The Effect of E-Resources on Technology Development

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Abstract

In this paper we discuss the increasing connection between scientific papers and patented technology. In the last 20 years, the number of references from patents to scientific papers has increased dramatically. We postulate that at least part of the reason for this is the increased electronic availability of white papers, technical reports, and especially journal articles and conference papers.

Introduction to Patent Referencing

Patents in most countries are essentially contracts between inventors and governments. The inventor discloses how an invention works so that society can benefit from the knowledge to build upon or improve the idea, and in exchange the government gives the inventor a limited monopoly. In most countries, the patent does not give the inventor the right to practice an invention, but rather the right to stop others from practicing the invention.

In order to obtain a patent, the inventor, their attorney, or the patent examiner will reference (or 'cite') all relevant prior art related to the new invention. Prior art consists mainly of earlier related patents, but it can also consist of journal articles, books, and technical documents. Indeed, it can include anything, such as comic strips or advertisements, that predates the patent application, is publicly available, and is relevant to the invention. Patent examiners use the prior art to limit the scope of the claims of the potential patent.

Prior art consists of items related to the patent application, but the nature of invention is such that it is not always clear whether the prior art led to the new invention, or whether the prior art was identified afterwards via a prior art search. Many inventions happen because an inventor sees a patent or article and gets an idea from that document for a new invention. For example, an inventor may see a patent for a mousetrap and, by examining the diagrams, see an immediate way to improve it. The new mousetrap patent will reference the earlier one as prior art and, even though the newer one may be an improvement, its claims will be limited by the prior mousetrap.

A similar case might occur when a company obtains a patent and launches a successful product. Competitors will study the patent and product intensely in order to build a competing product that does not infringe upon the existing patent. If

successful, the new patent will reference the original patent, which will in turn limit the claims of the new patent. An alternative case is where an inventor files a patent and then, after a prior art search, identifies patents and other documents that would be considered prior art. In this case, the prior art serves only to limit the new patent, while in the former two cases one could argue that the prior art in some way inspired the new invention.

In most cases, it is not possible from viewing a patent to determine whether a particular reference was cited because of a prior art search, or whether it was in some way an inspiration for the new patent. To obtain statistics on what percentage of references were inspirational rather than search related, one would require a fairly extensive survey that is well beyond the scope of this study. However, one can say with certainty that references identified and placed on the patent by the patent examiner, rather than the inventor, are the result of a prior art search and in no way inspired the new invention.

For US patents issued since the year 2000, an asterisk is placed next to any reference that the patent examiner adds to a patent. Table 1 shows the percentage of references marked with an asterisk on US patents issued in 2006.

Table 1 – Percent of 2006 References Added by Patent Examiner

Reference Type	# 2006 References	# Added by Examiner	% Added by Examiner
US Patent References	3,095,134	1,064,875	34%
Non-US Patent References	629,979	46,333	7%
Non-Patent References	851,233	60,845	7%

We separately identified three types of references: earlier US patents referenced, Non-US patents referenced, and non-patent references. The latter, which can be anything from technical reports to books to specification sheets and advertisements, are also known as NPRs. Table 1 reveals that most prior art references are earlier patents and that, in 2006, 34% of those were added by the patent examiner. The others are added by the inventor or applicant, or the applicant's attorney. As mentioned previously, the references added by the applicant or attorney may be as a result of a prior art search, or because the prior art somehow inspired or led to the new invention. The fact that only 7% of the NPRs are added by the examiner suggests that NPRs are more often inspirational than patent references. In other words, it is reasonable to assume that a relatively high number of non-patent references provide the building blocks to patented inventions.

For example, it is not difficult to imagine a scientist reading an article about a new lightweight material, and thinking it would be perfect for use in a product that his/her company currently produces. Similarly, a programmer may read about an algorithm

in a journal article, or see it at a conference, and modify the algorithm for use in a piece of software that he/she is currently building.

In this article we argue that, due to E-Resources, inventors have an unprecedented number of technical articles available to them. Furthermore, this increased availability is not only showing up as increased referencing to NPRs, but may be leading to significant numbers of new inventions.

US Patents in Technology and Innovation Studies

Policy analysts, economists, and other social scientists often use US patents when studying innovation or developments in technology. The current study is also based on trends in US patents. The US patent system is useful for doing international comparative analyses because the US is one of the most desirable consumer markets, so companies patent extensively there. Inventors from more than 150 countries patent in the US system, and about 50% of all US patents are issued to non-US inventors, including 20% to Japanese inventors, 6% to German inventors, and 4% to Taiwanese inventors. In general, Asian countries have a higher percentage of US patents than European Patent Office (EPO) patents or World Intellectual Property Organization (WIPO) patents.

Key Results of a Patent Study of Taiwan, Mainland China, and Hong Kong

Before embarking on our main topic regarding the effect of E-Resources on patent activity, we will first review some key results from recent study of Taiwan, Mainland China, and Hong Kong. This study was presented by the author at the Society of Competitive Intelligence Professionals national conference in April 2006, and provides a useful background for those readers less familiar with patent analysis. It also provides context for some of the choices made later in the analysis.

Figure 1 shows the seven fastest growing inventor countries producing US patents. Mainland China and India are the fastest growing. US patents from Chinese inventors have increased roughly 10-fold from 1995 to 2005, while those from Indian inventors have increased nearly 8-fold in the same period.

Taiwan and Hong Kong inventors have increased their US patenting roughly 4-fold in the same period, but both countries' US patenting has been flat or declining in recent years. One of the problems with Taiwan's growth is that, now that Taiwanese inventors form a significant part of the US patent system (they are fourth in terms of number of patents) it is difficult for Taiwanese patenting to grow at its former pace. Similarly, the number of patents from the top three inventor countries (US, Japan, and Germany) is also flat or declining in recent years.

Table 2 reveals that that, from 1995 to 2005, Taiwan went from the 7th ranked country in US patent output to 4th, and that Mainland China went from 24th to 15th. As noted above, given Taiwan's large patenting presence, it is difficult to maintain its current growth. Mainland China, on the other hand, while currently the fastest growing US patenting country, has only one-sixth as many US patents as Taiwan.

Figure 2 examines patent activity within the US patent system for Taiwan, Mainland China, Hong Kong, and the United States. This figure is interesting for several reasons. The US has a fairly large share of Medical Device patents, while China has a larger share of Electrical patents but, as a whole, patents invented in Mainland China have a similar technology distribution to patents invented in the US. Taiwan's distribution is far different. It has very few life-science patents, while one in five of its patents are semiconductor related. Meanwhile, Hong Kong has a large number of patents related to furniture and sports, games, and toys.

Table 2 – US Patent Rankings for China, Taiwan, and Hong Kong

Year	1995			2005		Percent
	Rank	# Patents		Rank	# Patents	Increase
China (mainland)	24th	82		15th	964	1076%
Taiwan	7th	1679		4th	6172	268%
Hong Kong	23rd	108		21st	489	353%

Before leaving this study, there are a few other key highlights worth pointing out. First, China's technology rise has a completely different pattern to those previously seen in Japan and Korea. Japan's technology rise was associated with Japanese-owned companies such as Sony, Canon, Hitachi, Toshiba, Toyota and Honda. China's rise is largely due to multinational companies setting up labs within China. The top assignee producing Chinese invented US patents, by a wide margin, is Hon-Hai (a Taiwanese company). Companies with the most Chinese invented patents include companies from the US, Hong Kong, and Germany. The largest Chinese companies producing US patents are Ningbo Beifa Group and Sinopec, but each have only a fraction of the patents that Hon Hai holds.

The Taiwanese rise in patenting is much more similar to the rise of Japan twenty years ago. The top companies producing US patents in Taiwan are all Taiwanese-owned, and all are related to information technology, communications, or semiconductors.

Increasing References

Figure 3 reveals that patent references of all types have increased in the last 20+ years in the US patent system. In 1984, on average a US patent referenced five earlier US patents, one earlier non-US patent, and about one-half of a non-patent reference. In contrast a 2006 US patent references an average of 18 earlier US patents, four non-US

patents, and four non-patent references. A logarithmic scale is used in Figure 3 to clearly show all three lines, so the growth of each type of reference is somewhat obscured. The growth is clearer in Figure 4, which reveals that there are now 3.5 times as many references to earlier US patents as in 1984, 4.25 times as many references to earlier non-US patents, and 10.65 times as many NPRs.

It is clear that the number of references of each type is increasing every year, but it is not clear why. It may be that products that were once protected by only a few patents are now protected by many more patents. For example, if a product has 15 patents protecting it, then a competing company may reference most of the 15 when creating a product that "builds-around" the first product's patents.

The growth in referencing may also be due to the increased availability of prior art caused by the growth in electronic databases. For example, back in 1984 it was fairly difficult to search for earlier patents. Patents were available as paper copies sorted by patent office classifications in a handful of patent depositories. By the early 1990s, CD-ROMs of patent information became available, allowing for keyword searching by applicants and their attorneys. By the late 1990s such databases were available online to a wider audience, often free of charge. Non-Patent reference materials such as journal papers and conference papers also became far more available as they went electronic.

As noted earlier, the growth in referencing may have multiple causes, and the influence of each cause is difficult to ascertain without a large scale survey. However, it is quite likely that the availability of E-Resources has had a significant effect on the increase. Electronic databases have not only increased the availability of patent and non-patent documents, they have also allowed for keyword searching by inventors and their attorneys, who may lack the expertise to identify documents that are not keyword indexed. Moreover, in economic studies (such as Branstetter, 2003) empirical evidence has been presented that suggests that the nature of inventive activity has changed such that scientific articles are leading to more inventive activity. These types of studies suggest that the increased availability of E-Resources should lead to increased technology development.

Since, as shown earlier, the increase in Non-Patent References has been the most dramatic, and because these types of references are least likely to be added by the patent examiner, we concentrate on NPRs in this paper. The first question to ask is whether the increase in NPRs is due to an increase in patents in a particular technology category. For example, it is well known that biotechnology patents reference more journal articles than automotive patents. Hence an increase in biotechnology patents could potentially explain the general growth in NPRs.

Referencing trends to non-patent literature in six broad technology areas plus 'other,' which contains all remaining patents, can be found in Figure 5. While Biotechnology and Pharmaceutical patents have the most references to non-patent literature, the average number of NPRs has grown in every category. For example, since 1984 the number of NPRs on Biotechnology/Pharmaceutical patents has increased nearly 11-fold, and the same can be said for chemical patents. Patents related to semiconductors and information technology have shown a 7-fold increase in non-patent references, while patents in the 'other' category have shown a 16.5-fold increase in non-patent referencing. In short, references to non-patent literature have increased in each technology category in the last 20+ years.

Figure 5 raises questions of how many patents are actually involved in the various categories. Figure 6 shows the percentage of all US patents issued in 2006 (from inventors in all countries) in each of the various categories. While Biotechnology/Pharmaceutical/Medical Device patents have the highest rate of non-patent referencing, patents in these categories actually only account for 10% of the granted patents. Currently about 39% of issued patents are in information technology categories such as semiconductor manufacturing, computer hardware and software, and telecommunications.

One might also wonder whether the increase in referencing to non-patent literature is just based on patents invented in the US or a few other countries. Figure 7 shows that the phenomenon is actually widespread, with patents from all countries having a higher NPR rate in the last 5 years compared to the first 5-year period. In this figure we abandoned the year-by-year line graphs in favor of bar graphs of 5-year periods in order to fit the top 24 significant inventor countries on one chart. Note that there is a wide difference in the numbers of NPRs per patent for each country, but that the trend is generally upwards for each country.

There may be numerous reasons for the disparity in NPRs among countries. For example, Table 2 revealed that Taiwan has very few biotechnology patents, so it is not surprising that its NPR rate is much lower than a country like the UK that has a lot of biotechnology patents. Also, even countries that patent in the same technologies may have different propensities to reference non-patent literature. For example, the availability of electronic databases of prior art may vary from country to country. In any case, the difference among countries is not important for our purposes. The main purpose of Figure 7 is to show that the increase in Non-Patent Referencing is widespread, and not a local trend.

Motivation for Focusing on Non-Patent References within Information and Communications Technology

The earlier sections of this paper establish that referencing to non-patent literature has been increasing steadily, and that the increase has occurred in all technologies and all countries, at least to some extent. For the remainder of the paper, we focus on patents related to information and communications technology (ICT), which includes patents in computer hardware and software, as well as semiconductor manufacturing and telecommunications.

One reason for our focus on ICT is that, as shown in Figure 6, this is the largest technology category among US patents. Another reason to focus on ICT is that the vast majority of Taiwanese invented US patents are contained in this category. Finally, we use ICT patents because there is an artifact in Biotechnology and Pharmaceutical patents that we wish to avoid, as outlined below.

Trends in Non-Patent Referencing by application date and by issue date can be found in Figure 8. Note the spike in 1995. This spike is an artifact in the data due primarily to a change in US patent law that was necessary as part of the TRIPS agreement. Patents filed after June 8, 1995 would expire 20 years after their application date, while patents issued prior to June 8, 1995 would expire 17 years from their grant date. However, patents filed before June 8, 1995, but not issued by that date, would expire at the longer of 17 years from grant date or 20 years from application date. As a consequence of the change in the law, a huge number of patents were filed in the months leading up to June 8, 1995 and the bulk of those patents were biotechnology or pharmaceutical related.

This spike in NPRs is worth a closer examination. Figure 9 is similar to the application year graph in Figure 8, except now the data is broken down by month of patent application. The spike from Figure 8 is building up prior to June of 1995, but peaks in May and June of 1995, with an average of 9.31 Non-Patent References for patents filed in June of 1995.

Figure 10 shows patents with application dates in June 1994, 1995, and 1996 (the vast majority of which will have issued by September of 2007). As suspected, the number of patent applications filed in June of 1995 is more than double the number filed in June of 1994 and June of 1996, as applicants were motivated by the rule change to file their patents before the June 8, 1995 deadline. More importantly, however, the composition of patents by technology changed wildly in June of 1995. In particular, while patent applications doubled overall, patent applications in biotechnology, pharmaceuticals, and health related technologies more than quadrupled, and patents in chemical related areas tripled. The net effect is that Health related patents, which are generally 12-14% of the applications in a typical month, made up 25% of the applications in June of 1995. Since Biotechnology, Pharmaceutical, and Chemical

patents have many more NPRs per patent than mechanical and electrical patents, this would cause a significant spike in NPRs for that month.

Other authors (notably Branstetter, 2003) have suggested that, because of the deadline, applicants and their attorneys had extra motivation to impress the patent examiners, so they added extra references to their patent applications. This theory may well have some merit, but it is likely that the change in composition of the applications towards biotechnology and pharmaceutical patents, and away from electrical and mechanical patents, is likely to be the larger driving force behind the spike.

Note that it is perfectly understandable that the June 8, 1995 change in patent law would result in many more applications related to biotechnology, pharmaceuticals, and health and chemical technologies. Long patent lives are hugely important in these industries where there are long FDA approvals processes. In other industries (notably semiconductor manufacturing, telecommunications, and computer software) patents are generally obsolete long before they expire, so there was less motivation to file prior to June 8 than in the health related industries.

In order to avoid this artifact in the NPR data, we focus the remainder of this paper on patents related to Information and Communications Technology.

NPRs in Information and Communications Technology

Figure 11 shows the average number of Non-Patent References (NPRs) for the countries with the largest number of patents in Information and Communications Technology (ICT). This figure is similar to Figure 7, except that Figure 11 is restricted to ICT patents while Figure 7 examined all patents. Figure 11 reveals that the growth in NPRs is most dramatic for Canadian and US invented patents, although NPRs for British invented ICT patents have nearly tripled from 20 years ago, and NPRs for French invented ICT patents have more than doubled. NPRs in Germany and Japan have nearly doubled in the same period. Only Taiwan has had a flat or declining number of Non-Patent References during the 20-year span.

At this stage we have seen that US patents have been increasingly referencing Non-Patent References in every technology, and in Information and Communication Technology categories in particular. What we have not examined is the type of documents that make up the NPR set, and to what extent these types of documents are available electronically.

Method for Identifying Specific Types of ICT Non-Patent References

Non-patent references can be to any published document, from comic strips and brochures, to scientific articles and standards documents. The main difficulty in identifying relevant non-patent references for a study such as this is that inventors do not use a standard form for listing references. As an example, Table 3 below contains eight different variants for the IEEE Global Telecom Conference. Note that some inventors just use the GLOBECOM shorthand, while others list the entire name. Sometimes IEEE is mentioned and sometimes it is not. When abbreviation variations are included such as Telecom, Tele, Tcom, Proc., Proceed., the number of variants increases further. The same issue exists for variants in journal names and standards documents.

Table 3 – Variants for IEEE Global Telecom Conference

Proceedings of Globecom '96
IEEE Global Telecommunications Conference
GLOBECOM '90:IEEE
Proceedings of IEEE Globecom '94
Globecom '97
IEEE Globecom, Global Telecommunications Conference and Exhibiton
Proc of the Global Tele Conf, U.S. New York, IEEE

Conference Identification – to identify conference proceedings among the non-patent references, we first identified references containing keywords such as meeting, symposia, conference, etc. We then used parsing software to identify 2-word and 3-word phrases that appear frequently in this set of papers. The full string was

identified for these string sub-sequences in order to identify frequently cited conferences. In this way, we able to identify 'GLOBECOM' as a conference, even for references that do not mention the keywords 'conference,' 'proceeding,' etc.

Standards Identification - There are relatively few standards referenced, and in general they are easy to identify by looking for strings such as 'standard' or 'std'. Once the records containing the standards were located, it was relatively easy to identify the organization that produced each standard (IEEE, ISO, JEDEC, ANSI, etc.).

Journal Identification – Identifying and standardizing journal names is a very difficult process because there are so many different journals, and their names can be abbreviated in many different ways. For mainstream journals such as the 11,000+ journals covered by the ISI/Thomson Scientific Database, it is possible to string match on variant names and abbreviations. For these journals, we developed software that transforms journal names into common abbreviations and then implements string matching. Care must be taken with string matching because, for example, searching for "Urology Journal" will also accidentally identify "Neurology Journal". Similarly, a search for the journal "Science" would accidentally pick up any reference with 'science' in the paper title as well as any of the 800+ journals with science in their titles such as "Game and Wildlife Science". Our proprietary software for journal identification deals with all of these problems, so that we generate an accurate match between the patent references and 11,000+ journals. For obscure journals, hand matching must be used to first identify the journal, but once it is added to the list of 11,000+ known journals, other references to the journal can be found automatically.

Online Articles – References to documents found on the internet can be identified by searching for strings such as 'Internet Article,' 'Article found on Web,' and so on. These types of references can also be identified by searching for strings such as 'http://', 'http:\\", "www.", "ftp:", etc.

Other References – References to Technical Reports, White Papers, Advertisements and other common references were identified by string matching. Books were identified by markers such as "handbook," "dictionary," "chapter," or by publisher names such as "MacMillan Publishing," "Academic Press," etc.

Fastest Growing Types of Non-Patent References in Information and Communications Technology

In the previous section, strategies were outlined for identifying different types of Non-Patent References that have appeared in patents. These strategies were applied to classify many NPRs and then, by searching through the remaining set, additional

keywords were identified such as “Dialog” or “Inspec” to further reduce the unidentified set. After several iterations, all except for 18% of the Non-Patent References were classified.

The distribution by type of NPR for the last 10 years of US patents can be found in Table 4. Just less than one-third of the NPRs are to journal articles, with another 15% to conference papers. It is perhaps surprising that 8.4% of the Non-Patent References are actually references to patent documents. Many of these are patent specifications that never issued, or partial references to patents that the patent office could not readily derive a number to use for a proper patent reference.

Table 4 – Identification of Non-Patent Reference Types (US ICT Patents 1997-2006)

Non-Patent Reference Type	Number of References	% of NPRs
Journal	436,800	32.8%
Unclassified	235,693	17.7%
Conference/Seminar/Meeting	191,344	14.4%
Patent Abstract/Application/Search Report	112,055	8.4%
Internet Article/Web Page	83,144	6.2%
Book Chapter	64,498	4.8%
Corporate Documents	32,386	2.4%
IBM Technical Disclosure Bulletin	24,307	1.8%
Standards Document	22,401	1.7%
Technical Report/Notes	21,123	1.6%
Magazine	20,877	1.6%
Brochure/Advertisement	20,450	1.5%
User Manual	14,222	1.1%
Press Release	11,205	0.8%
Specifications	8,772	0.7%
Request for Comments	5,738	0.4%
Newspaper	5,720	0.4%
Thesis/Dissertation	5,692	0.4%
Misc. Abstracts	4,751	0.4%
Inspec Reference	3,444	0.3%
Research Disclosure	2,666	0.2%
White Paper	2,573	0.2%
Dialog Search	1,301	0.1%
Newsletters	551	0.0%
Chemical Abstracts	341	0.0%
Request for Proposals	143	0.0%
Total	1,332,197	100.0%

The yearly trends for the most common types of NPRs, excluding some of the lesser categories in Table 4 such as Dialog Searches and References, can be found in Figure 12. Notice that Journals, Conferences, Patent Documents have all enjoyed a lot of recent growth, whereas Book Chapters and brochures have been relatively flat. References to web pages and internet articles have increased the most, from virtually

zero in 1997, to 0.4 references per ICT patent on average. The number of unclassified NPRs is rather large and growing.

Since most of the identification of journals was done by comparing the NPRs to a known dictionary of mainstream journals, it is likely that a large portion of the unclassified references are actually journal references. Similarly, many of the other types of references were identified via keywords that may not always be present. To examine this issue further, a random sample of 250 unclassified references were set aside and categorized by hand. The results of this categorization are shown in Table 5.

Table 5 – Hand Identification of 250 Randomly Selected Unclassified Non-Patent Reference Types from Table 4

Non-Patent Reference Type	Number of References	% of NPRs
Incomplete Reference	61	24.4%
Journal	54	21.6%
Tech Report	35	14.0%
Corporate Document	27	10.8%
Magazine	17	6.8%
Book Chapter	13	5.2%
Conference	11	4.4%
Internet Article/Web Page	7	2.8%
Patent	4	1.6%
Brochure	3	1.2%
Newspaper	3	1.2%
White Paper	2	0.8%
Personal Memorandum	2	0.8%
Court Exhibit	2	0.8%
Standard	2	0.8%
License Agreement	1	0.4%
Tech Disc Bulletin	1	0.4%
Trademark	1	0.4%
Western Union Shopping Order 1933	1	0.4%
Affidavit	1	0.4%
1948 Money Order	1	0.4%
National Highway Safety Administration Notice	1	0.4%

Table 5 reveals that 24% of the previously unclassified references are incomplete. Most of these references give an author, title, and year. They could be journal articles, technical reports, or even book chapters. Generally, journal articles contain a journal name, technical reports often give a university department or company name, and book chapters usually give a hint such as a chapter, a publisher, or a series of pages that span several hundred pages. Since the unclassified set was approximately 18% of NPRs, we can project that approximately 24.4% of these unclassified references (i.e. 4.3% of all NPRs) are incomplete references.

Almost 22% of the unclassified articles are to journals and 14% are to technical reports. The technical reports are often from university departments or corporations, and are now increasingly available electronically. Almost 11% of the unclassified documents are corporate documents. These are generally some type of white paper, specifications sheet, or advertising document. For example, Motorola published several technical articles for users of its microprocessors, while Apple Computer published tips for users of its computers.

As was previously mentioned, virtually anything can be referenced in a patent. As a result, several of the items identified by hand defy easy classification. Examples include personal affidavits, court documents, a money order from 1948 and a Western Union shopping order from 1933.

Figure 13 is similar to Figure 12, except the unclassified articles are projected onto the figure based on Table 5. For example, there were 0.4 unclassified references per patent in 1997. We assign 21.6% (or .088) additional references to Journals in 1997, 14% (or .057) additional references to Tech Reports and so on.

Figure 13 reveals that Journals and Conference Papers account for the most references, but that articles and other items found on web pages have shown the most growth.

To show the growth rates more clearly, we reconfigured the data of Figure 13 in terms of these growth rates. Specifically, Figure 14 contains the reference growth by category, which is obtained by taking the average number of references by year and dividing it by the 1997 rate. References to internet items have increased 30-fold from essentially zero (.014) references per ICT patent in 1997 to 0.43 references per ICT patent in 2006. References to Press Releases have grown more than 800%, which is also likely to be due to the rise of the internet. Press Releases that were formerly ignored by major media outlets are now picked up by online media outputs and also available on corporate web sites. Journal papers and conference papers have increased a more modest but still impressive 58% and 81% respectively over the last 10 years. References to Book chapters, which have been less available electronically than the other sources, have increased just 38% over the period. Meanwhile, references to the IBM Technical Disclosure Bulletin, which was a defensive publication available only in print form and discontinued in 1998, have declined 56% over the period.

Readers may be interested in seeing exactly what types of articles and periodicals are referenced in the Information and Communications technology patents. The top referenced journals, books, conferences, and other NPR types are shown in Figure 15. Not surprisingly, most of the items in Figure 15 are journal titles followed by conferences. The top entry is “Misc. IEEE,” which is not a specific journal title, but may refer to the “Proceedings of IEEE” in most cases. There are thousands of NPRs that specify an author, an article title, and IEEE as a journal. It is not clear whether the reference is meant to specify a particular IEEE journal, or whether the inventor

means the Proceedings of IEEE. The second most referenced item is Misc. IEEE Conferences, which has somewhat the same problem. An IEEE conference is referenced, but not a specific IEEE conference like ICASSP or GlobeCom. The third most referenced periodical, the IBM Technical Disclosure Bulletin, is somewhat of a surprise, given that it has not been published since 1998 and, as shown in Figure 14, references to it have been declining in recent years.

The most referenced journal with a complete reference is "Applied Physics Letters" with 19,052 references from ICT patents from 1997-2006. There is only one book referenced among the top 30 references – "Silicon Processing for the VLSI Era", by Wolf et al, is a book referenced 4,776 times by ICT patents. However, to call this a book is perhaps a bit misleading. It is actually a four volume set of collected journal articles bound into a hardcover volume.

Although web pages are the fastest growing category, there are no websites that make the most referenced list of Figure 15. The closest candidates are www.nvidia.com, which contains a number of technical articles about the company's programmable graphics processors, and www.microsoft.com, which contains a number of technical articles and documentation for its various products. No magazines make the list on Figure 15, but the top referenced magazines are PC Magazine with 1,582 references from ICT patents and PC Week with 1,282 references.

Figure 16 contains the list of publishers that produce the documents referenced most often as NPRs by the ICT patent set. Notice that IEEE leads by a very wide margin, followed by Elsevier and AVS (The American Vacuum Society). Each of these companies has had databases of their journal articles available electronically since the early 2000s, and IEEE had CD-ROM versions well before that time. The IEEE also benefits by having most of its conference proceedings available electronically.

Discussion

The so-called linear model of innovation postulates that Basic Research leads to Applied Research, which in turn leads to Development, Production, and Diffusion (Godin, 2005). In other words, innovation is a sequence from basic science, to development and invention, to products and industries.

Many attribute the linear model to Vannevar Bush's 1945 paper "Science: The Endless Frontier," where he made the case for publicly funded basic research. However, apparently Bush never specifically mentioned the model and variations of the model predate the 1945 paper (Godin, 2005).

The linear model has been used for over 50 years as justification for public funding of scientific developments, starting with Bush's arguments in 1945 to create a National Research Foundation that would publicly fund basic research. In his plea he suggested that advances in science, when put to practical use, mean more jobs, higher

standards of living, as well as a improved health, prosperity, and security of the nation (Bush, 1945).

Despite the apparent success of the linear model in advancing the cause of basic research, the linear model has frequently been criticized as overly simplistic. As Rosenberg stated in his 1994 book, "Everyone knows that the linear model of innovation is dead".

The linear model may be overly simplistic, but the idea that scientific developments ultimately make their way in some form into inventions remains a widely held belief. The empirical evidence presented in this paper suggests that scientific developments are indeed being used for technological developments. We cannot say whether this is a linear sequence, but it is clear that there is some connection between science and technology, and that connection appears to be gaining strength or, at the very least, becoming more visible.

The availability of E-Resources deserves at least some of the credit for the increasing connection between science and technology. Papers that were once seen by a few hundred people attending a conference are now available to the world via the internet. Journal articles that were once only available in journals that were subscribed to by a few major universities are now available to most college students via an E-Resource page accessible in a dorm room. Technical reports that were buried in the file cabinets of university departments or government labs are now are published in gray literature databases.

What this paper has shown empirically is that these resources are not published and ignored, but are instead found and used by companies, inventors, and universities creating patented technologies. These inventors are increasingly referencing scientific articles, technical reports, and web pages in their patent documents.

Branstetter (2003) suggests that knowledge spillovers from university science into patents are at least partially responsible for increases in R&D productivity. Specifically, he points out that surging patent applications and grants that started in the 1980s, and still persist today, have far outpaced investments in both public and private R&D. One explanation is that more efficient use of scientific research has led to more innovations from fewer dollars than in the past.

While economists speak of knowledge "spillovers" when discussing the increasing referencing from patents to scientific papers, what is really being modeled is an increase in dissemination. That is, articles, technical reports, product specifications, are all more available electronically, are seen by more people, including potential inventors, and are more efficiently incorporated into inventions.

This raises the question of the extent to which the availability of E-Resources leads to new inventions. The answer is hard to quantify. However, it is clear that the increased electronic availability of scientific literature should lead to at least some additional efficiency, because there should be fewer instances of things being invented twice because of a lack of information dissemination. Moreover, as stated earlier, it is extremely unlikely that all of the references to E-Resources are a result of a prior art search after an invention. Only 7% of the NPRs are added by patent examiners (compared with 34% of prior patent references) and the variety of items referenced makes it unlikely that these items were searched for as part of a routine prior art search.

In short, more research is needed to quantify the effect of E-Resources on technology development, but empirical evidence suggests that E-Resources are increasingly leading to new inventions, or at the very least making inventors more efficient.

Conclusions

In this paper a large amount of empirical data was presented showing the increasing referencing of patents to various kinds of literature. It was shown that the increased connection between science and technology is occurring in all countries, and in all technologies.

The data was further analyzed to identify the types of articles that are being referenced by patents. In semiconductor manufacturing, computer technology, and telecommunications it was found that journal papers, conference papers, and technical reports make up the bulk of the prior art. Increasingly, web pages, and corporate documents widely available on corporate web sites are being referenced in patents.

The links between science and technology, which probably always existed, are becoming more visible due to the increased referencing of scientific and technical articles by patents. One factor behind the increased referencing is the availability of scientific and technical documents as E-Resources. It is also possible that the increased availability of scientific and technical documents is also leading to new invention and higher inventive productivity.

This paper concentrates mainly on links between Information and Communication Technology (ICT) patents and scientific and technical articles. The linkage between patents and science is even more evident in the life science areas, as was touched on in this paper, and is well documented by others (Branstetter, 2003, Narin et al, 1997). Thus it is even more likely that E-Resources are leading to new and or more efficient development in life science technologies such as biotechnology, pharmaceutical development, and chemistry.

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