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Geographic characteristics of the growth of informetrics literature 1987–2008

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ABSTRACT

Recent studies have concluded that American contributions to science literature have been in relative decline, whereas contributions from other parts of the world such as the European Union and Asia have increased. Is the same true for the areas of bibliometrics, informetrics and scientometrics? This study investigates the growth and geographic distribution of metrics research for the period 1987–2008. Similar to studies of other disciplines or science in general, the findings reveal that the United States continues to dominate, but there has been a recent relative decline in North American contributions overall. European and Asian contributions have grown substantially. National and institutional collaborations that contribute to this growth do not necessarily follow close geographic proximity, although European nations have been more active with international collaborations overall, both within Europe and elsewhere.

1. Introduction and literature review

The worldwide community of research in a given discipline constitutes an ever-changing group of contributors. Individuals enter and leave research areas over time. Contributions to the research base may be regional and chosen venues of publication may not be accessible to all members of the community. The dynamics of research contributions and collaborations represent a complex interaction of factors.

Centers of research contribution, whether defined by institutions, at national or regional levels can change over time. A number of research studies have compared the scientific productivity and impact (measured in citations) within and across disciplines to document and better understand these shifts. King (2004), for example, studied scientific productivity and citations between 1993 and 2001 worldwide for sources indexed by Thomson Reuters ISI databases. He noted that the share of American and Canadian publications and citations had decreased during the study period, whereas European contributions had increased. Increases were also found for a number of Asian countries, most notably China, Japan, Singapore, South Korea and Taiwan. Glänzel, Debackere, and Meyer (2008) examined the validity of the descriptive triad for international scientific collaboration, consisting of the United States, European Union (EU) and Japan, and proposed that a tetrad that includes China be considered. More recently, Archambault (2010) released findings of a study that further corroborates the tremendous growth in Asian science productivity.

The rise of China in scientific productivity has been of particular interest. Jin and Rousseau (2004) noted the exponential growth of papers with Chinese addresses. Zhou and Leydesdorff (2006) stated that China was now only second to the United States in nanoscience and nanotechnology. Similarly, Shelton and Foland (n.d.) used a number of science and technology

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indicators to gauge American, European and Chinese performance and potential. They concluded that the trend is unfavorable for the United States and European Union, with China predicted to take a leading role in at least some of the indicators in the future.

Shelton (2008) notes the paradox of the United States' declining share of scientific publications despite its ongoing large investment in research and development in science and technology. It is conceivable that this could be a product of the data collection method. One contributing factor to outcomes could be changes in the inclusiveness of international journals indexed by Thomson Reuters ISI or Scopus in which North Americans are less likely to publish. However, Shelton, Foland, and Gorelskyy (2007) have found that this is not the case, at least for the Science Citation Index.

The apparent decline of American contributions has been a specific topic of focus. Shelton and Holdridge (2004) noted that the EU leads in several important metrics and is catching up in others. Leydesdorff and Wagner (2009a) studied whether there has been a measurable decline in American scientific performance. They concluded that, based on data from the Science Citation Index, the United States is still by far the strongest nation in its scientific performance, but observed relative declines that are a result of increasing productivity by Asian nations, with European contributions also contributing to this decline. This is reinforced in a study on macro-indicators (Leydesdorff & Wagner, 2009b). With greater internationalization of research and development, there are increasing opportunities (or pressure) for researchers to collaborate across national boundaries. Earlier, Leydesdorff (2000) had examined whether the formation of the European Union had begun to lead to an emerging singular publication system. He noted that at the time of the study there was not a lot of evidence to support that this was the case.

This investigation was prompted by interest in whether shifts in productivity based on geography are observed in the bibliometrics, informetrics and scientometrics areas. The term "metrics" is used hereafter for simplicity but does not refer other metrics fields that do not deal with the production and use of information or scientific communication. Research activities in metrics continue to have a high profile in Europe and a growing profile in Asia based on publications and recent scholarly events with a metrics focus. Perceptually, this does not seem to be the case in North America, where few meetings with a metrics focus have been held in recent years and only a small number of metrics-themed papers are presented at annual North American meetings in the information sciences. One of the authors conducted a pilot study to determine whether there have been clear declines in North American contributions to the metrics literature base (Wolfram, 2008). The author found that there was indeed a notable relative decline in North American contributions and a sharp increase in European contributions. A more thorough study of this area is warranted with a broader range of data and a research focus that examines global contributions to metrics research.

The metrics-based study of metrics literature has been covered by several researchers. Of particular note are two studies. Hood and Wilson (2001) examined the growth of literature of the metrics area. They provided an historical treatment of the development of these areas that included earlier studies of the field. In their research, literature associated with bibliometrics, informetrics and scientometrics was compared for the period 1968–2000. The authors noted that bibliometrics was still the most widely used term for metrics research. Included in their investigation was a summary of the most frequent publication outlets. Six of the top ten publications were European-based; two were based in North America, and one each in South America and Asia. More recently, Stock and Weber (2006) conducted a Web of Science search for records specifically including metrics terms and allied areas. They observed contributions had grown substantially since 1980. The relative dearth of recent studies examining metrics literature, in particular, merits further investigation.

Specific questions of interest for the present research include:

(1) What are the growth patterns for metrics research in different areas of the world?
(2) Are the contributions by North Americans in absolute or relative decline when compared to other areas of the world?
(3) Are there clear patterns in collaborations for metrics-based research?

Aspects of each of these questions are addressed at higher levels of granularity than the individual author level. Specifically, this study examines geographic aspects of metrics literature at the regional, national, and institutional levels.

2. Methodology

Thomson Reuters Web of Science (WoS) was used to identify literature relevant to metrics research for the period 1987–2008. WoS was selected because of its broad coverage of literature and the ability to search by address, which is central to this research. The time frame reflects electronic database availability to the authors. Search parameters included the Boolean ORed result of bibliometrics, scientometrics, informetrics, cybermetrics and webometrics, in truncated form (e.g., webometri*), along with the phrases "citation analysis", "link analysis" and "citation indexes". Although link analysis can deal with the allied area of social network analysis, it also represents a major component of webometrics (Thelwall, 2009). These search results were ORed with the two primary journals that publish metrics research that are indexed by WoS, namely *Scientometrics* and the *Journal of Informetrics*. Results were limited to articles, proceedings papers, editorial material and reviews. Given their nature, editorial materials might not be considered citable items and, therefore, may not be deemed worthy of inclusion. Although these records represented a small percentage of the returned items (less than 5%), approximately 60% were cited at least one time, which provides an indication of their value as a citable contribution to the literature.

The returned set served as the base retrieval set for identifying geographic affiliations of the authors of the papers. Totals for each country and other metadata over the time frame could be extracted using the Analyze Results feature of WoS, but would not also break down the data by year. We were also interested in geographic affiliations at the continent level to ascertain contributions at a higher geographic level. Results from the base set were ANDed with the ORed country names associated with each continent that appeared in the author addresses. We acknowledge there may be some debate over continental boundaries. For this study, Africa consisted of all nations that are part of the African continent. Asia consisted of all countries east of the traditional boundary of Europe and included Southeast Asia and republics of the former Soviet Union fully contained within the continent of Asia, as well as the country of Turkey. Europe consisted of all countries in Eurasia west of Asia, including Russia. North America consisted of all nations within the continental mass, including central America and islands in the Caribbean. Oceania consisted of Australia, New Zealand, New Guinea and Pacific islands excluding the Indonesian archipelago. South America consisted of all nations that are part of the South American landmass.

Collaboration patterns, in particular at the institution and country level, were also of interest. A collaboration was defined as multiple institutions or countries appearing in the same record. Address fields from the retrieved data set were parsed for institutional and national affiliations. In the case where an author had multiple affiliations listed, these were treated by the program as a form of collaboration. The same institution or country, however, appearing more than one time in the same record was counted only once. Authors with multiple affiliations were particularly evident with Belgian, and more specifically Flemish, institutions, where university mergers during the study period and relationships among different institutions made for a convoluted interpretation of affiliations. This was also observed by Leydesdorff and Persson (n.d.) in their study of information science. The authors recognized that multiple affiliations can result in a high number of "virtual" collaborations. The high levels of productivity by a number of researchers at Flemish institutions holding multiple affiliations resulted in strong collaborative ties among these institutions. It should be noted that a number of the Belgian researchers also list international affiliations, which could strengthen relationships with institutions in other countries. This is a limitation of the data collected. Identifying author affiliations in downloaded records when there were more (or fewer) affiliations than authors and then unambiguously associating a given author to a singular institution proved problematic.

A pair-wise comparison of all collaborations at the national and institutional levels was then conducted from which a co-occurrence matrix could be compiled. Multidimensional scaling (MDS) analysis was used to visualize the relationships among countries. Because the data represent a type of similarity measure represented as a symmetric matrix, SPSS PROXSCAL was used to construct the map, as recommended by Leydesdorff and Vaughan (2006). The recently developed visualization tool VOSviewer (van Eck & Waltman, 2010) was also used to provide an alternate visualization of the relationship outcomes. Like MDS, VOSviewer (http://www.vosviewer.com/) relies on a distance-based approach to mapping informetric relationships. Instead of using more traditional similarity measures to produce a normalized outcome for co-occurrences as used in MDS, relationships are based on association strengths, so the algorithm is somewhat different than PROXSCAL and, therefore, can produce different outcomes. Details of the comparison of different measures can be found in van Eck and Waltman (2009). The network visualization software Pajek (http://vlado.fmf.uni-lj.si/pub/networks/pajek/) was used as well. Unlike the distance-based mapping of PROXSCAL and VOSviewer, Pajek produces directed or undirected network maps, with the strength of the relationships represented by the thickness of connecting lines between vertices on the map. Distances are used more for clarification, but proximities do not necessarily indicate a stronger relationship.

3. Results

The search parameters retrieved 4404 publications. Data were analyzed in WoS when supported by the Analyze Results features of the WoS system, or were downloaded and analyzed using developed routines in Java and MS Access.

3.1. Regional analysis

The absolute annual contributions based on continent affiliation appear in Fig. 1, with relative contributions appearing in Fig. 2. Europe shows the highest levels of contribution, both in absolute and relative terms over the time period of the study. Growth patterns in absolute terms are nonlinear based on trend line analysis in MS Excel; however, the *R*-squared goodness-of-fit values for even the best fitting models (higher order polynomials) were never more than 0.95, indicating a less than desirable fit.

Relative contributions based on geographic divisions have been largely stable. An exception is Asia, which had an increasing relative contribution over the 22-year time frame of the study. Although North American contributions have continued to increase in absolute numbers, the relative contribution shows a slow average decline over time. This decline is not as dramatic as found in an earlier pilot study (Wolfram, 2008). These differences may be accounted for by the broader inclusion parameters in the current study.

Preferred publication outlets varied by continent of origin. Because the journal *Scientometrics* was explicitly included in the search and has a long history of publication for metric-related topics, it was the top publication venue for all regions. (Note that the *Journal of Informetics* had only been in existence for 2 years during the data collection period, but did appear in the top five journals for Europe.) The percentage of all publications by each continent appearing in *Scientometrics* varied considerably, with a low of 24.5% for North America and a high of 59.5% for Asia. The top five journals listed for each continent demonstrated a regional preference for publication outlets from that region. So, for example, four of the top five

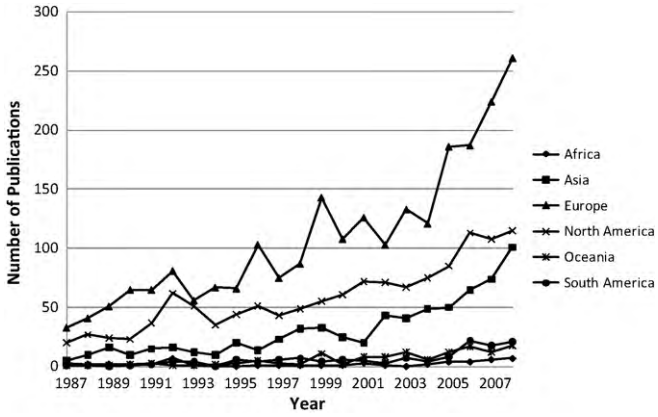

Fig. 1. Publication contributions over time by continent.

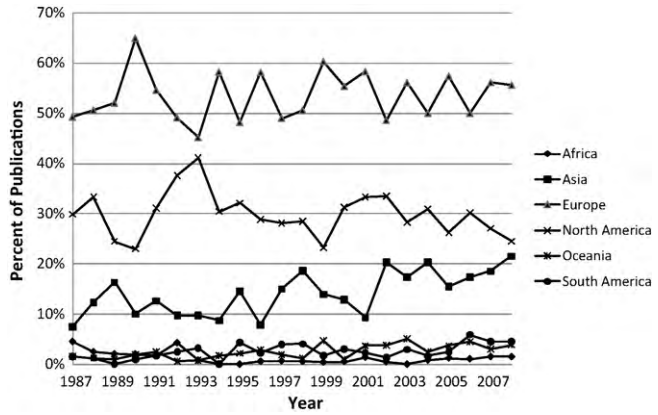

Fig. 2. Relative publication contributions over time by continent.

journals for European publications were published in Europe, and four of the top five journal outlets for South America were South American. The exception to this was Asia. Four of the top five journals for Asian publications were European and one was North American. This outcome may be a reflection of the data extraction method, the indexing practices of WoS, or a preference during the study time frame for Asian scholars to publish in Western journals.

The time frame of the study includes the fall of the Iron Curtain. One wonders if the greater openness between Western Europe and former Eastern Bloc countries resulted in research synergies that may have contributed, at least in part, to the tremendous growth in European contributions overall. Fig. 3 summaries contributions by Western European and former Eastern Bloc countries. The number of contributions by former Eastern Bloc member countries, which had been equal to Western Europe at the beginning of the study time period, has remained relatively flat. Western Europe's increases appear

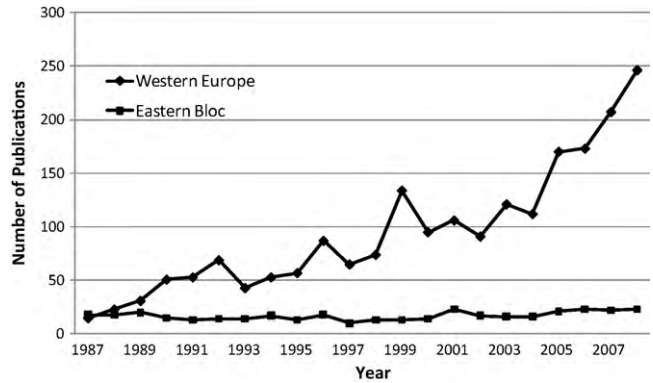

Fig. 3. Publication contributions over time by Western European and former Eastern Bloc countries.

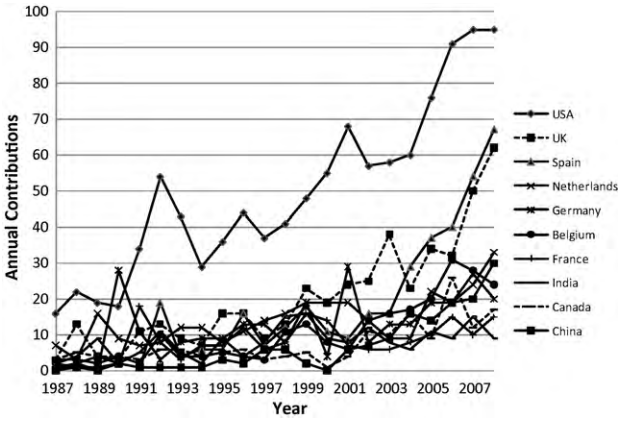

Fig. 4. Contributions by most prolific countries.

to account for almost all of this growth. This supports Leydesdorff's earlier contention that Europe is not yet operating as a single publication unit, at least in the East (Leydesdorff, 2000), and does not exhibit the same growth in the sciences for some former Eastern Bloc countries as observed by Archambault (2010).

3.2. Country-level analysis

Contributions by specific countries were tallied in WoS by focusing geographic searches on individual nations. Seventy-five countries were represented in the record set. The 10 most prolific nations based on their contributions over the last 10 years of the time period appear in Fig. 4. Focusing on the last 10 years as the cut-off makes it possible for countries that have experienced high growth in more recent years (i.e., China) to be included. Note that the United States has been the largest contributor over the study time frame, but Spain and the United Kingdom have shown substantial growth.

The level of international collaboration varied greatly, and is limited by the number of publications produced by a given nation. A summary of the most collaborative countries appears in Table 1. The number of metrics papers published annually that represent collaborations between two or more countries has increased greatly since the mid-1990s. Prior to this time, the number of internationally collaborative papers ranged from 1 to 19 papers annually. Over the last decade this number has increased to a high of 96 papers in 2008. Glänzel (2001) observed for the Science Citation Index that the United States had the highest share of international papers and represented a more important partner for other parts of the world than Europe. In metrics research, the United States also has the highest share of international collaborations, but the average number of collaborations with European countries was higher (5.78 publications per country) than for other parts of the world (4.47 publications per country). Because of the numbers of countries involved and the relatively low incidence of international collaboration overall, only countries that had collaborated with at least five other countries as identified in the initial dataset were included in the MDS analysis. The value of five was selected as a compromise to balance the number of different international collaborating partner links while maintaining a sufficiently large and interpretable number of countries represented on the map. Note that the number of remaining collaborations included in the analysis after applying the five country cut-off may result in fewer than five national collaborators because one or more collaborations could exist with countries that were not part of the final dataset because they did not meet the minimum cut-off value.

The map resulting from the PROXSCAL analysis of the 30 most collaborative countries appears in Fig. 5. Note that with PROXSCAL, different goodness-of-fit values are returned than that for the more traditional ALSCAL algorithm, which provides a singular stress value. A reasonable fit was obtained (Raw Stress: .02187; Dispersion Accounted For: .97813). Close collaborative relationships are not apparent among nations with relatively close geographic proximities. The VOSviewer output reveals similar proximities, except as a mirror image and with several notable differences resulting from the different dimensionality reduction approach (Fig. 6). Like the MDS outcome, the United Kingdom, United States and Netherlands occupy central positions in the map. Belgium is notably farther from the center of this map. Countries from Asia and Oceania are concentrated on the left or right sides of the map. India is more closely aligned with European countries on the VOSviewer output, but Brazil is more closely aligned with European countries in both cases. Of note, Spanish-speaking countries, as well as Germanic/Nordic countries, are more closely aligned to one another in the VOSviewer map. The Pajek output produced similar relationship outcomes (Fig. 7). To keep the thickness of the lines manageable for improved legibility, a square root transformation was performed on the data. Although the resulting map is not distance dependent, the countries with the most numerous and strongest links (Belgium, Netherlands, United Kingdom, United States) appear in the center of the map, with many of the other countries with the strongest links appearing in a second ring. The countries on the periphery generally have fewer and weaker links.

Table 1
International collaborations summary 1987–2008.

Country	Number of collaborating countries	Tally of international collaborations[a]
USA	43	220
UK	31	169
Netherlands	25	114
Belgium	22	151
Germany	19	88
Spain	19	70
Sweden	18	39
Canada	17	50
France	16	60
Australia	14	50
People's Republic of China	14	75
Finland	11	48
Greece	11	24
India	11	31
Denmark	10	15
Mexico	10	18
Hungary	9	60
Switzerland	9	29
Italy	8	16
Japan	8	21
Norway	8	12
South Africa	8	13
Austria	6	11
Brazil	6	17
Cuba	6	7
Ireland	6	8
Iran	5	10
New Zealand	5	8
Russia	5	9
South Korea	5	14
6 countries	4	41
3 countries	3	11
3 countries	2	10
15 countries	1	20

[a] Tally includes counts if more than two countries collaborated on the same paper.

3.3. Institution-level analysis

More than 1300 institutions in the collected data engaged in collaborative work with at least one other institution. A summary of the most prolific contributing institutions appears in Table 2. For this study, an institution consists of a university/college, government agency, or private organization. Sixteen of the institutions on the list are European, eight are North American, and one is Asian. The United States has the largest number of institutions represented (five), followed by Belgium (four – note: one institution merged with another institution to form a new entity). There has been steady growth in inter-institutional collaboration over the 22 years. The mean number of collaborative institutional partners within the dataset has steadily increased from a low mean of 1.1 institutions per publication in 1987 to a high of 1.96 institutions per publication in 2007.

As with the country-level data, a cut-off value for institutional collaborations was identified to keep the number of mapped institutions manageable and interpretable. The resulting MDS outcome for the 31 institutions with at least 14 inter-institutional collaborations appears in Fig. 8. Most institutions represent universities whereas others like DDL Omni Engineering (United States) or the Office for Naval Research (United States) represent industry and government agencies, respectively. An acceptable fit was achieved (Raw Stress: .004; Dispersion Accounted For: .99601). Most institutions are clustered in a main group regardless of geographic location with representation from Europe, Asia and North America. It is notable that several North American and one European institution appear on the periphery of the right side of the map. Although the mapped institutions represent those that are most collaborative, this does not mean that they are all very collaborative with one another. Those institutions on the periphery do collaborate with other institutions, just not frequently with those appearing on the map. This is supported with VOSviewer map of the institutional data; however, the resulting map produced an output with a largely one-dimensional representation of the associations along the *x*-axis, with little dispersion of the data along the *y*-axis (Fig. 9), indicating a possible limitation of the VOSviewer software for displaying some relationships. Whether this is an anomaly resulting from the data used is unknown. Because of the overlap of most institutional names within a small space, the names have been added above their position in the map. Along the *x*-axis, the resulting distribution of institutions was similar to the *x*-axis dispersion of the data with distinct clusters, but with greater relative *x*-axis distance between groups of institutions. Some institutions, like the Universities of Valencia and Granada, appear farther to the right on the VOSviewer map. The Pajek network interpretation produces a similar outcome

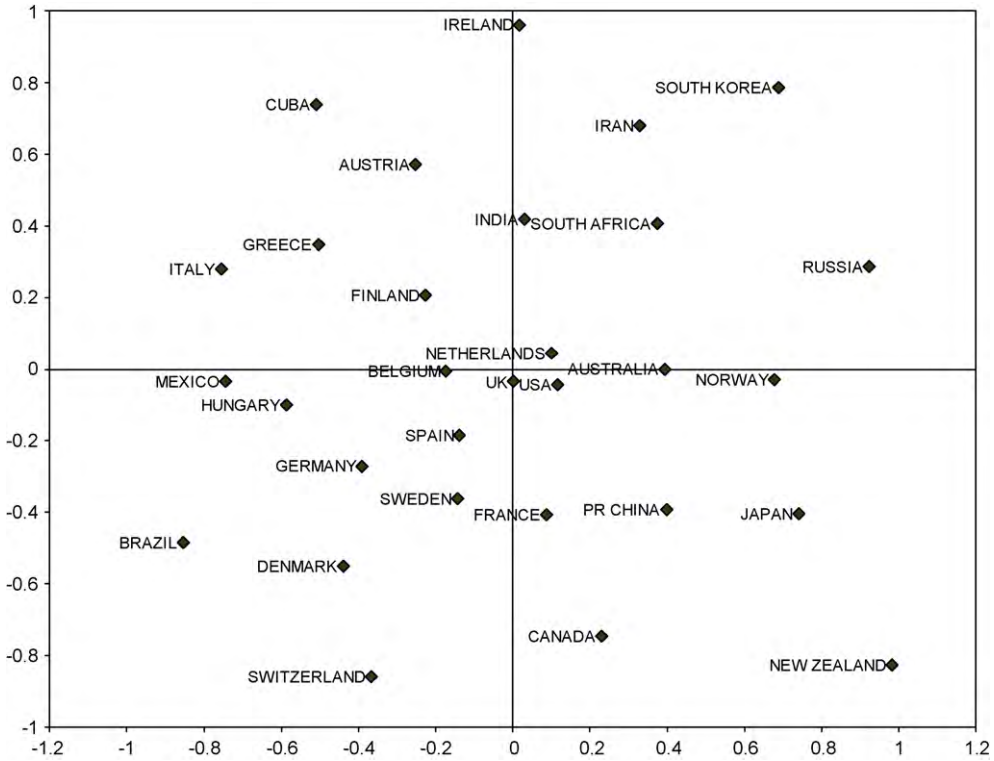

Fig. 5. MDS map of collaborations by country (minimum 5 international collaborators).

Table 2
Most prolific contributing institutions 1987–2008.

Institution	Country	Contributions	Collaborating Institutions
University of Leiden	Netherlands	100	25
CSIC	Spain	99	22
Catholic University of Leuven	Belgium	99	55
Hungarian Academy of Sciences	Hungary	86	20
National Institute of Science Technology and Development Studies	India	76	25
University of Wolverhampton	UK	75	23
University Institution Antwerp[a]	Belgium	74	20
University of Granada	Spain	71	16
Indiana University	USA	70	19
Royal School of Library and Information Science	Denmark	49	11
University of Genoa	Italy	49	17
Institute for Scientific Information	USA	45	8
Office of Naval Research	USA	45	33
University of Illinois	USA	45	12
University of Valencia	Spain	43	31
Cornell University	USA	42	7
University of Western Ontario	Canada	39	14
Drexel University	USA	39	13
Limburg University Centre[b]	Belgium	35	7
University of Antwerp	Belgium	35	19
University of Amsterdam	Netherlands	35	22
City University London	UK	31	15
University of Wisconsin (all campuses)	USA	31	11
Catholic University College of South-West-Flanders	Belgium	31	2
University of Sussex	UK	30	22

[a] Predecessor institution to the University of Antwerp.
[b] Now the University of Hasselt.

Fig. 6. VOSviewer generated map of collaborations by country (minimum 5 international collaborators).

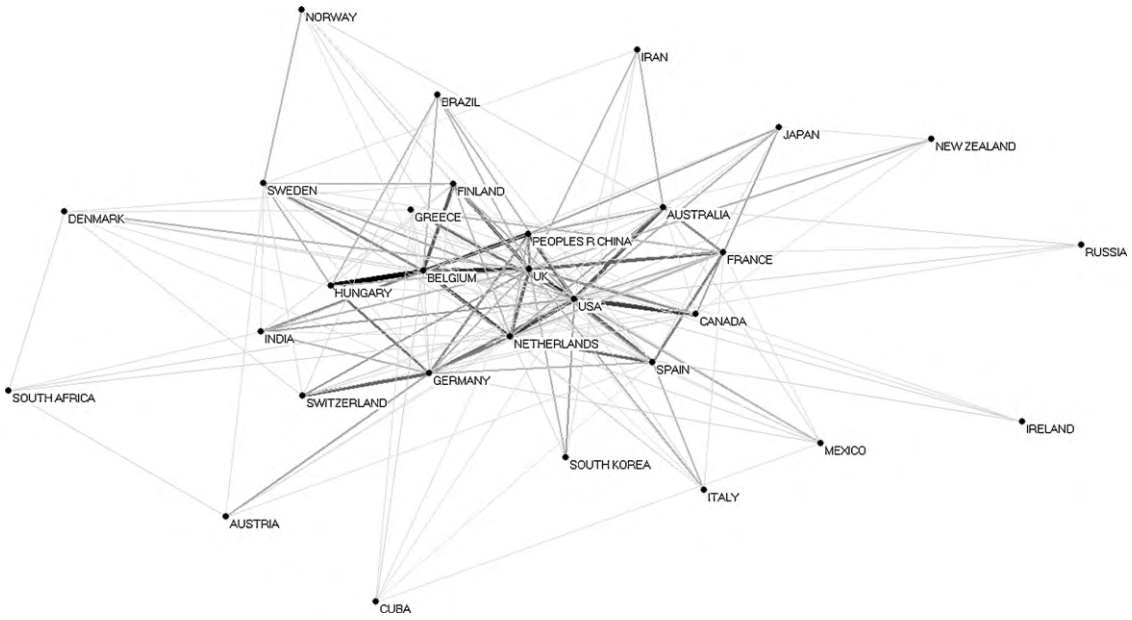

Fig. 7. Pajek network map of collaborations by country (minimum 5 international collaborators).

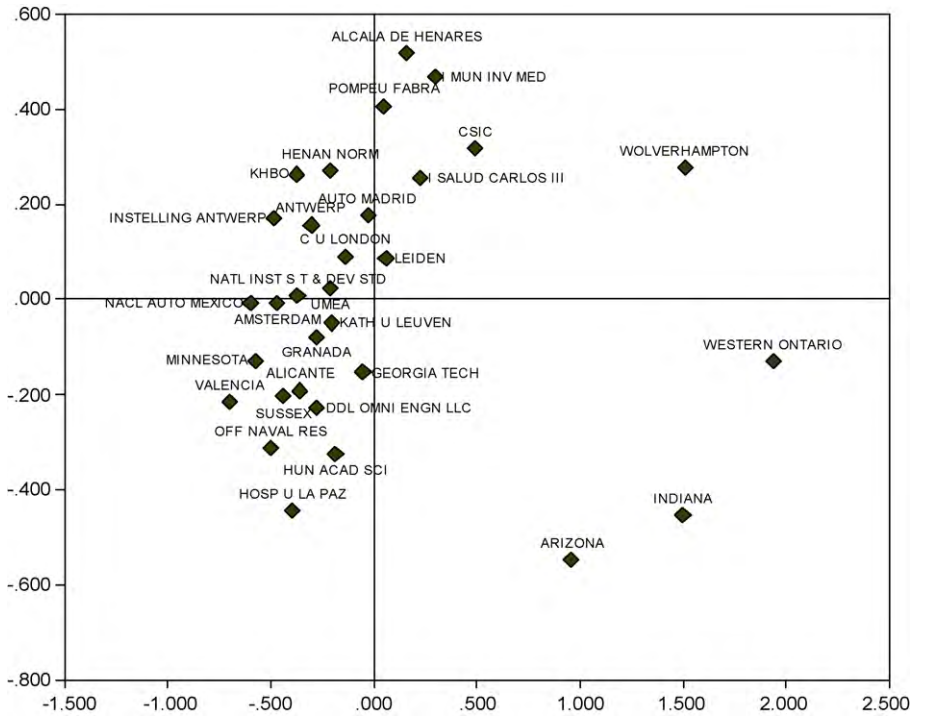

Fig. 8. MDS map of collaborations by institution (minimum 14 collaborating institutions).

Fig. 9. VOSviewer map of collaborations by institution (minimum 14 collaborating institutions).

(Fig. 10), but with three distinct clusters. The same institutions on the periphery appear as their own group, with a cluster of Spanish institutions, and a main cluster. The strong collaborative relationship between the Hungarian Academy of Sciences and the Catholic University of Leuven is particularly evident and is undoubtedly due, in part, to prolific researcher Wolfgang Glänzel's affiliation with both institutions.

4. Discussion

What do the findings of the present study of the publication patterns over the past 22 years reveal about metrics literature? The results largely parallel those found for other scientific disciplines. Europe, and in particular Western Europe, clearly dominates in the production of metrics literature. The United States continues to be the largest singular contributor, but this appears to be changing. North American contributions as a whole continue to increase, but represent a smaller percentage of worldwide production. European contributions have grown tremendously, especially during the last 5 years of the study period. This same period is marked by impressive growth from Asia. In answer to one of the primary research questions, then, North American contributions continue to grow in absolute terms, but are in relative decline. This is similar to what Leydesdorff and Wagner (2009a) observed for science in general. If the Asian growth to metrics research continues, it could surpass North American contributions in the next few years. It should be noted that WoS increased its coverage in 2008 by including more regional journals. These inclusions possibly could contribute to the increase in Asian contributions, but the observed growth for Asia was already evident prior to any such additions.

International and inter-institutional collaborations do not necessarily reveal strong geographic affinities, although the multiple institutional affiliations by a number of scholars associated with Flemish institutions do contribute to the strengthening of regional ties. Undoubtedly, the growth of the Internet and increasing availability of other telecommunication

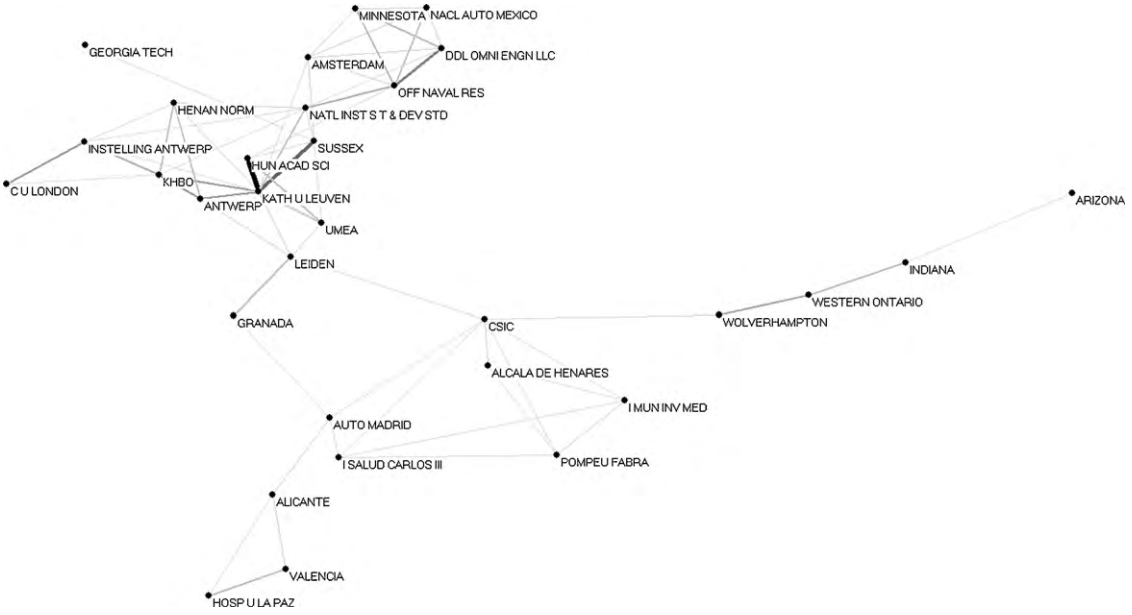

Fig. 10. Pajek network map of collaborations by institution (minimum 14 international collaborators).

technologies have made these collaborations less distance dependent. Researchers from European countries were more likely to collaborate with researchers other European countries. At the same time, researchers from most other continents, except Oceania, were more likely to collaborate with Europeans than with researchers from their own continent or other continents. This is explained, at least in part, by the large number of European countries that have active research agendas in the metrics area in comparison to other parts of the world, where fewer researchers create fewer opportunities for collaboration. The large number of institutions represented and the sparseness of the collaboration between most institutions make these connections less cohesive at a finer level of investigation, although a reasonable fit was achieved.

Limitations of the current study arise from the data collection and the analytical methods used. Although English has been the primary language for scholarly communication, relevant contributions, particularly in regional sources, may not be indexed in WoS, which could under-represent some national contributions. Furthermore, the terminological and publication source parameters used to identify relevant publications could result in false drops (i.e., sources that are not relevant to metrics) for broader terms, or false negatives (i.e., relevant sources that are not retrieved) because the terms used in the missed publications were not captured by the queries. Finally, mapping techniques are exploratory and are not intended to provide definitive proof of outcomes. They do, however, shed light on relationships among objects of interest that may not be evident from the numbers alone. The three tools used provided similar, but distinct, outcomes for the relationships among the country and institution data.

5. Conclusion

Metrics research continues to grow by absolute measures in most areas of the world, including North America. In relative terms, North America is showing a slight decline in contributions to the literature when compared to other parts of the world. This finding is similar to other disciplines, where the United States, in particular, has been losing ground in its scholarly contributions. It is still, nevertheless, singularly dominant as a nation. As a geographic unit, Western Europe is much more productive on the whole given roughly similar populations when compared to North America. The growing contributions by Asian researchers to the metrics area must be acknowledged. Asia's relative share of the metrics research produced and indexed in WoS is likely to surpass that of North America in the near future given its recent growth. Inter-institutional and international collaborations have become more common over the last decade. Visualization tools can be helpful in revealing patterns in collaborations, but with potentially different outcomes. PROXSCAL and VOSviewer produced similar outcomes, but with a few differences in how collaborative relationships were mapped. Pajek's network representation provided a complementary interpretation of the strengths of these collaborative relationships by demonstrating central and peripheral relationships. Although not regionally specific, the United States as a nation continues to enjoy the broadest international collaborations. Finally, as a unit, Europe is more likely to generate a higher level of international collaborative research with countries around the world.

Acknowledgment

We are grateful to Ronald Rousseau for his clarifications on the convoluted affiliations that exist among Flemish institutions of higher education in Belgium.

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