the topics that can be analysed. The term became more popular with the foundation of the journal *Scientometrics* in 1978 by Tibor Braun. The scientometrics field is also characterized by another two specialized journals, *Journal of Informetrics* and *Journal of the American Society for Information Science and Technology* (Milojevic and Leydesdorff 2012).

A large number of papers in the field of scientometrics have been published in scientific collaboration. Existing bibliometric studies on this field have adopted citation analysis (Persson 2000), content analysis (Dutt Garg and Bali 2003) and co-authorship pattern (Afshar et al. 2011) to measure research collaboration with very few exploring the research community from a social network perspective. Katz and Martin (1997) summarized some advantages for utilizing co-authorship data to measure formal research collaboration: verifiability, stability over time, unobtrusiveness and ease of measurement. Moreover, the co-authorship of papers creates a network which can be visualized and studied in order to understand the characteristics of the whole network as well as individual properties of network actors. In the research field of complex networks and bibliometrics, collaboration network analysis represents an important area of study. Co-authorship networks are social networks constructed by connecting actors if they have co-authored together. Social network analysis has been used in a variety of ways to examine various aspects of co-authorship networks, for instance, the performance of individuals in a collaboration network (Morrison Dobbie and McDonald 2003), the collaboration network of institutions (Wang et al. 2008; Katerndahl 2012) and co-authorship network of countries (Haiqi and Hong 1997; De Stefano Vitale and Zaccarine 2010; Yu Shao and Duan 2012). These analysis also have been conducted in a number of fields, such as tourism and hospitality (Benckendorff 2010; Racherla and Hu 2010; Ye Li and Law 2011), medicine (Gonzalez-Alcaide et al. 2012; Yu Shao and Duan 2012), health care (Godley Baron and Sharma 2011), energy (Monteiro et al. 2009; Sakata Sasaki and Inoue 2011), library and information science (Pluzhenskaia 2007; Yan Ding and Zhu 2010), computer science and information systems (Xu and Chau 2006; Cheong and Corbitt 2009; Takeda 2010; Bazzan and Argenta 2011), sociology (Moody 2004) and economics (Krichel and Bakkalbasi 2006).

A few studies have investigated social network measures in the area of scientometrics. Hou, Kretschmer and Liu (2008) studied the structure of scientific collaboration network at micro level by using data of all paper published in the journal *Scientometrics* during 1978 to 2004. Guns, Liu and Mahbuba (2010) measured the research collaboration in the fields of informetrics, bibliometrics, webometrics and scientometrics during the period 1990-2009, and found a relatively low degree of international collaboration. Their study of individual performance of authors showed that only a few of these researchers have the highest global Q-measures, suggesting that they were extensively involved in relationship with other authors. In another study, Yan, Ding and Zhu (2010) visualized library and information science (LIS) collaboration network in China using both macro and micro level measures. Results of the study revealed a small-world network that follows the scale-free character. The researchers also conducted correlation analysis between citation counts and centrality values (measures), and discovered that they are highly correlated. Chen, Fang and Borner (2011) studied the development of the journal *Scientometrics* from 2002 to 2008 and mapped the distribution and collaboration network of countries as well as top institutions. They analyzed the co-author network to map the collaboration among different authors. They also mapped the co-citation network of papers to show the major topics that affected the development of this journal.

Although a few previous studies have attempted to analyze co-authorship network of scientometricians using social network analysis, these studies were limited in their sample size, time span, targeted regions and the studied metrics. Therefore, intensive and comprehensive studies are required to understand the characteristics and structure of co-authorship networks in scientometrics research. This study will use social network analysis (SNA) to depict scientific collaboration among scientometricians based on the 3125 papers published in the journal *Scientometrics* from January 1980 to February 2012.

OBJECTIVES AND METHOD

The journal *Scientometrics* has been chosen as the data source to reveal the scientometrics collaboration network for the same reason given by Chen, Fang and Borner (2011) i.e. the journal *Scientometrics* is the flagship journal in the field of scientometrics. The study is structured around the following specific research objectives:

a) to visualize and study the scientometrics co-authorship networks of authors;
b) to visualize and study the scientometrics co-authorship networks of institutions;
c) to visualize and study the scientometrics co-authorship networks of countries; and
d) to visualize and study the scientometrics co-authorship networks by academic fields.

The study has been conducted in three consecutive phases: data elicitation, verification and conversion, and social network analysis (SNA). First, bibliometric data were retrieved from the Thomson-Reuters' Web of Science® (WoS) database. The data contained all document types published in the journal *Scientometrics* during the examined years. Records from this database were imported through EndNote programme. Some related data which could not be imported directly (such as discipline and country) were manually entered into an Informatics Data Analysis Portal (Figure 1) specifically developed for this study. Author information that could not be ascertained from WoS was identified from other sources such as Google Scholar and other World Wide Web resources. Variant names of authors as well as their institutions were also verified. During the studied period, there were 3125 articles published in the journal *Scientometrics* by 3024 unique authors. Data verification showed that a total of 110 authors published their papers under variant names. Also, 123 inconsistent university names were edited to collate all papers.

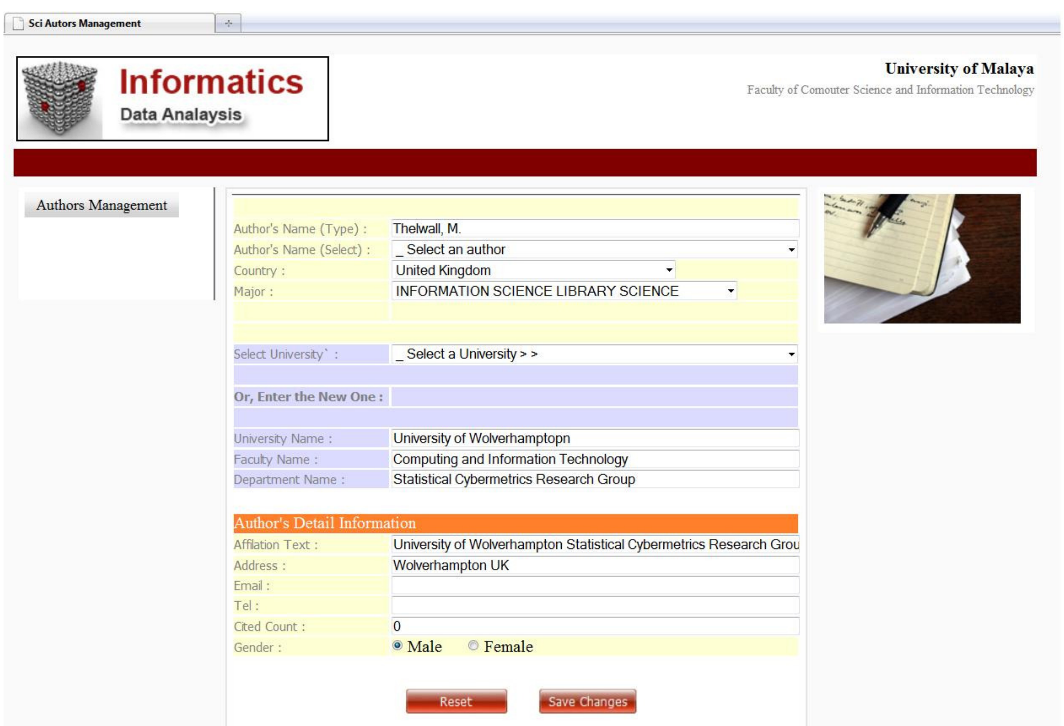

Figure 1: Authors Management Page in the Informatics Data Analysis Portal

After data verification, a total of 3024 authors affiliated to 6589 institutional addresses of 1189 parent organisations from 68 countries were identified. These datasets were converted into a recognized format of input files to be ready for SNA using UCINET application software. A C# application was developed to convert the required datasets. The co-authorship data among authors, countries, institutions and academic fields were retrieved from the portal's database for the development of the co-authorship graphs. The SNA approach was carried out to describe co-authorship networks in the journal *Scientometrics* on macro and micro-levels. Macro-level metrics concentrates on the topology features of a network as a whole with the aim to capture the overall structure of a network; while micro-level metrics focuses on the evaluation of individual actors with the aim to capture the features of each actor in a network (Yan Ding and Zhu 2010).

This study focuses on four macro-level features of the network: density, component, mean distance and clustering coefficient which are defined as follows:

Density: Network density is defined as the number of links in a network, expressed as a proportion of the maximum possible links. It is calculated as the number of links ,*L,* divided by the *n(n-1)* total possible links, with *n* being the total number of vertices in the network (Racherla and Hu 2010).

$$\Delta = L/n(n-1)$$

Component: A component is a set of vertices that can be reached by paths running along links of the network (Cheong and Corbit 2009).

Mean distance: Mean distance is the mean length of the shortest path between two vertices in a network (Yan Ding and Zhu 2010).

Clustering coefficient: Clustering coefficient is measures of the likelihood that two associates of a node are associate themselves (De Stefano Vitale and Zaccarin 2010). The clustering coefficient of a network, *C, is computed by the following formula:*

$$C = \frac{3 \times number\ of\ triangles\ in\ the\ network}{number\ of\ connected\ triples\ of\ vertices}$$

We also apply three centrality measures (degree centrality, closeness centrality and betweenness centrality) to identify key vertices. The definitions and calculations used for the three micro-level measures are as follows:

Degree centrality: The degree centrality is defined as the number of an actor's links divided by the maximum possible number. The normalized degree centrality d_i of vertex *i* is given as

$$d_i = \frac{\sum_j a_{ij}}{(n-1)}$$

where a_{ij} indicates the existence or non-existence of a link between vertex *i* and vertex *j*, and *n* represents the number of vertices. If there is any link between vertex *i* and vertex *j*, a_{ij}= 1. If there is no link, a_{ij}= 0 (Chung and Hossain 2009). In this way, degree centrality is a highly effective measure to determine the influence and importance of a vertex (Benckendorff 2010).

Closeness centrality: Closeness centrality is the vertex's average geodesic distance from every other vertex in the network (Boyd and Ellison 2007). More precisely, the normalized closeness centrality c_i of vertex i is defined as

$$c_i = \frac{(n-1)}{\sum_j e_{ij}}$$

where n is the number of vertices and e_{ij} is the number of links in the shortest path from vertex i to vertex j. Closeness is an inverse measure of centrality in that a large value indicates a less central vertex, while a small value indicates a central vertex (Prell 2011).

Betweenness centrality: Betweenness centrality is an indicator of an actor's potential control of communication within the network. Betweenness centrality is defined as the ratio of the number of shortest paths (between all pairs of vertices) that pass through a given vertex divided by the total number of shortest paths. The normalized betweenness centrality b_i of vertex i is given as

$$b_i = \sum_{j,k \wedge i \neq j \neq k} \frac{g_{jik}}{g_{jk}} \Big/ \frac{(n-1)(n-2)}{2}$$

Where n is the number of vertices, g_{jk} is the number of shortest paths from vertex j to vertex k, and g_{jik} is the number of shortest paths from vertex j to vertex k that pass through vertex i (Prell 2011).

RESULTS AND DISCUSSION

Scientometrics Co-authorship Network of Authors

First the co-authorship network of authors in scientometrics field at the macro and micro-levels was analysed. The co-authorship network of authors consists of vertices and links: vertices represent authors, while links connect vertices in the form of co-authorships. There is a link between two vertices if they have co-authored at least one paper. The size of a vertex is proportional to the number of co-authorships that a given author has in the network. Additionally, the size of the total network denotes simply by the number of unique actors or vertices (3024) with 6884 co-authorship links (Figure 2). The degree of connectedness of a network is given by the density measure, which is the proportion of actual linkages to possible linkages among actors (Godley Barron and Sharma 2011). The density of the co-authorship network of authors in scientometrics field is 0.0005, which indicates only 0.05% of all possible links being present. The social relationships in such low-density network tend to be large, open, diverse and externally focused relationships (Baker 2000).

Although low density indicates low overall cohesion of the network, it should also be noted that the low density is inherent in large networks as it is inversely related to the network size. Similar to many other networks, the co-authorship network of authors in scientometrics field is composed of one large component (known as main, giant or core component) and many small components. A component is a connected subset of a network in which there are direct or indirect links between all vertices (Krichel and Bakkalbasi 2006). Newman (2004) found that the giant component occupied 82% to 92% of authors in different scientific disciplines. Additionally, Kretschmer (2004) suggested that the largest component usually has a ratio of more than 40% of all authors. The co-authorship network of scientometricians consists of 1570 components, the largest of which contains 459 vertices, yielded a ratio of 15.17% of the whole network. This is significantly larger than the second largest component, which contains only 18 vertices. The giant component forms the core of productivity in the network because the most prolific authors are usually located in this component; highly productive authors have an average, low geodesic distances and thus shorter paths to other authors compared with less productive authors. This component containing the authors clustered around the most active and collaborative authors with the highest number of collaborations such as Glanzel, Schubert, Rousseau, Braun and Debackere. Those vertices not belonging to the giant component typically form small isolated components. As can be seen in Figure 2, the main component fills the center of the graph, while other smaller components fill the rest. In total, the co-authorship network of authors in scientometrics field comprised 1096 isolates, 226 dyads, 84 triads, 36 quadruples and 127 components of between 5 to 18 vertices.

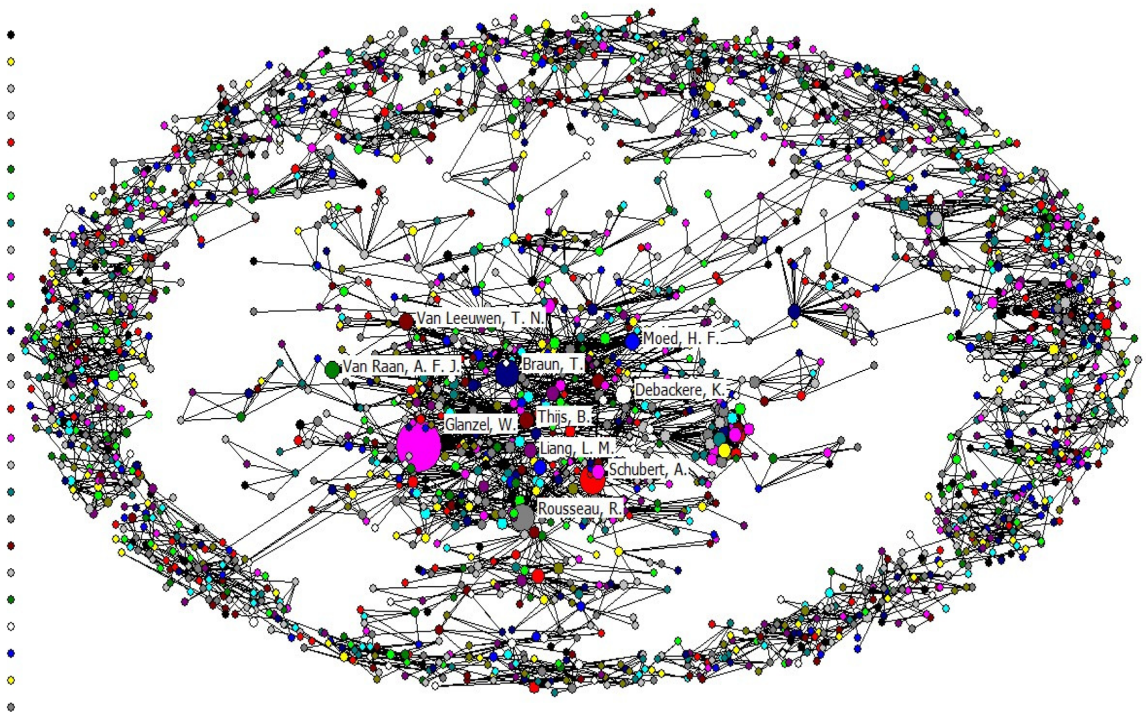

Figure 2: Scientometrics Co-authorship Network of Authors

The geodesic distance between two vertices is defined as the number of lines or steps on the shortest path that connects them (Newman 2004). Short mean distance allow authors to share information in the network more rapidly (Yan Ding and Zhu 2010). The UCINET calculation results show that the mean geodesic distance between two vertices in the co-authorship network of authors in scientometrics field is 5.79, which means that in this network, only an average of 5.79 steps are necessary to get from one randomly chosen vertex to another. According to this finding, the famous notion of "six degree of separation" can be valid in this network. Travers and Milgram (1969) found that for a large well-connected network, each vertex can reach any other vertex through a small number of links. They claimed that there are no more than six connections between any two people on this planet. The degree of separation has been studied widely in social media. Yu and Kak (2012) found that the average degree of separation in Facebook and Twitter is 4.74 and 4.12, respectively. Another network topology attribute, the clustering coefficient, indicates the extent to which vertices in a network tend to cluster together (Newman 2003). It describes the probability that two of a scientist's collaborators have themselves co-authored a paper. Considering all vertices of the network, the total clustering coefficient is 0.799, which indicates that the network is highly clustered. As a result, two authors typically have a high probability of collaboration if both have collaborated with a third author. This finding may interpret that authors tend to introduce pairs of their collaborators to one another, encouraging new collaborations and increasing clustering in the network (Newman, Watts and Strogatz 2002). The short mean distance coupled with high clustering coefficient indicates that the co-authorship network of authors in scientometrics field seems to exhibit "small world" network properties. A "small world" is a network in which any two vertices are only a few steps apart, regardless of network size. In this network, vertices are not necessarily all connected to each other, yet they are easily reachable from one another via short path (Watts and Strogatz 1998).

Micro-level metrics refers to centrality, which is one of the most important and frequently used measurements in social network analysis. Centrality measures indicate how central the actor is to the network, which offer a useful perspective for assessing researcher's performance according to their functions and roles in the network (Benckendorff 2010). Three common centrality metrics, namely degree centrality, closeness centrality and betweenness centrality were adopted to analyze the co-authorship network of authors in scientometrics field. Table 1 presents the top 30 authors in terms of centrality measures (degree, betweenness and closeness), productivity (number of papers in the journal *Scientometrics*) as well as collaboration (number of co-authors). Degree centrality of a vertex is the total number of links that are adjacent to this vertex (Newman 2004). In this study, it refers to the total number of co-authorships that an author has. Authors with higher degree centrality are more central to the structure of the network and tend to have greater capacity to influence others. The average degree centrality of authors in scientometrics co-authorship network is 4.069, while the degree distribution varies significantly. The results show a power-law distribution with a few authors showing a high degree centrality and majority of authors having very low degree centrality. In a dataset of 3024 authors, only 650 authors (21.49%) have a degree centrality of 5 or more and only one author reaches the highest degree centrality of 277. The most prolific authors in terms of degree centrality are: Glanzel (277), Schubert (142), Rousseau (128), Braun (125), Debackere (67), Van Raan (58), Moed (57), Thijs (56), Van Leeuwen (53), Liang and Courtial (47) respectively (Table 1). They are the most active and visible scientometricians with the highest extent of collaboration. These authors with the highest degree centrality are crucial to the robustness of the network as well as the transmission of information.

Closeness centrality can be defined as how close an author is on average to all others in the network (Benckendorff 2010). This measure can be interpreted as an indicator of the influence of an actor because the higher its value, the easier for that actor to obtain and spread information through the network (Martinez-Romo et al. 2008). Table 1 shows the top 30 authors ranked on the standardized closeness centrality measure. The top scorers in terms of closeness centrality are: Glanzel (0.00046983) closely followed by Rousseau (0.00046981), Meyer and Debackere (0.00046026), Kretschmer, Leta, Liang, Thijs, Wu, Persson and Moed (0.00046025). These authors are closest or more central actors of the network, because the sum of their geodesic distances to other actors is among the least. We can see that the closeness centrality of authors is very small because in such large network with more than 3000 vertexes, usually an actor is only close to a limited number of other actors.

Table 1: Top 30 Authors in Centrality, Productivity and Collaboration

Degree Centrality		Betweenness Centrality		Closeness Centrality		Papers		Collaborators	
Author	Freq.	Author	Freq. ($\times 10^2$)	Author	Freq. ($\times 10^3$)	Author	Freq.	Authors	Freq.
Glanzel, W	277	Glanzel, W	4.7117	Glanzel, W	0.46983	Glanzel, W	114	Glanzel, W	45
Schubert, A	142	Rousseau, R	2.6226	Rousseau, R	0.46981	Schubert, A	104	Rousseau, R	43
Rousseau, R	128	Leydesdorff, L	1.7696	Meyer, M	0.46026	Braun, T	68	Debackere, K	29
Braun, T	125	Meyer, M	1.6369	Debackere, K	0.46026	Rousseau, R	56	Ho, Y.S	26
Debackere, K	67	Zitt, M	1.2148	Kretschmer, H	0.46025	Egghe, L	51	Moed, H.F	26
VanRaan, A.F.J	58	Kretschmer, H	0.9683	Leta, J	0.46025	Leydesdorff, L	51	Anegon, F.D.M	26
Moed, H.F	57	Leta, J	0.9267	Liang, L.M	0.46025	Moed, H.F	33	Klingsporn, B	24
Thijs, B	56	Park, H.W	0.8772	Thijs, B	0.46025	Moravcsik, M.J	31	Schubert, A	23
VanLeeuwen, T	53	Debackere, K	0.8150	Wu, Y.S	0.46025	Vinkler, P	30	Courtial, J.P	23
Liang, L.M	47	Gupta, B.M	0.7239	Persson, O	0.46025	Gupta, B.M	28	Gupta, B.M	22
Courtial, J.P	47	Moed, H.F	0.6782	Moed, H.F	0.46025	Kretschmer, H	24	VanRaan, A.F.J	21
Anegon, F.D.M	46	Laville, F	0.6604	Zhang, L	0.46024	VanRaan, A.F.J	24	A.Mackensen, N	20
Sturm, A	44	Okubo, Y	0.6432	Zhou, P	0.46024	Courtial, J.P	23	Bocatius, B	20
Weller, K	44	Katz, J.S	0.6415	Jiang, G.H	0.46024	Garg, K.C	23	Bestakowa, L	20
Gupta, B.M	44	Hicks, D	0.6244	Gorraiz, J	0.46024	Lewison, G	23	Balicki, G	20
Werner, K	44	Chen, C.M	0.6077	Scharnhorst, A	0.46024	Meyer, M	23	Brehmer, L	20
VanLooy, B	40	Zhou, P	0.5688	Schubert, A	0.46024	Bonitz, M	22	Werner, K	20
Meyer, M	40	Zhang, J	0.5558	Katz, J.S	0.45978	Small, H	22	Sturm, A	20
Gomez, I	38	Courtial, J.P	0. 5545	Hornbostel, S	0.45978	Thijs, B	21	Brune, V	20
Egghe, L	38	Hornbostel, S	0.5212	Schoepflin, U	0.45978	Debackere, K	19	Borner, K	20
Ho, Y.S	35	Ho, Y.S	0.5212	Anegon, F.D.M	0.45978	Thelwall, M.	19	Weller, K	20
Sombatsompop, N	35	N.Berthelemot, N	0.4186	Hinze, S	0.45978	VanLeeuwen, T	19	VanLeeuwen, T	20
Markpin, T	35	V.D.Besselaar, P	0.4019	Gumpenberger, C	0.45978	Persson, O	18	Liang, L.M	20
Leydesdorff, L	33	Liang, L.M	0.3907	Janssens, F	0.45978	Zitt, M	18	Fritscher, R	20
Thelwall, M	32	Anegon, F.D.M	0.3838	Braun, T	0.45978	Ho, Y.S	17	Osterhage ,A	20
Bordons, M	32	VanLeeuwen, T	0.3809	Zimmerman, E	0.45978	Nederhof, T.J	17	Probost, M	20
Zitt, M	31	Thelwall, M	0.3745	Grupp, H	0.45978	Wilson, C.S	17	Kuntze, J	20
Huang, M.H	30	Schubert, A	0.3735	V.Quesada, B	0.45978	Abramo, G	16	Lee, J.R	20
Abramo, G	30	Kwon, K.S	0.3634	De Moor, B	0.45978	Bar-Ilan, J	16	Risch, T	20
Tijssen, R	30	Klingsporn, B	0.3634	Glenisson, P	0.45978	Bordons, M	16	Eigemeier, K	20

Another centrality measure that depicts the importance of a particular vertex is betweenness centrality. The betweenness centrality is defined as the probability that a particular vertex appears on the shortest path between any pair of vertices in the network (Yan Ding and Zhu 2010). It is a good measure of the brokerage role that various actors play in connecting others in the network. Additionally, vertices with high betweenness centrality are deemed highly central because they control the flow of information in the network (Racherla and Hu 2010). In regard to standardized betweenness centrality scores, the most influential scientometricians in this co-authorship network are: Glanzel (0.047117), Rousseau (0.026226), Leydesdorf (0.017696), Meyer (0.016369), Zitt (0.012148), Kretschmer (0.009683), Leta (0.009267), Park (0.008772), Debackere (0.008150) and Gupta (0.007239) (See Table 1). These authors and others with high betweenness centrality play the role of a broker to connect the vertices and clusters of the network. The network without these key brokers would display greater fragmentation into separate unconnected components. There are researchers who rank high on betweenness centrality but relatively low on closeness centrality. They are researchers who act as a bridge between sun-communities and the larger collaboration group.

Table 1 also shows the most productive scientometricians. Glanzel (114) and Schubert (104) leads, and they are followed by: Braun (68), Rousseau (56), Egghe (51), Leydesdorff (51), Moed (33), Moravcsik (31), Vinkler (30) and Gupta (28), which totally constitute more than 18% of the total papers in the journal *Scientometrics*. The total number of peoples with whom an author collaborated directly during the period of study was also calculated. Table 1 also shows the top 30 scientometricians that have the highest number of co-authors. The most connected author in the network is Glanzel, who has 45 different immediate co-authors, following by Rousseau (43), Debackere (29), Ho (26), Moed (26), Anegon (26), Klingsporn (24), Schubert (23), Courtial (23) and Gupta (22). Additionally, the average number of collaborators for each author is 1.61 (SD=2.38). The researchers with the highest number of collaborators are likely to be more active and influential in the academic community. Newman (2001) found that the probability of scientist to collaborate increases with the number of common collaborators. Accordingly, those authors with many collaborators are likely to be productive and influential. It is interesting to see that a few scientometricians are ranked high in all five measures, clearly indicating their important structural role in the network. Reviewing Table 1, we can see that individuals like Glanzel, Rousseau, Debackere, Schubert, Moed, Gupta, Braun, Thijs, Liang, Leydesdorf, Meyer, Kretschmer and Leta occupy the topmost positions in various rankings, which indicate their absolute status in scientometrics research. Amongst them, Dr. Wolfgang Glanzel, who is currently affiliated with University of Leuven, appears in the first rank when all five metrics are taken into consideration.

Scientometrics Co-authorship Network of Institutions

Using the affiliations listed for each author, the paper analysed the co-authorship network of institutions in scientometrics research collaboration. All authors from the same institution are aggregated into a single network vertex, while links represent a co-authorship relationship between two different institutions. The size of each vertex is an indication of the degree centrality of that vertex. Based on the institutional collaboration network shown in Figure 3, ten institutions with the highest degree centrality are identified. While 1207 institutions are presented by published articles in this network, 869 (72%) of these institutions have 6594 cross-institutional collaboration links. A total of 338 institutions are isolated, having no collaboration with the rest of the network, and 179 institutions have only a single link to the whole network (pendants). With a low density of 0.0018, the co-authorship network of institutions demonstrates low cohesion. The giant component of the network comprises 597 institutions which occupies 49.46% of the overall size of the network. Institutions not belonging to the main component form 439 isolated components, the largest one has only 12 vertices. The mean geodesic distance of the network is 5.28, suggesting that there are less than six degree of separation between most institutions in the network. Additionally, the clustering coefficient of co-authorship network of institutions is 0.623, which means that there is 62.3% chance that two institutions both collaborating with a third institution would also collaborate together.

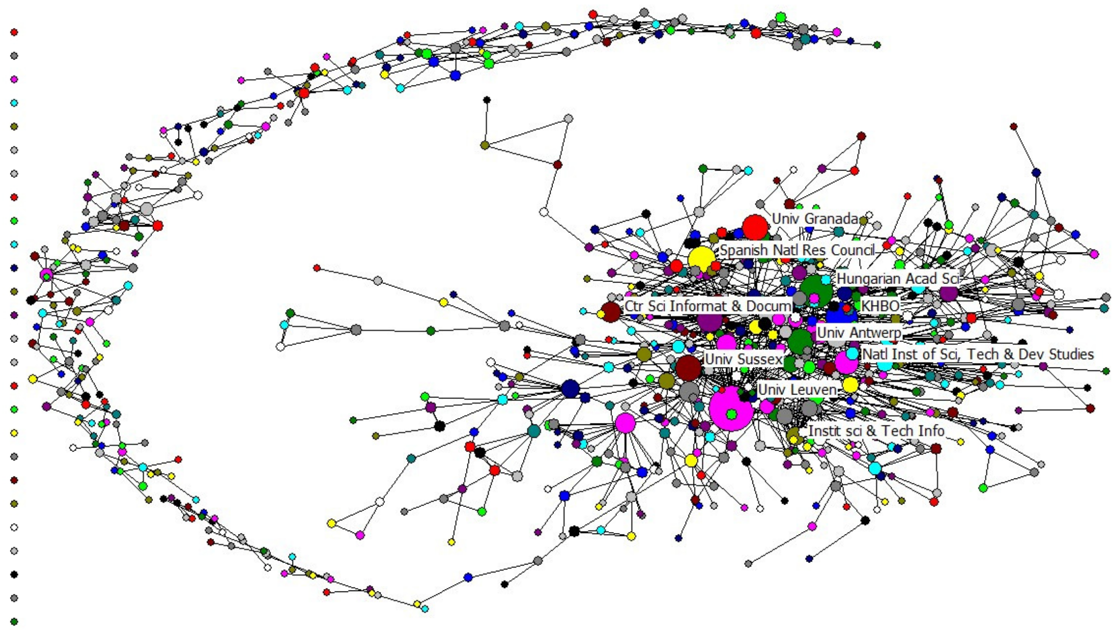

Figure 3: Scientometrics Co-authorship Network of Institutions

Micro level metrics which include degree centrality, closeness centrality and betweenness centrality were also calculated for institutions co-authorship network. Table 2 shows the top 20 institutions in centrality measures as well as productivity and collaboration. With respect to degree centrality, the top institutions are: University of Leuven (262), Hungarian Academy of Science (226), University of Antwerp (131), University of Granada (107), Katholieke Hogeschool Brugge-Oostende (107), Institute of Scientific and Technical Information of China (95), Spanish National Research Council (82), National Institute of Science, Technology and Development Studies (74), Institute for Information and Documentation in Science and Technology (73) and University of Sussex (67). These institutions with the highest degree centrality are more central to the structure of the network and tend to have a greater capacity to influence others. The mean degree centrality across all institutions, including isolates (with degree of zero) is 10.92, indicating the average number of links per institution. For the closeness centrality measure, again University of Leuven (0.00163399) and Hungarian Academy of Science (0.00163363) take the top two spots followed by University of Sussex (0.00163351), Katholieke Hogeschool Brugge-Oostende (0.00163348), Leiden University (0.00163341), National Institute of Science, Technology and Development Studies (0.00163338), University of Amsterdam (0.00163334), University of Antwerp (0.00163328), Institute of Scientific and Technical Information (0.00163328) and Elsevier (0.00163327). Since closeness centrality measures the distance of an institution to all others in the network, the closer the institution is to others, the more favoured the institution becomes.

Table 2: Top 20 Institutions in Centrality, Productivity and Collaboration

Degree Centrality		Betweenness Centrality		Closeness Centrality		Papers		Collaborators	
University	Freq.	University	Freq. ($\times10^2$)	University	Freq. ($\times10^3$)	University	Freq.	University	Freq.
Univ Leuven	262	Univ Leuven	7.97	Univ Leuven	1.63399	Hungarian Acad Sci	208	Univ Leuven	49
Hungarian AcadSci	226	Univ Sussex	4.62	Hungarian Acad Sci	1.63363	Leiden Univ	116	Hungarian AcadSci	35
Univ Antwerp	131	Hungarian AcadSci	3.45	Univ Sussex	1.63351	Univ Leuven	102	KHBO	31
Univ Granada	107	Georgia Inst Tech	3.13	KHBO	1.63348	Natl Inst Sci & Tech Dev Studies	99	Spanish Natl Res Council	28
KHBO	107	Univ Amsterdam	2.87	Leiden Univ	1.63341	Univ Antwerp	78	Univ Granada	25
Inst Sci & Tech Info	95	KHBO	2.69	Natl Inst Sci & Tech Dev Studies	1.63338	Univ Amsterdam	62	Univ Antwerp	24
Spanish Natl Res Council	82	Leiden Univ	2.33	Univ Amsterdam	1.63334	Inst Info & Docum in Sci & Tech	57	Univ Sussex	24
Natl InstSci, Techl & Dev Studies	74	Univ Western Ontario	2.12	Univ Antwerp	1.63328	Spanish Natl Res Council	50	Leiden Univ	24
Ctr Sci Informat & Docum	73	Univ Granada	2.02	Inst Sci & Tech Info	1.63328	Univ Sussex	49	Natl Inst Sci & Tech Dev Studies	22
Univ Sussex	67	Yeungnam Univ	1.98	Elsevier	1.63327	KHBO	49	Henan Normal Univ	21
Leiden Univ	66	Natl Autonomous Univ	1.92	Henan Normal Univ	1.63323	Univ Granada	45	Univ Amsterdam	18
Univ Fed Rio de Janeiro	65	Fraunhofer ISI	1.88	Fraunhofer ISI	1.63319	Acad Sci GDR	41	City Univ	16
Natl Taiwan Univ	53	Natl InstSci & Tech Dev Studies	1.76	Univ Granada	1.63317	Russian Acad Sci	39	Georgia Inst Tech	16
Henan Normal Univ	53	Univ Tokyo	1.76	Spanish Natl Res Council	1.63313	Inst Sci Informat	34	Univ Tokyo	16
Eotvos Lorand Univ	50	Univ Fed Rio de Janeiro	1.75	Acad Sci GDR	1.63310	Univ Oregon	34	Natl Autonomous Univ	15
Wuhan Univ	50	Russian AcadSci	1.67	Bar-IlanUniv	1.63309	Limburgs Univ Cent	34	Univ Fed Rio de Janeiro	15
Natl Ctr Sci Res	47	Univ Illinois	1.67	City Univ	1.63308	Georgia Inst Tech	27	Seoul Natl Univ	14
Univ Nantes	43	Spanish Natl Res Council	1.61	Dalian Univ of Tech	1.63308	Drexel Univ	27	Inst Sci & Tech Info	14
Dalian Univ Tech	43	City Univ	1.58	Univ Fed Rio de Janeiro	1.63302	Eotvos Lorand Univ	26	Wuhan Univ	13
Res Assoc Sci Commun & Informat	42	Seoul NatlUniv	1.57	Univ Western Ontario	1.63278	Univ Hasselt	25	Dalian Univ of Tech	13

Table 2 also shows the top 20 institutions with the highest betweenness centrality. The betweenness centrality scores indicate that University of Leuven (0.0797), University of Sussex (0.0462) and Hungarian Academy of Science (0.0345), Georgia Institute of Technology (0.0313), University of Amsterdam (0.0287), Katholieke Hogeschool Brugge-Oostende (0.0269), Leiden University (0.0233), University of Western Ontario (0.0212), University of Granada (0.0202) and Yeungnam University (0.0198) act as key brokers in connecting various institutions in the network. These institutions have the most favoured positions in the network by falling on the geodesic paths between other pairs of institutions. Additionally, Hungarian Academy of Science (208) is by far the leading institution when the productivity criterion is used. Other most productive institutions are: Leiden University (116), University of Leuven (102), National Institute of Science, Technology and Development Studies (99), University of Antwerp (78), University of Amsterdam (62), Institute for Information and Documentation in Science and Technology (57), Spanish National Research Council (50), University of Sussex (49) and Katholieke Hogeschool Brugge-Oostende (49).

The number of immediate collaborators, an indicator representing connection and collaboration of institutions, is 2.16 (SD=3.47) on average, with the maximum value of 49 for the University of Leuven. The second institution with the highest number of immediate collaborator institutions is Hungarian Academy of Science (35) followed by Katholieke Hogeschool Brugge-Oostende (31), Spanish National Research Council (28), University of Granada (25), University of Sussex, University of Antwerp and Leiden University (24), National Institute of Science, Technology and Development Studies (22) and Henan Normal University (21). The results show that the most productive institutions have established collaborative links with a great number of institutions. Studying the strength of collaboration between institutions shows that University of Leuven and Hungarian Academy of Science have the highest number of co-authoring links with 160 co-authorships. Strong co-authorship between institutions is mostly due to a large number of co-authored papers between productive individuals in those institutions. Another possible explanation for such strong links between institutions is that some authors have published their papers under different affiliations, which can increase the potential of co-authoring of those institutions. For example, Glanzel published his papers under the affiliation of both University of Leuven and Hungarian Academy of Science which can be effective in strengthening co-authoring links between these two institutions. It is noted that the strongest partnerships in the network exist between European universities, while there is a weak co-authoring between North American and European institutions. This finding is somewhat consistent with that of Katz (1994) who found that geographical proximity results in more collaboration.

It is also worth noting that the centrality, productivity and collaboration of a university are largely related to the individuals who are affiliated with that university. In other word, institutional centrality within collaboration network emerges and develops as authors affiliated with that institution create co-authoring links. For example Wolfgang Glanzel plays a vital role in increasing the centrality of the University of Leuven as well as Hungarian Academy of Science, just like the role of Ronald Rousseau at Katholieke Hogeschool Brugge-Oostende (KHBO), Andras Schubert at Hungarian Academy of Science, Mike Thelwall at University of Wolverhampton or Martin Meyer at University of Sussex. When all of the metrics are examined together, it is clear that there are important institutions strategically positioned in the network due to their centrality, productivity as well as collaboration. These institutions are University of Leuven, Hungarian Academy of Science, University of Antwerp, KHBO, University of Granada, University of Amsterdam, Spanish National Research Council, Leiden University and National Institute of Science, Technology and Development Studies. These institutions play critical roles in the production of scientometrics knowledge as well as central roles in the collaboration network, with a large number of links to a wide range of institutions.

Scientometrics Co-authorship Network of Countries

The international collaboration of countries can be further studied from the country information included in the author affiliation for each paper published in the journal *Scientometrics*. A collaboration network of countries is presented in Figure 4. The whole co-authorship network contains 68 vertices and 2824 links. There is a link between two countries if the authors affiliated with those countries have co-authored at least one paper. There are 12 isolated vertices, which represent countries that have not collaborated with other countries to the extent of co-authoring a paper. The analysis of the structural characteristics of the network shows that the number of actual links as a ratio of the number of possible links, or simply the density of the co-authorship network of countries is 0.086, which is fairly low. The results of component analysis obtained a total of 13 components consist of one giant component with 56 vertices (82.35% of all vertices) and 12 isolated components. The average path length between connected vertices is 2.24, which means that a vertex in the giant component can reach another vertex in about only 2.24 steps. Additionally, the overall clustering coefficient of 0.58 indicates that vertices of the network tend to form tightly connected, localized cliques with their immediate neighbors.

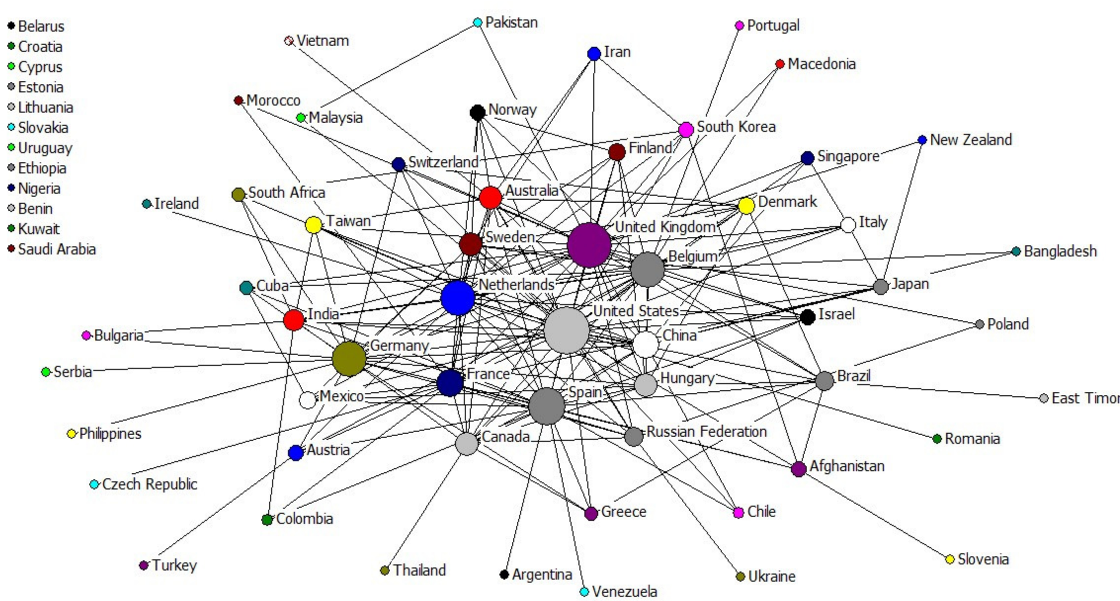

Figure 4: Scientometrics Co-authorship Network of Countries

Table 3 indicates the top 30 most important countries contributing to scientometrics research based on centrality, productivity and collaboration indicators. The United States occupies the topmost positions in closeness centrality, betweenness centrality, number of papers as well as number of immediate collaborators, which indicates its central role in collaboration network of countries in this field. This finding is interesting in view of the fact that none of the American institutions was among the top 20 most influential and central institutions discussed earlier. This indicates that many American institutions were engaged in scientometrics research with fewer outputs of papers. American scientometricians have published 528 papers with the collaboration of several colleagues from 31 various countries. Ranked the first in closeness centrality, United States is the closest to all other countries in the network, has the highest reachability. Moreover, with the highest betweenness centrality, this country plays an important role in the network by controlling the flow of information. United States and other countries with high betweenness centrality are intermediate vertices for the communication of the rest. Another case, all isolates and pendants, countries with no co-authorship or with only one co-authorship, have betweenness centrality score of zero.

With regards to degree centrality, Belgium occupies the top position with 383 co-authorships with foreign countries, followed by China (269) and United States (259). Although the United States has the highest number of papers, its collaboration activity was weaker than Belgium and China. Considering all measures together, United States, Belgium, Netherlands, Spain, UK, Germany, Hungary and China play the most pivotal and central role in the co-authorship network of countries in scientometrics field.

Studying the collaborative links of countries shows that Belgium and China have the strongest collaborative link in the network with 194 co-authorships. The second and third strongest collaborative links can be seen between Belgium and Hungary (166) and China and Taiwan (104). While Hungary is Germany's biggest partner with 78 shared papers, Belgium is Netherland's strongest collaborator with 134 co-authorships. Spain has the strongest collaborative links with France (44), while France itself has the highest number of shared papers with Russia (52).

The highest proportion of US international collaboration can be observed with China (84). Hungary, the forth country with regards to productivity, has 176 collaborative links with only 13 immediate neighbors, the highest shared papers with Belgium. Australian scientometricians are connected to Chinese (26) and American (18) colleagues, but isolated from Belgium, Hungary and Germany. An interesting finding is that United States has only 8 co-authorships with Belgium, but not with Hungary. Conversely, American scientometricians collaborate more with those in China, UK and Canada.

In general, European countries are the main source of scientometrics papers, followed by North America and Asia. Moreover, the co-authorship ties of European and North American countries are totally weak, except that of UK and US (74 shared papers). China is the only country which has strong collaborative ties with the most important and productive countries from various continents. Finally, it is noteworthy that a large number of collaborations may be explained by the strong cultural affinity between countries such as Belgium, Netherlands and Hungary or China and Taiwan.

Table 3: Top 30 Countries in Centrality, Productivity and Collaboration

Degree Centrality		Betweenness Centrality		Closeness Centrality		Papers		Collaborators	
Country	Freq.	Country	Freq.	Country	Freq. ($\times 10^2$)	Country	Freq.	Country	Freq.
Belgium	383	U.S.A.	0.1441	U.S.A.	7.4860	U.S.A	528	U.S.A	31
China	269	England	0.1341	England	7.4527	Netherlands	257	England	29
U.S.A	259	Spain	0.0914	Spain	7.4115	Belgium	229	Spain	23
Germany	191	Germany	0.0844	Netherlands	7.3951	Hungary	217	Belgium	22
Netherlands	187	Belgium	0.0680	Belgium	7.3869	Spain	210	Netherlands	22
Hungary	176	France	0.0520	Germany	7.3788	England	208	Germany	21
England	169	Netherlands	0.0514	France	7.3464	Germany	200	France	16
Spain	154	Australia	0.0327	Canada	7.3144	India	180	China	15
France	133	Russia	0.0296	China	7.3144	China	170	Hungary	13
Taiwan	87	Canada	0.0288	Hungary	7.2826	France	151	Sweden	13
India	68	Brazil	0.0284	Australia	7.2826	Canada	86	Canada	13
Australia	79	Afghanistan	0.0257	Sweden	7.2747	Russia	85	Australia	13
Sweden	54	Austria	0.0244	India	7.2668	Taiwan	78	India	11
Russia	51	China	0.0210	Russia	7.2510	Australia	68	Brazil	9
Canada	49	India	0.0148	Brazil	7.2354	Italy	66	Russia	9
Switzerland	48	Sweden	0.0113	Taiwan	7.2198	South Korea	66	Denmark	8
Finland	43	Hungary	0.0063	Denmark	7.2043	Japan	60	Finland	7
Brazil	34	S. Korea	0.0044	Israel	7.2043	Brazil	56	Mexico	7
S. Korea	33	Japan	0.0036	Mexico	7.1965	Sweden	54	Taiwan	7
Israel	29	Denmark	0.0023	Austria	7.1965	Finland	48	Austria	6
Austria	28	Mexico	0.0001	Finland	7.1888	Israel	47	Italy	6
Mexico	28	Greece	0.0001	Cuba	7.1888	Denmark	36	Norway	6
Denmark	22	Finland	0.0001	Italy	7.1811	Austria	35	South Korea	6
Cuba	17	Taiwan	0.0001	Switzerland	7.1811	Mexico	31	Israel	6
Chile	17	Cuba	0.0001	South Korea	7.1734	South Africa	31	Japan	6
Columbia	17	Switzerland	0.0001	Greece	7.1657	Switzerland	29	Greece	5
Ireland	16	Others Countires	0.0000	Norway	7.1581	Poland	26	Switzerland	5
Japan	16	-	-	Japan	7.1504	Iran	22	Cuba	5
Greece	15	-	-	Singapore	7.1504	Norway	22	Iran	4
South Africa	12	-	-	South Africa	7.1502	Turkey	21	South Africa	4

Scientometrics Co-authorship Network by Academic Fields

Finally, this paper studies the collaboration network of academic fields in scientometrics research. A collaboration network of academic fields was constructed based on the affiliation listed for each author. The department or faculty which an author is affiliated to is considered as his academic field. In many cases where the name of department or faculty was not indicated in the paper, the World Wide Web resources were used to determine the academic field of authors. However, the academic fields of 315 authors (10.4%) were excluded from the study as they could not be identified even after searching the World Wide Web. To show the collaboration network of fields and to prevent dispersion, the academic fields were mapped into 22 broad fields depicted in Essential Science Indicators (ESI). Figure 5 shows the co-authorship network of academic fields in scientometrics research. The network consists of 22 fields as vertices and 3508 collaboration links. As presented in Table 4, considering all five measures, the most active, central and collaborative academic fields are Social Sciences, Economics and Business, Clinical Medicine, Physics, Chemistry and Psychiatry and Psychology. The most productive discipline in social sciences is Information and Library Sciences (1212) followed by Policy of Science and Technology (456) and Sociology (114). Academic fields of scientometricians with the least centrality, productivity and collaboration are Immunology, Pharmacology, Microbiology and Space Sciences.

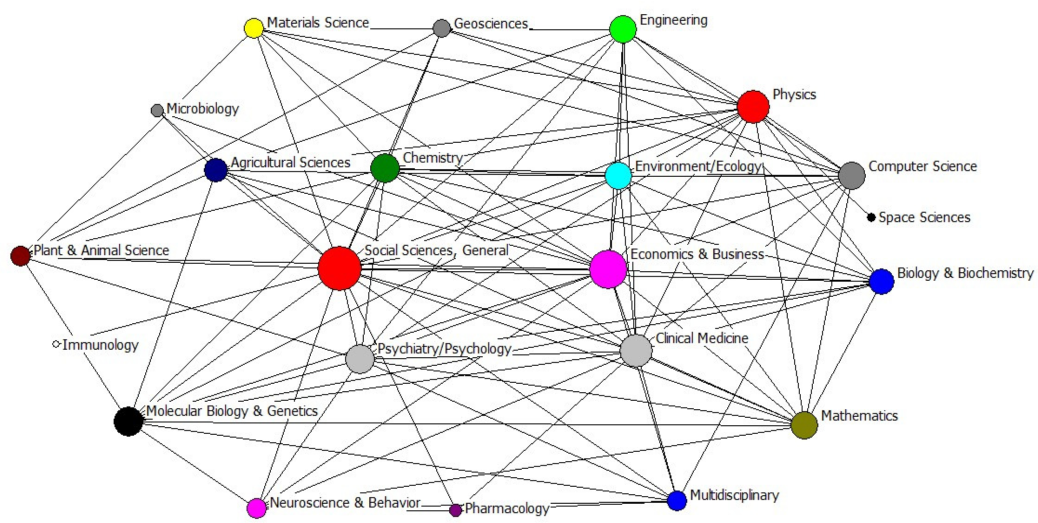

Figure 5: Scientometrics Co-authorship Network by Academic Fields

Table 4: Centrality, Productivity and Collaboration of Academic Fields in Scientometrics Research

Degree Centrality		Betweenness Centrality		Closeness Centrality		Papers		Collaborators	
Major	Freq.	Major	Freq.	Major	Freq.	Major	Freq.	Major	Freq.
Social Sci	2112	Social Sci	0.2116	Social Sci	0.9565	Social Sci	1923	Social Sci	21
Economics, Business	1152	Economics,Business	0.0605	Economics,Business	0.8461	Economics,Business	550	Economics,Business	18
Clinical Medicine	530	Physics	0.0547	Physics	0.7586	Physics	174	Physics	15
Mathematics	384	Clinical Medicine	0.0388	Clinical Medicine	0.7586	Clinical Medicine	163	Clinical Medicine	15
Chemistry	364	Psychiatry, Psychology	0.0201	Psychiatry,Psychology	0.7096	Chemistry	140	Molecular Biology, Genetics	13
Physics	316	Molecular Biology,Genetics	0.0200	Chemistry	0.7096	Engineering	117	Chemistry	13
Engineering	290	Chemistry	0.0165	Molecular Biology, Genetics	0.7096	Mathematics	108	Psychiatry,Psychology	13
Computer Sci	266	Computer Sci	0.0163	Engineering	0.6875	Computer Sci	103	Computer Sci	12
Psychiatry, Psychology	228	Agricultural Sci	0.0125	Environment,Ecology	0.6875	Psychiatry,Psychology	102	Mathematics	12
Agricultural Sciences	184	Engineering	0.0121	Mathematics	0.6875	Biology,Biochemistry	54	Environment,Ecology	12
Plant,AnimalSci	174	Mathematics	0.0106	Computer Sci	0.6875	Agricultural Sci	40	Engineering	12
Environment, Ecology	172	Plant,AnimalSci	0.0073	Biology,Biochemistry	0.6666	Environment,Ecology	35	Biology,Biochemistry	11
Biology, Biochemistry	152	Multidisciplinary	0.0066	Agricultural Sci	0.6470	Materials Sci	35	Agricultural Sci	10
Multidisciplinary	124	Environment,Ecology	0.0056	Materials Sci	0.6111	Geosciences	32	Neuroscience,Behavior	8
Neuroscience, Behavior	106	Neuroscience, Behavior	0.0053	Multidisciplinary	0.5945	Plant,AnimalSci	30	Multidisciplinary	8
Materials Sci	76	Materials Sci	0.0037	Plant,AnimalSci	0.5945	Molecular Biology, Genetics	28	Plant,AnimalSci	8
Geosciences	56	Geosciences		Geosciences	0.5945	Multidisciplinary	21	Materials Sci	8
Molecular Biology,Genetics	56	Biology,Biochemistry	0.0026	Neuroscience,Behavior	0.5945	Space Sci	21	Geosciences	7
Pharmacology	48	Space Sci	0	Microbiology	0.5500	Neuroscience,Behavior	15	Microbiology	4
Space Sci	26	Immunology	0	Pharmacology	0.5365	Pharmacology	12	Pharmacology	4
Microbiology	14	Pharmacology	0	Immunology	0.5000	Microbiology	7	Space Sci	2
Immunology	8	Microbiology	0	Space Sci	0.4680	Immunology	3	Immunology	1

CONCLUSION

This study has examined the scientometrics co-authorship networks of authors, institutions, countries and by academic fields using the data from the journal *Scientometrics.* This is a limitation of the study as it does not take into account papers on scientometrics published elsewhere such as *Journal of Informetrics, Journal of the American Society for Information Science and Technology* (JASIST) and *Research Evaluation.* The key findings of this study on the community of scientometricians are as follows:

a) The percentage of co-authored papers represents 54.78% of the total number of papers published in the journal *Scientometrics*;
b) The scientometrician's collaboration network forms "small-world" topology in which two authors randomly selected are typically separated by a short path, and has demonstrated the presence of clustering;
c) The distribution of vertices degree centrality in the collaboration network of scientometricians follows the power-law distribution. In this network, we have a great number of authors with small degrees and a small tail of authors with large degrees;
d) The co-authorship network of authors in the field of scientometrics consists of 1570 components, the largest of which contains 459 vertices, yielded a ratio of 15.17% of the whole network;
e) Thirteen scientometricians, Glanzel, Rousseau, Debackere, Schubert, Moed, Gupta, Braun, Thijs, Liang, Leydesdorf, Meyer, Kretschmer and Leta are strategically positioned in the network due to both their productivity and centrality.
f) University of Leuven, Hungarian Academy of Science, University of Antwerp, KHBO, University of Granada, University of Amsterdam, Spanish National Research Council, Leiden University and National Institute of Science, Technology and Development Studies occupy the topmost positions in various rankings, which indicate their absolute status in scientometrics research.
g) The United States, although has no representative in the top 20 most influential and central institutions, occupies the topmost positions in all measures except for degree centrality. Belgium, Netherlands, Span, England, Germany, Hungary and China come after US based on productivity, centrality and collaboration.
h) The most active, central and collaborative academic fields in scientometrics research are Social Sciences, Economics and Business, Clinical Medicine, Physics, Chemistry and Psychiatry and Psychology; with Information and Library Sciences as the most productive discipline in social sciences producing scientometrics research.

Although the study has included a time span of more than three decades (1980-2012*)* for the scientometrics co-authorship network, the temporal dimension, i.e. to see whether the practices of co-authorship of various institutions and countries relationships have changed over time, has not been explored in this study. However, the positive evolutions of the main component of the scientometrics collaboration network coupled with the presence of a number of key individuals are evidence of the healthy status of the scientometrics research community. Unlike a similar analysis of the information systems community (Xu and Chau 2006), the scientometrics scene was not dominated by a couple of key researchers as quite a significant number of popular researchers were identified. This is the proof of community's ability to attract new members over the years and to produce new generations of popular researchers. The scientometrics research community was found to be a healthy small-world community that kept evolving in order to provide an environment that supports collaboration and sharing of ideas between researchers in quantitative study of research communication.

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