Visualizing and mapping the research on patents in information science and management science

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ABSTRACT

The aim of this work is to present the development of patent-research through the years (1996-2011) from a bibliometrics and scientific visualization approach. Our corpus consists of 1529 original research and review articles obtained from an initial topic search on patents retrieved from the Institute of Scientific Information's (ISI) Web of Science (WoS) database. CiteSpace II software was used to represent the knowledge domains of country, institution, author co-citation network, journal co-citation network, document co-citation network, and networks of keywords, related with patent-research in the field of information science and management science. Results show that USA is the most productive country in patent-research; Katholieke University Leuven, University of Sussex, Georgia Institute of Technology, and Harvard University are the most productive institutions. Cohen WM is the mostly co-cited author, followed by Jaffe AB, Griliches Z, Hall BH and Narin F. "Research policy" is the most cited journal for published articles on patents research. The visualization of data with the CiteSpace II software revealed intellectual bases and research fronts for the patent-research development in the given time window.

Keywords: Patents analysis; CiteSpace; Visualization; Co-citation analysis; Scientometrics.

INTRODUCTION

Patents provide an ample source of technical and commercial valuable information, therefore patent analysis has long been considered a vital tool for Research and Development management/technology assessment, market value and potential and competitive intelligence by many researchers. Up to now, patent analysis has been used in many different contexts, such as intellectual property management, merger and acquisitions, targeting and due diligence, stock market valuation, intelligent transportation systems, innovation assessment, technological convergence, and strategic planning for technology development (Abraham and Moitra 2001; Breitzman and Mogee 2002; Breitzman and Thomas 2002; Karvonen and Kässi 2011; Liu and Shyu 1997; Wu and Lee 2007). There are also many studies in the literature on patent analysis for technology strategy from different perspectives. In order to exhibit the development of Taiwan to an "innovation-based economy", Chen et al. (2005) used patent analysis to define "core technologies and key industries" of Taiwan from 1978 to 2002. Levitas, McFadyen and Loree (2006) utilized patent analysis to investigate the decisions of a firm to pursue new technologies across varying levels of technological turbulence. Daim et al. (2006) forecast for emerging technology areas by integrating the use of bibliometrics and patent analysis. However, conventional patent analysis is subject to some limitations, since it usually uses bibliographic methods to generate the statistical figures. Recent studies have applied text-mining and data-mining methods to patent analysis to overcome these limitations (Tseng, Lin and Lin 2007; Yoon and Park 2004). Dereli and Durmusoglu (2009) used a fuzzy-based clustering methodology to discover technology trends related to the textile technologies. Lee et al. (2009) used patent analysis and road-mapping together to discover technological intelligence and new business opportunities. Daim et al. (2011) analyzed patents of wind energy technology via the patent alert system. Yoon and Kim (2011) proposed a patent network based on semantic patent analysis using subject-action-object (SAO) structures. Zhang et al. (2012) utilized the artificial neural network to explore the nonlinear relationships between patent performance and the corporate performance of the pharmaceutical companies. According to Kim and Seol (2012), core technologies were identified from the perspectives of co-occurrence, relatedness, and cross-impact based on patent co-classification information with consideration of the overall interrelationships among technologies.

As briefly described above, although there have been many works in literature about patent-research in the last decades, a few researchers (Sternitzke, Bartkowski and Schramm 2008; Kim, Suh and Park 2008) have used visualization and mapping techniques to study the literature of patent-research. These works are broader in scope than most of the previous domain-specific network analysis studies for example by Zhao and Strotmann (2008), Ding et al. (2009) and Hu et al. (2011). The present paper, in contrast, highlights some types of network analysis of patent-research data using visualizing and mapping software CiteSpace II. We shall address research questions such as: *What are the key subject categories in the patent-research field? Which journals or authors are the most cited? Which countries or institutions are major knowledge producers? What are the prominent articles? Which keywords are used mostly?*

This study analyzes patent research published from 1996 to 2011 with a total of 1529 papers in information science and management science. In order to address the research questions, CiteSpace II is applied as a systematic and objective way to map the structure of patent-research field.

MATERIALS AND METHODS

In this work, the literature is retrieved as of April 2012. A topical search on the Web of Science (WoS) database (SCI-EXPANDED, SSCI, A and HCI) using the term "patent*" was performed to identify papers on patent covering the time period between Jan 1st 1996 and Dec 31st 2011. We added the specifications: WC = (Information Science and Library Science OR Management), and document type=(articles or proceedings paper or review articles). It produced a total of 1529 records. Proceedings, book reviews, editorials, letters and other document types were excluded. The full bibliographic records including authors, titles, abstracts and reference lists for 1529 articles were downloaded.

CiteSpace was used to produce and analyze co-citation networks among highly cited articles. It is a freely Java visualization application developed by Chen Chaomei from Drexel University USA, which combines bibliometrics, information visualization methods, and data mining algorithms in an interactive visualization tool for extraction of patterns in citation data. CiteSpace supports author, article, journal, institution, and country nodes as well as phrases extracted from titles and abstracts of articles. Chen (2004) used CiteSpace I (the initial version of CiteSpace) to reveal turning points in superstring revolutions in physics. Later the new version called CiteSpace II appeared, with three central concepts: burst detection, betweenness centrality, and heterogeneous networks as its new features. These concepts are helpful in addressing three practical issues: identifying the nature of a research front, labeling a specialty, and detecting emerging trends and abrupt changes in a timely manner. The general procedure of visualization analysis with CiteSpace consists of nine steps: (1) identify a knowledge domain; (2) data collection; (3) extract research front terms; (4) time slicing; (5) threshold selection; (6) pruning and merging; (7) select the layout styles; (8) visual inspection; and (9) verify pivotal points (Chen 2006). Recently, this software has become the most distinctive and influential visual information software in field of information analysis in the world. Various types of fields are as follows: data and knowledge engineering (Chen et al. 2008), latent semantic analysis (Tonta and Darvish 2010), heat integration techniques (Morar and Agachi 2010), pervasive and ubiquitous computing (Zhao and Wang 2011), agent-based computing (Niazi and Hussain 2011), nanobiopharmaceuticals (Chen and Guan 2011), regenerative medicine (Chen et al. 2012), terahertz technology (Liu 2012), knowledge visualization (Chen, Zhao and Xu 2012), and information retrieval (Rorissa and Yuan 2012).

RESULTS AND DISCUSSION

Analysis of Country (Region)

Figure 1 presents a network consisting of 61 nodes and 41 links on behalf of the collaborating countries between 1996 and 2011. As can be seen, the major contribution of the total output mainly came from four countries or regions, namely, USA, England, Taiwan and Germany. Clearly, USA is the largest contributor publishing 463 papers. In other words, USA has a dominant status in the patent-publications productions, which produced about one third of world's total during this period. England with a frequency of 136 articles ranks second. Taiwan ranks third with 108 papers. Germany is at the fourth place with a frequency of 105 articles. These countries are mainly distributed in Europe, North America, Asia and South America. The contribution of European countries is very significant and mainly includes England (136), Germany (105), Italy (89), Spain (86), Netherlands (59), Belgium (59), France (58), and Sweden (30). Besides USA, Canada is another North America country ranking the seventh with 65 papers.

The six nodes coming from Asia are Taiwan, South Korea, Japan, China, India, and Singapore with 108 times, 53 times, 50 times, 46 times, 28 times, and 28 times, respectively. Brazil in South America published 19 papers and ranks nineteenth. At the same time, the other two countries in BRICS also participate in patent-research, namely, Russia (3) and South Africa (4). An interesting observation is that there are certain countries which have relatively low frequency but have high value of centrality among all other countries. England leads other countries, which are shown as node rings in purple in Figure 1. This is followed by papers originating from France, Germany, Switzerland, Italy, and so on. In other words, they are pivotal nodes in the network with the highest betweenness centrality. In addition, five countries or region are found to have citation bursts: Taiwan (8.52), England (7.72), India (7.46), Netherlands (5.72), and China (5.21), suggesting that they have abrupt increases of citations detected.

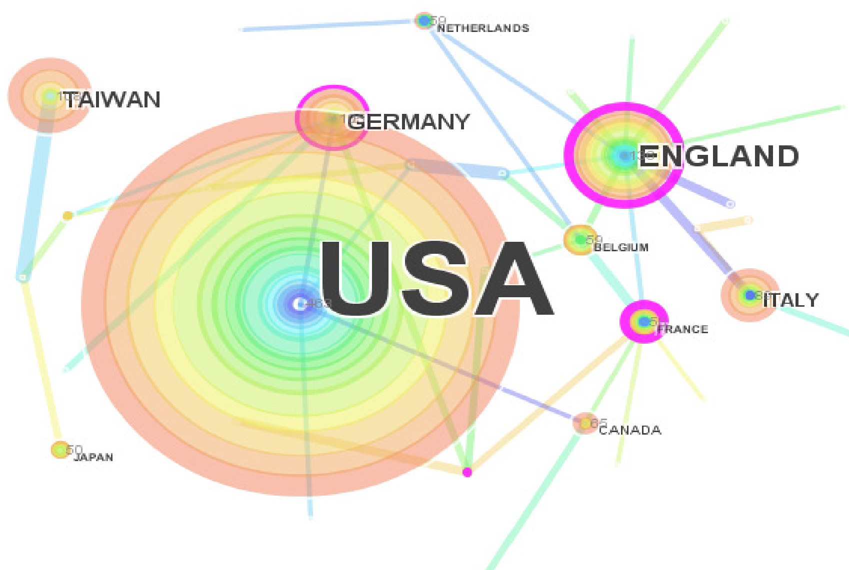


Figure 1: A Network of Country of 61 Nodes and 41 Links on Patent-research Publications

Analysis of Institution

Figure 2 depicts the visualization of the distribution of institutions. Note that the frequency analysis was based on a total of 269 institutions. Obviously, the important research institutions are mainly located in USA, Europe (UK, Belgium), Taiwan, and Canada. The research institutions in USA are Georgia Inst Technol, Boston Univ, Harvard Univ, Univ Calif

Berkeley, and Univ Michigan. Georgia Inst Technol in the USA takes the first place with a frequency of 41 articles. The second place is Boston Univ with a frequency of 31 articles. Apart from that, there are still other institutions participating in patent-research, such as Katholieke Univ Leuven (Belgium), Univ Sussex (UK), Natl Taiwan Univ (Taiwan), Natl Tsing Hua Univ (Taiwan), and Univ Toronto (Canada). In addition, Asian institutions have also played an important role in the patent-research. For example, Natl Inst Sci Technol and Dev Studies (India) and Natl Univ Singapore (Singapore) published 15 papers in this field respectively. Therefore, we regard these institutions the most productive based on the number of patent-research papers published.

Figure 2: An Institution Network of 269 Nodes and 101 Links on Patent-research Publications

Analysis of Journal Co-citation Network

Figure 3 displays a journal co-citation network of patent-research papers published between 1996 and 2011. The network contains the most frequently cited 74 journals along with 409 co-citation links among them. The journals are identified based on their centrality. First, we focus on the journals sorted in terms of article frequency. It can be seen that ‘‘RES POLICY’’ is at the top with a frequency of 1099 times, followed by ‘‘AM ECON REV’’ and ‘‘MANAGE SCI’’ with 591 and 582 co-citation frequencies respectively. ‘‘STRATEGIC MANAGE J’’ is the next with 480 frequencies. This is followed by ‘‘RAND J ECON’’, ‘‘SCIENTOMETRICS’’, ‘‘ADMIN SCI QUART’’ ‘‘REV ECON STAT” and “J ECON LIT’’. Top 10 journals can be divided into 3 subject categories, namely “Management”, Economics”, and “Information Science and Library Science”. Management is the leading subject category. Three important journals in this category are Research Policy (RES POLICY), Management Science (MANAGE SCI) and Strategic Management Journal (STRATEGIC MANAGE J). It gives a slightly different set of core journals sorted in terms of centrality and article frequency. ‘‘SCIENTOMETRICS’’ has the highest value of centrality among all the journals, suggesting that it serves as a broker bridging the adjoining journals in the journal co-citation network. In addition, ''RES POLICY'', and ''STRATEGIC MANAGE J'' are also some of the top journals in terms of centrality. These three journals are core nodes that make connections to other nodes in the journal co-citation network.

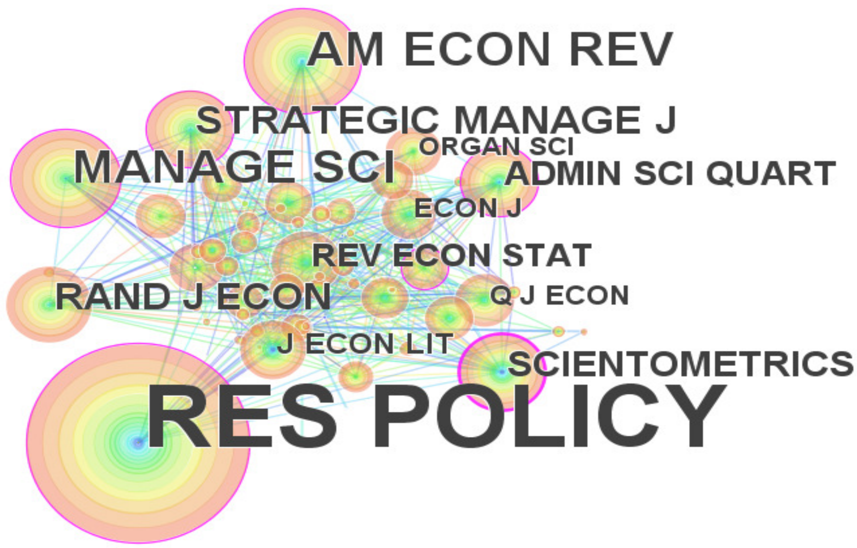


Figure 3: A Journal Co-citation Network of 74 Nodes and 409 Links on Patent-research Publications

Analysis of Author Co-citation Network

In this section, we present the co-authorship map of 123 authors and 1246 co-authoring links (1996-2011, slice length=1 year) (Figure 4). All 123 authors have at least one citation. Each node stands for one author; citation tree rings represent the citation history of an article. The larger the rings are, the more papers they represent. Links between authors are co-authorship. The most prominent node in the visualization is COHEN WM with 386 citations, and the centrality is 0.13. The second prominent node is JAFFE AB, whose frequency is 383, and the centrality is 0.11 in the network. JAFFE AB is usually associated with research on innovation, patent citation and knowledge spillover (Jaffe, Trajtenberg and Henderson 1993; Jaffe and Trajtenberg 1996; Jaffe, Fogarty and Banks 1998; Jaffe 2000; Jaffe, Trajtenberg and Fogarty 2000). GRILICHES Z, with a frequency of 356 and a centrality of 0.15, ranks third in the network. GRILICHES Z (Griliches, Pakes and Hall 1987; Griliches 1990; Griliches, Hall and Pakes 1991; Griliches 1992) focuses on the relationship between patents and economic growth, research and development spillovers and productivity. As shown in Figure 4 that the node for NARIN F has purple rings, indicating that it is pivotal node with the highest value of betweenness centrality (0.16). His representative work entitled "The increasing linkage between US technology and public science" (Narin, Hamilton and Olivastro 1997) had been cited more than 900 times in Google Scholar as of December 2012. Here we observe that GRILICHES Z (0.15), COHEN WM (0.13), JAFFE AB (0.11) and MANSFIELD E (0.11) are also some of the top authors in terms of centrality.

Therefore, these five authors are core nodes that make connections to other nodes in the author co-citation network of patent-research publications.

Figure 4: An Author Co-citation Network of 123 Nodes and 1246 Links on Patent-research Publications

Analysis of Document Co-citation Network

In this part of the study, we identify the most cited patent-research papers using document co-citation analysis. Figure 5 displays a time-zone view of document co-citation network between 1996 and 2011. The network is composed of 174 reference nodes and 171 co-citation links between these 174 documents on the network. Pivotal-point papers with high betweenness centrality scores are depicted by nodes with purple rings. They are the bridges that connect different parts of the network together.

Figure 5 enables the identification of the most important documents that constitute the knowledge base for the present patent-research. It may be seen that the key documents with most cited frequencies belong to the earliest period, which include GRILICHES Z (1990) with a total of 257 citations, and COHEN WM (1990) with 201 times (Table 1). It is clear that the time-zone visualization graph shows that the earlier publications, e.g., NELSON R R (1982), HAUSMAN J (1984), TEECE DJ (1986) and JAFFE AB (1986) present intellectual bases for later patent-research. Subsequently, LEVIN RC (1987), GRILICHES Z (1990), COHEN WM (1990), TRAJTENBERG M (1990), and JAFFE AB (1993) become patent-research fronts, and provide intellectual bases for the follow-up patent-research. Hall BH (2001) and Hall BH (2005) present intellectual bases for the latest patent-research.

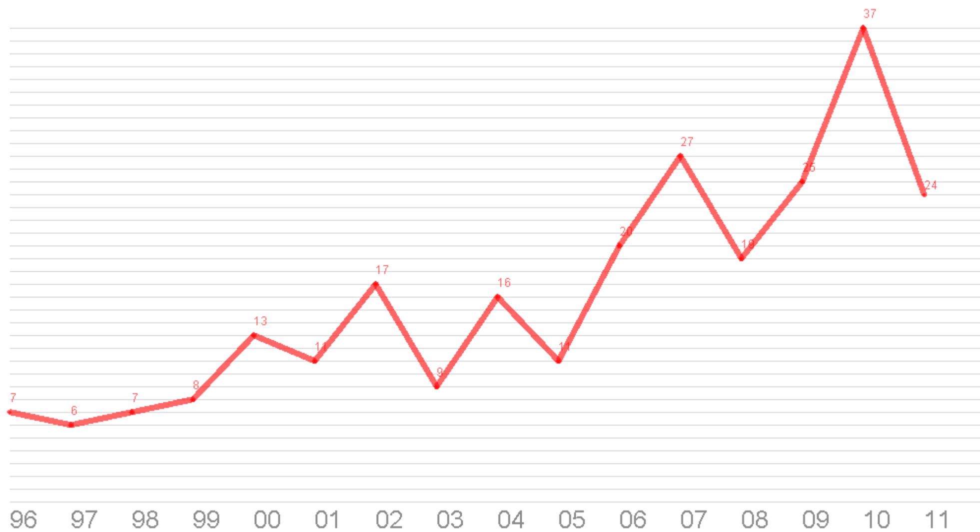
Figure 5: A Network of Document Co-citation of Patent-research Publications between 1996 and 2011. This Network consists of 174 Papers and 171 Salient Co-citation Links

The top 10 cited papers with co-citation frequency over 90 times are presented in Table 1, along with Cluster ID. These papers are distributed in different clusters. Top 10 highly cited papers were cited a total of 1324 times between 1996 and 2011, with an average 132 times per year. Note that, as shown in Figure 5 and Table 1, the most prominent article in the visualization is Griliches (1990) in Cluster #48 in terms of its frequency. The paper entitled "Patent statistics as economic indicators: A survey" was previously published in the *Journal of Economic Literature* in 1990, and later as a chapter appeared in the National Bureau of Economic Research (NBER) book "R and D and Productivity: The Econometric Evidence". This work has received a total of 256 citations in the Web of Science. The citation figure is well over 3680 in Google Scholar. The second important paper on patent-research by Cohen (1990) in Cluster #1, entitled "Absorptive capacity: a new perspective on learning and innovation", was published in the *Administrative Science Quarterly.*

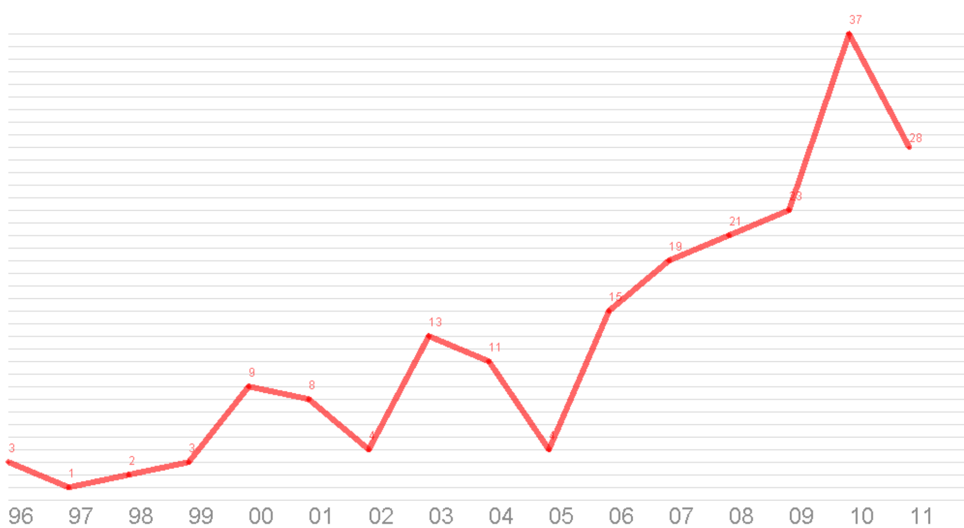
Table 1: The Most Cited Papers with Co-citation Frequency of over 90 Times

Rank	Frequency	Author	Source	Year	Cluster #
1	257	GRILICHES Z	J ECON LIT	1990	48
2	201	COHEN WM	ADMIN SCI QUART	1990	1
3	175	JAFFE AB	Q J ECON	1993	39
4	164	NELSON RR	EVOLUTIONARY THEORY	1982	6
5	159	LEVIN R	BROOKINGS PAPERS EC	1987	41
6	142	TRAJTENBERG M	RAND J ECON	1990	18
7	119	HAUSMAN J	ECONOMETRICA	1984	43
8	112	TEECE DJ	RES POLICY	1986	42
9	103	JAFFE AB	AM ECON REV	1986	37
10	93	NARIN F	RES POLICY	1997	27

Figure 6 presents the citation history graphs for the two most cited papers. The horizontal axis is the year and the vertical axis is the number of citations. Both of them started to be cited in 1996, and little citations were generated on patent-research in the next three or four years. These two papers experienced a sharp upturn from 2005 to 2006, but a stronger decrease from 2010 to 2011. Interestingly, both papers reached a peak of 37 in 2010.



GRILICHES Z (1990)



COHEN WM (1990)

Figure 6: The Citation Histories of GRILICHES (1990) (top) and COHEN (1990) (bottom)

Analysis of Co-citation Clusters

CiteSpace can divide the co-citation network of co-cited documents into different clusters. The cluster view provides an overview of research areas within the field of patent during the years from 1996 to 2011. Figure 7 shows a co-citation timeline visualization of the network with 49 clusters labellings. Table 2 lists ten major clusters by their size (or number of members in each cluster), together with one of the most representative citing papers in each cluster. Larger clusters tend to be more representative than that of small clusters. We notice here that cluster #26 (novel field) and #31 (academic) are the largest clusters which both consist of 7 publications. Next are cluster # 8 (highest technological opportunity) and #15 (country), which have 6 publications respectively. There are 5 publications in the other six clusters.

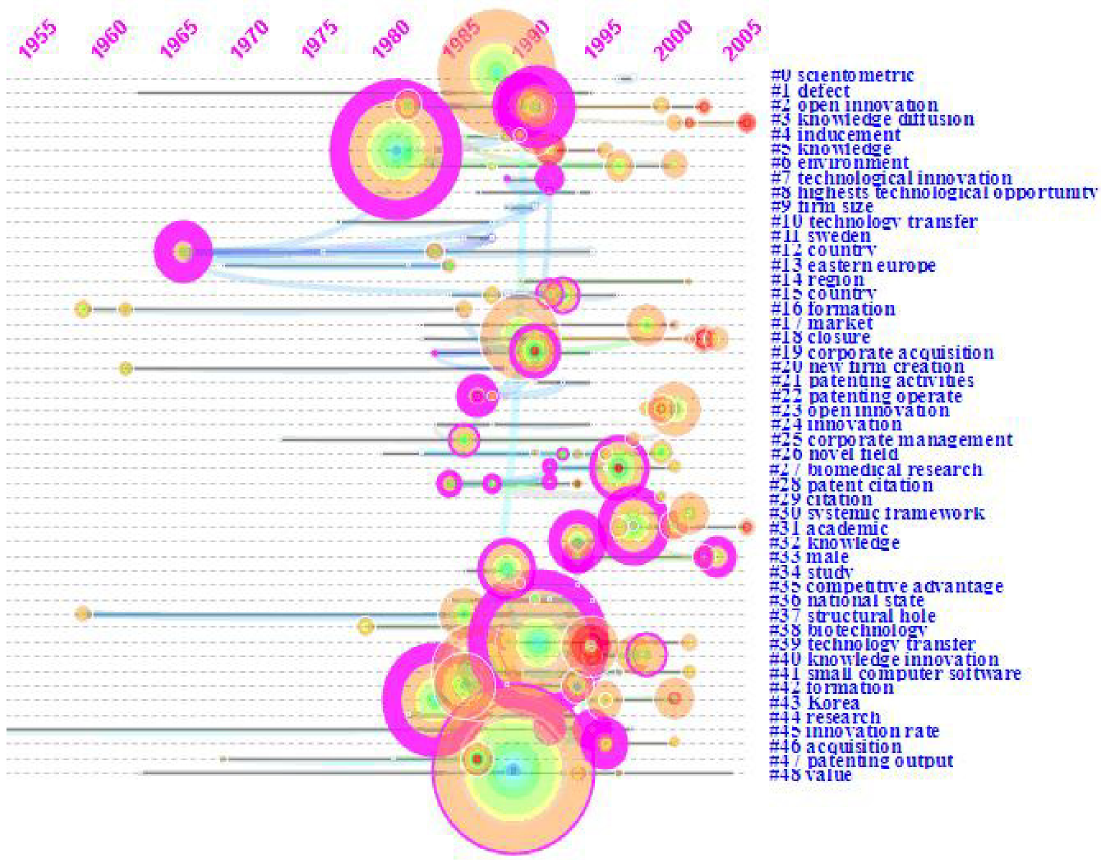


Figure 7: A Co-citation Timeline Visualization of 49 Clusters (1996–2011, Modularity = 0. 11119, Mean Silhouette = 0.9971). Clusters are labeled on the right.

Table 2: Major Clusters of Co-cited Documents of Patent-research Publications

Cluster ID	Size	Label (LLR)	Representative citing papers
#26	7	Novel field	/
#31	7	Academic	/
#8	6	Highest technological opportunity	/
#15	6	Country	/
#18	5	Closure	TRAJTENBERG(1990)
#27	5	Biomedical research	NARIN (1997)
#36	5	National state	/
#43	5	Korea	HAUSMAN (1984)
#45	5	Innovation rate	/
#48	5	Value	GRILICHES Z(1990)

Paper with citation bursts refers to a papers that has an abrupt increase of citations in a given time period. Table 3 lists the documents with the strongest citation bursts during the period of 1987-2006. The article with the most abrupt burst citation pattern is the paper by Hall BH (2005), on market value and patent citations. Five references with strong citation bursts were published before 2000, with the oldest one in 1987. Two articles published in 2006 are found to have strong citation bursts. Three documents are from books (No.3, 5 and 10).

Table 3: Top 10 Documents with the Strongest Citation Bursts

Rank	Burst	Author	Source	Year	Cluster #
1	12.91	Hall BH	RAND J ECON	2005	48
2	9.64	Narin F	RES POLICY	1987	47
3	8.1	Jaffe AB	*Patents, Citations, and Innovations*	2002	3
4	7.6	Basberg BL	RES POLICY	1987	22
5	7.28	Chesbrough H	*Open Innovation*	2003	2
6	7.26	Pavitt K	HDB QUANTITATIVE STU	1988	11
7	7.01	Alcacer J	REV ECON STAT	2006	3
8	6.45	Geuna A	RES POLICY	2006	31
9	6.38	Archibugi D	SCI PUBL POLICY	1992	7
10	6.35	Porter ME	*Competitive Advantage*	1990	35

The betweenness centrality of a node in the network measures the extent to which the node connects other nodes in the network. Table 4 lists the details of top 10 cited documents with high betweenness centrality value of more than 0.7, suggesting that they are hub articles in connecting different theme clusters on patent-research. We can see that two papers are in Cluster #2 and Cluster # 45, respectively. Here, it can be observed that Hausman J's (1984) article has the highest value of centrality. It is closely followed by

March JG's article (1991), and then the book by Nelson RR's (1982) entitled "An evolutionary theory of economic change".

Table 4: Cited Documents with the Highest Betweenness Centrality

Rank	Centrality	Author	Source	Year	Cluster #
1	1.19	Hausman J	ECONOMETRICA	1984	43
2	1.04	March JG	ORGAN SCI	1991	2
3	1.01	Nelson RR	*An evolutionary theory of economic change*	1982	6
4	1	Jaffe AB	Q J ECON	1993	39
5	1	Schmookler J	*Invention and economic growth*	1966	12
6	0.98	Henderson RM	ADMIN SCI QUART	1990	2
7	0.95	Podolny JM	AM J SOCIOL	1995	45
8	0.91	Stuart TE	STRATEGIC MANAGE J	1996	46
9	0.9	Tushman ML	RES ORGAN BEHAV	1992	45
10	0.72	Archibugi D	SCI PUBL POLICY	1992	7

Analysis of Keywords

A co-occurrence network of keywords extracted from titles and abstracts of patent-research papers is shown in Figure 8. Table 5 lists the top 20 terms with co-occurrence frequency of over 65 times. As can be seen from Figure 8 and Table 5, the most-frequently used term is "innovation" with 504 times. Patent-related terms-"Patents", "patent citations", "patent" and "intellectual property", are the second largest hotspots and appear 327, 106, 96 and 84 times respectively. The term "research-and-development" is the third largest hotspot with 236 occurrences. The other similar high-frequency terms are "technology", "industry", "firms", "biotechnology", and "growth". "Knowledge" is the fourth active topic of research and its occurrence is 166 times. Other related hot topics on ''knowledge'' are "science" and "spillovers". The high-frequency keywords also show other hotspots on patent-research: performance, indicators, networks, absorptive-capacity, determinants, and so on. Some of the most-frequently used keywords also have higher betweenness centrality value, such as "innovation", "patents" and "research-and-development". The betweenness centrality of a node is depicted as a red ring outlined the node. The map shows that pivotal nodes with red rings are technology, industry, indicators, citations, and patterns. Although the degree of keyword burst is not shown in Figure 8, the burstness of keywords is also taken into account in our study. The most recent macroscopic burst patterns are indicators, research-and-development, technology, linkage, globalization and patent statistics. In general, keywords identify thematic topics at macroscopic levels.

Figure 8: A Co-occurrence Network of Keywords with 134 Nodes and 119 Links

Table 5: Keywords with Frequency more than 65 times in Patent-research Publications

Rank	Keywords	Frequency	Rank	Keywords	Frequency
1	innovation	504	11	patent citations	106
2	patents	327	12	patent	96
3	research-and-development	236	13	biotechnology	91
4	technology	232	14	spillovers	90
5	performance	179	15	intellectual property	84
6	knowledge	166	16	growth	82
7	industry	164	17	networks	79
8	science	161	18	citations	77
9	firms	149	19	absorptive-capacity	67
10	indicators	143	20	determinants	65

CONCLUSIONS

In conclusion, patent as a research subject has been used by many scientists in various scientific fields for the past few decades. We have analyzed citation data in the patent-research field in information science and management science between 1996 and 2011 using co-citation maps derived from CiteSpace II. The results are presented in terms of author co-citation network, journal co-citation network, document co-citation network, and networks of country, institution and keywords. Our study shows that patent-research is a rapidly emerging field. USA is the most productive country. There are still other countries participating in the research of patent, such as England, Taiwan, Germany, and so on. Katholieke University Leuven, University of Sussex, Georgia Institute of Technology, Harvard University, and Boston University are important research institutions in this field.

RES POLICY, AM ECON REV, MANAGE SCI and STRATEGIC MANAGE J are the mostly cited journals in the field of patent-research. In addition, SCIENTOMETRICS is one of the highly cited journals under the category "information science and library science". COHEN W M, JAFFE A B, GRILICHES Z, HALL B H and NARIN F are the most co-cited authors of patent-research literatures. On the other hand, NARIN F, GRILICHES Z, COHEN W M, JAFFE AB and MANSFIELD E are the five authors which have highest betweenness centrality. Two out of the ten most frequently co-cited documents are published in RES POLICY, whereas the remaining eight are published in eight different journals. It is revealed that the major research strands and hot topics are innovation, research-and-development, technology, knowledge, and industry. It is believed that this study could be useful for novice researchers in the field of patent study. In the future, we will perform a detailed analysis of patent-research publications using cluster analysis, multidimensional analysis, factor analysis and other visualization and mapping techniques.

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