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Scientific literature citations of patents: a preliminary investigation of "reverse" citation relationships

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Abstract

The article presents a novel strategy for investigating the connection between science and technology. Our work differs from previous contributions in that we focus on the reverse—examining how patents cite scientific literature—rather than the reverse (tracing citations of scientific literature in patents). Papers included in the CD-Edition of Science Citation Index (SCI) of the Institute for Scientific Information (ISI) from 1996 to 2000 and patent data given by the US Patent and Trademark Office formed the basis of our study. Almost thirty thousand US patents were referenced in scholarly articles. Separately for each scientific and technical domain, we examined the citation linkages. Patents were cited more often in chemistry-related subfields compared to other scientific areas. Among technological sectors, chemical clearly dominates followed by drugs and medical patents as the most frequently cited categories. Further analyses included a country-ranking based on inventor-addresses of the cited patents, a more detailed inspection of the ten most cited patents, and an analysis of class-field transfers. The paper concludes with the suggestions for future research. One of them is to compare our 'reverse' citation data with 'regular' patent citation data within the same classification system to see whether citations occur, irrespectively of their directionality, in the same fields of science and technology. Another question is as to how one should interpret reverse citation linkages.

Introduction

Research on the interplay of policymakers, scientists, and technological developments may take several forms. A bibliometric study of the connection between academic papers and patents is one such method. One prominent measure of the "science-intensity" or "science-dependence" of a technology, according to some observers (SMITH et al., 1998), is the amount of scholarly literature referenced in patents. See, for example, NARIN & NOMA, 1985; NARIN et al., 1995 and 1997; HICKS et al., 2001 for more on how Francis Narin and colleagues at CHI Research created and pioneered this method of patent citation analysis. Their analysis showed that the correlation between patents and the cited scholarly articles was becoming stronger with time. A rising

In order to examine what they call "science-based technologies" or the "scientification" of technology, some scholars have turned to this patent citation approach (e.g., GRUPP & SCHMOCH, 1992; SCHMOCH, 1993, or more recently, VERBEEK et al., 2002). It is possible that the interpretation of patent citations has been clouded by the emphasis on patents quoting scientific publications. One potential pitfall is attributing technological advancements to scientific discoveries based on patent citations (MEYER, 2000). For a more in-depth analysis, refer to the article by BHATTACHARYA et al. (2003) in this special issue. A heated controversy has arisen in recent years about the meaning of this signal.

The interconnectedness of its three domains is highlighted by the Triple Helix, which serves as a framework for this complexity. In light of this concept and the literature highlighting the interdependence of science and technology (e.g., BROOKS, 1994) and the notion of technology-based sciences (ZIMAN, 1984), we want to examine the inverse informational link, i.e., the citations of patents in publications. Thus far, there has been no enthusiasm for quantifying possible technical contributions, at least within the informetric community. We are unaware of any effort to investigate reverse citation relationships. This kind of citation relationship seems to have escaped the attention of even patent citation experts. In her work on 360° linkage analysis, HICKS (2000) makes passing reference to the kind of connection, but she fails to provide any evidence about it. Attempting to provide a more nuanced perspective on the science-technology nexus, this research delves more into the "reverse" citation relation. Since it is simply a first step towards a more complete understanding of the information flows in the Triple Helix, the research should only be considered exploratory in character.
Our research covers the years 1980–2000 and includes information on all citations to patent filings in the Science Citation Index. We begin by looking at how often and what kinds of scientific publications reference patents. The cited articles are also categorized according to the scientific field. We found that patent citations are only used by a tiny subset of SCI articles. Additionally, we may differentiate between patents that reference a large number of patents and those that cite a small number of papers.
We will provide statistics about the types of patents referenced in scholarly articles in the second section of the research. In this case, we had to limit ourselves to data collected by the United States Patent and Trademark Office. Using the patent number, we were able to link the referenced patent with the citing article. We next proceed to classify the referenced patents according to the different technical fields. The US Patent categorization and the categorization method were used to categorize the technical domains in this case. The nation of the innovator must also be considered. Our results have important implications for informetric research on science-technology interactions, which will be covered in the last part.

Information gathering and analysis

Previous research (such as GLÄNZEL, 2001) has provided the foundational ideas for building fundamental indicators and the methods for processing bibliographic and bibliometric data. We included all publications that were indexed in the CD-Edition of Science Citation Index (SCI) of the Institute for Scientific Information (ISI) from 1996 to 2000. In terms of technology, the research used all utility patents from 1980 to 2000 that were indexed in the USPTO database. The topic categorization of publications was determined by assigning journals to twelve key scientific disciplines. These fields were the ones in which the articles in question were published. According to GLÄNZEL et al. (2002) and GLÄNZEL & SCHUBERT (2003), the topic categorization system that is used has been created in collaboration with Steunpunt O&O Statistieken and the Budapest research group of the Hungarian Academy of Sciences. Table 1 provides the topic fields along with their acronyms.

Table 1. SCI subject classification scheme according to GLÄNZEL & SCHUBERT (2003)

#	Subject field	Abbr.
1	Agriculture & Environment	AGRI
2	Biology (Organismic & Supraorganismic Level)	BIOL
3	Biosciences (General, Cellular & Subcellular Biology Genetics)	BIOS
4	Biomedical Research	BIOM
5	Clinical and Experimental Medicine I (General & Internal Medicine)	CLI1
6	Clinical and Experimental Medicine II (Non-Internal Medicine Specialties)	CLI2
7	Neuroscience & Behavior	NEUR
8	Chemistry	CHEM
9	Physics	PHYS
10	Geosciences & Space Sciences	GEOS
11	Engineering	ENGN
12	Mathematics	MATH

References to patents have been identified through patent numbers that appear instead of the first authors name in the reference search string of the 'cited author/reference' field. Cited US patents have been retrieved from the 1980–2000 volumes of USTPO database. Only utility patents have been taken into account. Patents have been assigned to 27 patent sub-categories on the basis of the classification of patent classes into technological categories and sub-categories according to HALL et al. (2001). The scheme of technological sub-categories is presented in Table 2. The technological categories comprise Chemical (#1 – #6), Computers & Communications (#7 – #10), Drugs & Medical (#11 – #14), Electrical & Electronic (#15 – #21) and Mechanical (#22 – #27).

Table 2. Patent sub-categories according to HALL et al. (2001)

#	Sub-Category	Abbr.
1	Agriculture, Food, Textiles	AGR
2	Coating	CTG
3	Gas	GAS
4	Organic Compounds	ORG
5	Resins	RES
6	Miscellaneous-chemical	CHM
7	Communications	COM
8	Computer Hardware & Software	CHS
9	Computer Peripherals	CPP
10	Information Storage	INF
11	Drugs	DRG
12	Surgery & Medical Instruments	SMD
13	Biotechnology	BTG
14	Miscellaneous-Drugs & Medical	DRM
15	Electrical Devices	ELD
16	Electrical Lighting	ELL
17	Measuring & Testing	TST
18	Nuclear & X-rays	NXR
19	Power Systems	PWR

20	Semiconductor Devices	SEM
21	Miscellaneous-Electrical & Electronic	EEM
22	Materials Processing. & Handling	MAT
23	Metal Working	MET
24	Motors, Engines & Parts	MOT
25	Optics	OPT
26	Transportation	TRA
27	Miscellaneous-Mechanical	MEM

Citations to patents have been determined on the basis of patents numbers indicated in the 'cited author/reference' field of the SCI database. Citations have been cumulated from the year when the patents were issued till 2000.

Methods and results

The bibliometric approach

On an average, about 13500 publications yearly are citing patents. This is about 1.7% of all publications indexed in the SCI database. Among these papers, yearly 7800 papers cite US patents. For USPTO patents, the corresponding share is thus around 1%. As expected, most patent-citing papers are articles. We have chosen 1998 as the reference year. 92% of papers that have cited patents were articles and notes, followed by reviews (6.8%) and letters (0.8%). The rest (2.2%) are editorial material and meeting abstracts. The distribution in other years is similar, however, among patent-citing papers we also find corrections and one book review in those years. The distribution by document type is thus not significantly different from that of the complete database.

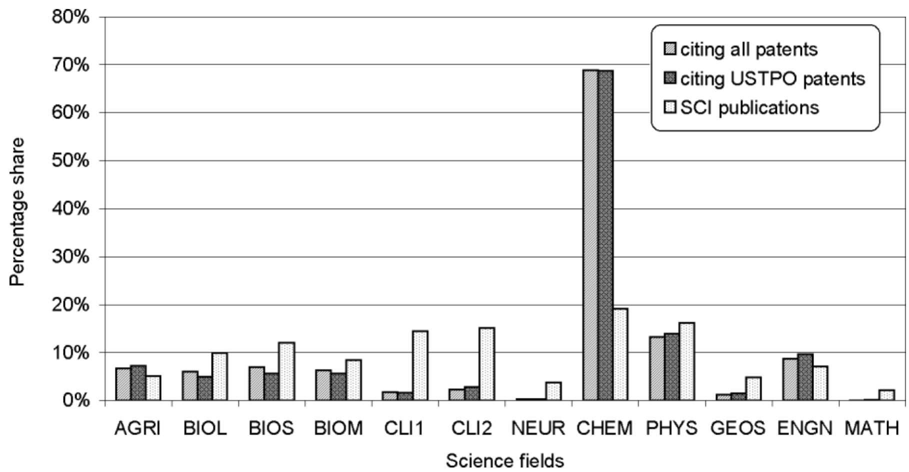

Figure 1. Distribution of SCI papers citing patents

This picture of 'representativity' dramatically changes if the distribution over subject classifications is analysed. Figure 1 presents the distribution by fields for all SCI publications,* for papers citing patents, in general, and papers citing US patents, in particular. There is practically no significant deviation of USPTO patterns from the general ones. With regard to the subject matter of citing papers, US patents can thus be considered representative. The bias in favour to chemistry for patent is quite dramatic. Almost 70% of papers citing patents are concerned with chemistry. The biases towards Agriculture & Environment and Engineering are by less striking. On the other hand, papers in clinical and experimental medicine and in mathematics are least frequently citing patents.

Table 3. Distribution of chemistry papers citing patents over subfields

Subfield	Share
Physical chemistry	20.6%
Organic & medicinal chemistry	20.3%
Materials science	16.9%
Polymer science	15.3%
Multidisciplinary chemistry	15.1%
Analytical, inorganic & nuclear chemistry	13.6%
Applied chemistry & chemical engineering	12.3%

The large share of chemistry papers citing patents is worth to be studied in detail. The distribution of chemistry papers citing patents over subfields is presented in Table 3. The most important 'users' of patent information are physical chemistry and organic & medical chemistry; the least important ones in chemistry are analytical, inorganic & nuclear chemistry and applied chemistry & chemical engineering.

The technometric approach

Almost 30000 USPTO patents issued between 1980 and 2000 have been cited in SCI journals. This amounts to 1.5% of all patents indexed in the 1980–2000 USPTO volumes, that is, the share of patents cited in scientific publications indexed in the SCI roughly corresponds to the share of SCI publications citing USPTO patents. Among cited patents, Chemical clearly dominates; 53% of all cited patents were classified into this technological category. It is followed by Drugs & Medical with 17.5%. The categories Computer & Communication and Mechanical are least relevant. Within the category Chemical, Miscellaneous-chemical (25% of all cited patents), Organic Compounds and Resins (12% each) are the most important sub-categories. The distribution of cited patents over technological categories is presented in Figure 2.

A further interesting aspect, namely the weight of nations in the USPTO database can be analysed by means of the addresses of the inventors. Both, the distribution of all patents over countries and of patents cited in SCI journals are presented in Table 4. The table is restricted to the 20 'most active' countries. Also there is a change in the share of all countries if cited patents are compared with the total, nevertheless the most dramatic changes take place in the first three ranks. About 55% of all patents have an inventor from the USA; by way of contrast, the US share amounts to 70% for SCI-cited patents.

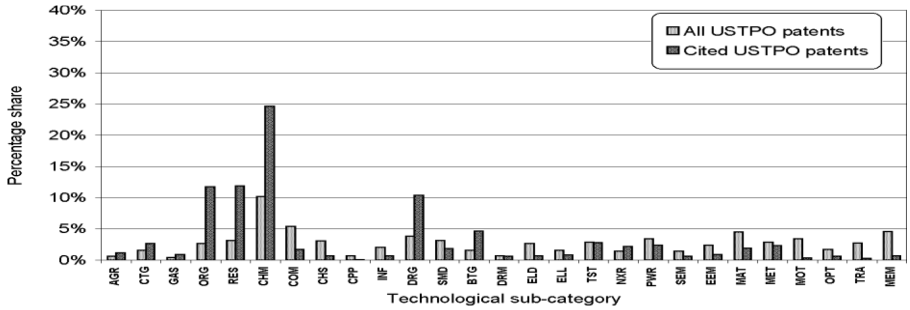

Figure 2. Distribution of USTPO patents cited in the SCI

Table 4. The twenty most frequent countries according to the addresses of inventors of patents indexed in the USPTO database

Rank	All USTPO patents		Cited USTPO patents	
	Country	Share	Country	Share
1	USA	54.7%	USA	70.5%
2	JPN	19.8%	JPN	9.5%
3	DEU	7.7%	DEU	3.9%
4	FRA	2.9%	CAN	2.9%
5	UKD	2.8%	UKD	2.6%
6	CAN	2.0%	FRA	2.2%
7	CHE	1.3%	ITA	1.2%
8	TWN	1.2%	CHE	1.1%
9	ITA	1.2%	NLD	1.0%
10	NLD	0.9%	ISR	0.5%
11	SWE	0.9%	AUS	0.5%
12	KOR	0.9%	SWE	0.4%
13	AUS	0.5%	BEL	0.4%
14	BEL	0.4%	KOR	0.3%
15	AUT	0.4%	FIN	0.3%
16	ISR	0.4%	RUS*	0.3%
17	FIN	0.3%	TWN	0.3%
18	DNK	0.2%	DNK	0.3%
19	RUS*	0.2%	AUT	0.2%
20	ESP	0.1%	IND	0.2%

* RUS covers Soviet Union till 1991; thereafter, RUS is for the Russian Federation

On the other hand, the share of Japanese and German patents are practically halving when patents are cited in SCI journals (cf. Table 4). We can conclude as a rule of thumb that the gain in weight of the USA through SCI citations appears at the same time as a loss of weight of Japan and Germany.

The changes for the other countries are comparatively small.

Not only the number of patents cited in scientific periodicals is relatively small, also the number of citations received by them is much less than in the case of cited literature. As already mentioned above, 98.5% of all USTPO patents have not been cited in SCI journals and roughly 73% of cited patents were cited only once. Nevertheless, a simple rank statistic on citation frequencies shows that quite high citation rates are possible. The ten most cited patents are presented in Table 5. The first three patents in Table 5 have received even more that 100 citations each within a five-year period.

The most cited patent, an invention by M. Taramasso et al. entitled "Preparation of porous crystalline synthetic material comprised of silicon and titanium oxides" has received 270 citations in papers published in high-impact chemistry journals. The same applies to the invention by D. H. Solomon et al. "Polymerization process and polymers produced thereby" cited 138 times in the 5-year period under study and by S. T. Wilson et al. "Crystalline metallophosphate compositions" cited 130 times. This small example might visualise that technology has a measurable impact on basic and applied research in several fields, above all, in chemistry and engineering sciences.

Table 5. The ten most cited USTPO patents issued between 1980–2000 and cited in SCI journals between 1996 and 2000

Rank	Pat#	Sub-category	Issue year	Inventor	Citations
1	4410501	CHM	1983	ITA	270
2	4581429	RES	1986	AUS	138
3	4310440	CHM	1982	USA	130
4	4440871	CHM	1984	USA	99
5	4853202	CHM	1989	USA	69
6	4480228	TST	1984	USA	57
7	5026798	RES	1991	USA	57
8	5272236	RES	1993	USA	54
9	5098684	CHM	1992	USA	46
10	4410688	RES	1983	USA	44

The techno-bibliometric approach

In what follows, we will analyse the linkage between technology and science measured through patent citations in scientific publications, to be more precise, we will investigate the transfer of scientific-technological information from patents to scientific literature. In order to measure information flow from technological sub-categories to scientific subject fields the numbers of subcategory-field links have been arranged to a non-symmetric techno-bibliometric transaction matrix. This matrix can be found in the Appendix. All elements of the matrix have been divided by its grand total. The sums of the rows or columns then express the probability that information is transferred from a particular (sub-)category or to a particular subject field, respectively. Here, information flow is, of course, measured by citation links.

The following four most important transactions have been observed, particularly, from sub-category Miscellaneous-chemical (26.95%), from Resins (11.37%), from Organic Compounds (10.90%) and from sub-category Drugs (9.94%). On the other hand, information flow to subject field Chemistry (57.50%), Physics (10.20%), Engineering (7.84%) and to subject field Agriculture & Environment (6.62%) was most significant. Results of the analysis of individual subcategory-field links are presented in Table 6. The links are arranged in descending by their percentage shares, shares below 1% have been omitted.

Table 6. The most relevant technological subcategory – subject field links on the basis of patent citation in scientific publications (patents issued between 1980–2000, cited between 1996 and 2000)

Rank	Subcategory-Field transfer	Share
1	Miscellaneous-chemical □ Chemistry	19.30%
2	Resins □ Chemistry	9.63%
3	Organic Compounds □ Chemistry	8.18%
4	Drugs □ Chemistry	4.63%
5	Miscellaneous-chemical □ Physics	2.24%
6	Drugs □ Biomedical Research	2.19%
7	Miscellaneous-chemical □ Agriculture & Environment	2.15%
8	Coating □ Chemistry	1.72%
9	Metal Working □ Chemistry	1.60%
10	Biotechnology □ Biology	1.58%
11	Power Systems □ Chemistry	1.42%
12	Miscellaneous-chemical □ Engineering	1.38%
13	Materials Processing. & Handling □ Chemistry	1.21%
14	Measuring & Testing □ Physics	1.03%
15	Biotechnology □ Biosciences	1.02%
16	Biotechnology □ Chemistry	1.00%

Table 7. Ratio (r) of observed and expected transfer from technological sub-categories to science fields on the bases of patent-citations in SCI publications (Conditions: $r \geq 3.0$ and $a_{ij} \geq 50$)

PC/SF	AGRI	BIOL	BIOC	BIOM	CLI1	CLI2	NEUR	CHEM	PHYS	GEOS	ENGN	MATH
AGR	3.15											
CTG												
GAS												
ORG												
RES												
CHM												
COM									3.11	5.85	5.27	
CHS											7.74	
CPP												
INF									4.73		4.86	
DRG				4.65	3.07		4.45					
SMD				4.97	5.85	10.62						
BTG		8.74	5.09		4.58							
DRM				7.37		12.88						
ELD											6.13	
ELL									5.68			
TST						3.37			3.35			
NXR						3.70			3.09			
PWR											3.71	

SEM	3.60		3.83
EEM			4.61
MAT			
MET		4.83	
MOT			3.90
OPT	5.74		
TRA			
MEM			3.67

The high share of the Chemical–Chemistry links ranking first, second and third is striking though but not really unexpected. They make up more than one third of the total. As all distributions obtained in this study, also this one is extremely skewed. All distributions discussed here are by far more skewed than usual bibliometric distributions.

This is also reflected by the transaction patterns as presented in Table 8 (Appendix). This is a typical transaction matrix similar to those scientometrics transaction matrices studied by PRICE (1981) and SCHUBERT et al. (1983). An entry a_{ij} of the transaction matrix A given in Table 8 represents the number of patents assigned to sub-category i and cited by papers assigned to science field j. The underlying theoretical model of such transactions is the linear interdependence of the rows and columns of the transaction matrix. According to this postulate, the actual transfer from one given 'source' to one given 'target' is determined by a measure of the total transfer from the corresponding source and of the total transfer to the corresponding target alone. In such cases, the matrix can be decomposed, and represented by a dyadic product of two vectors the components of which are the sums of the elements of the matrix over rows and columns, respectively, normalised by the grand total (see, for instance, SCHUBERT et al., 1983). Consequently, we can write $A = a' \cdot a''^T$, where $A = (a_{ij})$ is the original transaction matrix, and $a' = (a_{i\cdot} / a_{\cdot\cdot})$ with $a_{i\cdot} = \sum_j a_{ij}$, $a'' = (a_{\cdot j} / a_{\cdot\cdot})$ with $a_{\cdot j} = \sum_i a_{ij}$ and $a_{\cdot\cdot} = \sum_{ij} a_{ij}$. The dyadic product can thus be used to represent the expected transfer from technological sub-categories to science fields. It is known that the maximum likelihood estimator of the expected number of transactions e_{ij} can then be obtained from the observed transactions a_{ij} in the following manner

$$e_{ij} = a_{i\cdot} \cdot a_{\cdot j} / a_{\cdot\cdot} .$$

The ratio $r = a_{ij}/e_{ij}$ of observed and expected transfer is given in Table 7, provided $r \geq 3.0$ and $a_{ij} \geq 50$. These criteria guarantee the evaluation of truly significant deviations on the basis of a sufficiently large underlying transaction sets. Those rows and columns the elements of which are much above their expectation have been shaded. Although the science field Chemistry is dominant and many 'transactions' to this field are also above their expectations, the really significant deviations could be found in the fields Physics and Engineering, as well as for the technological category Drugs & medical. However, it must be mentioned here that the unexpectedly high transfer from Drugs & medical does not take place to Physics and Engineering but to the life sciences. At the same time, transfer to Physics and Engineering which has been considered to be above expectation is originated in Computers & Communications, Electrical & Electronic and Mechanical.

Conclusions

We have presented a new approach to study the science-technology linkage. Naturally there are many limitations future research could address. For instance, we just linked USPTO data to scientific papers. Further research should be more comprehensive and also examine patents issued by other important offices.

The strikingly high share of publications in chemistry *citing* patents and chemistry-related patents *cited* by scientific papers might give cause for speculations. One of the possible explanations for this outstandingly strong technology-science transaction link could be found in the importance of specific processes and instruments relevant in scientific research. The relevance of patent literature in chemistry research is reflected by the fact that the database *Chemical Abstracts* is the only large traditional bibliographic database in which also patents are indexed.

One of the future tasks is

to compare our 'reverse' citation data with 'regular' patent citation data within the same classification system to see whether citations occur, irrespectively of their directionality, in the same fields of science and technology.

Another question is as to how one should interpret reverse citation linkages. We believe the existing frameworks of scholarly citation theory are a good starting point. However, at this stage it is not clear why researchers decided to cite patents in particular. Here, exploratory case studies may provide us with insights.

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