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Abstract

This paper provides a comprehensive review of more than 120 social science studies in nanoscience and technology, all of which analyze publication and patent data. We conduct a comparative analysis of bibliometric search strategies that these studies use to harvest publication and patent data related to nanoscience and technology. We implement these strategies on the 2006 publication data and find that Mogoutov and Kahane (2007) [Mogoutov, A. and B. Kahane, 2007. Data search strategy for science and technology emergence: A scalable and evolutionary query for nanotechnology tracking. *Research Policy*, 36: 893–903.], with their evolutionary lexical query search strategy, extract the highest number of records from the Web of Science. The strategies of Glanzel et al. (2003) [Glanzel, W., et al., 2003. *Nanotechnology: Analysis of an Emerging Domain of Scientific and Technological Endeavour*. Steunpunt O&O Statistieken, Report. Leuven: K.U. Leuven.], Noyons et al. (2003) [Noyons, E.C.M., et al., 2003. *Mapping excellence in science and technology across Europe Nanoscience and nanotechnology*. Draft report of project EC-PPN CT-2002-2001 to the European Commission.], Porter et al. (2008) [Porter, A.L. et al., 2008. Refining search terms for nanotechnology. *Journal of Nanoparticle Research*, 10(5):715-728.] and Mogoutov and Kahane (2007) produce very similar ranking tables of the top ten nanotechnology subject areas and the top ten most prolific countries and institutions.

Key words : Nanotechnology; research and development; productivity; publications; patents; bibliometric analysis; searching strategy
JEL Classification : O14; O31

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1. Introduction

Modern nanotechnology is an emerging and dynamic field. It is multidisciplinary in nature, using knowledge from the fields of physics, chemistry, biology, materials science, and engineering. As generally acknowledged, the origin of nanotechnology was a 1959 talk given by Richard Feynman, "There's plenty of room at the bottom." However, the actual term "nanotechnology" was not coined until 1974 by Norio Taniguchi. The impulse for modern nanotechnology was driven by interest in interface and colloid science together with the development of analytical tools such as the scanning tunneling microscope (1981) and the atomic force microscope (1986). These instruments enabled one to not only measure, organize, and manipulate matter but also observe novel phenomena on a nanoscale.

Analysts argue that nanotechnology is likely to have a horizontal impact across an entire range of industries and great implications on human health, the environment, sustainability, and national security. To address the great potential of the emerging technology and promote its development, various governments have prioritized nanotechnology in their national agenda of science and technology development. Such a trend has led to an escalation of investment in nanotechnology R&D, a rapidly growing body of scientific publications and patent applications, and greater attention to the development of the field by the policy community, industry, and the general public. As a result, social scientists have also been motivated to study the characteristics of the newly established field, the dynamics of worldwide R&D activities, and the economic and societal implications of the technology. To conduct such studies, a majority of these scientists have relied on nanotechnology publications and patent data. Methodologies for examining publication and patent data were developed well before nanotechnology came into prominence. However, the distinct features of nanotechnology, such as multidisciplinarity, not only pose challenges to state-of-the-art analytical approaches with regard to publication and patent data, but also arouse interest of seeking methodological improvement. For example, delineating the boundary of the field of nanotechnology is a daunting task, given its multidisciplinarity and rapid expansion of the field. Thus, scholars have attempted to map the field by publication citations (Zitt and Bassecoulard, 2006)) or using an iterative process to derive robust search keywords (Kostoff et al., 2006a, 2006b; Zucker et al., 2007; Mogoutov and Kahane, 2007).

In this paper, we contribute to the growing literature by implementing a comprehensive review of more than 120 social science studies on nanoscience and technology, most of which analyze the publications and patents in nanotechnology. We offer an updated summary of the main findings of the studies. In addition, we provide a thorough analysis of the bibliometric search strategies used in these different studies to harvest nanotechnology publications and patents. The rest of the paper is organized as follows. Section 2 classifies the literature according to different topics. Section 3 compares the various search strategies used to identify the nanotechnology publications and patents, and Section 4 reviews the source of nanotechnology publications and patents. Section 5 concludes.

2. Social science studies by nanotechnology publication and patent analysis

Analysts have argued that nanotechnology will lead to the next industrial revolution, ushering in a new era of manufacturing and engineering capabilities. Lux Research, Inc. (2007) contended that nanotechnology is completing a 20-year transition from lab to market, matching a historical pattern previously seen in fields such as plastic materials and biotechnology. The company found that more than 50 billion USD in products sold worldwide in 2006 incorporated nanotechnology with very diverse applications. According to the National Science Foundation (2001), the projected worldwide market size of nanotechnology will top $1 trillion USD annually by 2015. Consequently, social scientists devoted a great deal of energy to studying the characteristics of emerging technology and its economic and societal implications.

2.1. Benchmarking performance of countries, institutions, and scientists

As a result of its great potential, nanotechnology has become the focus of science and technology policy in various countries and transnational organizations. Individual scholars, funding organizations as representatives of national governments, and transnational organizations are engaged in the exercise of mapping the worldwide research and development of nanotechnology and benchmarking the strengths and weaknesses of various countries or country blocs. Examples of such efforts are reports prepared by the European Commission (2003), Warris (2004) for the Australian Academy of Science, Holtum (2005) for the British Engineering and Physical Sciences Research Council, and research articles by Meyer and Persson (1998), Dunn and Whatmore (2002), Heinze (2004), Santo et al. (2006), Meyer (2007), Zhou and Leydesdorff (2006), Miyazaki and Islam (2007), and Youtie, Shapira, and Porter (forthcoming).

In 2001, the European Commission contracted a group of experts to conduct bibliometric and patent analyses and to identify the leading European institutions and regions in the field of nanotechnology (Meyer et al., 2001). In 2002, also sponsored by the European Commission, the scholars, residing at Leiden University in the Netherlands and Fraunhofer ISI in Germany, employed a more robust methodology to identify centers of excellence in Europe in the field of nanotechnology (Noyons et al., 2003). A set of bibliometric indicators that address the inter-disciplinarity of nanoscience and nanotechnology were developed in the study to assess the performance of researchers and institutions in Europe. Using indicators such as the average number of citations per publication normalized by traditional science areas, the authors were able to correct the bias of the evaluation which resulted from higher probability of being cited in the basic sciences than in the applied sciences.

Hullmann (2001, 2006a, 2006b, 2007), Compano and Hullmann (2002), and Hullmann and Meyer (2003) conducted a series of studies that analyzed the development of nanotechnology worldwide. They revealed the strengths and weaknesses of the European countries, compared to those of the United States, Japan, and the rest of the world, by presenting prospects of sales volumes of nanotechnology products, public and private funding for nanotechnology research, nanotechnology-related jobs and companies, global patents and scientific publications in the field, and other indicators. With a focus on the United States and the use of USPTO patent data, Huang, Chen, Roco and co-authors (Huang et al., 2003, Huang et al. 2004, Huang et al, 2005, Huang et al. 2006, Hu et al., 2007, Li et al., 2007a, and Li et al., forthcoming) analyzed the general trends of nanotechnology research and development, the key players (with respect to countries and institutions) in the field, and the evolution of technology topics. In addition, Huang et al. (2005) matched the names of awardees of nanotechnology funding from the National Science Foundation of the United States and those of the inventors of the USPTO nanotechnology patents. They found that the patents applied by the NSF-funded researchers received more citations than the patents filed by the other comparison groups. Zucker and Darby (2005) analyzed geographic concentration, knowledge transfer, and firm entry in nanotechnology in the United States based on the data from the Nanobank Project, which aims to provide an on-line data archive that documents the socio-economic impact of nanoscience and technology.

To map the world's nanotechnology scientific publications that appeared from 2002 to 2006, Leydesdorff and Wagner (forthcoming) focused on the ten core journals in the field. They demonstrated that the EU-25 is losing more than one percent of its world share of nanotechnology publications per year. China has become the second largest nation in both numbers of papers published and citations behind the United States. To measure nanotechnology patent applications from 1997 to 2005, Igami and Okazaki (2007) studied the data from the European Patent Office (EPO). They found that the United States, the European Union (EU), and Japan hold almost the same share of nanotechnology patent applications to the EPO. Igami and Okazaki (2007) argued that nanotechnology encompasses a wide range of technologies and science that fuel technological innovation and development in the field in various ways.

Kostoff, R.N. et al. (2006b). The structure and infrastructure of the global nanotechnology literature. *Journal of Nanoparticle Research*, 8: 301-321. argue that the number of global nanotechnology research articles has grown exponentially for more than a decade. This growth is a worldwide phenomenon, but the most rapid growth during that time period has occurred in East Asian nations, notably China and South Korea. While the United States remains the leader in the production of aggregate nanotechnology research articles, China has achieved parity or taken the lead in some selected nanotechnology sub-areas.. However, the publication practices of the three most prolific Western nations (the United States, Germany, and France) are clearly distinct from the three most prolific East Asian nations (China, Japan, and South Korea): The East Asian nations generally publish in domestic journals that have a low impact factor while the Western nations publish in international journals that have a higher impact factor.[1] Being more diversified than the Asian or European nations, the United States allocates its nanotechnology funding over a wide range of institutions.

Alencar, Porter, and Autunes (2007) benchmarked nanotechnology R&D in various countries through the nanotechnology patents of 1994-2005, documented in the Derwent World Patents Index database. They classified the patents into three categories according to product life cycle, namely nano-raw material, intermediates, and products. Using this classification, they examined the profile of the patenting activity of the United States, Japan, and Germany. Their findings showed that Japanese patents were concentrated in the categories of nano-raw materials and intermediates while German patents largely fell in the category of nano-product.

2.2. Knowledge flow, economic development, and technological change

The emergence and development of nanotechnology have been characterized by knowledge generation and transfer within and among universities, governmental research institutions, and private firms. Scholars are interested in studying the mechanism that determines the advance of scientific research, technological development, and commercialization of nanotechnology through publication and patent data.

In this section of the literature, Darby and Zucker (2003) found that U.S. firms become involved in nanotechnology wherever and whenever scientists publish breakthrough academic articles, similar to the case of biotechnology. A high average education level is also important to the entry of nanotechnology companies, but the past level of venture-capital activity in a region is not. They also found that breakthroughs in nanoscale science and engineering frequently transfer to industrial applications, which involve the collaboration of firms and the scientists who made the discoveries. Zucker, Darby, Furner, Liu, and Ma (2007) argued that regional growth of new knowledge in nanotechnology, as measured by article and patent counts, has been positively affected by both the size of existing regional stocks of recorded knowledge in all scientific fields and the extent to which tacit knowledge in all fields flows among the institutions of different organizational types. The level of federal funding has a large, robust impact on the numbers of both publications and patents.

Shapira and Youtie (2006) proposed the assessment of nanotechnology-related knowledge assets as a means of measuring knowledge-based economic development in the southern United States. Niosi and Reid (2007) argued that large developing countries such as China, India, and Brazil have the necessary commitments to investment and the

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[1] This point was echoed by Guan and Ma (2007), in their analysis of Chinese nanotechnology publications. Lin and Zhang (2007) suggested that Chinese-language publications of nanotechnology are likely to be located far from the research frontier and mostly isolated the international nanotechnology research community. However, Lin and Zhang (2007) argued that these publications serve to a) connect English speaking researchers with the non-English-speaking research community, b) educate students and other scientists new to the field, and c) provide a natural outlet for non-English-speaking researchers to communicate their scientific results.

capabilities to make use of the windows of opportunity offered by biotechnology and nanotechnology to achieve productivity growth and economic development. The authors proposed two strategies that smaller developing countries can use to promote the development of emerging technologies: leveraging existing technologies in related areas to reduce the cost of developing the emerging technologies; and establishing alliances and clusters. Through cluster analysis Shapira and Youtie (2008) examined the top 30 U.S. "nanodistricts", or metropolitan areas, that led in nanotechnology research activities over the period between 1990 and 2006. They found that nanotechnology emerged in several nontraditional places of technological development because of a large concentration of research at a single government laboratory or university research institution. They argued that concentrating investment in nanotechnology R&D into a single institution can elevate the profile of a region that has not been associated with technological prominence before.

Libaers, Meyer, and Geuna (2006) found that university spin-off companies contributed significantly to nanotechnology development in the United Kingdom. However, their roles were less dominant than those of the large enterprises or new technology-based companies. Rothaermel and Thursby (2007) studied a sample of biotechnology and nanotechnology firms and argued that an incumbent firm's ability to exploit new methods of invention initially depends on its access to tacit knowledge with regard to the employment of the new methods. Over time, however, as firms learn and/or the knowledge becomes codified in routine procedures or commercially available equipment, inventive output, which is measured by the number of USPTO patents, becomes more dependent on traditional R&D investments. Avenel et al. (2007) found that firms with a smaller number of nanotechnology publications and patents diversify their firm-specific knowledge about nanotechnology by grouping researchers and engineers from different backgrounds. However, firms with larger numbers of publications and patents diversify through investing in various traditional scientific disciplines in parallel.

The notion that nanotechnology may be a breakthrough innovation with long-term economic and societal effects that render it a "general purpose technology" was studied by Youtie, Iacopetta, and Graham (forthcoming). They used USPTO patent data, a citation analysis, and a "generality" index derived from patent classifications to demonstrate that nanotechnology exhibits a similar level of "pervasiveness" to that of information and communication technology, an existing general purpose technology.

2.3. The relationship between science and technology

Nanotechnology, as a newly emerging, interdisciplinary field, is deemed interesting by scholars who investigate the relationship between science and technology. In studies on this topic, publications on nanotechnology, considered the outcome of scientific research, represent science. Patents, by contrast, are regarded as the output of technological development. The relationship between science and technology is examined by linking publication and patent data, namely, matching the authors of publications with the inventors of patents or locating publications in patents' non-patent literature references.

Meyer (2006a, 2006b) collected the publication data of nanotechnology from SCI-Expanded and the patent data from the USPTO for Belgium, the United Kingdom, and Germany. Both datasets cover the period from 1992 to 2001. He matched the inventors and the authors based on the surnames and initials of the inventors. To prevent false connections due to homonymy, the inventors were linked to authors from the same country only. Meyer found that patenting activity does not appear to have an adverse impact on the publication and citation performance of researchers. Furthermore, patenting scientists outperformed their solely publishing, non-inventing peers in terms of publication counts and citation frequency.

Bonaccorsi and Thoma (2007)harvested the records from the SCI and SSCI databases, and matched the authors of nanotechnology publications between 1988 and 2001, and the inventors of nanotechnology-related USPTO patents after 1971. They found that the quality of the patents whose inventors have no scientific publications is lower than that of the patents that have at least one inventor who is an author of a scientific publication. Based on this finding, the authors contended that complementarity in terms of having at least one academic collaborator in the group that applies for patents, has a positive impact on inventive performance.

Matching publications and patents through patent citation, Meyer (2000a, 2001a) found that only 3.4 percent of nanoscience and technology-related scientific papers were cited by nanotechnology-related patents. However, he argued that the percentage of publications cited in patents in the nanotechnology field is still higher than the percentages in the fields of applied physics and basic biomedical research. In one case study, Meyer (2000b) further explored the nature of patent citations in the nanotechnology field. He found that the scientific findings revealed in the academic papers play an indirect role in technological development which leads to the patents. Verbeek et al. (2003) analyzed the non-patent references in USPTO and EPO nanotechnology patents and found that about 30 percent of all paper citations present in U.S.- and Japan-invented patents and filed in USPTO and EPO, are linked to EU-originated research.

2.4. Miscellaneous topics

Apart from the previously discussed studies there are several publications which concentrate on other topical areas.

2.4.1. Co-authorship

Larsen (forthcoming) studied the co-authorship network in the field of nano-structured solar cells to measure the scientific output, impact, and structure in the emerging research field. To study the validity of the co-authorship indicator in measuring the quality of publications, Schmoch and Schubert (2007) selected nanotechnology as one of the four disciplines. However, they ended up rejecting the validity of the co-publication indicator. Calero et al. (2006) researched co-authorship to identify research groups and potential research partners in the field of nanoscience and nanotechnology.

2.4.2. Creativity

Heinze, Shapira, Senker, and Hullmann (2007) proposed a typology of creativity of scientific research and identified the creative research achievements and creative scientists in the fields of nanotechnology and human genetics in Europe and the United States. Heinze and Bauer (2007), in their research pertaining to the scientific creativity of scientists in the field of nanotechnology, identified a group of highly creative scientists who were also award winners and nominees by international peers. They found a benchmark group of scientists who published the same number of SCI papers as the creative scientists. Heinze and Bauer subsequently compared these two groups of scientists and concluded that the creative scientists' ability to communicate with peers and address a broad field enhances their visibility and the novelty of their research.

2.4.3. Development of the nanotechnology field

Gupta and Pangannaya (2000), Garfield and Pudovkin (2003), and Gupta (1999) used the bibliometric analysis of publications and patents to identify trends in the sub-fields of carbon nanotubes, nano-ceramics, and fullerenes, respectively. Kostoff et al. (2006a) developed a method of so-called "citation-assisted background" to determine the seminal literature in nanotechnology field. Robinson, Ruivenkamp, and Rip (2007) visualized and assessed the possible development of an emerging sub-field of nanotechnology: molecular mechanical systems.

Lucios-Arias and Leydesdorff (2007) used the development of nanotechnology research as a starting point from which to explore the emergence of knowledge from scientific discoveries, namely the discovery of fullerenes in 1985 and their effects on the structure of scientific communication. Rafols and Meyer (2007) conducted case studies on research projects to investigate the multidisciplinarity of nanotechnology and identified a high degree of cross-disciplinarity in terms of references and instrumentalities in the nanotechnology field, but a narrower degree in terms of affiliation and researchers' background.

2.4.4. Technology assessment and foresight

Katz et al. (2001) executed a science foresight project to gather information about emerging short- and long-term research developments primarily in the physical and engineering sciences. They invited international experts to submit their predictions about emerging developments in their research fields, including nanoscience and nanotechnology. Guston and Sarewitz (2002) proposed a research program of so-called "real-time technology assessment" that provides a mechanism with which to observe, critique, and influence social values as they become embedded in nanotechnology innovations. Real-time technology assessment includes four components: analogical case studies, research program mapping, communication and early warning, and technology assessment and choice. Chau et al. (2006) documented their experience of constructing a web portal in the field of nanoscience and nanotechnology. The web portal incorporates various functions such as collection building, meta-searching, keyword suggestion, and various content analysis and mapping techniques such as document summarization, document clustering, patent analysis, topic map visualization, and so on.

Malanowski and Zweck (2007) combined market research and foresight modules in an exercise of analyzing the economic potential of nanoscience and technology. They argued that this integrating approach bridges the gap between foresight research targeting long-term trends and traditional market research focusing on medium- and short-term change. Lee and Song (2007) surveyed Korean experts in the field of nanotechnology to conduct a technology cluster analysis in which they grouped research activities according to the extent to which basic knowledge is shared in the activities and identified three major technology clusters of nanotechnology: the nano-material-related cluster, the nano-device-related cluster, and the nano-bio-related cluster. They found that the three clusters match the core technology fields that the Korean national R&D program on nanotechnology emphasizes.

2.4.5. Intellectual property rights

Bowman (2007) argued that the blurring of the interfaces between invention and discovery and the probable convergence of nanotechnology and biotechnology in the medium term may challenge the current nanotechnology intellectual property rights (IPRs) regime. He contended that a wide interpretation of Article 27(1) of the Trade-Related Intellectual Property Rights Agreement of the World Trade Organization may result in the monopolization of fundamental molecules and compounds. The early recognition of these concerns should enable policy makers and governments to contemplate future applications of nanotechnology and tailor the international IP framework accordingly.

Clarkson and DeKorte (2006) discussed the problem of patent thickets in nanotechnology, or "nanothickets." After visualizing the presence of nanothickets by using an analytical network technique, they studied the potential organizational responses to patent thickets. Bawa (2007) also recognized the emerging thicket of nanotechnology patent claims, caused by patent proliferation as well as continued issuance of broad patents by the USPTO. He argued that the widely-cited definition of nanotechnology by the U.S. National Nanotechnology Initiative is the cause of the inadequate nanotechnology patent classification system. He also contended that the increasing number of new nano-medicine patent applications filed at the USPTO and the continuous issuance of broad patents is creating a complex patent landscape in which competing players are unsure about the validity and enforceability of numerous issued patents.

3. The methodologies applied in nanotechnology publications and patent analysis

Researchers who study the development of nanoscience and nanotechnology through the analysis of publication and patent data are confronted with a fundamental question: *Which publications or patents fall within the field of nanotechnology?* Furthermore, there are different definitions of nanotechnology proposed by various organizations (Bawa, 2007). It is thus notoriously difficult to define the boundary of a multi-disciplinary and emerging field such as nanotechnology and harvest the relevant publications and patents of the field. The lexical query approach of harvesting nanotechnology publications and patents dominates the literature that we review, together with the citation analysis. Less used is the strategy based on Bradford's Law that identifies core journals in a science field.

3.1. Lexical query

In conducting lexical queries, scholars use different methodologies to construct their search strategies. Tolles (2001), Meyer et al.(2001), and Dunn and Whatmore (2002) used nano* as their search string. Glanzel et al. (2003) and Noyons et al. (2003) adopted nanotechnology-related keywords to build their search strategies. Porter et al. (2008) implemented a modular search in which they combined nano* and nanotechnology-related keywords. After obtaining a search outcome, scholars usually exclude irrelevant records that include the keywords that are not related to nanotechnology such as $NaNO_3$, nanoliter, and nanoplankton, etc. Nanotechnology scientists usually provide assistance in this process of keyword selection. In the studies reviewed in this paper, almost every individual or research group tended to develop his, her or its own search queries.

Fast expansion of the nanotechnology field is posing challenges to the lexical query approach. Mogoutov and Kahane (2007) claimed that as the field of nanotechnology expands, the core of related keywords will experience an even more rapid growth than the entire database of nanotechnology publications. Early bibliometric analysis by, for instance, Braun, Schubert and Zsindely (1997) and Tolles (2001), which harvested publications through respective nano-prefixed keywords, or merely the simple term "nano*," suffered from the omission of biotechnology-related publications whose keywords were less likely to contain the prefix "nano". Another criticism of the lexical query approach is the subjectivity of the search strategies. The nanotechnology literature has not assumed a unique and standardized terminology (Hullmann, 2007). Thus, search outcomes will inevitably be biased toward fields that comprise specialized nanotechnology scientists.

3.3. Evolutionary lexical query

The evolutionary lexical query differs from the lexical query primarily because of its automatic and iterative way of obtaining search keywords that minimizes the input of experts. Using the evolutionary lexical query approach, scholars first retrieve a core set of nanotechnology publications. In the Nanobank Project, Zucker et al. (2007) obtained core nanotechnology publications from the weekly *Virtual Journal of Nanoscale Science & Technology*, which includes the latest research articles appearing in a variety of source publications in the field. Mogoutov and Kahane (2007) retrieved core publications through a simple nano prefix search strategy. After obtaining these, the researchers harvested a set of keywords from the publications and ranked the keywords by their level of relevance to the field, based on the frequencies of the keywords or combined keywords in the core publications. Zucker et al. (2007) and Kostoff et al. (2006a, 2006b) used these expanded keyword sets to harvest additional publications and repeated the process until the publications converged on a relatively consistent set of keywords that changed only slightly between iterations. Different from Zucker et al. (2007) and Kostoff et al. (2006a, 2006b), Mogoutov and Kahane (2007) did not adopt a multiple-stage iterative process but involved experts in verifying and modifying the expanded keyword set.

The minimization of expert intervention represents a significant advantage of the evolutionary lexical query approach over the standard lexical query approach. However, the selection of keywords in the evolutionary lexical query approach, based on the probability of relevance of the keywords, is still determined by researchers, and it needs to be validated by experts.

3.3 Citation analysis

To retrieve nanotechnology publications, Zitt and Bassecoulard (2006) demonstrated a hybrid lexical-citation approach. In the first step, they harvested a set of "seed" nanotechnology publications by using a search strategy largely identical to the one used by Noyons et al. (2003). Secondly, they identified a set of "core" literature cited by the seed literature. In the third step, they identified a final set of nanotechnology literature that cited the "core" literature. They controlled the selection of the core literature and the final set of nanotechnology literature by finely-tuned threshold parameters that strike a balance between the specificity and the coverage of the publications. In the jargon of information science, researchers should manage the trade-off between the exclusion of relevant publications (i.e., the recall problem known as "silence") and the inclusion of irrelevant publications (i.e., the precision problem known as "noise"). By carefully choosing the parameters, Zitt and Bassecoulard obtained the final set of literature, which contains 178,000 publications, 56,000 more than the seed literature. In the seed literature, the publications on material sciences, applied physics, condensed matter physics, and physical chemistry are in descending order according to their shares in total. In the final literature, the publications on these four subfields are also prominent, but the ranks of their shares are reversed.

Unlike lexical query, which is more subjective, citation analysis depends very little on experts' intervention. However, subjectivity has not been fully removed from the process because the size of the final literature set is still determined by the parameters chosen by the researchers. While the final literature set would be larger and its coverage more comprehensive, it would also contain more "noise." Another difficulty with implementing the methodology is that it necessitates setting up a citation linkage between all the papers in the database. According to Mogoutov and Kahane (2007), no more than a dozen institutions in the world would have access to the full Web of Science database to use the pre-built citation links.

Bassecoulard, Lelu, and Zitt (2007) used the methodology of citation analysis to obtain a database of all the nanotechnology publications from 1999 to 2003. They subsequently used cluster analysis to classify the literature into different disciplines (themes) according to the similarity of the papers in the references, that is, the source of knowledge or information. Igami and Saka (2007), through a citation analysis, mapped the nanotechnology field and classified the nanotechnology publications into 30 subfields.

3.4 Publications in the core nanotechnology journals

Unlike most researchers, who identify nanotechnology publications through lexical queries or citation analysis, Leydesdorff and his co-authors, using journals as the unit of analysis, extracted articles from the core nanotechnology journals as the set of nanotechnology publications to research. Zhou and Leydesdorff (2006) distinguished a core set of three nanotechnology journals and a set of 85 journals related to the field. Based on the concept of "between centrality," proposed by Leydesdorff (2007) as an indicator for measuring the interdisciplinarity of scientific journals, Leydesdorff and Zhou (2007) identified ten core journals on nanotechnology. By examining the publications in these journals, Leydesdorff and Wagner (forthcoming) benchmarked the nanoscience and technology publications of the leading countries.

Compared to using lexical queries and citation analysis, collecting nanotechnology publications from a limited number of journals is relatively easier. Nevertheless, examining the core journals provides only a snapshot of the entire field of nanotechnology. To draw a comprehensive picture and precisely characterize the dynamics of the field, one needs to resort to more complex search strategies.

3.5 Search strategies for patent analysis

In some studies, researchers use the same set of keywords as those used in searching nanotechnology publications to find nanotechnology patents from the databases of the United States Patent Office (USPTO) and the European Patent Office (EPO). However, when the nanotechnology working group in EPO conducted a keyword search in the EPO abstract and full text database to identify nanotechnology patents, they found that a high percentage of the retrieved documents did not fall into the category of nanotechnology

(Scheu et al., 2006), arguably because patent applicants use “nano” as a “buzzword” in their documents even though the technologies they have invented have little to do with nanotechnology. In this sense, patent search is more technology driven as it follows the functionalities of the database while publication search is language driven. Scheu et al. (2006) concluded that keyword searches alone, independent from their level of sophistication, deliver “noisy” datasets. Thus, the EPO created the Y01N tag within its tagging system to assist patent examiners to identify nanotechnology patents.

3.6 Comparative analysis of search strategies

Table 1 summarizes the characteristics, strengths, and weaknesses of the lexical query, the evolutionary lexical query, citation analysis, and the search strategy based on core journals in the field. We compare the following six different strategies:

1. Glanzel, W., et al. (2003) (from now on called GLANZEL)
2. Leydesdorff, L. and P. Zhou (2007) (from now on called LEYDESDORFF)
3. Mogoutov, A. and B. Kahane (2007) (from now on called MOGOUTOV)
4. NANO* (from now on called NANO*[2])
5. Noyons, E. C. M., et al. (2003) (from now on called NOYONS)
6. Porter, A. L. et al. (2008) (from now on called PORTER)

(Here insert Table 1)

Out of the myriad lexical queries, we compare the above six queries for the following reasons. NANO*, GLANZEL, NOYONS and PORTER are standard lexical query strategies. NANO* is the simplest and most straightforward search strategy, providing a benchmark dataset. Actually, NANO* are included in GLANZEL, NOYONS and PORTER. GLANZEL and NOYONS’ reports are two major studies sponsored by the European commission. These search strategies are widely cited in other literature that we review in this paper. PORTER,developed in the United States, possibly involved different nanoscientists in defining the keywords, but not those employed on EU projects. Different from the above four strategies, MOGOUTOV falls in the category of the evolutionary lexical query. LEYDESDORFF is an alternative strategy based on a selection of core journals. We were not able to replicate the citation analysis because we did not have access to the full Web of Science database to use the pre-built citation links.

In June and July 2008, we applied NANO*, GLANZEL, NOYONS, PORTER, MOGOUTOV, and LEYDESDORFF to the ISI/SCI-E database (ISI Web of Knowledge [v.4.2] and [v.4.3]),

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[2] The asterisk “*” represents any group of characters (a “wildcard”), including no character in the Web of Science. Because articles containing only the keywords ”nanoliter,” “nanometer,” “nano3,” and so on are not necessarily nanotechnology articles, the publication obtained by nano* certainly includes some irrelevant records. The complete list of exclusion terms for the nano* search strategy can be found in Table 3 of Porter et al. (2008, p. 722).

specifically to the topic field for the publication year 2006, all languages, and articles only. For NANO*, this resulted in the search: "TS=nano* AND PY=2006, All languages, Article, SCI-Expanded."

We were able to extract 46,177 articles by using GLANZEL, 47,002 articles using NOYONS, 57,900 using PORTER, 86,751 using MOGOUTOV, and 9,027 articles published in the ten core nanotechnology journals defined by LEYDESDORFF (Table 2). We also extracted 39,889 articles by simply searching "nano*." However, since GLANZEL, NOYONS , PORTER, and MOGOUTOV include nano* (and other keywords) in their strategies, naturally, we find that the sets of nanotechnology articles, retrieved by GLANZEL, NOYONS , PORTER, and MOGOUTOV, are more comprehensive than the one obtained by the relatively simplistic nano* strategy.

(Here insert Table 2)

PORTER and MOGOUTOV cover significantly more publications than GLANZEL and NOYONS. The size of the nanotechnology publication dataset established by PORTER is 25 percent larger than the one by GLANZEL. MOGOUTOV extracts the most records: 88 percent more than GLANZEL. The publications harvested from the ten core journals as defined by LEYDESDORFF are the smallest batch, accounting for only 10 percent of MOGOUTOV.

The top seven subject areas in which most of the articles in the different datasets (of GLANZEL, NOYONS, PORTER, and MOGOUTOV) are published are identical. However, the subject area ranking for LEYDESDORFF differs significantly. Because Thomson ISI can assign multiple subject categories to a journal, and GLANZEL, NOYONS, PORTER, and MOGOUTOV all cover more than 500 journals, it is understandable that the subject area ranking for the publications in only ten journals will be very different from a subject ranking based on more than 500 journals. Moreover, further examination of the journals covered by the different strategies demonstrates that LEYDESDORFF does not include a number of the top ten journals identified by the other strategies (marked in bold in Table 3). Moreover, 35 percent of the publications in these ten core journals are not covered by the publications extracted by other strategies. (See the comparison of the ratios of unique records to total records in Table 4.) These findings cast doubts on the comprehensiveness of the set of journals covered by LEYDESDORFF in terms of measuring nanotechnology scientific publication output.

(Here insert Table 3)

As seen in Table 2, GLANZEL, NOYONS, PORTER, and MOGOUTOV produce identical top ten country rankings and similar institution rankings. However, LEYDESDORFF is biased towards the United States since the share of articles from this country is 24.8 percent larger than those calculated based on the results of the other strategies. Given that the ten core journals are relatively more frequently cited journals, which publish better articles, the strength of the scientific research in the United States is reflected by the distinct visibility of the American scientists in these top journals. If we calculate the share of institutions, we obtain the same top three institutions by the strategies of GLANZEL, NOYONS, PORTER, and MOGOUTOV. The Russian Academy of Science, ranked second in the results by the four strategies, is nowhere to be found in the top ten results of LEYDESDORFF. Overall, LEYDESDORFF differs significantly from the other strategies in terms of the ranking of the top ten subject areas, countries, and institutions.

In order to study the possible bias of the search strategies, we obtain a unique article set for each one. A unique article set includes articles that are retrieved by only one strategy, but not by the others. Table 4 shows that NOYONS is biased towards the field of biotechnology, for the unique articles identified by this strategy include many biotechnology articles. In all the unique article sets, the United States is always ranked the most prolific country. However, the ranking results of the other top five countries differ slightly. The rankings of the top five institutions in different unique article sets differ more significantly than the rankings of the top countries. A number of institutions such as RIKEN and Harvard University do not even appear in the results of the complete article sets, as shown in Table 2.

(Here Insert Table 4)

4. Data sources of nanotechnology publications and patents

4.1 Source for nanotechnology publications

Not only does the early study on nanotechnology publication output by Braun, Schubert and Zsindely (1997) analyze the SCI database, a sub-database of the Web of Science and a product of Thompson/ISI,[3] but almost all other studies reviewed in this paper also obtained the pool of scientific articles from the databases of Thompson/ISI. The few exceptional cases are studies by Kostoff et al. (2006a, 2006b) and Miyazaki and Islam (2007), which analyzed the Engineering Compendex database, and research by Hullmann and Meyer (2003), who collected the publications from INSPEC.[4] The dominance of SCI/SCIE data in social science studies on nanotechnology publications is open to discussion. Braun, Glanzel and Schubert (2000) and van Leeuwen et al. (2001), among others, argued that the SCI is biased towards literature in English and the large publishing houses. A recent article by Norris and Oppenheim (2007) compares four different databases: Web of Science, Scopus, CSA Illumina, and Google Scholar. Through their comparison, Norris and Oppenheim confirmed the arguments by Braun, Glanzel, and Schubert and others that the Web of Science, and thus, SCI & SCIE, are indeed biased towards English language articles. They also claimed that when comparing social science

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[3] The databases of the Science Citation Index (SCI), the Science Citation Index Expanded (SCIE) and the Web of Science (WoS) provide access to about 3,700, 5,900, and 8,700 journals, respectively.

[4] Compendex is an engineering database referencing 5,000 engineering journals and conference proceedings dating from 1970. INSPEC is a database with records taken from 3,500 technical and scientific journals and 1,500 conference proceedings.

coverage, CSA Illumina and Scopus have a considerably broader coverage than Web of Science. Because the citation coverage of Google Scholar and CSA Illumina are seriously limited, they are less usable for citation analysis. Scopus, therefore, remains the only viable competitor. It would be interesting to investigate whether a study using Scopus data would lead to similar results compared with nanotechnology studies based on SCI/SCI-E data.

4.2 Source for nanotechnology patents

Three major patent offices, namely the USPTO (United States Patent and Trademark Office), the EPO **(**European Patent Office**)**, and the JPO (Japan Patent Office), have made intense efforts to improve their own classification systems and combine all nanotechnology-related patents into one single patent class. The USPTO established an informal nanotechnology classification Class 977 (Digest I) in October 2004 and later expanded it to a cross-reference collection with over 250 new subclasses. The Japanese patent office created the ZNM class.

In 2003, the EPO created a nanotechnology working group that worked on a definition of nanotechnology and created the Y01N tag specifically for nanoscience and technology patents based on the European Classification System (ECLA), used by the EPO for carrying out patent application searches. For the ECLA entries, within which a part of the classified documents fall within the scope of Y01N, the documents were treated in an ad hoc manner; that is, any EPO classifier of any technical area can send individual nanotechnology documents to Y01N classifiers for ad hoc tagging. A detailed description of the EPO approach and its advantages and limitations can be found in Scheu et al. (2006).

Most scholars investigate the USPTO, EPO and/or JPO databases. In addition, some scholars, such as Bachmann (1998) and Alencar, Porter and Antunes (2007), searched the World Patent Index (Derwent World Patents Index from Thomson Scientific). Igami and Okazaki (2007) harvested the data from the OECD/EPO patent database, which includes citation information. Porter, Youtie, Shapira, and Schoeneck (forthcoming) searched the databases of MicroPatent and INPADOC to harvest nanotechnology patents filed in about 70 countries.

5. Conclusion

We have classified more than 120 social science studies on nanoscience and technology. These studies analyze the publication and patent data by their research topics. The bulk of this literature focuses on benchmarking the performance of countries, institutions, and individual scientists in the emerging field of nanotechnology. Great scholarly interest is also demonstrated in the research that explores topics such as knowledge flow, economic development and technological change, science and technology relationships, co-authorship, creativity, the development of the nanoscience and technology field, technology assessment and foresight, and intellectual property rights with regard to nanotechnology.

We conducted a comparative analysis of bibliometric search strategies, including lexical queries, evolutionary lexical queries, citation analysis, and the use of core journal sets to find nanotechnology articles. These strategies were used in different studies to harvest the publications and patents related to nanoscience and technology. We found that Mogoutov and Kahane (2007), with their evolutionary lexical query strategy, extract the highest number of specific records from the Web of Science (for 2006). However, most of the lexical queries (GLANZEL, NOYONS, PORTER, and MOGOUTOV) that we compared produce very similar ranking tables of the top ten nanotechnology subject areas, the top ten most prolific countries and institutions. Only LEYDESDORFF differs significantly from all the lexical query strategies in terms of the ranking of the top ten subject areas, countries, and institutions. The data sources of nanotechnology publication and patent data are also discussed at the end of the paper.

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Table 1 Strengths and Weaknesses of Different Searching Strategies

	Lexical query	Evolutionary lexical query	Citation analysis	Publications in the core nanotechnology journals
Characteristics	•Involves experts	•Start the search with a core set of nanotechnology publications •Harvest a set of keywords from the core publications and rank the keywords by their frequency and specificity to the field •An automatic and iterative process to improve the keywords	•Start the search with seed literature which is extracted based on the lexical query analysis •Define the core literature cited by the seed literature and then identify the literature which cites the core literature •The size of the final literature set is determined by the parameters of the citation analysis chosen by the researchers	•Unit of analysis is journal instead of publication •All the publications in the core journals are taken as nanotechnology publications
Strengths	•Easy to be implemented •Suitable for searching both publications and patent databases	•Minimize the input from experts •As the field develops, new keywords can be added and the searching strategy is updated accordingly	•Minimize the experts' involvement •By choosing the parameters objectively, researchers can decide the size of the final literature set	•Easy to be implemented •Data noise should, in theory, be low
Weaknesses	•Biased by the specialization of the experts •Difficult to use static keywords to measure a dynamic field	•The selection of keywords is still decided by researchers and validated by experts, though the keywords are selected based on their frequency and specificity to the field.	•Difficult to be implemented because setting up the citation links among a large number of the publications is time-consuming; only a dozen places in the world have the full access to the database of Web of Science which includes citation linkage •The parameters to define core and final literature set are chosen subjectively by researchers	•The articles published in the a limited number of core journals only represent a small proportion of total nanotechnology publications

Table 2: Searching Outcomes by Different Strategies (Science Citation Index Expanded, 2006)[1]

GLANZEL [2]		NOYONS [2]		PORTER [2,3]		MOGOUTOV		Nano*		LEYDESDORFF	
Total papers: 46177		Total papers: 47002		Total papers: 57900		Total papers: 86751		Total papers: 39889		Total papers: 9027	
Top 10 Subject Areas	% of 81055 subject counts	Top 10 Subject Areas	% of 82990 subject area counts	Top 10 Subject Areas	% of 99950 subject area counts	Top 10 Subject Areas	% of 151399 subject counts	Top 10 Subject Areas	% of 70643 subject counts	Top 10 Subject Areas	% of 19613 subject counts
Materials Science, Multidisciplinary	14.1	Materials Science, Multidisciplinary	13.3	Materials Science, Multidisciplinary	13.5	Materials Science, Multidisciplinary	13.9	Materials Science, Multidisciplinary	14.7	Chemistry, Physical	35.1
Physics, Applied	13.4	Physics, Applied	11.7	Physics, Applied	12.3	Physics, Applied	12.2	Physics, Applied	12.5	Materials Science, Multidisciplinary	21.0
Chemistry, Physical	9.6	Chemistry, Physical	9.4	Chemistry, Physical	9.6	Chemistry, Physical	8.1	Chemistry, Physical	9.7	Nanoscience & Nanotechnology	11.4
Physics, Condensed Matter	8.6	Physics, Condensed Matter	7.3	Physics, Condensed Matter	8.3	Physics, Condensed Matter	7.6	Physics, Condensed Matter	7.4	Chemistry, Multidisciplinary	8.3
Chemistry, Multidisciplinary	5.8	Chemistry, Multidisciplinary	6.1	Chemistry, Multidisciplinary	5.6	Chemistry, Multidisciplinary	4.4	Chemistry, Multidisciplinary	6.2	Physics, Atomic, Molecular & Chemical	8.3
Nanoscience & Nanotechnology	5.6	Nanoscience & Nanotechnology	5.2	Nanoscience & Nanotechnology	4.7	Nanoscience & Nanotechnology	4.0	Nanoscience & Nanotechnology	5.6	Physics, Applied	8.0
Polymer Science	3.7	Polymer Science	3.9	Polymer Science	4.2	Polymer Science	3.4	Polymer Science	3.8	Engineering, Multidisciplinary	5.2
Materials Science, Coatings & Films	2.3	Chemistry, Analytical	2.4	Materials Science, Coatings & Films	2.5	Metallurgy & Metallurgical Engineering	3.2	Materials Science, Coatings & Films	2.1	Physics, Condensed Matter	2.8
Engineering, Electrical & Electronic	2.3	Materials Science, Coatings & Films	2.1	Physics, Multidisciplinary	2.2	Materials Science, Coatings & Films	2.9	Metallurgy & Metallurgical Engineering	2.0		
Physics, Multidisciplinary	2.2	Electrochemistry	2.1	Metallurgy & Metallurgical Engineering	2.1	Engineering, Electrical & Electronic	2.3	Engineering, Electrical & Electronic	2.0		
Top 10 Countries/Regions	of 97219 country counts	Top 10 Countries/Regions	of 99535 country counts	Top 10 Countries/Regions	of 121227 country counts	Top 10 Countries/Regions	of 178999 country counts	Top 10 Countries/Regions	of 83372 country counts	Top 10 Countries/Regions	of 19332 country counts
USA	22.0	USA	22.8	USA	20.3	USA	20.0	USA	22.2	USA	24.8
Peoples R China	15.5	Peoples R China	15.1	Peoples R China	15.9	Peoples R China	14.8	Peoples R China	16.4	Peoples R China	12.5
Japan	9.3	Japan	9.2	Japan	9.1	Japan	10.2	Japan	9.0	Japan	9.7
Germany	6.2	Germany	6.2	Germany	6.2	Germany	5.9	Germany	5.8	Germany	5.7
South Korea	5.5	South Korea	5.3	South Korea	5.4	South Korea	5.6	South Korea	5.5	France	4.9
France	4.8	France	4.6	France	4.7	France	4.8	France	4.6	Italy	4.3
Taiwan	3.5	Taiwan	3.2	Taiwan	3.3	Taiwan	3.3	Taiwan	3.3	South Korea	4.2
Italy	3.1	Italy	3.2	Italy	3.3	Italy	3.2	Italy	3.2	England	3.6
England	2.9	England	2.9	England	2.9	England	3.0	England	2.7	Spain	3.4

India	2.5	India	2.6	India	2.8	India	2.8	India	2.7	Taiwan	2.7

Top 10 Institutions	of 64345 organization counts	Top 10 Institutions	of 64739 organization counts	Top 10 Institutions	of 77775 organization counts	Top 10 Institutions	of 109314 organization counts	Top 10 Institutions	of 54654 organization counts	Top 10 Institutions	of 14278 organization counts
Chinese Acad Sci	4.3	Chinese Acad Sci	4.1	Chinese Acad Sci	4.4	Chinese Acad Sci	4.3	Chinese Acad Sci	4.4	Chinese Acad Sci	4.0
Russian Acad Sci	1.4	Russian Acad Sci	1.3	Russian Acad Sci	1.5	Russian Acad Sci	1.4	Russian Acad Sci	1.6	Natl Univ Singapore	1.1
CNRS	1.1	CNRS	1.1	CNRS	1.1	CNRS	1.1	Tsing Hua Univ	1.1	Univ Calif Berkeley	1.0
Natl Univ Singapore	1.0	Univ Texas	1.0	Tsing Hua Univ	1.0	Tsing Hua Univ	1.0	Natl Univ Singapore	1.1	Univ Illinois	0.9
Tsing Hua Univ	1.0	Natl Univ Singapore	1.0	Natl Univ Singapore	0.9	Tohoku Univ	1.0	CNRS	1.0	MIT	0.9
Univ Illinois	0.9	Tsing Hua Univ	1.0	Univ Tokyo	0.8	Univ Tokyo	0.9	Univ Sci & Technol China	0.9	Univ Tokyo	0.8
Univ Tokyo	0.9	Univ Illinois	0.9	Univ Sci & Technol China	0.8	Osaka Univ	0.9	Univ Texas	0.9	CNR	0.8
Univ Sci & Technol China	0.8	Univ Sci & Technol China	0.8	Univ Illinois	0.8	Natl Univ Singapore	0.8	Nanjing Univ	0.9	Georgia Inst Technol	0.8
Univ Texas	0.8	Univ Tokyo	0.8	Tohoku Univ	0.8	Univ Texas	0.8	Univ Illinois	0.8	Univ Sci & Technol China	0.8
Tohoku Univ	0.8	Osaka Univ	0.8	Zhejiang Univ	0.8	Seoul Natl Univ	0.8	Tohoku Univ	0.8	Nanjing Univ	0.8

Note:

1. A journal in the database of Science Citation Index Expanded can be tagged with more than one field. An article can have multiple authors who are from different organizations and countries. That is the reason why the share of the records in different fields adds up to be more than 1.
2. The search queries we implemented for the search strategies of GLANZEL, NOYONS and PORTER are slightly different from the original queries in the way that we search keywords or combined keywords with quotation mark in Web of Science. Without quotation mark, unrelated keywords which are separately scatted in its title, keyword or abstract can be wrongly regarded as a combined keyword. The articles including these separated keywords would be accordingly wrongly retrieved in the latest of version of Web of Science. By adding the quotation mark, we retrieve the articles which encompass the exact combined keywords in its title, keyword or abstract.
3. We did not implement the modular 8 in the PORTER’s search algorithm because we consider the modular 8, which only includes a small number of journals and it contributes to less than 1 percent of total articles retrieved by PORTER’s search strategy, is an ad hoc addition to the overall search algorithm.

Table 3: The Top 10 Journals (in Descending Order) in Terms of Publishing Most of Nanotechnology Articles (Science Citation Index Expanded, 2006)[1]

GLANZEL	NOYONS	PORTER	MOGOUTOV	Nano*	LEYDESDORFF
APPLIED PHYSICS LETTERS	**APPLIED PHYSICS LETTERS**	**APPLIED PHYSICS LETTERS**	**APPLIED PHYSICS LETTERS**	**APPLIED PHYSICS LETTERS**	JOURNAL OF PHYSICAL CHEMISTRY B
PHYSICAL REVIEW B	JOURNAL OF PHYSICAL CHEMISTRY B	**PHYSICAL REVIEW B**	JOURNAL OF APPLIED PHYSICS	JOURNAL OF PHYSICAL CHEMISTRY B	CHEMICAL PHYSICS LETTERS
JOURNAL OF PHYSICAL CHEMISTRY B	PHYSICAL REVIEW B	JOURNAL OF PHYSICAL CHEMISTRY B	**PHYSICAL REVIEW B**	**PHYSICAL REVIEW B**	NANOTECHNOLOGY
JOURNAL OF APPLIED PHYSICS	NANOTECHNOLOGY	JOURNAL OF APPLIED PHYSICS	JOURNAL OF PHYSICAL CHEMISTRY B	NANOTECHNOLOGY	CHEMISTRY OF MATERIALS
NANOTECHNOLOGY	JOURNAL OF APPLIED PHYSICS	**LANGMUIR**	**THIN SOLID FILMS**	JOURNAL OF APPLIED PHYSICS	JOURNAL OF NANOSCIENCE AND NANOTECHNOLOGY
LANGMUIR	**LANGMUIR**	NANOTECHNOLOGY	**LANGMUIR**	**LANGMUIR**	JOURNAL OF MATERIALS CHEMISTRY
JOURNAL OF THE AMERICAN CHEMICAL SOCIETY	JOURNAL OF THE AMERICAN CHEMICAL SOCIETY	**THIN SOLID FILMS**	NANOTECHNOLOGY	JOURNAL OF THE AMERICAN CHEMICAL SOCIETY	ADVANCED MATERIALS
THIN SOLID FILMS	**THIN SOLID FILMS**	JOURNAL OF THE AMERICAN CHEMICAL SOCIETY	APPLIED SURFACE SCIENCE	NANO LETTERS	NANO LETTERS
PHYSICAL REVIEW LETTERS	PHYSICAL REVIEW LETTERS	JOURNAL OF APPLIED POLYMER SCIENCE	SURFACE & COATINGS TECHNOLOGY	**THIN SOLID FILMS**	JOURNAL OF NANOPARTICLE RESEARCH
NANO LETTERS	NANO LETTERS	PHYSICAL REVIEW LETTERS	JAPANESE JOURNAL OF APPLIED PHYSICS PART 1-REGULAR PAPERS BRIEF COMMUNICATIONS & REVIEW PAPERS	JOURNAL OF NANOSCIENCE AND NANOTECHNOLOGY	FULLERENES NANOTUBES AND CARBON NANOSTRUCTURES

Note: 1. A few of the top 10 journals, which are identified by GLANZEL, NOYONS, PORTER and MOGOUTOV but are excluded in LEYDESDORFF’s ten core journal list, are marked in bold.

Table 4: The Unique Records Extracted by Different Searching Strategies (Science Citation Index Expanded, 2006)

	GLANZEL	NOYONS	PORTER	MOGOUTOV	LEYDESDORFF
Number of unique records:	297	1689	6766	33167	3188
Ratio of unique records to total records:	1%	4%	12%	38%	35%
Top 5 Subject Areas	Physics, Condensed Matter	Biochemistry & Molecular Biology	Physics, Applied	Materials Science, Multidisciplinary	Chemistry, Physical
	Physics, Multidisciplinary	Biotechnology & Applied Microbiology	Physics, Condensed Matter	Physics, Applied	Physics, Atomic, Molecular & Chemical
	Physics, Applied	Chemistry, Analytical	Materials Science, Multidisciplinary	Physics, Condensed Matter	Materials Science, Multidisciplinary
	Chemistry, Organic	Biochemical Research Methods	Polymer Science	Chemistry, Physical	Chemistry, Multidisciplinary
	Physics, Atomic, Molecular & Chemical	Polymer Science	Chemistry, Physical	Metallurgy & Metallurgical Engineering	Nanoscience & Nanotechnology
Top 5 Countries/Regions	USA	USA	USA	USA	USA
	Japan	Japan	Peoples R China	Peoples R China	Japan
	Peoples R China	Germany	USA	Japan	Peoples R China
	Germany	Peoples R China	Peoples R China	South Korea	France
	France	Italy	Japan	Germany	Germany
Top 5 Institutions	Chinese Acad Sci	Univ Texas	Chinese Acad Sci	Chinese Acad Sci	Chinese Acad Sci
	Russian Acad Sci	Univ Tokyo	Russian Acad Sci	Russian Acad Sci	Kyoto Univ
	Kyoto Univ	Harvard Univ	CNRS	Tohoku Univ	Univ Calif Berkeley
	RIKEN	Chinese Acad Sci	Univ Tokyo	Osaka Univ	Univ Tokyo
	Univ Oxford	Stanford Univ	Indian Inst Technol	Univ Tokyo	CNRS

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