Scientific linkage of nanotechnology: from pubic science to industrial technology - preliminary study

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Abstract

In this preliminary study, the author demonstrated the linkage between the research of public science and the development of industrial technology of Nanotechnology, highlighting the impact of public science on the industrial technology through non-patent citation analysis. The study aimed to reveal the important entities of science research that had significant impact on industrial technology, and if there were any citing preferences existed.

Introduction

It is widely accepted that public science is the driving force behind the development of industrial technology and economic growth both in scientific and economic communities. The utilization of public science output in the development of technology is seen as presentation of the usefulness of science research done in academic community. It is helpful to the researcher to understand the dissemination of knowledge gained from public science to industrial technology by constructing the linkage between public science and industrial technology. By the same token, the demonstration of the usefulness of public science is valuable to the decision maker when drafting strategic plan.

In early studies, the researches focus on the discussion of whether there was any correlation between science and technology [Collins and Wyatt. 1988; Narin and Noma, 1985; Narin and Olivastro, 1992]. Empirical studies were carried out later on to enforce the validity of the linkage and the importance to establish such linkage, and several researches showed the dependence of industry development on public science [Anderson, Williams, Seemungal, Narin and Olivastro, 1996; Narin, Hamilton and Olivastro, 1997; McMillan, Narin and Deeds, 2000]. Citation analysis was the most common approach taken to define the correlation between science and technology [Bhattacharya, S., Kretschmer, H. & Meyer, 2003; Meyer, 2000a; Meyer, 2000b; Narin, 1994; Verspagen, 1999].

In this study, the author tried to demonstrate the linkage between research of public science and development of industrial technology of nanotechnology, focus on the impact of public science on the industrial technology through non-patent citation analysis. The study aimed to reveal the important entities of science research that had significant impact on industrial technology, and if there were any citing preferences existed.

Research Problems

The purpose of this study was to reveal the linkage between research of public science and development of technology by examining the non-patent literatures cited in patents. Non-patent literatures, especially journal articles, were seen as representation of the science research output and patents were taken as tokens for results of technology development. The author examined the patents granted in Nanotechnology by United States Patent and Trademark Office (USPTO), which covers the patents granted by USPTO since 1976. The patents in the patent database were re-classified in 2006 based on the International Patent Classification (IPC) 8th edition. The patents included in this study were identified by IPC Numbers and patents and non-patent literatures cited by the identified patents were also examined in this study. The linkage between citing patents and cited materials was reviewed to construct the link between science research and technology to answer the following research questions.

- What is the distribution of research productivity in Nanotechnology?
- Did science research influence the development of technology in Nanotechnology? And what were the sources of impact?
- If institutions from public sector showed greater influence on the research than the ones from private sector did?
- Can the scientific linkage show the value of the research works done in the public science?

Data and Methods

Data

The data source used in this study was USPTO Patent database. The study analyzed 213 USPTO patents granted during the period of 1985 to 2008, which were identified as Nano-technology patents by IPC Numbers. The patents that had IPC numbers of Class B82, "Nano-technology" were defined as Nanotechnology patents. The 4,161 cited patents and 4,593 cited non-patent literatures referenced by 213 Nanotechnology patents were included in the study.

This study further examined patents granted to the most productive assignee, Nanosphere, and works cited by the granted patents, which included 1,579 cited patents and 1,890 non-patent citations to explore the science and technology interface in Nanotechnology research. The data sets used in this study were constructed through the following steps.

1. Retrieving patents with IPC numbers of B82 class from USPTO patent database (Data Set 1)
2. Extracting cited patents from the front pages of patents in Data Set 1 from USPTO patent database (Data Set 2)
3. Extracting cited non-patent literatures from the front pages of patents in Data Set 1 from USPTO patent database (Data Set 3)
4. Extracting patents granted to the most productive assignees and cited references of the patents in Data Sets 1-3 (Data Set 4)
5. Identifying origin of the cited non-patent literatures in Data Set 4 by examining the copies of cited works (Data Set 5)

Methods

This study took bibliometrics approach; Patent Count was used to show the research productivity. Further analyses were done by employing Bradford's model [Garfield, 1980; Narin, 1977] to identify the core assignees. In this preliminary study, the patent citations and non-patent citations referenced by the patents granted to the most productive assignees were examined. Citation Count was applied to reveal the linkage of science research and technology development [Karki, 1997]. The following attributes were examined in this study: types of non-patent citations, major resources of citations, and key institutions contributed to development of Nanotechnology.

Findings

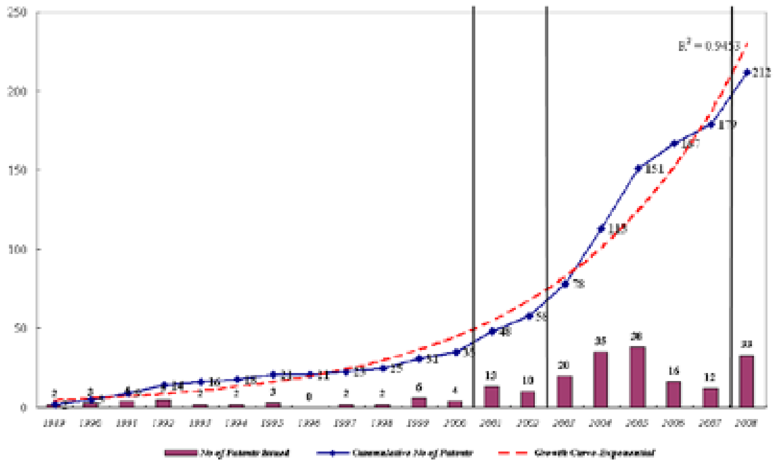
Basic Analysis

Basic patent count and Bradford's model analysis were applied for productivity analysis. The results were presented by time, technologies, countries and assignees.

(1) Time Distribution
The first Nanotechnology patent granted by USPTO was granted to International Business Machines Corporation in 1985. After the first patent granted, starting from 1989, there were patents granted in Nanotechnology each year, except 1996. But it was not until 2001 that there were more than 10 patents issued annually. Examining the patents

granted each year, despite the slow starting and declining in number of patents issued in 2006 and 2007, the exponential growth curve provides an implication that Nanotechnology research is in the prime time and it is expected that at least 30 patents will be granted in 2009. Figure 1 shows the number of patents granted and the cumulative number of patents during the period of 1989 to 2008.

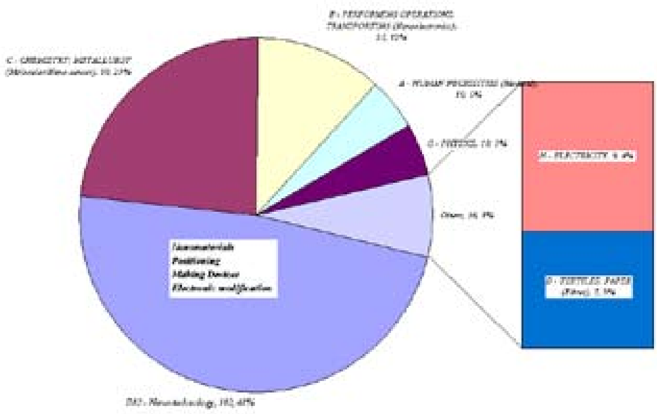
Figure 1: Patent Count - 1989-2008.



(2) Nanotechnology distribution

The patents included in this study were selected by IPC numbers. Those patents with the classification numbers listed as sub-categories of B82 were identified as Nanotechnology patents and put in the data set for further analysis. The results showed that 48% of patents involved with the treatments of Nanostructure, including Nano-materials, Positioning, Making Devices and Electronic Modification, 52% of patents focus on the applications of Nanotechnologies in various technological fields, two major technology areas, the process or methods in Nano-electronics and Molecular Nanotechnology, were identified by examining the distribution of the classification numbers. Figure 2 shows the distribution of technologies. The numbers of patents issued in basic Nanotechnology (B82) and applications in other tech fields maintained stable growth. The only exception was in 2004, USPTO granted greater amount of patents in Nano Molecular (sensor).

Figure 2: Distribution of Patent Technologies



(3) Countries and Assignees

Assignees country was used as a counting base to analyze countries' research productivity in Nanotechnology. It was counted once if the patent was co-owned by the assignees based in the same region. If the patent was co-owned by the assignees from different regions, it was counted one patent for each country where the assignees were based. With the local advantage, the United States was the most presentable country in Nanotechnology research in USPTO database. Out of 213 patents, there were 150 patents were granted to the assignees based in the United States. Japan was listed at the second place, 37 patents were granted to the institutes or individual based in Japan. Denmark, Korea and other 9 countries were also granted USPTO patents in Nanotechnology, but all owned less than 10 patents.

Further patent counts and analysis were done for assignees. There were 99 assignees were identified from the patent data. Two third of assignees (66, 57.94%) were from private sector, one fourth of assignees (27, 25.23%) were from educational sector. There were also patents granted to government agencies, 4 assignees and 8 patents. There were 9 patents, which did not have any assignee information listed. Analyzing the geographic areas where the assignees based, the United States and Japan are two major research bases, 57 assignees were based at the United States and 19 assignees were based in Japan. Examining the number of patents owned by the identified assignees, it was found that over 90% of assignees owned less than 3 patents (included), 63 (63.43%) assignees only owned one patent, 17 assignees owned 2 patents and 10 assignees owned 3 patents. Among 99 assignees, Nanosphere, based in Illinois (US), was the most productive assignee, owned 31 patents and followed by William Marsh Rice University, which owned 17 patents. Hitachi was the one of a few productive non-US based assignees, owned 11 patents. Besides Nanosphere, William Marsh Rice University and Hitachi, Hewlett-Packard Development and International Business Machines Corporation were the other two primary assignees recognized by Bradford's Model, which owned one third of the patents. Table 1 lists the primary assignees, numbers of patents granted and the patent technologies.

Table 1: Top Five Productive Assignees

Assignees	**Region**	**No. of Patents**	**Technologies**
Nanosphere, Inc.	Northbrook, IL	31	Molecular Nanotechnology
William Marsh Rice University	Houston, TX	17	Carbon Nanotube
Hitachi, Ltd.	Tokyo, JP	11	Nano-materials (process)
Hewlett-Packard Development Company, L.P.	Houston, TX	8	Electronic devices
International Business Machines Corporation	Armonk, NY	7	Microscopic particles, Positioning

Research Impact and Scientific Linkage

To reveal how science research influences the development of Nanotechnology, this study further examined the patents granted, especially the ones granted to the top 5 productive assignees and cited references listed on the patent front pages. The author continued to trace the origin of non-patent citations of patents granted to Nanosphere to establish the linkage between science research and industrial technologies of Nanotechnology.

(1) Research Impact

All the 213 patents cited at least 1 reference, there were total 8,754 cited references, each patent cited 42 references in average. Examining the material types of those citations, it was found that there were 4,161 patents and 4,593 non-patent literatures, each patent cited 20 patents and 22 non-patent literatures in average. Over 65% of patents cited less references in average, the results of citation count showed that 62 patents cited less than 10 references. There were also a few patents cited greater amount of references, 33 patents cited more than 100 references. Among them, the patent granted to Natero in 2005 cited the most number of references, 521 in total, 240 patents and 281 non-patent literatures. The number of cited references implied the influence of prior art on the development of Nanotechnology. The top 5 productive assignees present two different types of innovation strategies. The patents granted to Nanosphere and William Marsh Rice University tended to cite significant amount of references and it showed the high dependence on prior art during the research and development stage. With the high productivity, it is also could be taken as a token that both assignees perform well in transferring the outcomes of science research into invention that could be industrially reproduced or enhancing the existing invents and discovers. The other three assignees, Hitachi, Hewlett-Packard Development and International Business Machines Corporation presented very different strategy, advancing technologies through internal research and development.

Looking into the distribution of number cited patents and cited non-patents literatures and found that the numbers of cited non-patent literatures were greater than the numbers of cited patents with limited margin, it was about 20.3 (46.5%) : 23.3 (53.5%) (Number of cited patents £∫ Number cited non-patent literatures). The only exception was the distribution in 2005; more patents were cited than non-patent literatures were in average. As for the types of the non-patent citations, it was found that the non-patents citations were either journal articles, proceeding papers, chapters from books or theses, which most of the authors of the works were affiliated with organizations from public sector. This could be used as an explanation that citing non-patent literatures is seen as an indicator of influence from scientific research on the development of industrial technology and the higher non-patents citation rate presents the evidence that the public science is the driving force behind the development of Nanotechnology.

(2) Scientific Linkage - the case study of Nanosphere

To have better understanding of source of the influence, the author examined the cited works in details. The most productive assignee was sampled for further study. Nanosphere a Nanotechnology-based healthcare company located in Illinois, US, was granted 31 Nanotechnology patents (not include the patents deal with chemical and biological structure but were not classified under B82) since founded in year 2000. Chad A Mirkin is one of the founders and the leading researcher in Nanosphere, with Robert L. Letsinger and a 6-people research group, the research team fabricated 90% of the Nano-inventions granted to Nanosphere. A new research team appeared while analyzing the patents issued in 2006, 3 researchers with 3 patents granted by 2008. By the number of citations, the research teams highly depend on the previous works, 1,579 patents and 1,890 non-patent literatures were cited by 31 patents. Both patent and non-patent citations showed the influence of research done in public sector. The 1,579 patent citations, 1,489 were issued and 90 were pending during the research period. There were total 87 patents were identified after synchronizing and those 87 patents were contributed by 38 assignees including the ones granted to Nanosphere (Self-citation). There were 4 assignees were cited more than 100 times. Besides the self-citation, two out three most cited assignees by Nanosphere were educational institutes, University of California (based at Oakland, CA) and Massachusetts Institute of Technology, were cited 122 and 111 times. The other influential source was the researches done by Syva Company in early 1980s. Syva Company was bought by Behring Diagnostics and is part of Siemens Healthcare Diagnostics.

Further reviewing the non-patent citations, 132 works were identified from 1,890 non-patent citations and contributed by 53 source titles. There 46 titles (86.8%) of sources titles were journal articles, 4 titles were proceedings and 3 titles were monographs. Among the different material types, journal articles were heavily referenced, over 90.5% (1,171) of non-patent citations were journal articles. Among the source titles, Journal of the American Chemical Society was the most cited work that it was cited by Nanosphere 276 times. Langmuir came as the second place, it was cited 164 times. Besides those articles issued on the journals in “Multidisciplinary Sciences”, the journals in “Chemistry-multidisciplinary” and “Biochemistry” were also valuable information bases for Nanosphere. If the journal articles are taken as representations of science research output, the result gave a very good demonstration that the development of Nanotechnology were highly influenced by the basic research and the distribution of the influence sources could be seen as an indicator to show the value of works done in science research. To validate the observation, the author continued to review the first authors’ affiliations of the 132 cited works and the results showed that over 88% of cited works were contributed by the authors from public sector , including the authors from educational institutes, governmental departments and research institutes, the works were cited 1,470 times. Among the influential affiliations, Northwestern University and William Marsh Rice University were the two leading institutions to Nanosphere. The former was located in the same geographic area and was the main technology base of Nanosphere’s development, which was cited 424 times, and the latter one was one of the productive assignees and it was cited by Nanosphere 158 times. New York University was another institution that had major impact on Nanosphere. The works done by the authors affiliated with New York University were cited 120 times. Table 2 lists the top 10 influential sources to Nanosphere Inc. The works done by the members of Nanosphere research team from their previous positions in Northwestern University were also listed as prior art.

Table 2: Top 10 Influential Sources of Nanosphere Inc. Nanotechnology				
	Institutions		**Publications**	
	University	**Times Cited**	**Source Title**	**Times Cited**
1	Northwestern University	424	Journal of the American Chemical Society	276
2	Rice University	158	Langmuir	164
3	New York University	120	Nature	120
4	Harvard University	83	Chemical & Engineering News	119
5	University of California, San Diego	60	Biochemistry	90
6	University of California, Los Angeles	60	Science	77
7	Pennsylvania State University	59	Analytical Biochemistry	60
8	University of Delaware	53	Clinical and Biological Applications	60
9	University of Melbourne	33	New Journal of Chemistry	60
10	Iowa State University	30	Nucleic Acids Research	57
10	Massachusetts Institute of Technology	30		
10	The University of Liverpool	30		
10	University of Alabama	30		
10	University of California at Berkeley	30		
10	University of Cambridge	30		
10	University of Salzburg	30		
10	University of Utah	30		
10	Wesleyan University	30		

Observations

From the results of this preliminary study, the author made the following observations.

- The patenting activity in Nanotechnology is into rapid growth period

The concept of the Nanoscale could be traced to 1959, but there was no significant patent activity until 2001 by the numbers of patents granted in USPTO. Observing the growth of numbers of patents issued annually, more patenting activities could be expected.

- With local advantage, the United States is the leading country both in productivity and research impact in Nanotechnology research

With the research resource support and possible local bias, the outcome of Nanotechnology research of the United States was well represented in USPTO patent database. Japan also showed higher productivity in USPTO patenting comparing to other non-US countries.

- With Northwestern University as technology base, Nanosphere has leading position in Molecular Nanotechnology

Nanosphere, a nanotechnology-based healthcare company, with the technical support from the discoveries at Northwestern University offers proprietary breakthrough technologies that provide a unique and powerful solution to greatly simplify diagnostic testing and becomes one of the productive institutions in Molecular Nanotechnology.

- Nanomaterials, Positioning process, Making devices and Electronic modification are the major sub-categories of patenting Nanotechnologies.

With the applications in various areas, the discoveries were distributed mainly in Nanomaterials, Positioning process, Making devices and Electronic modification. The development in Molecular Nanotechnology is also promising.

- Research outcomes of both public science and industrial technology play import roles in the development of Nanotechnology

From the number of citations of the patents included in this study, the development of Nanotechnology is highly dependant on the prior works from both science and technology researches.

- Through the affiliation analysis, the institutions from public sector hold influential position in the development of Nanotechnology

The results of case study on Nanosphere showed that not only the technology base founding the company in the same region had great impact on industrial technologies involved in the patents granted, the science works done within other research institutions, such as William Marsh Rice University, also provide open and fruitful sources for making continuous enhancements.

- Scientific linkage could use as an indicator to show the value of the research works in public science

The result of scientific linkage reveals the bridge between science research and technology development. With the high linkage ratio both to patents granted to and journal articles written by the authors affiliated with institutes from public sector, the linkage presents the evidence that the public science does hold a crucial place behind the development of industrial technology and the potential effects on global economics with the wide ranging applications of Nanotechnology.

Conclusions

In this study, the author examined 213 Nanotechnology patents and 8,754 cited references to establish the linkage between science research and technology development. The results showed that the development of Nanotechnology was highly dependent on the science researches, especially the works done by public sector, in terms of numbers of journal articles cited in the selected patents and the origin of the cited works. It confirms the findings from previous studies [Narin, Hamilton and Olivastro, 1997; McMillan, Narin and Deeds, 2000] and provides the evidence that the science research was the driving force behind technology development. From administration point of view, the linkage could be seen as a token to demonstrate the contribution of science research to industrial technology development.

By calculating the frequency of citation, it offers a clear picture of main sources for research impact. Comparing the works cited in science research, the highly cited journals by patents were heavily used by both sides. Citing preferences were observed from the results. Works done by researchers in the same institutions or affiliations, as well as institutions geographically close to each other, tend to be cited more. For strategic planners, the results provide useful information for policy making, such as in collaboration

References

01. J. Anderson, N. Williams, D. Seemungal, F. Narin & D. Olivastro (1996). Human genetic technology: exploring the links between science and innovation, Technology Analysis & Strategic Management, 8(2), pp. 135-156.
02. S. Bhattacharya, H. Kretschmer & M. Meyer (2003). Characterizing intellectual spaces between science and technology, Scientometrics, 58(2), pp. 369-390.
03. P. Collins & S. Wyatt (1988). Citations in patents to the basic research literature, Research Policy, 17(2), pp. 65-74.
04. F. Garfield (1980). Bradford’s law and related statistical patterns, Current Contents, 19, pp. 5-12.
05. M. M. S. Karki (1997). Patent citation analysis: a policy analysis tool. World Patent Information, 19(4), pp. 269-272.
06. G. S. McMillan, F. Narin & D. L. Deeds (2000). An analysis of the critical role of public science in innovation:

the case of biotechnology, Research Policy, 29(1), pp. 1-8.

07. M. Meyer (2000a) Does Science push technology? Patents citing scientific literature, Research Policy, 29(3), pp. 409-434.
08. M. Meyer (2000b). Patent citations in a novel field of technology - what can they tell about interactions between emerging communities of science and technology, Scientometrics, 48(2), pp. 151-178.
09. F. Narin (1994). Patent bibliometrics, Scientometrics, 30(1), pp. 147-155.
10. F. Narin, K. S. Hamilton & D. Olivastro (1997). The increasing linkage between U.S. technology and public science, Research Policy, 26(3), pp. 317-330.
11. F. Narin & J. K. Moll (1977) Bibliometrics. Annual Review of Information Science and Technology, 12, pp. 35-58.
12. F. Narin & E. Noma (1985).Is technology becoming science? Scientometrics, 7(3-6), pp. 369-381.
13. F. Narin & D. Olivastro (1992). Status report - Linkage between technology and science, Research Policy, 21(3), pp. 237-249.
14. B. Verspagen (1999). Large firms and knowledge flows in Dutch R&D system: a case study of Philips electronics, Technology