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Analysis of the evolution of technology commercialization literature: a scientometric study

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Abstract
The objective of this study was to investigate the evolution of technology commercialization literature to determine the conceptual trends over the past 50 years to identify the key scientific documents in this field, which is the basis for knowledge development, and fill the gap between the field of commercialization and other knowledge networks and scientific structures. This study is applied scientometric and co-citation analysis has been used. We calculated the betweenness centrality index of the nodes and combined it with the burstness index of scientific documents over time to calculate the sigma index, which we then used to identify transformative documents. The study found that seven scientific documentaries, based on the sigma index, could potentially change the field of knowledge about commercializing technology. These documentaries were part of a co-citation network with 855 articles taken from the Web of Science (WOS) database. The results of the analysis showed that the betweenness centrality index and the burstness index by themselves can't give a full picture of how knowledge trends are changing in the field of technology commercialization. The sigma index, on the other hand, did a better job of this.

Keywords: Technology commercialization, Co-citation network, co-authorship network, Betweenness centrality, Burstness index, Sigma index.

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1. Introduction

Today, technology is the most important factor in competitiveness among countries and companies (Unger, 2019). In the age of knowledge, technology experts acknowledge that commercialization is a characteristic of applying inventions and innovations to technology and production (Behboudi & Jalili, 2011). The progress and welfare of societies, economic prosperity, expansion of industries, creation of wealth, and creation of competitive advantage are the results of applying technology and its commercialization (Khalil, 2000). In other words, commercialization is one of the most important and basic issues in technology management. It seems that conducting research using scientific and research works on this important issue is very useful to understand the current position and the development trend of these studies. By reviewing these studies, one can identify influential scientific works, authors, leading universities, and institutions involved in the production of technology commercialization science.

The detailed analysis and review of scientific publication trends, especially in valid databases, can determine the course of subject fields and help high-level policymakers and planners of countries draw the scientific map of their country (Hamdipour, 2020). Today, in order to review the development trend of a scientific topic, draw a scientific map, review the research literature in a field of science, and identify the top countries and researchers, it is common to use scientometric methods (Vošner et al., 2016). There are different approaches to examining the trend of science production. Some studies have investigated the trend of science production in different fields of science in a bibliographic manner (Zancanaro, 2015). Bibliometrics basically measures the characteristics of documents by quantitatively analyzing scientific publications through relevant statistical methods (Godin, 2006). Bibliometric researchers have developed different methodological principles to collect data by specific methods, such as citation analysis, social network analysis, content analysis, and text mining, in existing studies (Leung et al., 2017). Researchers mostly use bibliometrics today to understand trends, particularly in basic knowledge (Moyle et al., 2020). The main objective of examining potential changes in a scientific structure is to identify the gaps that a scientific field faces over time. For scientific trends, determining scientific documents that can transform over time, i.e., they not only have an important effect on the formation of a field of knowledge but can also fill the gap between two or more scientific fields, is a subject that has received the attention of scientometric scientists (Roshni et al., 2017). Chen et al. (2009) introduced the sigma index, an index that describes transformative scientific discoveries indicating fundamental and revolutionary changes in a scientific structure.

Our search of scientific references on technology commercialization revealed a lack of studies that address the bibliographic review of technology commercialization articles to identify scientific products and transformative discoveries. The present study aims to investigate and identify the dynamics and production of research literature in the field of technology commercialization and transformative scientific products and to draw a scientific map of this field, addressing the identified gaps and necessities. Furthermore, the study discusses the trend of publications and citations, as well as the calculation of the burstness index, betweenness centrality (BC), and sigma index. It also explores co-authorship, the most cited articles, top journals, researchers, universities, and institutions, along with the most frequent keywords and the evolution trend of the most frequent words over time among the articles indexed in the field of commercialization in the Web of Science (WoS) database.

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2. Theoretical foundations and literature review

2.1 Technology commercialization

One of the important mechanisms to achieve scientific and meaningful applications based on scientific knowledge is technology commercialization, which is the process of transforming scientific knowledge into new products or improving the status of goods and services in the market. Public investments in scientific research usually transfer scientific knowledge and inventions to society and the market (Fini et al., 2018). "Technology commercialization is the process of designing, producing, and marketing products with developed technology or transferring technology through licensing or other joint activities (Ambos et al., 2008). Also, technology commercialization can be defined as the process of transferring a technology-based innovation by the technology developer to an organization that uses technology for marketable products (Kirchberger & Pohl, 2016).

Technology commercialization is a very complex process, the success of which depends on various factors. Kirchberger and Pohl (2016) looked at the literature and records of successful technology commercialization in many different areas and put these factors into groups. They came up with these: proximity to the industry, a culture of innovation, the support of middlemen, management styles, network activities, intellectual property rights, the personal traits of researchers, the availability of resources, team structure, the value of technology application, and the suitability of technology for commercialization.

2.2 Scientometrics

Scientometric studies are based on the accurate evaluation of explicit citation links between scientific documents. During the last decade, as research output has increased significantly, datasets have also started to become direct research targets in scientometric studies. Accordingly, researchers track the quantitative scientific effect of specific data sets (Peters et al., 2016). Also, bibliometrics has become an essential tool for evaluating and analysing the output of scientists' research, cooperation between universities, the effect of the government's scientific budget on national research and development performance and educational efficiency, and other applications. Therefore, experts and scientists need a wide range of theoretical and practical tools to measure empirical data (Moral-Muñoz et al., 2020). One of the objectives of scientometric is to measure and determine criteria for measuring and evaluating various managerial and organizational dimensions of science. Therefore, quantitative evaluation of science in relation to the internal and external comparison of scientific activities, which leads to scientific development, can be a great help for officials and planners who intend to make the most use of financial and human resources by spending the least amount of money and are effective in optimizing the socio-economic structure of the country (Sengupta, 1992).

Cipresso et al. (2018) in an article entitled "Past, Present and Future of Virtual and Augmented Reality Research: Network and Cluster Analysis of Literature", by reviewing the existing literature in the field of virtual and augmented reality, and using advanced scientometric techniques and Citespace, collected all the articles in the scientific database of WoS in the scientific field of virtual and augmented reality, and discussed the bibliographic background including various fields of author, title, abstract, country and all references (which are necessary for citation analysis) along with network analysis and existing literature clusters, evolution and changes in literature in this field over time with emphasis on future capacities and challenges.

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In their 2017 paper called "Identifying transformative scientific documents based on the sigma index: the knowledge field of factor-based modelling in the social sciences," Roshni et al. argued that the betweenness centrality (BC) index and burstness index, which were made to measure transformative documents in a scientific field, had a lot of variation. They suggested that utilizing the sigma index could provide a more effective understanding of the paths of development and evolution in a scientific field.

Li and Shen (2013) analysed the trend and evolution of key technologies in the field of 3G mobile communications using the sigma index calculated by CiteSpace and the Derwent Innovation Index.

Kashani and Roshni (2019) analysed and outlined the evolution of innovation system literature by integrating two criteria, burstness, and BC, into the sigma index. Kashani and Roshni (2019) analysed and outlined the evolution of innovation system literature by integrating two criteria, burstness, and BC, into the sigma index. They stated that in citation and co-citation analysis, the BC index and burstness index are not enough to show the most important works. Chen et al. (2009) developed the sigma index, which researchers have used to fill this gap.

3. Methodology

The results of bibliographic analysis can clarify the factors that strengthen the contribution of studies to a research field and guide scientists to conduct more effective studies (Akhavan et al., 2016). Scientists mainly use the co-citation network to discover the hidden patterns of knowledge development and dissemination (Nerur et al., 2008). The co-citation network links two scientific works cited in a third work. The higher the number of these types of citations, the more related the two works are (Garfield, 1983).

Based on the importance of the references included in the analysis, the researcher should set a threshold and discard information related to cited documents that do not significantly affect the research (Small & Greenlee, 1980). The researcher removed works with less than five citations from the list of important and influential documents. For data analysis, we used co-citation analysis, and to determine transformative scientific documents, we employed the sigma index. On the other hand, according to the formula of the sigma index, which is a combination of the burstness index and the BC index, it is necessary to make necessary calculations regarding the measurement of the mentioned indices.

The betweenness centrality index is another practical criterion for identifying the structural importance of a node within a network, and it indicates the number of times that node is in the shortest path between any two other nodes in the network (Roshani et al., 2014). The high BC index indicates that a node is located at a smaller distance from other nodes in the network. Central nodes connect intellectual concepts to each other and serve as a criterion for connectivity in the network (Freeman, 1977).

$$g(v) = \sum_{s \neq v \neq t} \frac{p_{st}(v)}{p_{st}}$$

Where g is the betweenness centrality for node v, and p_{st} is the shortest path that passes through the pair of nodes s and t. If a work receives more citations over time, it means that its importance increases (Kleinberg, 2003). Calculating the cumulative citation of works overtime can use the burstness index as a criterion to identify important works in a scientific field. The burstness index is the document that caused the evolution of a field or received more attention during a period (Roshni et al., 2014).

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Chen et al. (2009) developed the sigma index to combine both the burstness index based on the speed of citations over time and the BC index based on the identification of intellectual foundations.

$$\sum(v) = (g(v) + 1)^{Burstness(v)}$$

Where $\sum(v)$ represents the sigma index, and for node *v*, the value of g (*v*) is the betweenness centrality index, and the burstness index of node v is defined by the term *Burstness(v)*. Therefore, it can be inferred that scientific works identified as the most important, with a high sigma index, should possess a suitable combination of a high burstness index and a high BC index (Kashani & Roshni, 2019).

For a bibliometric analysis, the first stage is to decide to select the best data source that matches the scientific correlation of our research field (Moral-Muñoz et al., 2020). Therefore, one of the most important issues in data analysis is having a dataset containing useful, reliable, and unbiased data (Chen et al., 2010). WoS is a website that provides access to numerous databases and citation data for 256 disciplines (sciences, social sciences, arts, and humanities). Access to Web-of-Science data is possible by making a subscription. At the beginning of the establishment, the Institute for Scientific Information (ISI) was the main producer, and then Thomson Reuters had its intellectual property, and now Clarivate Analytics is responsible for its maintenance. This database covers various formats of scientific documents, such as full-text articles, review articles, editorials, periodicals, abstracts, collections of articles (journals and books), and technical articles. The total number of records is more than 90 million, and its time coverage is from 1900 until now (Moral-Muñoz et al., 2020).

Researchers use WoS as a leading platform to search for scientific citations and analytical information worldwide. It serves as a research tool supporting a wide range of scientific actions across various fields of knowledge and as a large-scale data set for data studies (Li et al., 2017). In this study, data from scientific documents registered in WoS has been used. The statistical population of the research is the result of searching the scientific documents published in WoS using the keyword technology commercialization[1] and applying the publication time limit to 1973–2022. The researchers extracted 855 scientific documents as the result of the search. These documents were in the form of text format files from WoS and were saved on a personal computer. The documents were then selected and analyzed as the statistical population. We downloaded all records, including title, abstract, keywords, and other important information.

Visualization is useful for using the perceptual abilities of humans to find features in the structure of the network and data (Perer & Shneiderman, 2006). CiteSpace is very useful to map and visualize fields of knowledge using graphic maps (Olawumi & Chan, 2018). We used CiteSpace, Gephi, and RStudio to identify, form, and visualize co-authorship and co-citation networks in this study. We entered the downloaded data into the software to draw the relevant networks and graphs, and extract the corresponding results for presentation.

4. Results

During 1973–2022, the WoS registered 855 scientific documents related to the commercialization of technology, with 1873 people participating in their publication. On average, 2.68 people write each article (Table 1).

[1] Searching term: PY=”1973-2022” AND (TS=”Technolog* Commercializ” OR TS=”Technolog* Commercialis*” OR TS=”Commercializ* of Technolog*” OR TS=”Commercialis* of Technolog*”)

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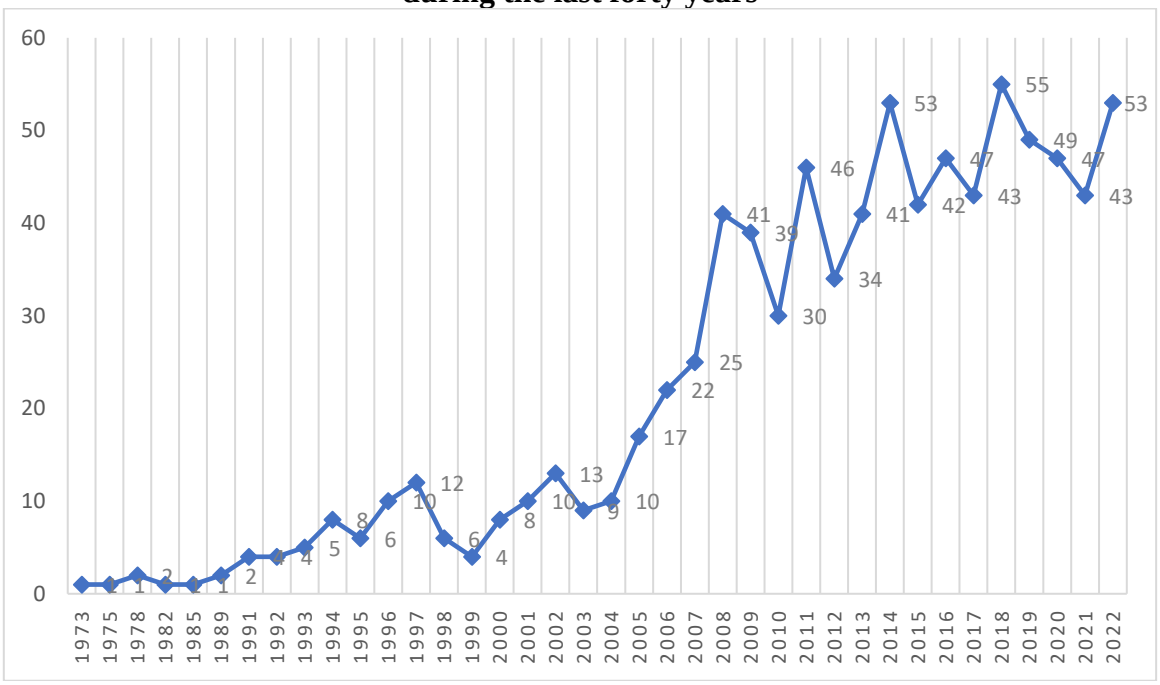
Table 1. General data on scientific products in the field of technology commercialization

Description	Results
Timespan	۱۹۷۳-۲۰۲۲
Documents	۸۵۵
Sources (Journals, Books, etc)	۴۹۳
Authors	۱۸۷۳
Co-Authors per Doc	۲/۶۸
Annual Growth Rate %	۱/۴
International co-authorships %	۱۷/۴۳
References	۲۸۴۲۱
Author's Keywords	۲۰۹۰

We observed the publication dynamics of articles in this field from 1973 to 2021, with the highest number of articles (n = 55) in 2018, accounting for 6% of all articles. Chart 1 shows that there was a significant increase during 2007–2014, suggesting the establishment of a robust social network of knowledge regarding technology commercialization and emerging trends in this field.

Chart 1. Trend of publishing articles in the field of technology commercialization during the last forty years



Constantine Vaitsos published the first article indexed in the field of technology commercialization in WoS. The article, titled "Strategic Choices in Technology Commercialization: the Perspective of Developing Countries," was published in 1973 in the International Social Science Journal. This was the beginning of the growing trend of interdisciplinary research in the category of technology commercialization in the fields of management, economics, social sciences, engineering, agriculture, biology, etc.

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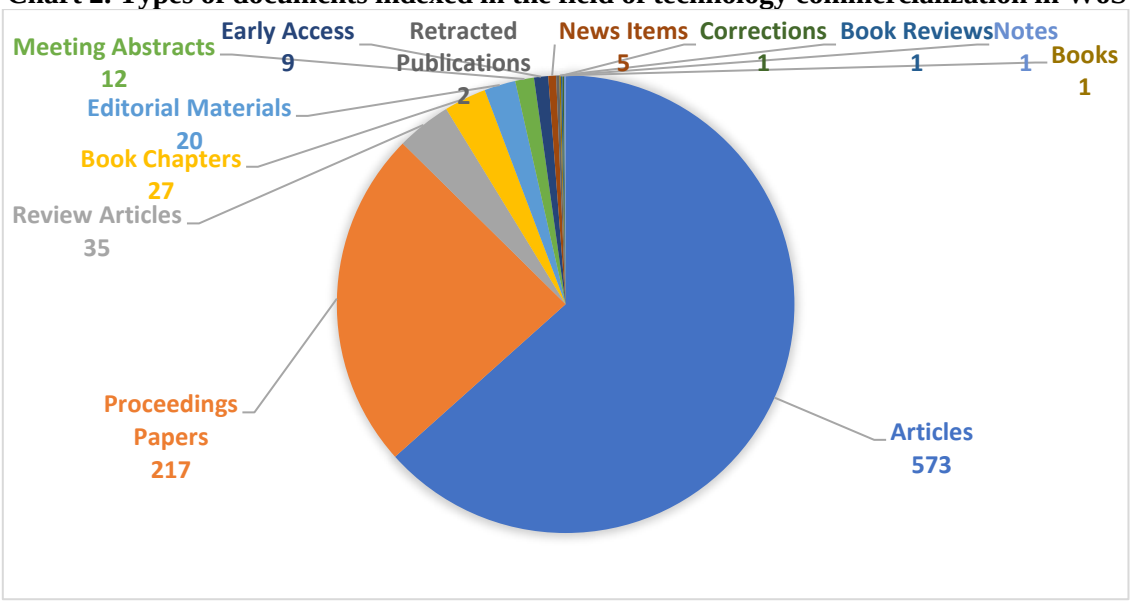
For the types of published texts, the results showed that among the reviewed scientific products, the largest number (n = 573, 67%) were original research articles. Conference articles ranked second, comprising 217 articles (25%), while review articles ranked third with 35 publications (4%) (Chart 2).

Chart 2. Types of documents indexed in the field of technology commercialization in WoS



The review results of scientific products published by the scientists of each country show that the USA and China, in terms of the number of scientific products (47% in total) and citations to articles (57% in total) in the field of technology commercialization, have a significant advantage over other countries in the world and are the flagships of the expansion of this field of knowledge in the world. Table 2 shows the top five countries in terms of the number of scientific products and citations to articles in the field of technology commercialization.

Table 2. Number of scientific products and citations to articles in the field of technology commercialization in countries

Rank	Country	Documents	% of All	Rank	Country	Documents	Average Citations
۱	USA	۳۱۱	36.37%	۱	USA	۷۰۰۰	۲۸/۲۳
۲	CHINA	۹۵	11.11%	۲	CHINA	۲۰۴۳	۱۸/۲۴
۳	KOREA	۷۲	8.24%	۳	UNITED KINGDOM	۱۲۹۹	۴۹/۹۶
۴	UNITED KINGDOM	۴۰	4.67%	۴	GERMANY	۱۰۱۴	۳۷/۱۸
۵	GERMANY	۳۵	4.09%	۵	KOREA	۶۵۴	۹/۹

Among the scientific institutions in the world, the researchers at the University of Austin, Texas, USA, have been the leaders in the production of science in this field with 23 scientific degrees. Also, among the top ten universities, Chulalongkorn University, Thailand, and the National University of Singapore ranked second each with 12 scientific products (Table 3).

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Table 3. Institutions with the most publications in the field of technology commercialization

Rank	Institution	Documents
1	University of Texas at Austin	23
2	Chulalongkorn University	12
3	National University of Singapore	12
4	Case Western Reserve University	11
5	Korea University	11
6	Osaka University	11
7	University of Cambridge	10
8	Kuwait University	9
9	Yonsei University	9
10	Beijing University of Technology	8

The results showed that a total of 493 journals have published all documents related to technology commercialization. Two publications, Technology Transfer and Sustainability, have published the most articles in this field: 30 articles and 26 articles respectively (Table 4).

Table 4. Publications with the most participation in the publication of scientific documents in the field of technology commercialization

Rank	Journals	Documents
1	JOURNAL OF TECHNOLOGY TRANSFER	30
2	SUSTAINABILITY	26
3	TECHNOLOGICAL FORECASTING AND SOCIAL CHANGE	18
4	IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT	17
5	RESEARCH POLICY	16
6	INTERNATIONAL JOURNAL OF TECHNOLOGY MANAGEMENT	14
7	R&D MANAGEMENT	13
8	TECHNOVATION	13
9	JOURNAL OF PRODUCT INNOVATION MANAGEMENT	12
10	TECHNOLOGY ANALYSIS & STRATEGIC MANAGEMENT	12

Among the researchers in the field of technology commercialization, based on the number of scientific documents produced, Jarunee Wonglimpiyarat from the Massachusetts Institute of Technology (MIT) is at the top of the authors in this field with the publication of 13 documents (Chart 3).

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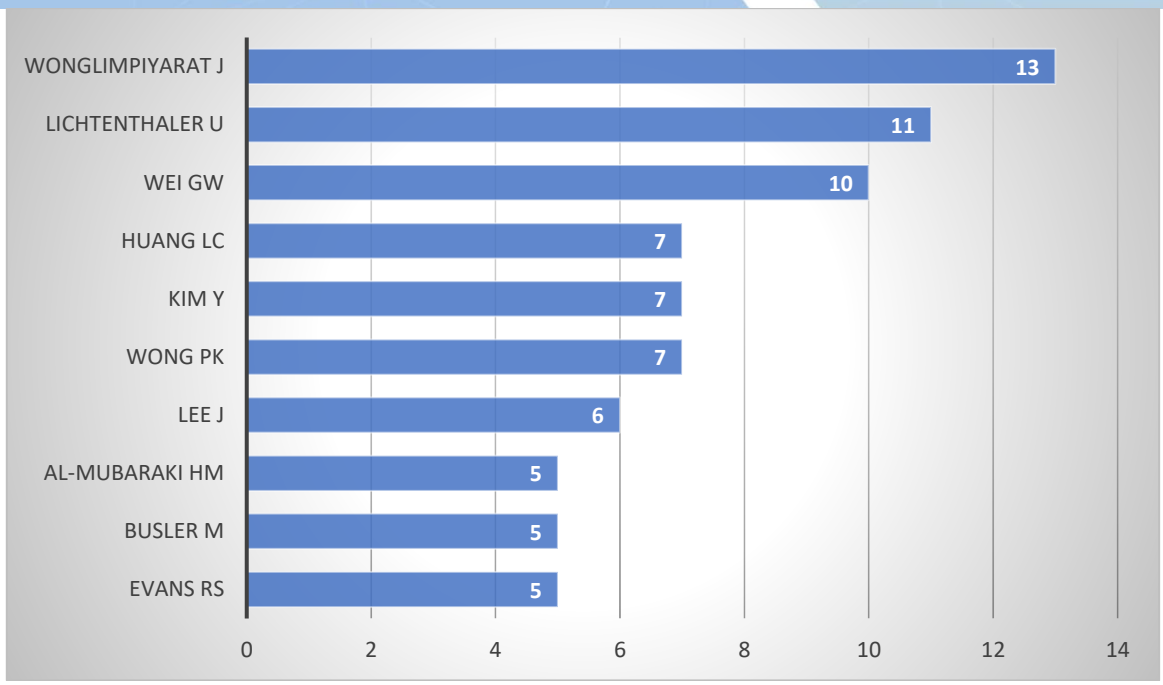

Chart 3. Top researchers in the world in the field of technology commercialization according to the number of scientific publications

Chart 4 shows the method of publication and citation of the scientific products of the authors who have the most articles over time. The size of the circles indicates the number of published articles, and the color intensity of the circles indicates the total citations to the articles (Chart 4).

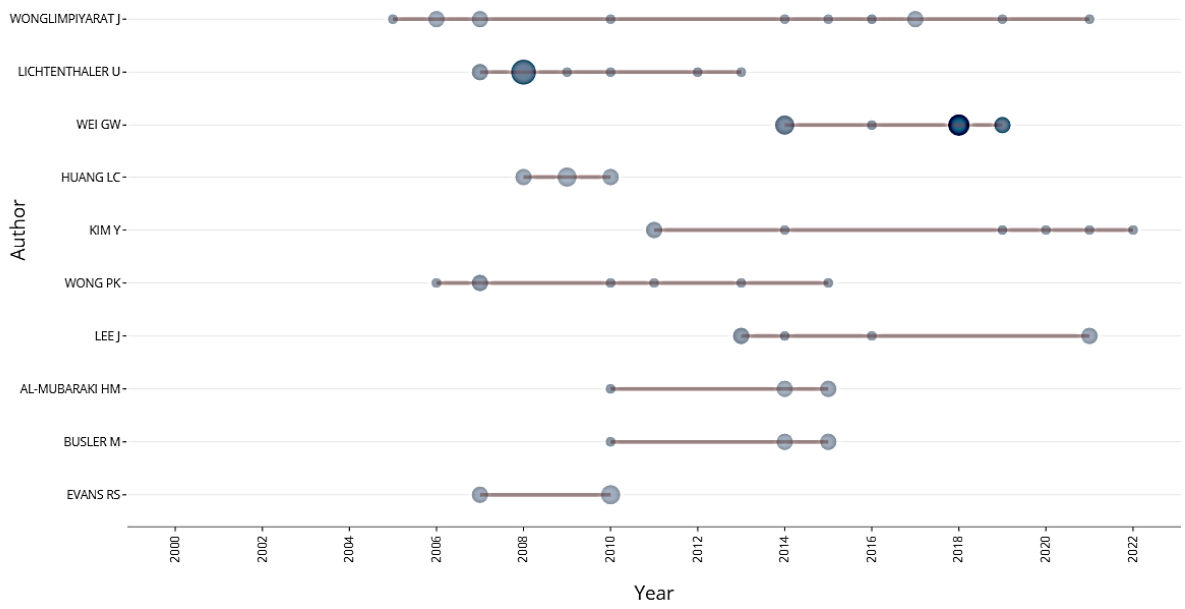

Chart 4. Publishing the scientific products of top authors over time

Investigating co-authorship networks allows researchers to get to know the pattern of researchers' participation in their field, identify individuals, institutions, and organizations with

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high productivity and the core of their field, and discover a topic of interest in their field (Soheili et al., 2015). Figure 1 shows part of the co-authorship network of active researchers in the field of technology commercialization using Gephi. The size of the circles and the labels of the corresponding names indicate the level of cooperation with other authors, and the color of the circles and edges indicate the clustering of the co-authors in the network.

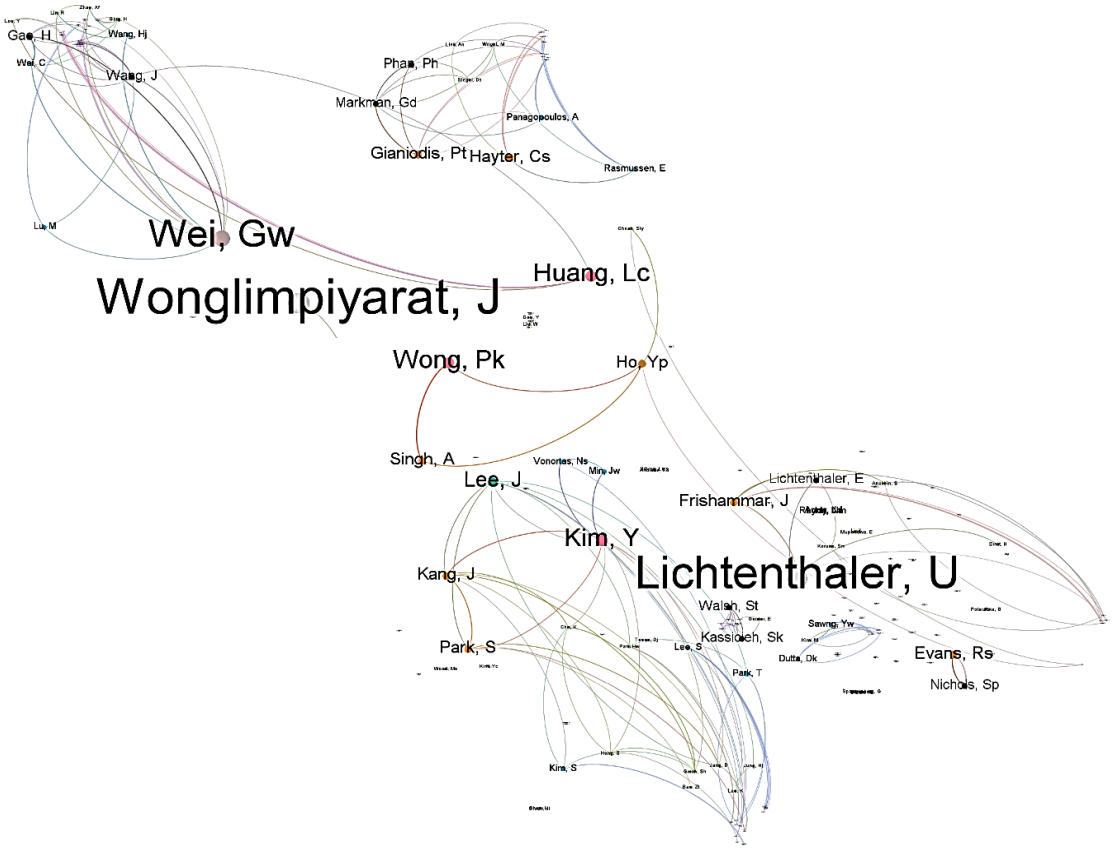

Figure 1. Co-authors network active in the field of technology commercialization.

An article titled "Successful Industrial Innovation: Critical Factors for the 1990s" by Rothwell, published in the Journal of Research and Development Management in 1992, has the highest number of citations (n = 609) in the technology commercialization category, as shown in Table 5.

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Table 5. Articles with the most citations in the field of technology commercialization

Rank	Authors	Title	Year	Documents	Citation per year
۱	Roy Rothwell	Successful industrial innovation: critical factors for the ۱۹۹۰s	۱۹۹۲	609	19.03
۲	Shaker A. Zahra, Anders P. Nielsen	Sources of capabilities, integration and technology commercialization	2002	384	17.67
۳	Ulrich Lichtenthaler	Open Innovation in Practice: An Analysis of Strategic Approaches to Technology Transactions	2008	350	21.80
۴	David J.Teece	Reflections on “Profiting from Innovation”	2006	347	19.24
5	Brad Barbazuk et al.	SNP discovery via 454 transcriptome sequencing	2007	291	17.12
6	Rohan Stanger et al.	Oxyfuel combustion for CO2 capture in power plants	2015	270	30.00
7	Colin C. J. Cheng, Eelko K. R. E. Huizingh	When Is Open Innovation Beneficial? The Role of Strategic Orientation	2014	249	24.90
8	Gideon D.Markmana et al.	Innovation speed: Transferring university technology to market	2005	247	13.00
9	Scott Shane	Encouraging university entrepreneurship? The effect of the Bayh-Dole Act on university patenting in the United States	2004	228	11.40
۱۰	Marc Gruber et al.	Look Before You Leap: Market Opportunity Identification in Emerging Technology Firms	2008	227	14.19

The co-citation network measures the number of cases in which two cases, such as authors, documents, journals, or institutions, are cited by the same article (Chen, 2006). Figure 2 shows part of the co-citation network of articles in the field of technology commercialization using Gephi. For this network, the size of each node (article) is proportional to the co-citation of that article.

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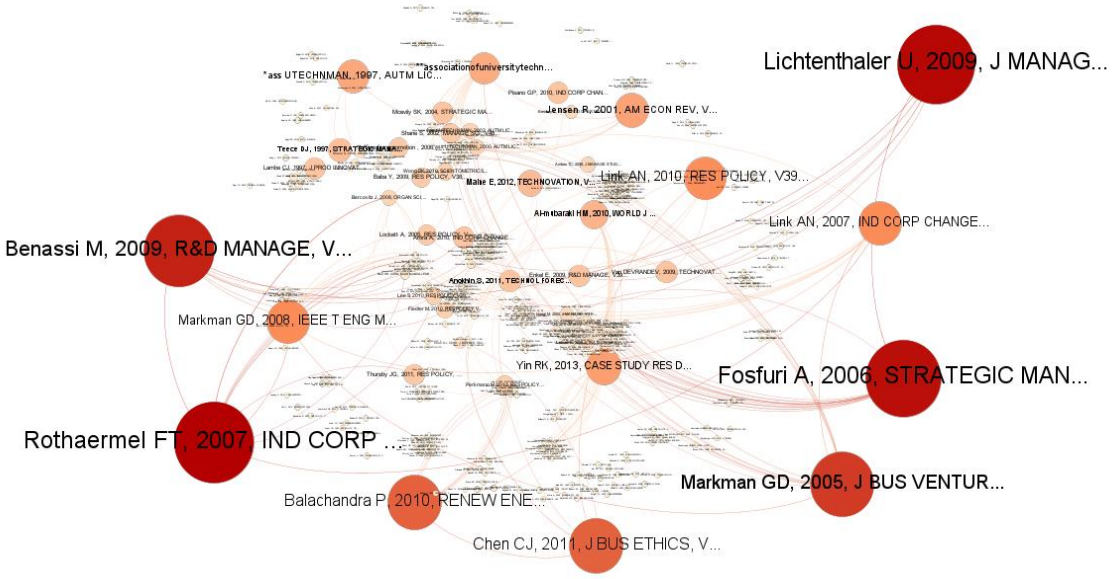

Figure 2. Part of the co-citation network of scientific documents in the field of technology commercialization indexed in WoS

We calculated the betweenness centrality (BC) index for all the nodes of the co-citation network of the articles indexed in WoS using Gephi. The results for the 10 documents with the highest index are listed in Table 6.

Table 6. Highest centrality of co-citations of scientific documents in the field of technology commercialization

Rank	Title	BC
۱	Rothaermel FT, 2007, IND CORP CHANGE, V16, P691	0.06076854
۲	Lichtenthaler U, 2009, J MANAGE STUD, V46, P1315	0.05902828
۳	Fosfuri A, 2006, STRATEGIC MANAGE J, V27, P1141	0.05735099
۴	Benassi M, 2009, R&D MANAGE, V39, P68	0.0533034
۵	Markman GD, 2005, J BUS VENTURING, V20, P241	0.0476614
6	Chen CJ, 2011, J BUS ETHICS, V104, P525	0.03959811
7	Balachandra P, 2010, RENEW ENERG, V35, P1842	0.03945974
8	Markman GD, 2008, IEEE T ENG MANAGE, V55, P29	0.03020364
9	Link AN, 2007, IND CORP CHANGE, V16, P641	0.03020364
10	Link AN, 2010, RES POLICY, V39, P589	0.02962665

We measured the betweenness centrality index and burstness index of technology commercialization articles using CiteSpace. CiteSpace offers a spectrum of colours to indicate the period when a scientific document has flourished and the number of citations to that document has increased. In this spectrum, the white area indicates the lowest citation, and the red area indicates the highest citation during the specified period. In this study, the burstness index of scientific documents has been calculated over five ten-year periods, as shown in Table 7. The results show that among the 855 scientific documents published in the field of technology commercialization, 7 documents have the highest burstness index.

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Table 7. Burstness index of scientific documents in the field of technology commercialization

Rank	References	Begin-End	Burst	BC	1982-2021
1	Arora A, 2008, ACAD MANAGE REV, V27, P1275	2008-2011	5	0.001406687	
2	Kirchberger MA, 2016, J TECHNOL TRANSFER, V41, P1077	2017-2021	4.82	0.00	
3	Chen CJ, 2009, J BUS RES, V62, P93	2009-2016	4.8	0.00464098	
4	Perkmann M, 2013, RES POLICY, V42, P423	2013-2021	4.52	0.01006678	
5	Lichtenthaler U, 2005, INT J MANAG REV, V7, P231	2007-2011	4.11	0.003256282	
6	Chesbrough H, 2003, CALIF MANAGE REV, V45, P33	2007-2011	4.04	0.00213835	
7	Lichtenthaler U, 2009, J MANAGE STUD, V46, P1315	2009-2016	3.91	0.05902828	

As mentioned earlier, the sigma index shows which academic document has the most effect on the field of knowledge. In fact, this index indicates which document has the highest burstness index and betweenness centrality index in a scientific field. These documents can play a central role in research related to their scientific structure and connect one or more different scientific fields with the scientific structure (Roshni et al., 2017). Now, according to the results of the calculation of the betweenness centrality index and burstness index, the sigma index will be calculated according to the sigma index formula as follows:

$$Sigma = (Betweenness\ Centrality + 1)^{Burstness}$$

Table 8 shows the results of calculating sigma index values for the top scientific documents in the field of technology commercialization indexed in WoS.

Table 8. Data on the best scientific documents in the field of technology commercialization based on the value of the sigma index

Rank	Authors	Title	Year	Sigma	Citations	Burstness Rank
۱	Ulrich Lichtenthaler & Eckhard Lichtenthaler	A Capability-Based Framework for Open Innovation: Complementing Absorptive Capacity	2009	1.2513781	1413	7

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۲	Markus Perkmann et al.	Academic engagement and commercialization: A review of the literature on university–industry relations	2013	1.04631487	2470	4
۳	Chung-Jen Chen	Technology commercialization, incubator and venture capital, and new venture performance	2009	1.02256868	337	3
۴	Ulrich Lichtenthaler	External commercialization of knowledge: Review and research agenda	2005	1.01345124	299	5
۵	Henry Chesbrough	The Logic of Open Innovation: Managing Intellectual Property	2003	1.00866705	1283	6
۶	Ashish Arora et al.	Markets for Technology: The Economics of Innovation and Corporate Strategy	2008	1.00705325	2053	1
۷	Markus A. Kirchberger & Larissa Pohl	Technology commercialization: a literature review of success factors and antecedents across different contexts	2016	1	155	2

The article "A Capability-Based Framework for Open Innovation: Completing Absorptive Capacity" by Ulrich Lichtenthaler and Eckhard Lichtenthaler (2009) ranked first in Table 8 as the most influential scientific document in the field of technology commercialization. An article entitled "Academic Partnership and Commercialization: A Review of University-Industry Relations Literature" by Perkmann et al. (2013) ranked second. An article by Chen (2009) entitled "Technology Commercialization, Incubator and Venture Investment, and New Risk-Taking Performance" ranked third among the most influential scientific products in the field of technology commercialization. Ulrich Lichtenthaler (2005) published an article entitled "External Commercialization of Knowledge: An Agenda for Investigation and Research," which ranked as the fourth most influential scientific document in this field of knowledge. An article entitled "Logic of Open Innovation: Management of Intellectual Property" by Chesbrough (2003) ranked fifth, which is the first influential article on the field of technology commercialization. The book "Technology Markets: Economics of Innovation and Corporate Strategy" by Arora et al. (2008) ranked sixth. Kirchberger and Pohl's (2016) article, "Technology Commercialization: A Review of the Literature of Success Factors and Records in Different Fields," ranked seventh, making it the most recent influential article in the field of technology commercialization.

Keywords used by authors in scientific documents are important because they are the primary concepts that the author uses to communicate with the reader (Akbari et al., 2020). Through reviewing scientific documents published in the field of technology commercialization, we

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discovered that authors in this field utilized 1425 keywords in their scientific products. Figure 3 shows the most frequently used keywords of the authors in the form of hyper-words.

Figure 3. The most frequently used keywords by authors in the field of technology commercialization

Keywords are descriptive and meaningful words and serve as a reference point for finding and understanding the concepts and content of research articles. They also show the development of the research field over time (Zhao, 2017). In order to better understand the relevance of keywords in this field of knowledge, we drew the co-occurrence network of keywords of authors in the field of technology commercialization using Rstudio (Figure 4). The size of each node (keyword) in this network represents the centrality of the keyword, and the color of the node represents the clustering of keywords in the network. As shown in Figure 4, after the keyword "technology commercialization," the keywords "technology transfer," "innovation," and "entrepreneurship" play the greatest role in the connection of knowledge concepts in this field.

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Figure 4. Co-occurrence network of keywords of authors in the field of technology commercialization

5. The discussion and conclusion

The concept of technology commercialization has been increasingly considered by researchers around the world. In this study, it was attempted to present a general picture of the world situation in the field of technology commercialization through a selective review of WoS as a research topic. Based on the literature review, we assumed that WoS as a research tool and data collection tool has a significant place in many academic fields, and a detailed analysis enables us to quantitatively address technology commercialization. The results showed that researchers around the world started publishing ISI articles on this topic 40 years ago, and the number of articles in this field is still increasing. For the trend of scientific production in general, the number of articles was less than 10 before 1993, and it gradually grew. The greatest increase in the number of articles occurred from 2007 onwards. Most of the documents in this study were original research articles. The most productive journals in this study were Technology Transfer with an impact factor of 5.337 and a quartile of 1, which started operating in 1977, and Sustainability with an impact factor of 3.889 and a quartile of 2, which started in 2009, respectively. It should be noted that among the top ten articles with the most citations in the field of technology commercialization, two articles have been published in Research Policy, which, as shown in Table 3, ranked fourth among the top publications in this field of knowledge in the world. The universities of California, Texas, and Georgia have the best performance, with a total of 53 articles and 8.5% of scientific products in this field. 1309 authors from 52

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countries around the world have participated in the production of scientific documents in the field of technology commercialization, and the three most productive authors were Jarunee Wonglimpiyarat, Ulrich Lichtenthaler, and Guiwu Wei, who published a total of 34 articles and 5.5% of the products in this field.

According to the study results, by identifying the authors and key institutions active in the field of technology commercialization, government organizations and private companies can develop policies or patterns of technology commercialization and consult on plans. Academics can also use the results to network with other researchers in their specialized field.

The results of the analysis and review of the co-citation network in the field of technology commercialization showed that seven scientific documents have had the most effect on the trend of this field of knowledge, in the sense that both the number of citations and the frequency of citations were together for a long time and played an effective role in connecting the scientific topics of this field. Since in these articles the most important topics of the scientific field of technology commercialization have been discussed, a new topic classification for the literature in this field can be considered. Upon examination of these transformative scientific documents in the field of technology commercialization, we discovered that the articles discuss topics including open innovation, industry and university relations, venture investment, foreign commercialization, intellectual property, and technology markets.

One of the articles in the field of technology commercialization, which is ranked seventh among transformative scientific documents in this field (Table 8), is an article entitled "Technology Commercialization: Review of the Literature of Success Factors and Records in Various Fields" by Kirchberger and Pohl (2016). In Table 9, the classification of the most important topics of transformative scientific documentation obtained from this research is compared with the classification proposed by Kirchberger and Pohl (2016), and the factors introduced by these researchers are in the subcategory of the relevant scientific field. The study includes the results.

Table 9. Thematic comparison of transformative scientific documents with the classification proposed by Kirchberger and Paul (2016)

Transformative Issues in Technology Commercialization	Success Factors of Technology Commercialization by Kirchberger and Pohl (2016)
Open innovation	Innovation culture Networking activities
Industry and university relations	University policy and structure Researchers' individual characteristics Industry closeness Management techniques Team structure
Intellectual property	Property rights
Technology markets	Technology suitability for commercialization Technology application value Intermediaries' support Resource availability
Foreign commercialization	Technology transfer strategy
Venture investment	----------

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Comparing the contents in Table 9, we can conclude that "venture investment" has influenced the literature on technology commercialization, which is one of the topics in this study. It is one of the key factors in the suggested categories.

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