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Additional Information

Co-citation, bibliographic coupling and leading authors, institutions and countries in the 50 years of Technological Forecasting and Social Change

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Abstract

Technological Forecasting and Social Change (TF&SC) is a leading international journal that publishes major advances related to technological forecasting and future studies. The journal was launched in 1969 and in 2019 celebrated its 50th anniversary. To celebrate 50 years of outstanding contributions, this study presents a bibliometric analysis of TF&SC publications and patterns of citations within TF&SC in terms of authors, institutions and countries. The analysis relies on the Web of Science Core Collection database for bibliographic content and Visualization of Similarities viewer software for mapping of

bibliometric data. Our analysis identifies leading authors, universities and countries that produce publications in TF&SC. This study also applies bibliometric analysis of co-citations and bibliographic coupling. Results suggest that authors and publications originating in the USA and the Netherlands are particularly influential. However, the journal is becoming more geographically diverse. Mapping of co-citations and bibliographic coupling suggests that work published in TF&SC is represented by several heterogeneous clusters.

Keywords: Bibliometrics; Co-citation; Web of Science; VOS viewer.

1. Introduction

The journal *Technological Forecasting and Social Change* (TF&SC) launched in 1969, and has just celebrated its 50th anniversary. TF&SC publishes research that deals directly with the methodology and practice of technological forecasting as a planning tool, and with the interaction of technology with the social, behavioral and environmental aspects in integrative planning. According to the 2018 Journal Citation Reports, TF&SC has an impact factor of 3.82. TF&SC is ranked in the 32nd position of 147 journals in the Web of Science category of Business and 6th of 39 journals in Planning & Development. The journal has a 5-year impact factor of 4.04.

Over the last 50 years (1969-2018), TF&SC has published 4794 articles. During this period, 31,205 items have cited at least one TF&SC article; these items come from 7529 different sources (journal articles, book chapters and conference papers) and generated 56,233 citations of TF&SC. We celebrate the journal's golden anniversary by presenting the second part of a bibliometric analysis of 50 years of TF&SC publications conducted by overlapping author teams. In the first paper ([citation withheld]), the author team explores how often TF&SC is cited by other journals (citation outflow), how often other journals are cited by TF&SC (citation inflow), citations by Web of Science and SCImago disciplinary categories, most-cited articles in TF&SC, co-citation of journals, and co-occurrence of author keywords.

In this paper, we examine TF&SC publications and citations by year, the most productive and influential TF&SC authors, the most productive and influential universities

contributing to TF&SC, and the most productive and influential countries and supra-regions contributing to TF&SC. We also analyze co-citation of authors, and bibliographic coupling of authors, institutions and countries. Analysis is conducted by using the Web of Science (WoS) database and the Visualization of Similarities (VOS) viewer software (Van Eck and Waltman, 2010).

This study addresses the following queries. First, what was the yearly performance and citation structure of the TF&SC over the last 50 years? Second, which authors, institutions, countries and regions contributed the most to TF&SC publications during the first journal's 50 years? Third, how have contributions to TF&SC by country changed over time? Fourth, which authors, institutions, countries and regions were most cited during the first 50 years of the TF&SC? Fifth, what clusters of influence exist between TF&SC authors that might be identified through co-citations (when two documents that receive a citation from the same third document)? Finally, what clusters of influence exist between TF&SC authors, institutions and countries that might be identified through bibliographic coupling (when two documents cite the same third document)?

This kind of introspection informs a healthy critical self-evaluation of the journal. This study offers several contributions. A systematic analysis of TF&SC publications and their authors, authors' university affiliations and their countries tells us much about the history of the journal and its content. Readers, reviewers, authors/potential authors and the editorial team will learn more about the scope of the journal and how it has changed over time. These results will provide insights that will assist leaders in the field to shape the future direction of TF&SC and related journals.

The rest of this paper is organized as follows. Section 2 describes the methods used. Section 3.1 presents the results of the bibliometric analysis done for the leading authors, institutions and countries. Section 3.2 uses mapping techniques to illustrate patterns of co-citations, co-authors and bibliographic coupling. Finally, Section 4 offers a discussion with concluding remarks.

2. Methods

Bibliometrics can be defined as the quantitative study of bibliographic material (Broadus, 1987). Bibliometrics has been applied in many *subject areas*, including

management (Podsakoff et al., 2008), innovation (Cancino, Merigó and Coronado, 2017; Fagerberg et al., 2012), entrepreneurship (Landström et al., 2012), business-to-business marketing (Valenzuela-Fernández, Nicolas, Merigó and Arroyo-Canada, 2019), technology and innovation management (Sarin, Haon and Belkhouja 2018a), and international marketing (Samiee and Chabowski, 2012). Other bibliometric studies have explored the publications of regions (Bonilla et al., 2015), countries (Merigó et al., 2016), institutions and authors (Coupe, 2003). Bibliometrics also lends itself to the use of mapping techniques to illustrate patterns in the data (Cobo et al., 2011; Small, 1999).

A bibliometric study of a journal is a popular approach for identifying the leading trends of a *journal* in terms of topics, highly cited papers, authors, institutions and countries. Many journals have published bibliometric analyses of journal content and impact, such as:

- *European Journal of Marketing* (Martinez-Lopez et al., 2018);
- *Industrial Marketing Management* (DiBenedetto, Sarin and Haon, 2018; Martinez-Lopez et al., 2020);
- *Information Sciences* (Merigó et al., 2018);
- *Journal of Business Research* (Donthu et al., 2020; Merigó et al., 2015a);
- *Journal of Business & Industrial Marketing* (Valenzuela-Fernández et al., 2017; Valenzuela-Fernández, 2019);
- *Journal of Knowledge Management* (Gaviria-Marin et al., 2018);
- *Journal of Personal Selling & Sales Management* (Schrock, Zhao, Hughes and Richards, 2016);
- *Journal of Product Innovation Management* (Biemans, Griffin and Moenaert, 2010; Sarin, Haon and Belkhouja 2018b);
- *Journal of Strategic Marketing* (Brown, Abduljabbar, Englund and Treen, 2018);
and
- *Technovation* (Garcia-Merino et al., 2006; Thongpapanl, 2012).

Bibliometric analysis can rely on a variety of calculations, such as citation counts or publication counts by author, institution or country, keyword occurrence or co-occurrence, or co-authorship. For the analysis reported here, we examine TF&SC publication counts and citation counts by authors, universities and countries. For the country analysis, we normalize the results by population size to more effectively compare TF&SC contributions from countries of different sizes.

We also consider the *h*-index (Hirsch, 2005), a popular metric used in bibliometric research (Gaviria-Marin, Merigó and Baier-Fuentes, 2019). The *h*-index indicates the *h*

number of documents that have received h number of citations or more. For example, an author has an h -index of 50, it would suggest that the author has published 50 papers that earned at least 50 citations (Gaviria-Marin, Merigó and Baier-Fuentes, 2019). In our analysis, h -indices are calculated considering only publications in TF&SC.

The study applies a mapping technique to the bibliographic information by using Visualization of Similarities (VOS) viewer software (Van Eck and Waltman, 2010; Van Eck et al., 2010). VOS is a software tool specifically designed for constructing and visualizing bibliometric maps; such science mapping illustrates the structural and dynamic aspects of scientific research (Cobo, López-Herrera, Herrera-Viedma and Herrera, 2011). With this software, we demonstrate patterns of influence in co-citations (Small, 1973) and bibliographic coupling (Kessler, 1963). Co-citation occurs when two documents receive a citation from the same third document. Author co-citation analysis (ACA) provides insight into how authors, as domain experts, connect ideas between published works (Chen, Paul and O’Keefe, 2001). Bibliographic coupling occurs when two studies cite the same third document. While ACA is relevant to authors, bibliographic coupling is relevant to authors, institutions and countries.

To collect the bibliographic material, we extracted data from the Web of Science (WOS) Core Collection database. WOS is a digital bibliographic platform that is widely recognized for high-quality standards, and is a common tool for conducting bibliometric research (Gaviria-Marin, Merigó and Baier-Fuentes, 2019). We retrieved each article published by TF&SC until 31 December 2017, finding 4531 documents, among which 3767 are classified as articles, reviews, letters or notes. At this date, TF&SC had received 57,583 citations, which represents an average of 15.29 citations per paper.

WoS assigns one unit to each co-author of the paper, one unit to each institutional affiliation, and one unit to each country; thus, advantage is given to articles with multiple co-authors. We retain this counting method when identifying TF&SC publications and citations by year, most productive and influential TF&SC authors, most productive and influential universities contributing to TF&SC, and most productive and influential countries and supra-regions contributing to TF&SC (Donthu, Kumar and Pattnaik, 2020). As is done in similar studies, in the mapping process with VOS viewer, we used fractional counting in which each paper has only one unit that it is fractioned according to the number

of co-authors (Cancino, Merigó, Coronado, Dessouky and Dessouky, 2017; Gaviria-Marin, Merigó and Popa 2018; Martínez-López, Merigó, Gázquez-Abad and Ruiz-Real, 2020). Fractional counting is used to normalize the influence of documents with multiple authors. When fractional counting is used, the strength of a co-authorship link between two authors is determined not only by the number of documents coauthored by the authors, but also by the number of authors of each coauthored document. There are similar differences between the two counting methods in the context of bibliographic coupling and co-citations (Van Eck and Waltman, 2019).

3. Results

In the sections that follow, we present our results. First, we present bibliometric analysis: publications and citations by year; most productive and influential authors; most productive and influential universities; most productive and influential countries and supra-regions, and numbers of authors, institutions and countries over time. Second, we present network visualization: co-citation of authors; co-authorships, and bibliographic coupling of authors, institutions and countries.

3.1. Bibliometric Analysis

In this section, we present publications and citations by year, most productive and influential authors, most productive and influential universities, and most productive and influential countries and supra-regions.

3.1.1. Publications and Citations by Year

Our first step is to examine the publication and citation history of TF&SC between 1969 and 2017. Table 1 and Figure 1 present the total number of published papers (TP) and the total number of citations (TC) for each publication year. The table also identifies the number of articles that have surpassed a specific number of citations. We consider minimum thresholds of 200, 100, 50, 25, 10, 5 and 1 citations.

----INSERT TABLE 1 ABOUT HERE----

Table 1 results suggest that approximately 88 percent (3316/3767) of published papers were cited at least once, and approximately 52 percent (1975/3767) of published papers were cited at least five times. As a general pattern, the total number of papers and the total number of citations increase over time.

The number of articles per year receiving over 10 citations each accelerated rapidly in the early 1990s, and continued to increase over through the 2010s. However, the number of articles per year receiving over 10 citations each peaked in 2015 and declined sharply in 2016 and 2017. This apparent recent decline may represent a lag in time between publication of an article and its being cited by future publications. That is, 2015 and 2016 publications have not yet been cited because they were published only recently.

----INSERT FIGURE 1 ABOUT HERE----

3.1.2. The Most Productive and Influential Authors

In this section, we identify the top authors associated with papers published in TF&SC. Table 2 presents the top 50 contributing authors ranked in terms of number of publications. The leading author in quantity of TF&SC publications is Joseph F. Coates with 76 publications. In terms of quantity of publications, Coates published nearly three times more papers than the second ranked author. Coates' most cited TF&SC articles deal with technology future analysis and technological assessment, scenario planning, methods and techniques for comprehensive impact assessment and the future of foresight and technological forecasting. After Coates, there are nine authors with 20 or more articles published in TF&SC: Linstone (27 articles), Porter (24), Kostoff (23), Sharif (22), Martino (22), Mitroff (22), Ayres (21), Gordon (21), and Modis (20). Each of the top 50 authors have published at least eight papers in TF&SC.

Of these top authors, the one earning the most citations is Marko P. Hekkert. Hekkert has published 11 articles in TF&SC, which earned 1080 citations. In particular,

Hekkert authored a top-cited TF&SC publication titled “Functions of innovation systems: A new approach for analyzing technological change” (Hekkert, Suurs, Negro, Kuhlmann, and Smits, 2007), in which the authors analyze how the emergence and the changes of a new innovation system co-evolve with the technological change process. Moreover, Hekkert has two other articles that earned more than 100 citations each: “Functions of innovation systems as a framework to understand sustainable technological change: Empirical evidence for earlier claims” (Hekkert and Negro, 2009) and “Cumulative causation in the formation of a technological innovation system: The case of biofuels in the Netherlands” (Suurs and Hekkert, 2009).

The author ranked second in number of times cited is Keywan Riahi with 13 papers earning 986 citations. The author ranked third in number of times cited is Alan Porter with 24 papers earning 970 citations. Among the top 50 authors in terms of the number of papers published in TF&SC, 43 have earned more than 100 citations each.

As noted in Table 2, 13 authors have an *h*-index values greater or equal to 10 (reported *h*-indices are calculated considering only the publications in TF&SC). Ronald N. Kostoff and Alan L. Porter, both of Georgia Institute of Technology, earned the highest *h*-index values (16 and 15, respectively). This suggests that Kostoff has published 16 papers that earned at least 16 citations each, and Porter has published 15 papers that earned at least 15 citations each.

The top 50 authors ranked by number of TF&SC publications come from three regions: the USA (18 authors), Europe (18 authors), and Asia (14 authors). None of the top 50 TF&SC authors are from the Middle East, Africa, Oceania, or the Americas outside of USA.

Figure 2 presents authors mapped by total publications and total citations. According to Cole and Cole (1973), there are four categories of academics based on two criteria: productivity and citations. *Prolific* authors are those characterized by a high productivity and a high number of citations. *Mass producers* are authors with high productivity but a low number of citations. *Perfectionists* are those with a low productivity but a high number of citations. *Silent* authors have both low productivity and low numbers of citations.

Relative to other top authors, Porter, Kostoff and Linstone appear to be *prolific*. By comparison, Hekkert appears to be a *perfectionist*. Many authors are clustered around the bottom of this graph; note that these comparisons are among only the journal's top authors.

----INSERT TABLE 2 ABOUT HERE----

----INSERT FIGURE 2 ABOUT HERE----

3.1.3. The Most Productive and Influential Universities

Table 3 presents the top 50 university affiliations of authors that have published in TF&SC ranked by total number of citations. Of these, Utrecht University is the top university in terms of four different metrics: the total number of publications of 66; the total number of citations of 2986; the *h*-index (TF&SC only) of 31; and the average number of citations per publication of 45.27. The total number of publications and the total number of citations are absolute values, while the *h*-index and the ratio citations per publication are derived from the number of publications and the number of citations. A high *h*-index indicates a university has produced a considerable number of publications receiving a high number of citations each, whereas the citations per publication ratio favors those with fewer publications but many citations.

Overall, this ranking is dominated by universities in the USA (13), followed by universities in the UK (10) and The Netherlands (9). It also lists four universities in Taiwan, three in South Korea, two each in Finland, Germany and Israel, and one each in Russia, Portugal, Japan, France and Denmark.

Figure 3 presents institutions mapped by total publications and total citations. We can see here that there appears to be a positive correlation between number of publications and number of citations generated by authors from each institution. However, Utrecht University stands out as a highly prolific institution (Cole and Cole, 1973).

----INSERT TABLE 3 ABOUT HERE----

----INSERT FIGURE 3 ABOUT HERE----

Two of the top three universities are in the Netherlands. Despite being a small country, the Netherlands is represented near the top of almost all of the rankings. To explore this further, we examined the most cited publications from the Netherlands. The publications that have more than one hundred citations (18 documents) focus on innovation systems of technological changes and sustainability. Utrecht University produced six papers with more than one hundred citations each. The most cited of these papers is aforementioned Hekkert et al. (2007) “Functions of innovation systems: A new approach for analyzing technological change.” The other five publications with more than one hundred citations each are:

- Hekkert and Negro (2009). “Functions of innovation systems as a framework to understand sustainable technological change: Empirical evidence for earlier claims” (156 citations);
- Farla, Markard, Raven and Coenen (2012). “Sustainability transitions in the making: A closer look at actors, strategies and resources” (141 citations);
- Riahi et al. (2015) “Locked into Copenhagen pledges - Implications of short-term emission targets for the cost and feasibility of long-term climate goals” (136 citations);
- Wardekker, de Jong, Knoop and van der Sluijs (2010). “Operationalizing a resilience approach to adapting an urban delta to uncertain climate changes” (123 citations); and
- Smits (2002). “Innovation studies in the 21st century: Questions from a user's perspective” (100 citations).

3.1.4. The Most Productive and Influential Countries and Supra-Regions

Tables 4 and 5 present TF&SC contributions by country. Table 4 presents contributions from the top 40 countries over time, while Table 5 presents contributions from the top 50 countries relative to population size and R&D investments.

----INSERT TABLE 4 ABOUT HERE----

As presented in Table 4, in the first decade of TF&SC's publication (D1: 1969-1978), the most productive country was the USA, contributing approximately 72 percent of TF&SC publications during that decade, followed by Russia with 5 percent of the papers published during the decade. In the second decade (D2: 1979-1988), USA continued in the top ranking by contributing approximately 62 percent of the papers published during this decade, followed by India (5 percent), Canada (4 percent) and Austria (4 percent). In the third decade (D3: 1989-1998), USA contributed approximately 52 percent of papers published during the decade, Japan produced 5 percent, and a group composed of UK, Netherlands, Austria and India produced a combined 4 percent. In the fourth decade (D4: 1999-2008), the USA was again the main contributor (31 percent) followed by UK and Netherlands with 7 percent. In the fifth decade (D5: 2009-2017), papers published in TF&SC are much more dispersed compared to previous decades; the top country contributors in the fifth decade are: USA (13 percent), UK (13 percent), Netherland (9 percent), Germany (6 percent), South Korea (7 percent), Taiwan (5 percent), Italy (5 percent), China (5 percent), France (4 percent) and Spain (4 percent).

By dividing the total number of publications from a given country in the last decade (from D5 column of Table 4) by the total number of publications since the journal's beginning (from Total column of Table 4), we can explore to what extent a country's contribution is concentrated in the last decade. For example, approximately 24 percent of the publications from the USA were published in the last decade (333 papers in D5 divided by 1378 total papers). Many countries became much more productive only recently. Our data suggests that 100 percent of the TF&SC publications from Iran and Colombia were published in the last decade. Publications from other countries are similarly concentrated in

the last decade: China (93 percent), Malaysia (92 percent), United Arab Emirates (88 percent), Norway (85 percent), Spain (84 percent), South Korea (82 percent) and Ireland (82 percent).

The country in the last 50 years with the most articles in TF&SC is the USA (1378), followed by the UK (413). The sum of publications from the top 50 countries (Table 5) is 4651. The top five countries together contribute 2517 publications, or approximately 54 percent of the total published from the top 50 countries: USA (29.6 percent), UK (8.9 percent), Netherlands (6.3 percent), Germany (4.9 percent) and South Korea (4.4 percent).

----INSERT TABLE 5 ABOUT HERE----

----INSERT FIGURE 4 ABOUT HERE---

Table 5 presents summary data for the top 40 countries relative to population size of each country. We include the total population of each country to explore publication productivity per million inhabitants, as well as the R&D investment (% of GDP). In terms of total publications, the USA leads the ranking, followed by UK, the Netherlands, Germany and South Korea. Top countries in terms of total citations are USA, the Netherlands, UK, Germany and Taiwan. If we consider the total number of papers and citations relative to the country R&D investment level, the hierarchy remains the same with respect to the top 5 countries. However, compared to the USA, several countries including UK and the Netherlands have a higher ratio of citations per million inhabitants. Thus, relative to population size, UK and the Netherlands have a greater influence within TF&SC. If we consider citation counts relative to population size, the leading countries are the Netherlands (487 citations per thousand inhabitants), Iceland (393) and Austria (333).

Figure 4 presents countries mapped by total publications and total citations. We can see here that there is a high positive correlation between number of publications and

number of citations generated by authors from each country. The USA, the Netherlands and the UK appear to be the most *prolific* countries (Cole and Cole, 1973).

----INSERT TABLE 6 ABOUT HERE----

Table 6 presents the Table 5 information summarized by regions and supra-regions. Europe is the leading supra-region and Western/Northern Europe is the leading region by most of the indicators examined here (total publications, total citations, citations relative to population size). However, the rankings for one indicator, total publications relative to population size, vary from the pattern. North America produced 4.1 publications per million inhabitants, which is more than either Europe (3.09) or Western/Northern Europe (4.07).

3.1.5. Number of authors, institutions and countries over time

Table 7 and Figure 5 presents numbers of authors, institutions and countries over time. As seen in Figure 5, in the first years of TF&SC, numbers of authors, institutions and countries were similarly small. Numbers of each stayed below 100 until the early 2000s, when the number of authors per paper expanded rapidly. In 2004, the number of authors per published paper grew above 2.0 and it continued to increase. In 2017, the number of authors per published paper is 2.71. The numbers of institutions and countries lagged behind the numbers of authors because some authors shared institutions and countries.

----INSERT FIGURE 5 ABOUT HERE----

----INSERT TABLE 7 ABOUT HERE----

3.2. Network Visualization

In this section, we present network visualization: co-citation of authors; co-authorships; and bibliographic coupling of authors, institutions and countries.

3.2.1 Co-citation of Authors

Co-citation occurs when two documents receive a citation from the same third document (Cancino, Merigó, Coronado, Dessouky and Dessouky, 2017). Analysis of co-citation relies on the assumption that two papers cited together are highly related (White and Griffith, 1981), and thus should be concentrated in a cluster solution of a visualization map. Figure 6 presents network visualization resulting from the analysis of co-citation of authors in TF&SC. This analysis relied on a minimum citation threshold of 50 and the 100 most representative links. Each circle or node represents an author, and the relationship between authors (i.e., by co-citations) is indicated by the links between the nodes. The distance between two authors in the map approximately indicates the relatedness of the two authors in terms of co-citations (Van Eck and Waltman, 2019). The larger the author's name and the larger the circle, the greater the weight of the node; the weight of each node is determined by the total strength of all the links connected to the node.

----INSERT FIGURE 6 ABOUT HERE----

The Figure 6 map illustrates five numbered clusters. The first cluster (yellow) is anchored by authors Rogers, Mahajan, Mansfield and Marchetti; this cluster is heterogeneous, with authors working on topics related to diffusion of innovations, microeconomics and marketing. A second cluster (blue) is anchored by authors Freeman, Nelson, Schumpeter and the OECD; these authors tend to research topics related to innovation. The third one (red) is anchored by Kostoff. Kostoff and other authors in the cluster tend to conduct research on technology roadmapping. Research on technology roadmapping is increasing over time (Carvalho et al., 2013) and is well represented in

TF&SC (De Alcantara and Martens, 2019). The fourth cluster (green) is anchored by Linstone; authors in this cluster tend to research technological forecasting. A fifth cluster (purple) is anchored by Geels; authors in this cluster tend to research system innovation and sustainability.

3.2.2 Co-Authorships

Figure 7a illustrates the co-authorship network of authors publishing in TF&SC. Figure 7b offers an expanded view of the central clusters in this map. This map suggests four interconnected co-author clusters: 1) Bowonder, Sharif, Cho, Ramanathan, Miyake and Prapaporn (red); 2) Coates, Porter, Rossini, Zhu and Robinson (green); 3) Mitroff, Turoff and Udwardia (blue); and 4) Linstone and Grupp (yellow). Not surprisingly, the top three leading authors from Table 2 (Coates, Porter and Linstone) figure prominently in the co-author clusters. As can be seen in Figure 7b, particular authors (Mitroff, Rossini, Porter, Linstone, Bowonder, and Miyake) serve as liaisons between co-author clusters.

----INSERT FIGURE 7a ABOUT HERE----

----INSERT FIGURE 7b ABOUT HERE----

3.2.3 Bibliographic Coupling of Authors, Institutions and Countries

Bibliographic coupling occurs when two documents cite the same third document. As described by Martyn (1964, p. 236), “two papers that share one reference contain one unit of coupling, and the value of a relationship between two papers having one or more references in common is stated as being of strength one, two, etc., depending on the number of shared references.” Bibliographic coupling uses citations to give information about the similarities between two documents, authors, institutions or countries. This process relies on the assumption that two papers referencing a third paper are highly related, and should be concentrated in a cluster solution of the visualization map. The strength of the

bibliographic coupling is determined by the total number of references or citations of other third documents that they share. Figure 8 illustrates bibliographic coupling of authors published in TF&SC.

----INSERT FIGURE 8 ABOUT HERE----

A large cluster (red) of coupled authors is anchored by Coates, whose research focuses on future technologies: technology future analysis and technological assessment, scenario planning, methods and techniques for comprehensive impact assessment and the future of foresight and technological forecasting. In the same cluster, we find Martino, whose research also focuses on the analysis of future-oriented technology and the advances of technological forecasting, and Maruyama, whose research focuses on causal loops for strategy and management.

The other large clusters are anchored by Park (blue) and anchored by Heitor (brown). The blue cluster consists of authors who tend to research technological opportunities, impact and structure. The brown cluster consists of authors who tend to research human capital (training, academic system, higher education, etc.).

----INSERT FIGURE 9 ABOUT HERE----

Bibliographic coupling of institutions occurs when publications from two institutions reference publications from a third common institution. Figure 9 illustrates a complex network of coupling between institutions represented in TF&SC. We can observe seven institutions that dominate the coupling and anchor its largest clusters: Delft University of Technology (The Netherlands), The University of Utrecht (The Netherlands), Georgia Institute of Technology (USA), International Institute for Applied Systems Analysis (Austria), National Chiao Tung University (Taiwan), Portland State University

(USA), and University of Manchester (U.K.). Thus, the most productive and influential universities in TF&SC in terms of total publications and total citations (Table 3) also appear to be influential in bibliographic coupling. That Figure 9 presents a complex map of many clusters reflects the diversity and interconnectedness of work being published from various institutions.

----INSERT FIGURE 10 ABOUT HERE----

Figure 10 presents the bibliographic coupling of countries represented in TF&SC. Bibliographic coupling of countries occurs when publications from two countries reference publications from a third country. This figure suggests that USA has a central influence in TF&SC and that other countries are coupled to USA. However, the figure also illustrates frequent coupling among other countries such as England, Germany and Netherlands.

4. Discussion

This study provides a historical overview of TF&SC publications and citations by year, the most productive and influential TF&SC authors, the most productive and influential universities contributing to TF&SC, the most productive and influential countries and supra-regions contributing to TF&SC, and numbers of authors, institutions and countries represented in TF&SC authors over time. We also analyze co-citation of authors, co-authorships, and bibliographic coupling of authors, institutions and countries. The goal of our analysis is to determine who, among authors, institutions and countries, generates knowledge within and exerts influence on TF&SC. To do so, we relied on the bibliographic information from the WoS Core Collection database. We rely on a mix of descriptive results and graphical analyses.

At the author level, Joseph F. Coates is by far the author that has published the highest number of articles in the journal. Coates published nearly three times (2.8x) more papers in TF&SC than the second ranked author. Coates is well-known in the journal with publications that usually focus on future technologies (Godet, 2002). Nine authors have

published more than twenty papers in TF&SC, and thirty authors have published more than ten papers.

The TF&SC author who earned the most citations (1080) is Marko P. Hekkert. In particular, Hekkert authored a top-cited TF&SC publication in which the authors analyze how the emergence and the changes of a new innovation system co-evolve with the technological change process (Hekkert, Suurs, Negro, Kuhlmann, and Smits, 2007).

Ronald N. Kostoff and Alan L. Porter, both of Georgia Institute of Technology, earned the highest *h*-index values. Kostoff has published 16 papers that earned at least 16 citations each, and Porter has published 15 papers that earned at least 15 citations each.

From the university point of view, Utrecht University is the highest ranked in terms of four different metrics: the total number of TF&SC publications, the total number of citations, the *h*-index, and the average number of citations per publication. Universities ranked #2 through 5 have similar numbers of publications (49-58) and similar numbers of total citations (934-1517). In terms of citations per paper, Utrecht's performance is 73 percent higher than that of the second ranked university. Clearly, authors affiliated with Utrecht University have heavily influenced TF&SC, substantially more than other universities.

In terms of both total papers and total contributions, the countries with the most contributions to TF&SC are the USA, UK, the Netherlands, Germany and South Korea. When country results are normalized by population size, other countries outrank the USA both in terms of total papers per thousand inhabitants and total citations per thousand inhabitants. European countries such as the Netherlands and Iceland, and Asian countries such as Taiwan outperform USA in terms of total papers per million inhabitants and total citations per million inhabitants.

During the last decade of TF&SC, countries of author affiliations have become more diverse, with the UK contributing approximately the same number of publications as the USA. In addition, publications from developing economies have increased in frequency over time. During the last decade, China has become a major contributor to the journal. Converting to an electronic platform for submissions and managing the review process may have facilitated this increase by removing the burden associated with slower forms of communication. According to Phillips (2019), manuscript submissions to TF&SC from Europe and Asia now outnumber submissions from the USA about five to one.

The mapping analysis of co-citation of authors (Figure 6), co-authorships (Figure 7a and 7b) and bibliometric coupling (Figure 8) each resulted in several main clusters; some of those clusters are heterogeneous. The maps did not coalesce clearly around unifying dominant macronetworks, suggesting that TF&SC authors are diverse and only loosely organized around topical areas such as technology roadmapping.

The mapping analysis of bibliographic coupling of countries (Figure 10) suggests that USA is an influential contributor to TF&SC and that other countries are coupled to USA. While the figure also illustrates frequent coupling between other countries, the USA appears to anchor the map. Thus, when a publication is cited by work produced outside of the USA, it is also likely to be cited by someone in the USA. While we cannot conclude a direction of influence from this result, it does suggest that publications produced in the USA serve as links to publications produced outside of it.

Even though our analysis of co-citations and bibliographic coupling focuses on a single journal, TF&SC, it resulted in many heterogeneous clusters. Arguably, these maps reinforce that TF&SC publications represent an eclectic body of knowledge. These results suggest an opportunity for future conceptual work that brings together diverse topics represented in the journal.

We have used a range of bibliometric measures and techniques to examine the history of TF&SC on the occasion of its 50th anniversary. Much additional exploration could be done using other methods. Directions for future research include the following:

- Examine relationships among scholarly influencers other than authors, such as editorial board members.
- Examine other author characteristics, such as their PhD-granting institutions.
- Explore the issue of full vs. fractional counting in bibliometric studies; Perianes-Rodriguez, Waltman, and Van Eck (2016) offers an in-depth discussion.
- Examine trends in the journal that are punctuated with events such as changes in journal editorship or journal publisher, or major historical events such as the end of the Cold War.
- Analyze relationships between TF&SC with research in reference categories such as “business” or “planning and development”; researchers might consider InCites as a platform for conducting such analyses (Pagell, 2015).
- Consider additional methods for examining how the number of contributors (including authors, institutions and countries) to the journal have expanded over time; researchers might consider adapting the Gini index for this purpose (Bornmann, Mutz, Neuhaus and Daniel, 2008).

- Apply forecasting techniques and bibliometric data to forecast future trends in the journal (Daim and Suntharasaj, 2009).

As has been discussed elsewhere, bibliometric methods have limitations. Citations do not always indicate intellectual influence; some important articles might receive few citations, while other articles may be cited frequently for negative reasons. Both citation impact and co-citations tend to develop over time. The number of citations is dependent on the articles' age; articles published most recently have had only a limited time to garner citations (Biemans, Griffin and Moenaert, 2007). When two articles are linked by bibliographic coupling, they may be referencing unrelated content in the third document. Furthermore, bibliographic coupling is a retrospective static measure (Small, 1973). Despite these limitations, we believe that this research contributes to our understanding of the evolution of TF&SC.

In sum, our study provides insights into the evolution of research published in TF&SC over its 50-year history. Authors and publications originating in the USA and from Utrecht University in the Netherlands are particularly influential. However, the journal is becoming more geographically diverse. The mapping of co-citations and bibliographic coupling suggests that work published in TF&SC is represented by several heterogeneous clusters.

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Table 1. Total papers and total citations by year

Year	TP	TC	>200	>100	>50	>25	>10	>5	>1	DECADES	TP	TC
1969	22	48					1	2	13			
1970	35	367		1	1	2	6	10	30			
1971	17	556	1	1	1	2	4	7	12			
1972	37	449			3	6	9	13	27			
1973	40	225				1	7	9	35			
1974	25	226			1	1	5	12	22	70'	413	3572
1975	40	377			2	3	9	16	32			
1976	42	336			1	3	7	19	33			
1977	35	235			1	2	5	12	28			
1978	45	189				2	3	11	31			
1979	75	564			2	6	14	23	64			
1980	68	460		1	1	4	11	15	49			
1981	43	396			3	5	10	13	29			
1982	42	221				2	5	12	36			
1983	44	413			2	4	11	15	36			
1984	58	286			1	3	7	12	36	80'	491	3521
1985	47	493				6	15	23	42			
1986	48	364				5	9	16	38			
1987	46	315				4	10	16	35			
1988	47	373			1	4	8	15	39			
1989	48	200				1	3	10	44			
1990	54	368				2	11	18	43			
1991	50	752	1	2	3	6	8	15	38			
1992	54	264			1	2	6	12	40			
1993	49	687	1	1	2	2	15	20	38			
1994	60	635			2	4	18	28	48	90'	538	6727
1995	54	598		2	2	5	15	23	40			
1996	53	776		2	3	7	20	27	41			
1997	47	896	1	2	3	8	14	21	42			
1998	55	767			2	9	23	30	45			
1999	62	984		1	5	11	29	33	48			
2000	52	1362		1	7	19	32	40	49			
2001	38	977		1	5	9	23	29	37			
2002	46	1213		4	6	11	27	30	43			
2003	45	1427		3	9	15	32	34	42	00'	620	21312
2004	47	1826	1	4	12	16	32	38	46			
2005	62	2292	2	5	16	29	40	48	62			
2006	64	2773	2	5	16	30	52	58	64			
2007	91	3541	3	3	14	38	66	78	89			

2008	79	2355		3	15	33	63	69	78		
2009	96	3546		5	19	56	80	90	96		
2010	124	3811		6	27	52	86	109	122		
2011	131	3385		3	18	48	90	112	130		
2012	136	2777	1	2	10	35	82	109	135		
2013	138	2947		1	14	41	88	112	138		
2014	204	2741			7	26	88	135	201	10'	1705 22451
2015	322	3613		1	3	33	129	212	318		
2016	313	1997			2	11	55	111	257		
2017	337	1180		1	1	2	9	53	275		
Total	3767	57583	13	61	244	626	1392	1975	3316		
%	100.00%		0.35%	1.62%	6.48%	16.62%	36.95%	52.43%	88.03%		

TP = total papers; TC = total citations; >200, >100, >50, >25, >10, >5, >1 = number of papers with more than 200, 100, 50, 25, 10, 5 and 1 citations.

Table 2. Fifty leading authors in TF&SC

Rank	Full Name	Affiliation	Country	TP	TC	<i>h</i>	C/P
1	Joseph F. Coates	Coates & Jarrett Inc	USA	76	307	7	4.04
2	Harold A. Linstone	Portland State U	USA	27	575	11	21.30
3	Alan L. Porter	Georgia Institute of Technology	USA	24	974	15	40.58
4	Ronald N. Kostoff	Georgia Institute of Technology	USA	23	698	16	30.35
5	Nawaz Sharif	Johns Hopkins U	USA	22	334	10	15.18
6	Joseph P. Martino	U Dayton	USA	22	298	8	13.55
7	Ian I. Mitroff	U California Berkeley	USA	22	198	8	9.00
8	Robert U. Ayres	INSEAD	France	21	213	10	10.14
9	Ted J. Gordon	The Millennium Project	USA	21	153	7	7.29
10	Theodore Modis	Growth Dynam, Via Selva	Switzerland	20	248	10	12.40
11	Yongtae Park	Seoul Natl U	South Korea	17	637	11	37.47
12	Vijay Mahajan	U of Texas Austin	USA	16	510	11	31.88
13	Cesare Marchetti	Int Inst Applied Systems Analysis	Austria	16	400	8	25.00
14	Chieh-Peng Lin	National Chiao Tung U	Taiwan	16	141	7	8.81
15	B. Bowonder	Adm Staff Coll India	India	16	97	6	6.06
16	Magoroh Maruyama	Aoyama Gakuin U	Japan	16	72	4	4.50
17	Murray Turoff	New Jersey Institute of Technology	USA	15	561	10	37.40
18	George Wright	U Strathclyde	Scotland	14	666	10	47.57
19	Devendra Sahal	Inst Int Adm Berlín	Germany	14	119	7	8.50
20	Keywan Riahi	Int Inst Applied Systems Analysis	Austria	13	986	12	75.85
21	Heiko A. von der Gracht	U Erlangen Nuremberg	Germany	13	440	10	33.85
22	Fred Phillips	Yuan Ze U	Taiwan	13	148	7	11.38
23	Arnulf Grubler	Yale U	USA	12	727	9	60.58
24	Paul C. Nutt	Ohio State U	USA	12	118	5	9.83
25	Marko P. Hekkert	Utrecht U	Netherlands	11	1080	9	98.18
26	Yuya Kajikawa	Tokyo Institute of Technology	Japan	11	441	10	40.09
27	A.Wade Blackman Jr.	United Aircraft Res Labs,E Hartford	USA	11	239	7	21.73
28	Ozcan Saritas	National Research U	Russia	11	222	7	20.18
29	Jerome C. Glenn	Millennium Project	USA	11	66	4	6.00
30	Kan Chen	U Michigan	USA	11	29	4	2.64
31	Nebojša Nakićenović	Int Inst Applied Systems Analysis	Austria	10	655	8	65.50
32	Chihiro Watanabe	Tokyo Seitoku U	Japan	10	136	7	13.60
33	Renato Guseo	U Padua	Italy	10	109	6	10.90
34	Manuel Heitor	U Lisboa	Portugal	10	79	5	7.90
35	Detlef P. van Vuuren	Utrecht U	Netherlands	9	318	8	35.33
36	Jesse H. Ausubel	Rockefeller U	USA	9	287	7	31.89
37	Changyong Lee	Ulsan National Inst Sci & Tech	South Korea	9	242	6	26.89
38	Donghua Zhu	Beijing Institute of Technology	China	9	198	5	22.00
39	Hariolf Grupp	Karlsruhe Institute of Technology	Germany	9	186	6	20.67
40	Mariangela Guidolin	U Padua	Italy	9	166	6	18.44
41	K. Ramanathan	Asian Institute of Technology	Thailand	9	119	3	13.22
42	Yuan-Hui Tsai	Chihlee U of Technology	Taiwan	9	64	5	7.11

43	T. Miyake	Adm Staff Coll India	India	9	12	2	1.33
44	Robert Phaal	U Cambridge	UK	8	694	7	86.75
45	Jiyong Eom	Pacific NW Natl Lab	USA	8	388	7	48.5
46	Kerstin Cuhls	Fraunhofer Inst Syst & Innovat Res	Germany	8	219	5	27.38
47	Mei-Chih Hu	Natl Tsing Hua Univ	Taiwan	8	200	6	25
48	Mario Coccia	Arizona State U	USA	8	190	7	23.75
49	Knut Blind	Technical U of Berlin	Germany	8	154	6	19.25

TP = total papers; TC = total citations; h = h -index (TF&SC only); C/P = citations per paper (i.e., TC/TP).

Table 3. Most frequent university affiliations of authors published in TF&SC*

R	University	Country	TP	TC	h	C/P
1	Utrecht U	Netherlands	66	2986	31	45.27
2	Portland State U	USA	58	1517	18	26.16
3	Delft U Technology	Netherlands	53	934	18	17.62
4	Georgia Institute of Technology	USA	50	1180	18	23.60
5	U Manchester	UK	49	1193	20	24.35
6	National Chiao Tung U	Taiwan	40	747	15	18.68
7	U Sussex	UK	39	931	15	23.87
8	U Texas Austin	USA	38	768	18	20.21
9	Seoul National U	South Korea	33	1029	17	31.18
10	National Res U Higher Sch Econ	Russia	33	192	7	5.82
11	Vrije U Amsterdam	Netherlands	30	563	14	18.77
12	U Lisboa	Portugal	30	562	14	18.73
13	Erasmus U Rotterdam	Netherlands	29	502	13	17.31
14	U Tokyo	Japan	28	641	14	22.89
15	U California Berkeley	USA	27	202	8	7.48
16	U Michigan	USA	27	93	6	3.44
17	U Twente	Netherlands	26	633	11	24.35
18	Technical U Berlin	Germany	25	610	13	24.4
19	Yonsei U	South Korea	25	427	10	17.08
20	U Cambridge	UK	24	1010	13	42.08
21	Ohio State U	USA	24	232	8	9.67
22	Carnegie Mellon U	USA	23	418	11	18.17
23	U Strathclyde	UK	22	331	10	15.05
24	Eindhoven U Technology	Netherlands	21	960	13	45.71
25	European Business School	Germany	20	649	14	32.45
26	Harvard U	USA	20	344	9	17.2
27	George Washington U	USA	20	136	6	6.8
28	U Paris Saclay Comue	France	19	563	9	29.63
29	U New Mexico	USA	19	500	10	26.32
30	U Oxford	UK	19	443	11	23.32
31	Stanford U	USA	19	393	9	20.68
32	Tel Aviv U	Israel	19	311	7	16.37
33	Newcastle U	UK	19	284	10	14.95
34	George Mason U	USA	19	260	8	13.68
35	Aalto U	Finland	19	224	9	11.79
36	Technical U Denmark	Denmark	19	178	8	9.37
37	Hebrew U Jerusalem	Israel	18	294	7	16.33
38	Sungkyunkwan U	South Korea	18	134	7	7.44
39	National Tsing Hua U	Taiwan	17	313	8	18.41
40	National Cheng Kung U	Taiwan	17	260	10	15.29

41	U Turku	Finland	17	191	7	11.24
42	Maastricht U	Netherlands	16	312	8	19.5
43	U Leeds	UK	16	278	7	17.38
44	U Edinburgh	UK	16	238	9	14.88
45	U Warwick	UK	16	178	7	11.13
46	Tilburg U	Netherlands	15	336	10	22.4
47	National Chung Hsing U	Taiwan	15	193	7	12.87
48	U Groningen	Netherlands	14	303	7	21.64
49	Imperial College London	UK	14	294	12	21
50	U California Davis	USA	14	181	7	12.93

TP = total papers; TC = total citations; h = h -index (TF&SC only); C/P = citations per paper (i.e., TC/TP).

*Many authors that have two or more institutional affiliations at the same time, and many change their affiliations during their careers; for this reason, universities listed in Tables 2 and 3 cannot be compared in terms of total publications or total citations.

Table 4. TF&SC publications by country over time

R	COUNTRY	Total	D1	D2	D3	D4	D5	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1	USA	1378	229	316	288	212	333	34	20	15	24	30	19	21	37	53	82	52
2	United Kingdom	413	5	15	21	45	327	6	8	16	11	14	20	33	57	52	48	76
3	Netherlands	294	1	2	21	51	219	13	9	23	20	15	22	15	25	46	29	24
4	Germany	228	10	13	19	27	159	6	3	6	6	10	9	8	21	50	19	30
5	South Korea	204		2	9	26	167	2	5	7	12	10	14	6	18	42	35	23
6	Taiwan	180			3	38	139	6	12	13	9	24	15	8	18	24	16	12
7	Italy	153	4	2	9	21	117	6	3	6	5	4	7	8	15	25	18	29
8	China	143		2	2	6	133		2	1	5	5	9	7	9	27	44	26
9	France	137	8	4	10	20	95	1	2	3	13	3	5	13	14	17	5	22
10	Spain	124			1	19	104	4	4	2	5	6	8	10	12	20	15	26
11	Japan	120	3	11	29	30	47	3	4	7	4	4	3	4	3	14	3	5
12	Austria	115	6	21	21	18	49	7	2	2		1	2	4		23	6	11
13	Canada	108	11	22	18	11	46	5	2	1	5	4	5	2	5	7	9	8
14	Australia	98	1	9	3	13	72		1	5	1	6	5	4	12	9	14	16
15	India	84	3	24	22	13	22	5			3	1	4			2	4	8
16	Finland	80	1	2	3	18	56	3	3	3	3	3	3	5	9	11	7	12
17	Denmark	65	3	3	7	9	43	2		2	1	1	2	3	2	11	7	14
18	Russia	65	16	1	5	1	42					1		2	1	9	8	21
19	Portugal	60			3	20	37	5	1	1	4	2	3	1	2	5	14	5
20	Switzerland	59	2	1		13	43	3	2	4		2	4	2	3	12	13	3
21	Sweden	55	3	5	9	7	31	1	4	2		4	3	3	2	7	4	6
22	Israel	51	5	15	12	10	9	1				2		2		2		3
23	Brazil	43		2	2	8	31	1			6	1	2	7	1	6	2	6
24	Belgium	39		2	5	5	27	1			3		1	3	4	3	2	11
25	Greece	36		2	3	6	25	2	1	1	2	2	1	3	1	8	5	2
26	Turkey	34		1		8	25	3	1		1	1	1	3	5	5	4	5
27	Thailand	31	4	10	6	4	7			2				1	2	1	1	
28	Norway	27	1	1		2	23		1	1	2		1	2	3	4	4	6
29	Poland	26	3	10	3	2	8			1				1	2	3		1
30	Iran	25					25			1		1		2		1	3	17
31	South Africa	21		3	4	5	9	1				1			1	2	1	4
32	Singapore	20			3	8	9	1		1		2			2	2	2	
33	Mexico	18		1	2	5	10	1			4		1		1	1	2	1
34	New Zealand	16		5	3	2	6						2		1	2		1
35	Romania	13	1	4	3	1	4							2				2
36	Malaysia	12				1	11			1	1			1		3	2	3
37	Ireland	11				2	9	1						1			1	1
38	Colombia	9					9				1	1		1		1	2	3
39	U Arab Emirates	8				1	7					1		1		1	1	3
40	Czech Republic	6		1	1		4								1	2	1	

Abbreviations: D: decade; D1: 1969-1978; D2: 1979-1988; D3: 1989-1998; D4: 1999-2008; D5: 2009-2017

Table 5. Most productive and influential countries in TF&SC

R	Country	TP	TC	h	C/P	Population	TP/Pop	TC/Pop	R&D	TP/R&D	TC/R&D
1	USA	1378	18194	58	13.20	325,719,178	4.23	55.86	2.8	492.1	6497.8
2	United Kingdom	413	7705	43	18.66	66,022,273	6.26	116.70	1.67	247.3	4613.7
3	Netherlands	294	8339	47	28.36	17,132,854	17.16	486.73	2	147	4169.5
4	Germany	228	4646	33	20.38	82,695,000	2.76	56.18	3.04	75	1528.2
5	South Korea	204	2901	28	14.22	51,466,201	3.96	56.37	4.55	44.8	637.5
6	Taiwan	180	3657	31	20.32	23,571,000	7.64	155.15	--	--	--
7	Italy	153	2464	30	16.10	60,551,416	2.53	40.69	1.36	112.5	1811.7
8	China	143	1783	23	12.47	1,386,000,000	0.10	1.29	2.13	67.1	837
9	France	137	2524	26	18.42	67,118,648	2.04	37.61	2.19	62.5	1152.5
10	Spain	124	2039	25	16.44	46,572,028	2.66	43.78	1.21	102.4	1685.1
11	Japan	120	1819	25	15.16	126,785,797	0.95	14.35	3.2	37.5	568.4
12	Austria	115	2937	29	25.54	8,809,212	13.05	333.40	3.16	36.3	929.4
13	Canada	108	1721	21	15.94	36,708,083	2.94	46.88	1.59	67.9	1082.3
14	Australia	98	1325	19	13.52	24,598,933	3.98	53.86	1.92	51	690.1
15	India	84	1292	18	15.38	1,339,000,000	0.06	0.96	0.62	135.4	2083.8
16	Finland	80	1103	18	13.79	5,511,303	14.52	200.13	2.76	28.9	399.6
17	Denmark	65	1089	19	16.75	5,769,603	11.27	188.75	3.1	20.9	351.2
18	Russia	65	297	8	4.57	144,495,044	0.45	2.06	1.11	58.5	267.5
19	Portugal	60	949	18	15.82	10,293,718	5.83	92.19	1.33	45.1	713.5
20	Switzerland	59	1431	22	24.25	8,466,017	6.96	169.03	3.37	17.5	424.6
21	Sweden	55	1160	17	21.09	10,067,744	5.46	115.22	3.31	16.6	350.4
22	Israel	51	769	14	15.08	8,712,400	5.85	88.27	4.58	11.1	167.9
23	Brazil	43	669	14	15.56	209,288,278	0.21	3.20	1.27	33.8	526.7
24	Belgium	39	592	14	15.18	11,372,068	3.43	52.06	2.61	14.9	226.8
25	Greece	36	698	16	19.39	10,760,421	3.35	64.87	1.14	31.5	612.2
26	Turkey	34	460	11	13.53	80,745,020	0.42	5.70	0.96	35.4	479.1
27	Thailand	31	558	13	18	69,037,513	0.45	8.08	0.78	39.7	715.3
28	Norway	27	380	10	14.07	5,282,223	5.11	71.94	2.11	12.7	180
29	Poland	26	188	8	7.23	37,975,841	0.68	4.95	1.04	25	180.7
30	Iran	25	108	5	4.32	81,162,788	0.31	1.33	--	--	--
31	South Africa	21	292	10	13.90	56,717,156	0.37	5.15	0.82	25.6	356
32	Singapore	20	283	10	14.15	5,612,253	3.56	50.43	2.22	9	127.4
33	Mexico	18	139	7	7.72	129,163,276	0.14	1.08	0.49	36.7	283.6
34	New Zealand	16	115	7	7.19	4,793,900	3.34	23.99	1.23	13	93.4
35	Romania	13	58	4	4.46	19,586,539	0.66	2.96	0.5	26	116
36	Malaysia	12	141	5	11.75	31,624,264	0.38	4.46	1.44	8.3	97.9
37	Ireland	11	53	4	4.82	4,813,608	2.28	11.01	1.04	10.5	50.9
38	Colombia	9	89	6	9.89	49,065,615	0.18	1.81	0.24	37.5	370.8
39	U. Arab Emirates	8	86	5	10.75	9,400,145	0.85	9.15	0.96	8.3	89.5
40	Slovenia	6	73	4	12.17	2,066,748	2.90	35.32	1.85	3.2	39.4
41	Hungary	6	47	3	7.83	9,781,127	0.61	4.81	1.35	4.4	34.8
42	Czech Republic	6	28	2	4.67	10,591,323	0.57	2.64	1.79	3.3	15.6
43	Egypt	5	52	4	10.40	97,553,151	0.05	0.53	0.61	8.1	85.2
44	Philippines	5	46	2	9.20	104,918,090	0.05	0.44	--	--	--
45	Ethiopia	4	87	2	21.75	104,957,438	0.04	0.83	--	--	--
46	Lithuania	4	36	4	9	2,827,721	1.41	12.73	0.89	4.4	40.4
47	Iceland	3	134	3	44.67	341,284	8.79	392.63	2.18	1.3	61.4
48	Kenya	3	86	2	28.67	49,699,862	0.06	1.73	--	--	--

49	Chile	3	57	2	19	18,054,726	0.17	3.16	0.36	8.3	158.3
50	Saudi Arabia	3	36	3	12	32,938,213	0.09	1.09	--	--	--

TP = total papers; TC = total citations; h = h -index (TF&SC only); C/P = citations per paper (i.e., TC/TP); TP/Pop = total papers per million inhabitants; TC/Pop = total citations per million inhabitants. Population estimates are from the World Bank (<https://datos.bancomundial.org/indicador/SP.POP.TOTL>); R&D = Research and development expenditure (% of GDP) from the World Bank (<https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS>). The last year available was included (2015-2016-2017); TP/R&D = total publication per R&D expenditure as % of GDP; TC/R&D = total citation per R&D expenditure as % of GDP

Table 6. Most productive and influential regions and supra-regions in TF&SC

R	Region	TP	TC	h	C/P	Population	TP/Pop	TC/Pop
1	Europe	2015	39011	413	19.36	652,036,215	3.09	59.83
	Eastern Europe	131	1179	37	9.00	189,184,910	0.69	6.23
	Western and North Europe	1884	37832	376	20.08	462,851,305	4.07	81.74
2	Asia	925	13945	195	15.08	3,614,965,063	0.26	3.86
	Eastern Asia	470	6503	76	13.84	1,564,251,998	0.30	4.16
	South Asia	295	5507	62	18.67	1,431,608,513	0.21	3.85
	South East Asia	39	476	19	12.21	406,145,986	0.10	1.17
	Western Asia	121	1459	38	12.06	212,958,566	0.57	6.85
3	North America	1486	19915	79	13.40	362,427,261	4.10	54.95
4	Oceania	114	1440	26	12.63	29,392,833	3.88	48.99
5	Latin America	79	979	33	12.39	463,784,835	0.17	2.11
6	Africa	37	549	22	14.84	361,814,963	0.10	1.52

TP = total papers; TC = total citations; h = h -index (TF&SC only); C/P = citations per paper (i.e., TC/TP); TP/Pop = total papers per million inhabitants; TC/Pop = total citations per million inhabitants. Population estimates are from the World Bank (<https://datos.bancomundial.org/indicador/SP.POP.TOTL>).

Table 7. Authors, institutions and countries per paper over time

Year	TP	Authors	Institutions	Countries	Authors/TP	Institutions/TP	Countries/TP
1969	22	23	19	4	1.04	0.86	0.18
1970	35	36	30	6	1.03	0.86	0.17
1971	17	22	22	3	1.29	1.29	0.18
1972	37	40	35	6	1.08	0.95	0.16
1973	40	52	40	7	1.30	1.00	0.18
1974	25	29	27	5	1.16	1.08	0.20
1975	40	54	43	9	1.35	1.08	0.23
1976	42	47	38	6	1.12	0.91	0.14
1977	35	49	48	11	1.40	1.37	0.31
1978	45	65	54	14	1.44	1.20	0.31
1979	75	105	89	16	1.40	1.19	0.21
1980	68	93	75	17	1.37	1.10	0.25
1981	43	60	52	11	1.39	1.21	0.26
1982	42	57	45	7	1.36	1.07	0.17
1983	44	61	60	12	1.38	1.36	0.27
1984	58	79	67	12	1.36	1.16	0.21
1985	47	60	55	11	1.28	1.17	0.23
1986	48	57	45	12	1.19	0.94	0.25
1987	46	57	51	12	1.24	1.11	0.26

1988	47	67	59	13	1.47	1.26	0.28
1989	48	62	52	12	1.29	1.08	0.25
1990	54	76	59	16	1.41	1.09	0.30
1991	50	78	51	11	1.56	1.02	0.22
1992	54	71	92	19	1.32	1.70	0.35
1993	49	85	63	15	1.76	1.29	0.31
1994	60	83	79	21	1.38	1.32	0.35
1995	54	87	85	14	1.61	1.57	0.26
1996	53	79	79	17	1.49	1.49	0.32
1997	47	70	69	13	1.49	1.47	0.28
1998	55	97	76	21	1.76	1.38	0.38
1999	62	77	60	23	1.24	0.97	0.37
2000	52	92	66	21	1.77	1.27	0.40
2001	38	74	59	18	1.95	1.55	0.47
2002	46	87	66	20	1.89	1.44	0.44
2003	45	78	68	16	1.73	1.51	0.36
2004	47	102	68	15	2.17	1.45	0.32
2005	62	129	96	25	2.08	1.55	0.40
2006	64	150	88	27	2.34	1.36	0.42
2007	91	214	145	29	2.35	1.59	0.32
2008	79	162	104	25	2.05	1.32	0.32
2009	96	219	143	32	2.28	1.49	0.33
2010	124	277	183	29	2.23	1.48	0.23
2011	131	311	206	34	2.37	1.57	0.26
2012	136	310	202	34	2.28	1.49	0.25
2013	138	348	228	44	2.52	1.65	0.32
2014	204	569	318	37	2.79	1.56	0.18
2015	322	884	483	50	2.75	1.50	0.16
2016	313	692	424	50	2.21	1.36	0.16
2017	337	914	566	57	2.71	1.68	0.17

TP=Total Papers

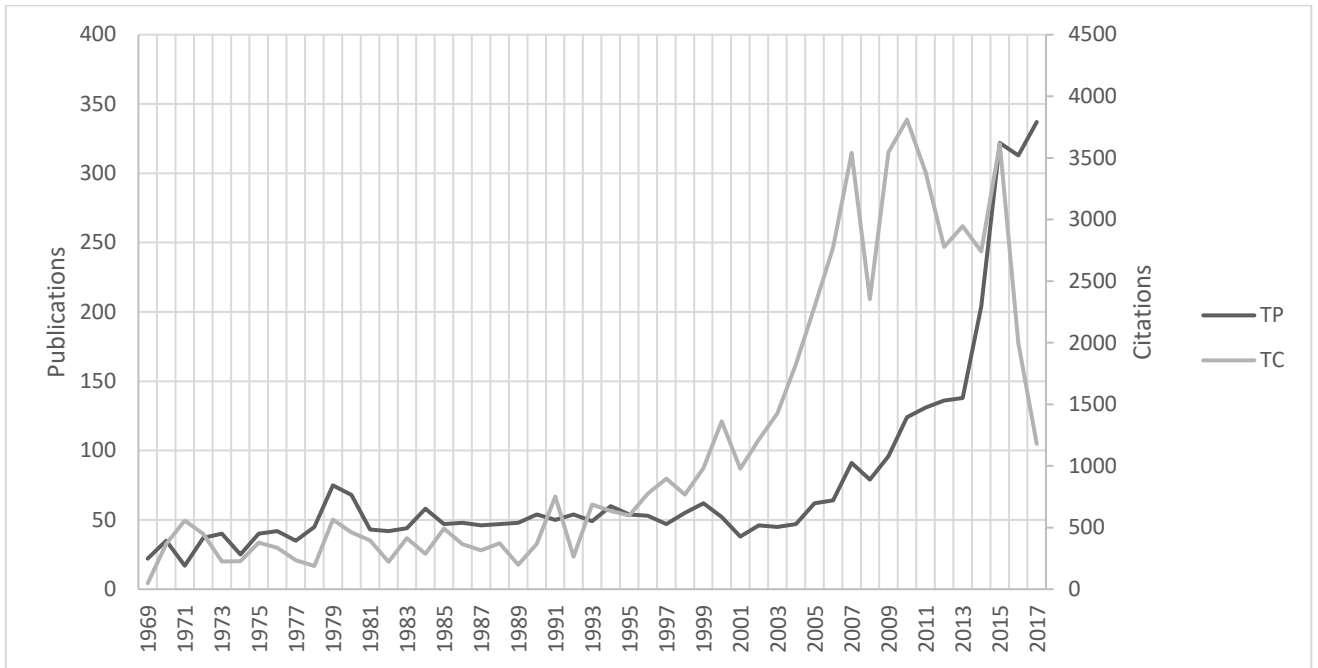


Fig. 1. Total publications and total citations by year
 TP=Total Papers; TC=Total Citations

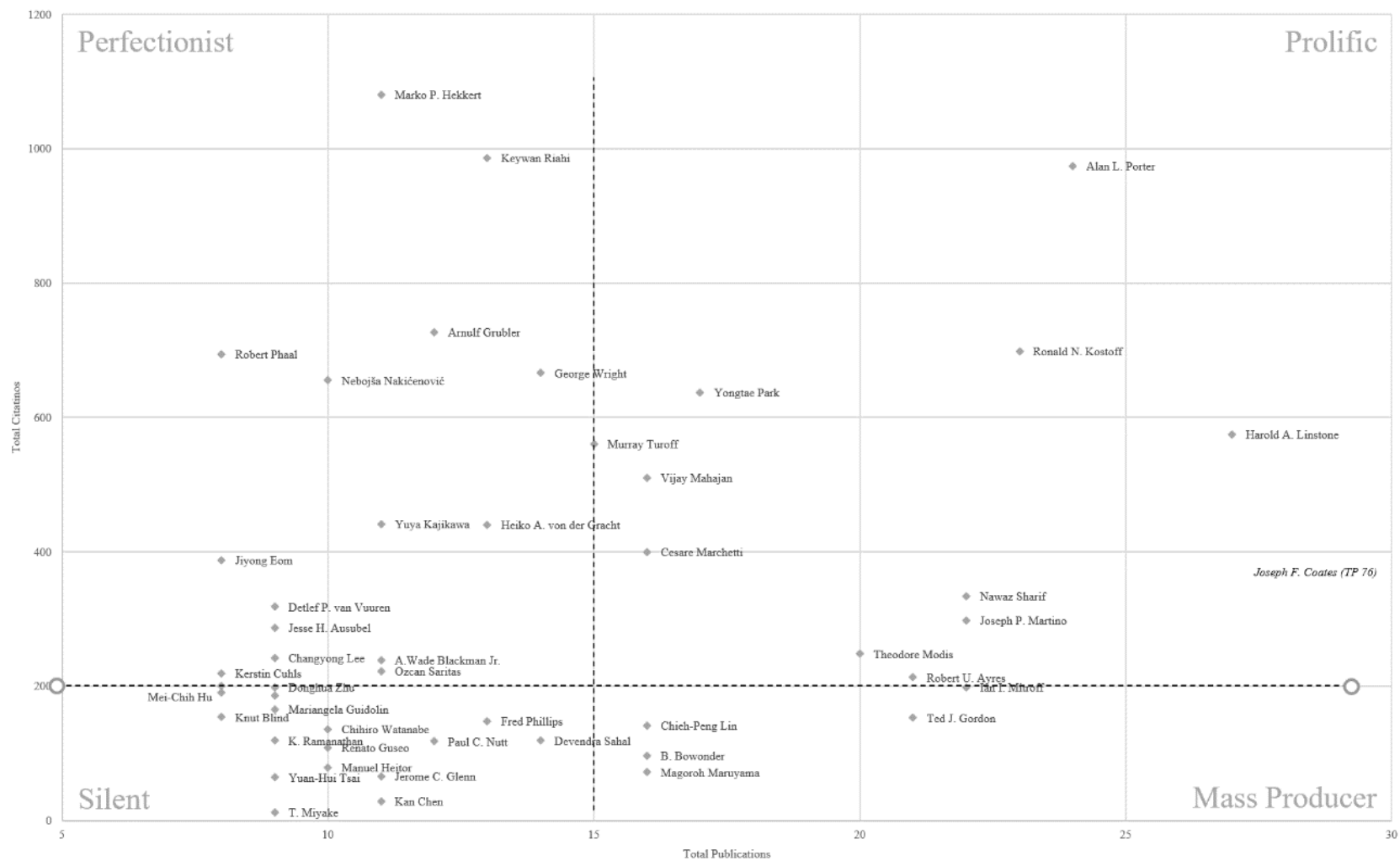


Fig. 2. Authors mapped by total publications and total citations

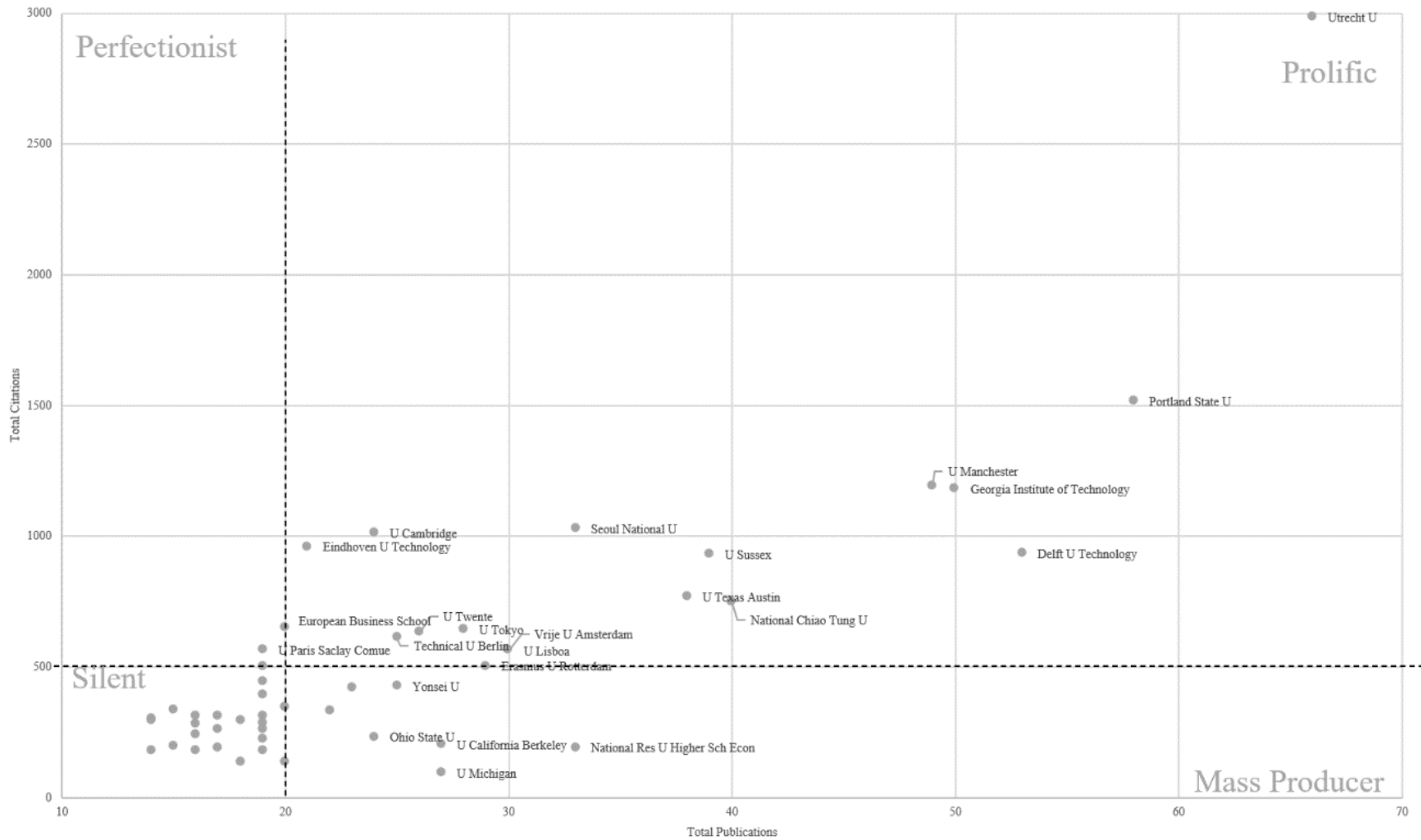


Fig. 3. Institutions mapped by total publications and total citations

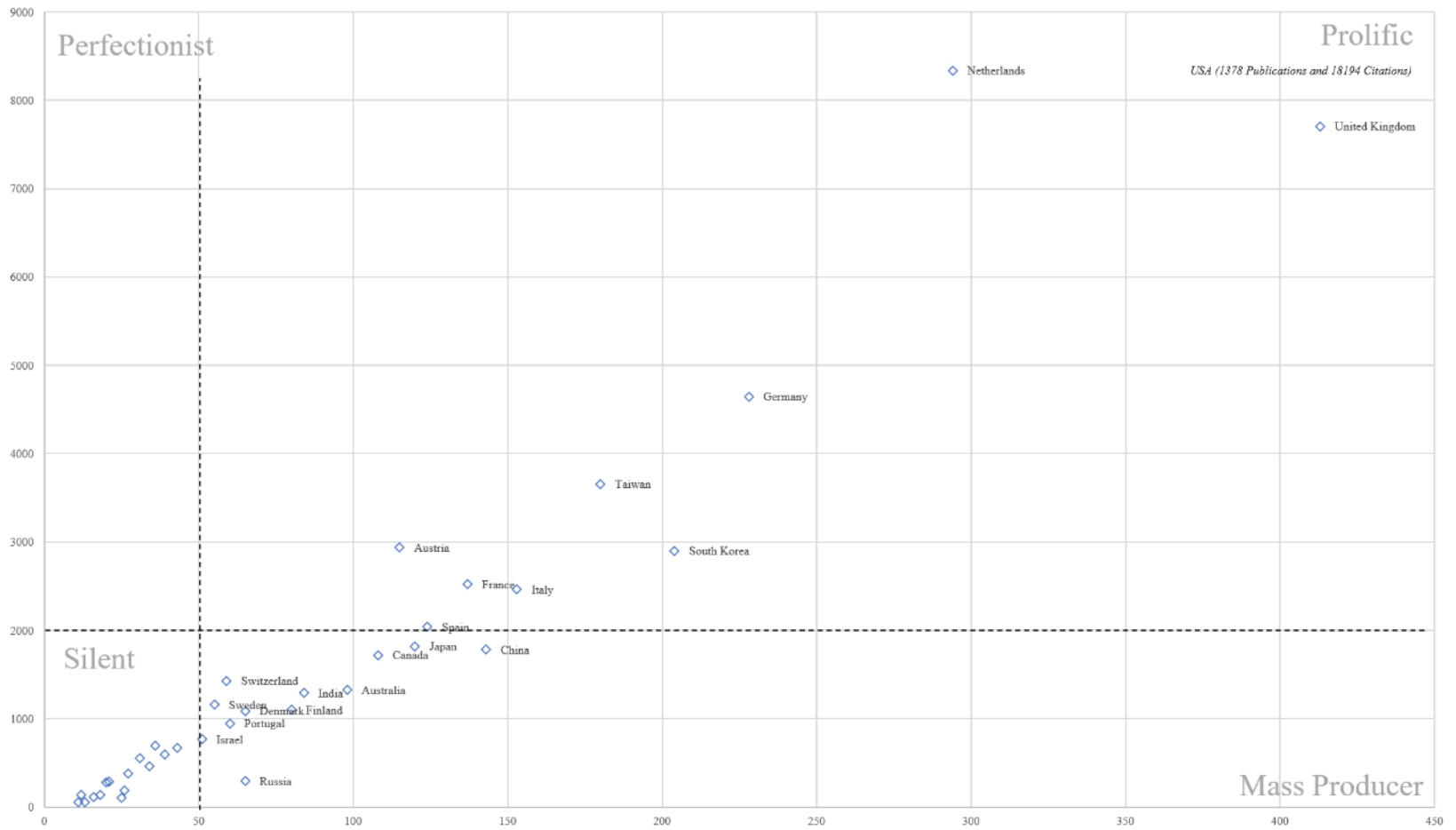


Fig. 4. Countries mapped by total publications and total citations

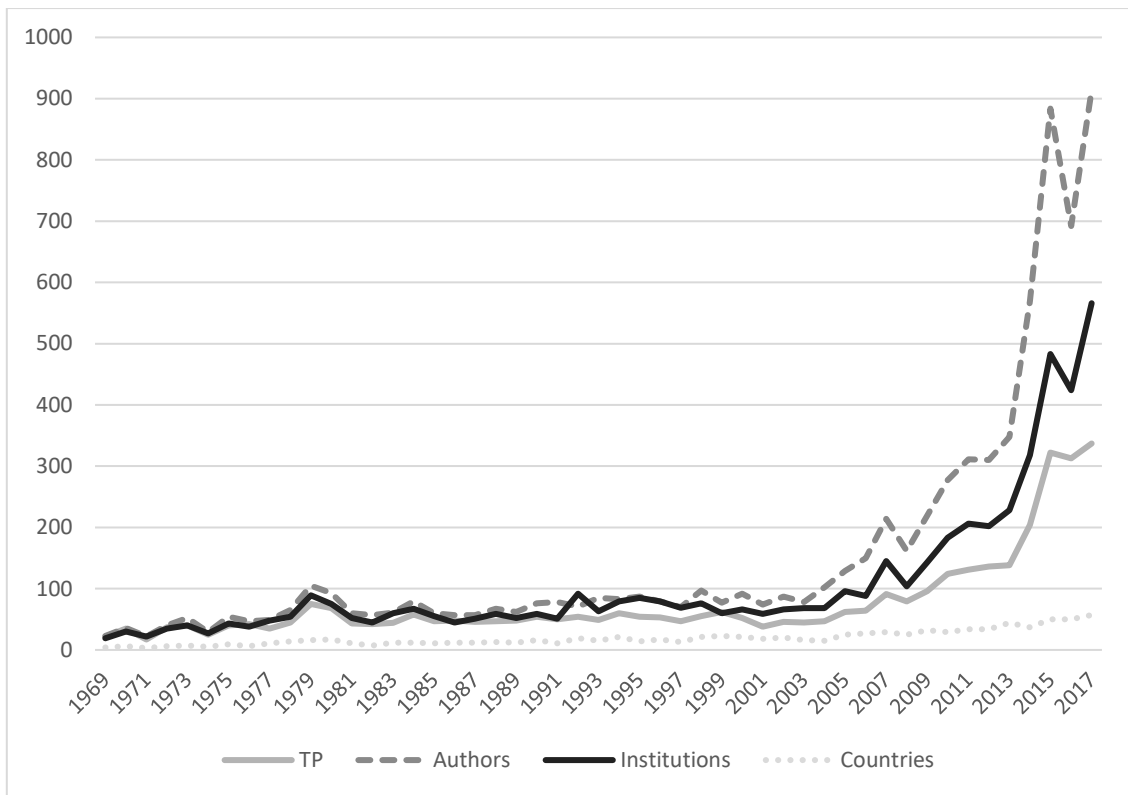


Fig. 5. Numbers of authors, institutions and countries over time
 TP=Total Papers

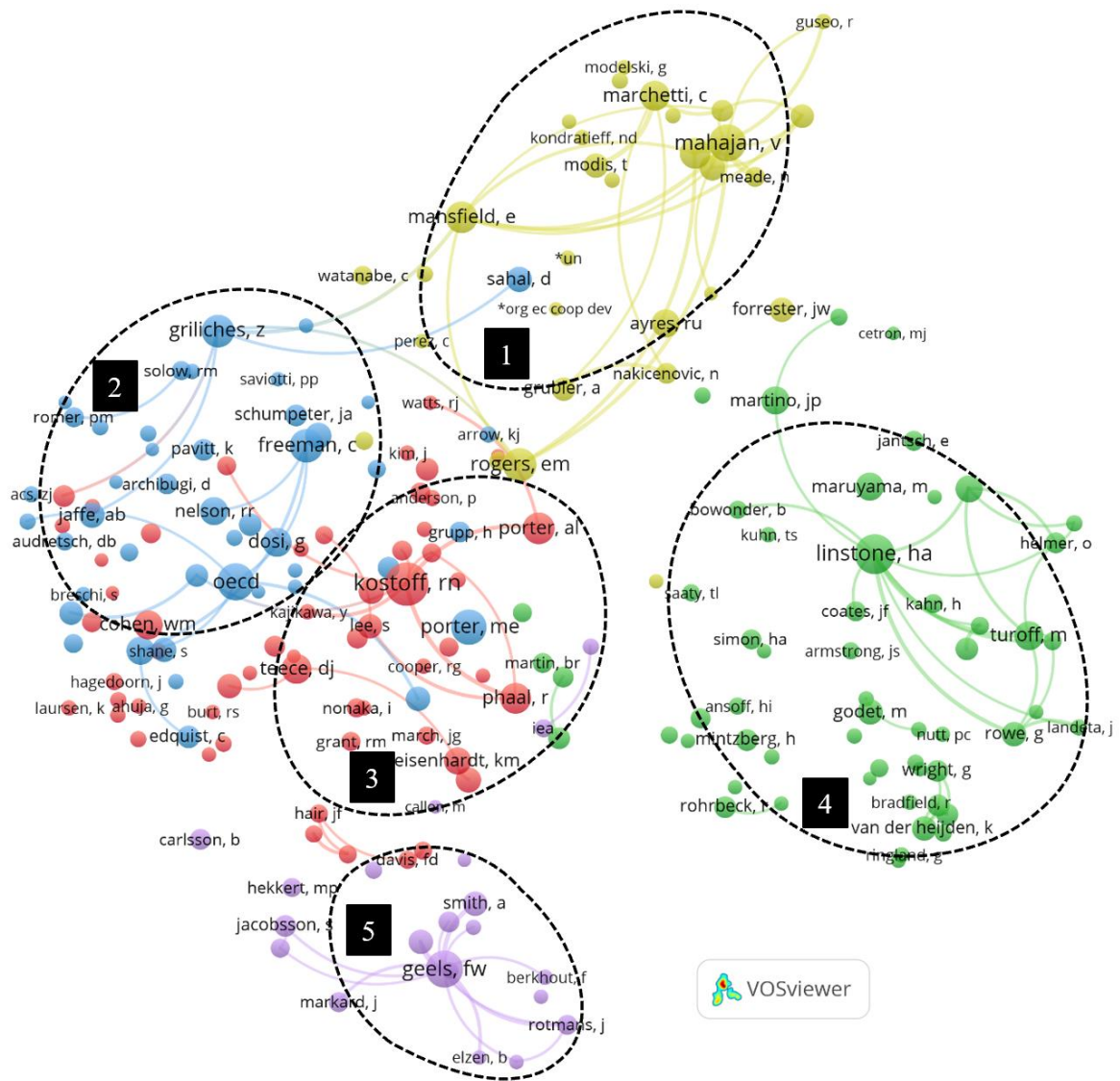


Fig. 6. Mapping of co-citation of authors in TF&SC

- Cluster 1 corresponds to diffusion of innovations, microeconomics and marketing;
- Cluster 2 corresponds to innovation;
- Cluster 3 corresponds to technology roadmapping;
- Cluster 4 corresponds to technological forecasting;
- Cluster 5 corresponds to system innovation and sustainability.

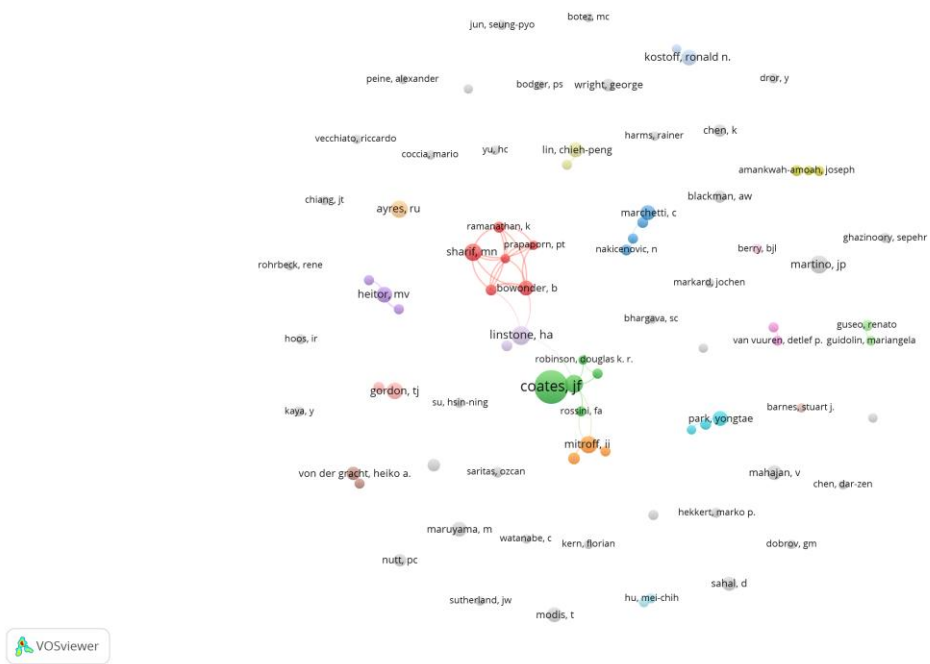


Fig. 7a. Co-authorship of authors publishing in TF&SC: minimum publication threshold of 6 documents and 100 links

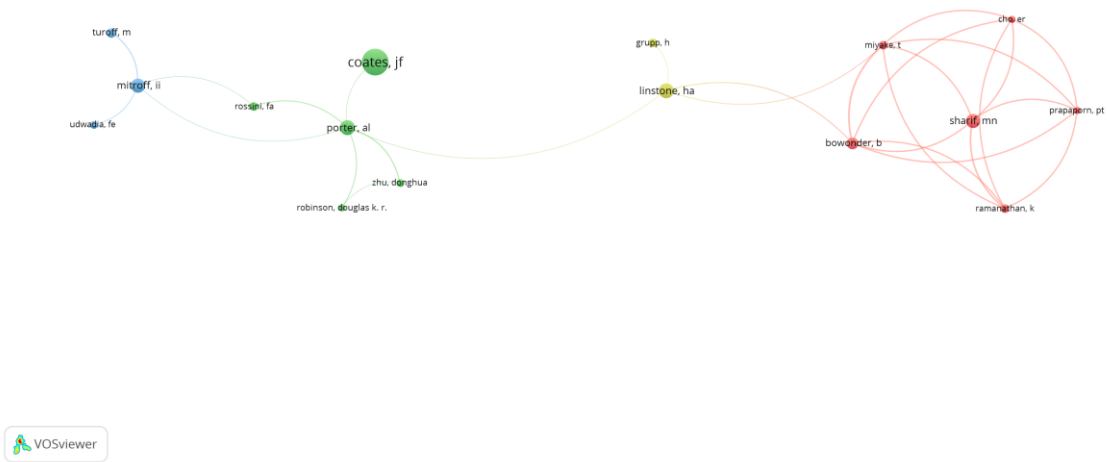


Fig. 7b. Expanded view: Co-authorship of authors publishing in TF&SC: minimum publication threshold of 6 documents and 100 links

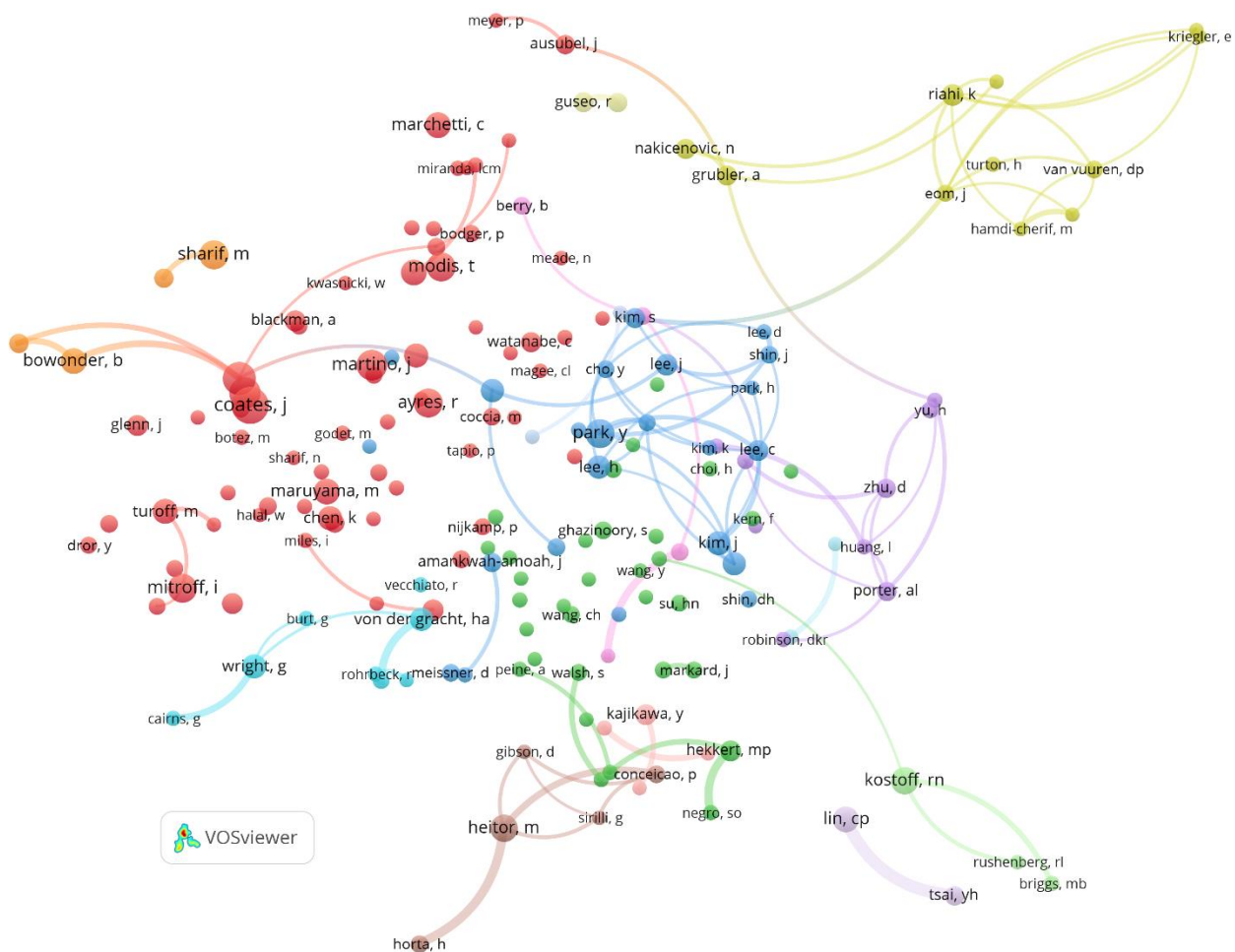


Fig. 8. Bibliographic coupling of authors publishing in TF&SC: minimum publication threshold of 5 documents and 100 links

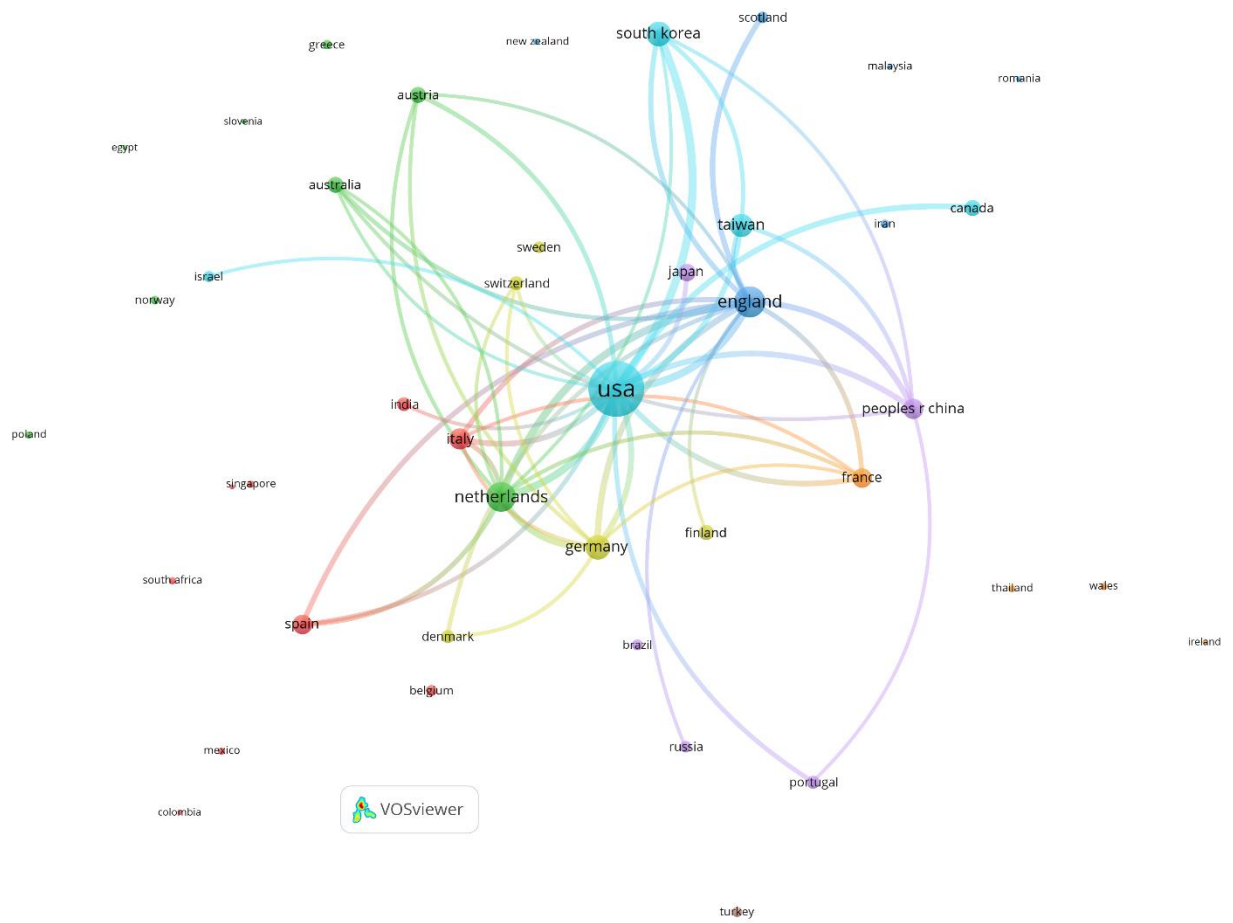


Fig. 10. Bibliographic coupling of countries publishing in TF&SC: minimum threshold of 5 documents and 50 links

Author Biographies

1. **Alicia Mas-Tur** is Associate professor in the Management Department at the University of Valencia. She has presented numerous papers at international conferences. She has also published articles and books in international journals including *Service Industries Journal*, *International Entrepreneurship and Management Journal*, and *Service Business*. She is or has been the guest editor and referee for international journals. She is or has been on the editorial board of several journals including the *Journal of Business Research* and *Contemporary Economics*.
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6. **Dr. Mustapha Belkhouja** is an Associate Professor of Quantitative Methods at Grenoble Ecole de Management. His research topics focus on academic visibility, knowledge diffusion, reputation and international business. His research has appeared in *Journal of Product Innovation Management*, *Industrial Marketing Management*, *M@n@gement*, *Research Policy*, *Technological Forecasting & Social Change*, and *Strategic Organization*, among others.
7. **Jose M. Merigo** is a Professor at the School of Information, Systems, and Modelling at the Faculty of Engineering and Information Technology at the University of Technology Sydney (Australia). He has published more than 400 articles in journals, books and conference proceedings. He is on the editorial board of several journals. He has also been a guest editor for several international journals, member of the scientific committee of several conferences and reviewer in a wide range of international journals.
8. **Dr. Alan Porter** is Professor Emeritus of Industrial & Systems Engineering at Georgia Institute of Technology (USA), where he also co-directs the Technology Policy and Assessment Center. His current research interests focus on computer-aided exploration of information in electronic Science & Technology databases. He has authored over 160 professional publications and 11 books.