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Science & Technology Indicators Trapped in the Triple Helix?
The Case of Patent Citations in a Novel Field of Technology

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Abstract

This paper deals with patent citations as a potential indicator of knowledge flows and exchange processes at the science/technology interface. Using the Triple Helix framework, we discuss the notions of science and technology critically and point to the complex interrelationships in this area. Based on this and the discussion of an exemplary analysis, we explore the nature of the patent citation. It is pointed out that patent citations establish only a highly mediated link between patents and the scientific literature they cite. Finally, we investigate the extent to which patent citations mirror the complexities of the triple helix in a novel field of technology.

Keywords:
Citation analysis, patents, science & technology indicators, triple helix.

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Introduction

The emergence of a new technology, or even more generally speaking, a new paradigm, presupposes an increasing number of individuals working on a certain subject-matter, a certain phenomenon, or some form of artifact. This work can be of a purely scientific nature, it can be essentially technological, or it may lie at the interface between these two spheres. Of which nature such a project may be, in order to be noticed, it must gain what one often describes as 'critical mass'. It must transcend the scale and scope of scattered and individual efforts. Something must arise that connects both efforts and individual actors. Some authors refer to this as *'leitbild'*,[1] a 'guiding image' that - by providing a shared overall goal - functions as an interpersonal stabilizer for actors from different professions and disciplines. The group of people working towards this 'leitbild' constitutes a heterogeneous collective; we shall refer to such collectives as 'developer communities' in the context of this study.[2] Since one of a leitbild's functions is to provide an adequate verbal form of representation for a problem, we can expect a developer community to share a certain vocabulary.

Therefore, one way of operationalizing developer communities is to focus on their textual output. The most common types of scientific and technological output are articles in scholarly journals and patents granted for novel technological developments. Developer communities in so-called science-based technologies have to embrace and integrate both scientific and technological actors. Various indicators have been developed to track developments at the science/technology interface. One of the more recent indicators is patent citations, which relates patents to the scientific publications they cite.

Citation measures have been used to explore the relationship between science and technology for a long time. Based on citation analysis of science and technology journals, De Solla Price developed a two-stream model that reflects much more the autonomy of science and technology as cognitive systems and the reciprocal nature of their interplay. Tracing citations in science and technology journals, De Solla Price found separate cumulative structures with scientific knowledge building on old science and technology on old technology. He also detected a weak and reciprocal interaction between the two.[3]

This used to be reflected in the traditional division of labor between public science and privately funded technological development. However, the area of university-industry-government is characterized by changing relationships between the major actors. In the study of university-industry-government interrelationships these new developments are often referred to as the 'triple helix'.[4] The notion of the Triple Helix provides a useful framework of orientation since it refers to various categories of actors that are of importance when investigating the science/technology interface. Attempting to measure the intensity of science and technology relation or the dependence of technology on science, the patent citation indicator could get easily trapped in the complex reality of Triple Helix relations.

This is so in particular because the terminology in this area is often both confused and confusing. Science and technology are often used as synonyms for academe and industry. Patent citations are a relatively new and undeveloped indicator at the science/technology interface. This research attempts to clarify the question as to what patent citations measure and investigate the way in which patent citations reflect this shift in the division of labor in a novel science-based field of technology.

The Science/Technology Interface And The Triple Helix

Patent citations are situated between science and technology within the triple helix environment of university-industry-government. We shall first discuss various definitions of science and technology before addressing the organizational aspects. Hinze et al. established that "the use of the concept 'science' in the literature is even more confusing than that of R&D, because many authors introduce the term without any definition or only with an implicit definition." [5] Generally speaking, Hinze et al. distinguish two major approaches, namely an 'institutional'[6] definition and a cognitive perspective of science.

> "The institutional approach [differentiates] between … 'scientific institutions' and … 'industry'. According to this definition, science is represented by universities and non-industrial research institutions, thus chiefly the public research sector or the academic research sector. In many articles a very simplistic association of these scientific institutions with basic research or even pure research is made. If this definition is clearly introduced, it can be helpful for a pragmatic distinction between the industrial and the non-industrial research sector."[7]

Characteristic of the cognitive approach is that it tries to define science without linking science to any specific organizational forms ('institutions'). Such a definition makes the notion of science apparently very close to the notion of knowledge. Grupp and Schmoch pointed out that 'knowledge-oriented' is often used as a synonym or equivalent for 'science-oriented'.[8]

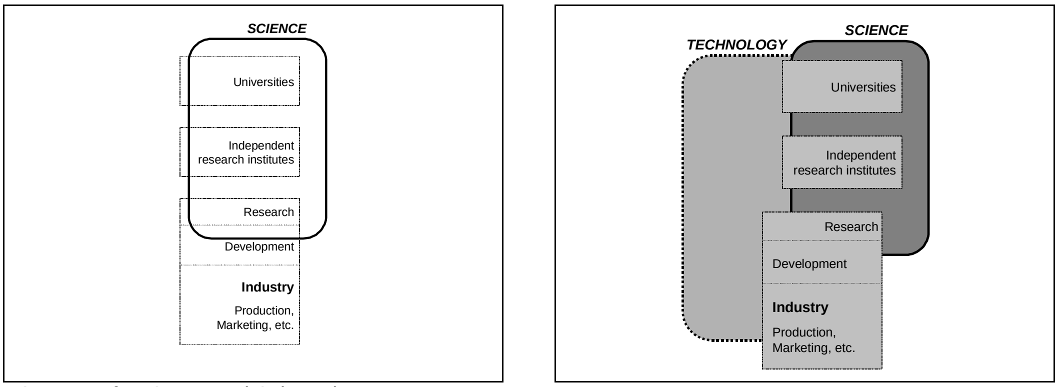
Grupp and Schmoch attempt to locate science in R&D performing organizations.[9,10] A chief implication of a cognitive definition of science is that a considerable share or scientific activities are performed in industry. Furthermore, not all activities carried out in universities and other non-industrial research organizations can be described as 'science'. Hinze et al. list a number of examples to underline their point, such as standard tests and analyses as well as 'consultancy activities not related to R&D'. The resulting location of science in institutions can be illustrated in Exhibit 1. This immediately relates to the triple helix model.

At its center, universities and industry, until now relatively separate and distinct institutional spheres, are assuming tasks in the development of novel technologies that were originally in each other's domains.[11] This is especially the case in the field of so-called science-based technologies, an area of growing economic importance[12] where industrial technology relies heavily on scientific results from universities and other research organizations. The triple helix model also underlines the difference between organizational and cognitive definitions of science and technology by drawing our attention to the ongoing processes that make it increasingly difficult to associate science with academe and technology with industry.

Exhibit 1. Cognitive definitions of science and technology.

(a) Cognitive understanding of science and its organizational location

(b) Science and technology as cognitive activities and their organizational bases



Source: After Grupp and Schmoch

One caveat of a cognitive understanding of science is that it relies on a respective understanding of technology. This is often problematic. Definitions of technology are often as diverse as definitions of science. Not unlike the discussion on definitions of science, the concept of technology can be defined in many ways[13] and the definitions of technology vary also in their scopes[14]. This can lead to very broad definitions of the term. For instance, Autio ultimately refers to the Old Greek origins of the term:

> "The classical Greek origins of the word technology are [τεχνη] and λογοσ. The word [τεχνη] can be interpreted as skill of hand, or technique. The word λογοσ can be interpreted as knowledge or science. Thus, technology can be viewed as a knowledge of skills or techniques or a science of skills or techniques."[15]

Based on such a fundamental understanding, Autio then refines the concept of technology:

> "Technology comprises the ability to recognize technical problems, the ability to develop new concepts and tangible solutions to technical problems, the concepts and tangibles developed to solve technical problems, and the ability to exploit and to use the concepts and tangibles in an effective way."[16]

Such an understanding might be useful to investigate technology, or rather, knowledge transfer phenomena. However, paired with a corresponding definition of science, science and technology would be hard to distinguish from each other, in spite of clear differences between both institutions.

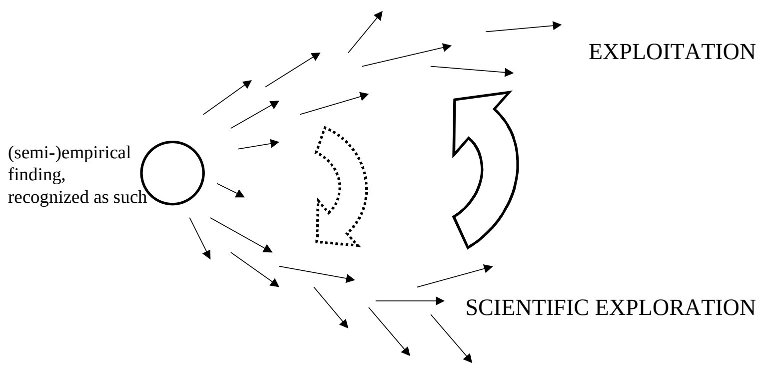
Not only definitional issues complicate the understanding of patent citations, but also fundamental assumptions as to how science and technology are related to each other obscure a clear understanding of this indicator. The field of patent bibliometrics can be characterized by biased rhetoric. Let us take the writings of one great pioneer of the patent bibliometric method, Francis Narin, as an example. On the one hand, Narin acknowledges that the old 'linear model' is "simplistic and highly inaccurate", and he also says that it "ignores the much more intimate relationship between science and technology".[17] Then again, Narin et al. put their research in the context of a basically linear understanding of the innovation process when they explain:[18]

> "The notion that technology springs from a science-base was originally embedded in the 'linear model' of innovation: from basic research through applied research continuing into technology and resultant economical benefit. This simple linear model has been supplanted by much more complex views of the process, with many feedback loops and major contributions of technology to science, but the origins of research knowledge in basic research still lie at the core of the process (Turney, 1991)"

Other authors suggest that "the model of 'two way' interaction is a much more appropriate way of linking industry and universities, especially in the area of science-based technologies".[19] Scientific and technological activities do not always follow each other sequentially.

Referring to Derek de Solla Price and Arie Rip, one should not consider science and technology as separate and hardly communicating entities, but rather view them as dancing partners. Science and technology are still relatively independent, but closely interacting. This idea is taken up in the two-branched model of innovation suggested by Rip.[20] Its starting point is an empirical or semi-empirical finding. Two different kinds of activities branch out from there: (1) Exploitation understood as technological development, pilot processes and feedback, and (2) exploration to increase the understanding. The latter is done through scientific research and can be considered a rationalization process: "The insights derived from the exploration branch may sometimes be called in to assist and improve exploitation, and what can be called 'transformation of the exemplar'."[21]

Exhibit 2. The two-branched model.



Source: Arie Rip, Science and technology as dancing partners. The Sociology of Sciences II, p. 236.

The Triple Helix model mirrors the complexity of activities and relationships at the science/technology relationship. By making a distinction between scientific and technological activities on the one hand and pointing to the shift in the organizational setting on the other, it allows for both linear and reciprocal types of relationships between science and technology.

This paper will illustrate how patent citations as a science and technology indicator could lead to a deterred image of what goes on between academe and industry at the science-technology interface. Moreover, it will illustrate by tracking patent citations that there is a variety of scientific and technological links between academe and industry.

The attentive observer might wonder where the third strand of the triple helix has gone. In this research, it has a more covert, but nonetheless important role. Actors in government are a chief user of the analytical tool applied, but more importantly, the government strand of the triple helix is central to providing the legal and regulatory frameworks underlying patenting and patent examination processes. The impact of this strand in terms of the interpretative framework is non-trivial as we shall see in the section.

Method and Materials

This section will briefly outline the overall framework of methods employed and material analyzed. This study addresses patent citation analysis as a tool to capture relevant interaction in an emerging field at the science/technology interface. To investigate this issue we selected nanotechnology as object of study since it represents a field that is young, rapidly growing and strongly scientific.

As a recent study shows, there is little consensus on what exactly is nanotechnology[22]. However, Franks' definition[23] of nanotechnology as *'the technology where dimensions or tolerances in the range 0.1 to 100 nm (from the size of an atom to the wavelength of light) play a critical role'* seems to have commanded wide acceptance.[24] In practice, the label 'nanotechnology' also includes methods used to build structures up to a micron.[25] A number of technology foresight studies[26] identify nanotechnology as a key technology in the 21st century revolutionizing information technology, materials and medicine.

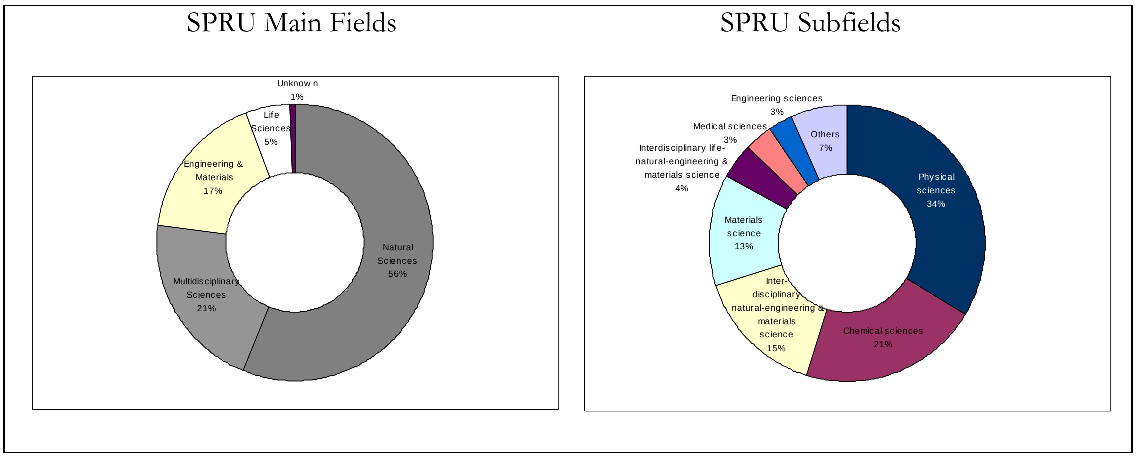
In order to analyze the interface between nano-technology and nano-science, we use two different databases: (1) a database of all US patents in that technological area, and (2) a bibliometric database of all scientific research papers related to nanotechnology. Both databases were compiled applying a keyword approach. Following Braun et al., we retrieved all publication titles of journal articles in the Science Citation Index and patents downloaded from the USPTO Internet database that included the term 'nano' as such or as a prefix. Subsequently, irrelevant records that contained only terms like nanogram, nanosecond were deleted.[27]

The patent database comprises approximately 2,600 patents, mainly in instrumentation, electronics and electrical engineering, and chemicals/pharmaceuticals. One can recognize a clear focus on instruments, electronics, and chemcals-/pharmaceuticals. These sectors are generally attributed a certain proximity to the science-base.

The bibliometric database contains 5,000+ scientific research papers on nano-related subjects. Exhibit 3 illustrates the paper distribution after major and sub-disciplines.

With physical and chemical sciences as well as materials-related fields, disciplines are strongly represented in this database that are thought to correspond with the major areas of patenting. Therefore, one should expect a substantial overlap between nano-science and nano-technology, which is to be indicated by a considerable number of relevant nano-research papers being cited by nano-patents.

Exhibit 3. Nano-Publication Database after disciplinary distribution



The citation analysis was carried out matching the two databases. For the nano-publications, search keys based on author names, journals and publication dates, were defined. Those were then searched for in the patent database. It should be noted that this study analyses front-page patent citations only. This is due to the fact that patent citations in the specification part of the patent document are usually not made available in a bibliographic database.

The matching procedure enables us to determine the overall overlap between nano-patents and papers and allows us to set up a database of patent citations. For each patent citation, the databank provides information about

- title, inventor name, inventor address, assignation, and technical classification of the citing patent, and
- title, author name, author affiliation, and journal classification of the cited article.

The database will provide the basis for our citation analyses. Firstly, we analyze patent citations after technological sectors and scientific domains. Then, we investigate patent citations by author affiliation and patent assignation. In a final step, we combine both types of analysis by looking at the organizational distribution of patent citations in a number of technological subfields.

However, to fully comprehend the results of this exemplary analysis, it is important to clarify the meaning of patent citations and the link they establish. This is done in a twofold manner. Firstly, we shall relate the theme of patent citations to the literature on the patent system in general. This is necessary to facilitate an understanding of the essentially different character of patent citations, as compared to citations in scholarly journals. Here, we can mostly rely on a review of the existing literature.

Secondly, after clarifying the peculiarities and various forms of patent citations, we shall explore the nature of the link that is established by the citations between the patents and the papers they cite. This area, however, is a widely unexplored field.[28] To document and illustrate the complexities of the patent system and their impact on patent citations we carried out a number of case studies. As we attempt to investigate the reasons for citing scientific literature and shed some light on patent practices, the case study format seems to be most appropriate. Since our primary interest is to gain a better understanding of the citation data we generated, the cases were taken from our nano-patent database. Such a focus is a bias if one wants to say something about patents in general, but a useful entrance point to investigate the phenomenon of science-dependence or science links.

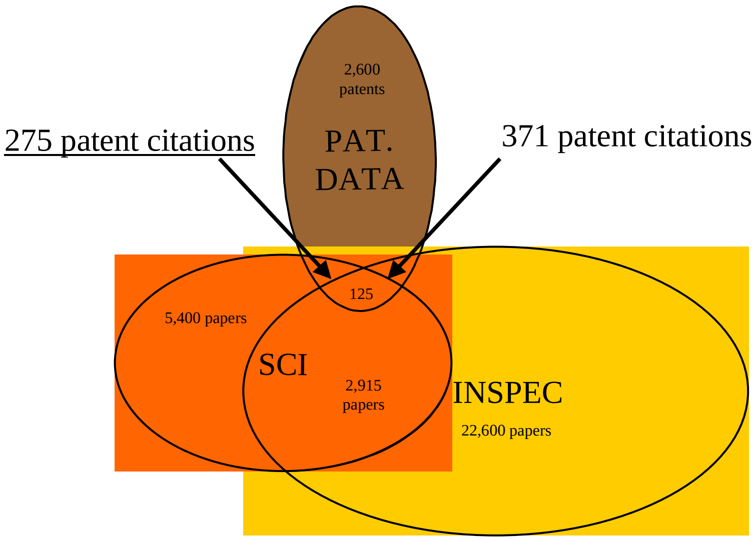
An Exemplary Analysis of Patent Citations

Patent citations as link between patents and publications

The patent citation analysis confronted us with somewhat surprising, counter-intuitive results. One should assume that a technological field that is generally acknowledged as science-based[29] would encompass patents that frequently cite to the corresponding set of scientific research papers. This, however, is not the case.

Matching the 5,000 plus nano-papers identified in the Science Citation Index (1991-96) with the nano-patents resulted in 275 matches.[30] A test matching procedure, with 22,000 papers related to the nano-scale found in the INSPEC database, also resulted in 371 matches. Given the size of the source databases, the relatively small number of corresponding citations can be taken as an indicator of weak interaction between nano-science and technology. Exhibit 4 gives an overview of the results of the matching procedures.

Exhibit 4. The different data sets and their overlap.



PATENT CITATIONS AFTER SCIENTIFIC AND TECHNOLOGICAL FIELDS

Exhibit 5 gives an overview of nano-patent citations after industrial sectors and SPRU-main classes. The instruments sector appears to be the sector that relies on nano-science the most (with 49 citations). Instruments are followed by electrical machinery (40 references), electronics (35), pharmacy (29), and chemistry (21). Other sectors refer to scientific domains less than 20 times. The most referenced scientific domain is natural sciences, followed by multidisciplinary sciences.[31]

Exhibit 5. Patent citations after industrial sectors and Spru main-classes.

	NATURAL	MULTIDISCIPLINARY	ENGINEERING & MATERIALS	LIFE	**Grand Total**
Instruments	30	13	3	3	**49**
Electr. Mach., ex. Electronics	26	13	1		**40**
Electronics	27	7		1	**35**
Pharmacy	4	12	2	11	**29**
Chemistry, ex. Pharmacy	6	11	4		**21**
Metal products, ex. Machines	14	2	3		**19**
Other industrial products	7	7	4		**18**
Other machinery	5	6	1	1	**13**
Non ferrous basic metals	6	2	2		**10**
Computers and office machines	5	.			**7**
Ferrous basic metals	1	3	3		**7**
Stone, clay and glass products	1	1	3		**5**
Paper, printing and publishing	4				**4**
Food, beverages, tobacco		1			**1**
No classification	2				**2**
Others[1]	7	7		1	**16**
Grand Total	**145**	**87**	**26**	**17**	**275**

PATENT CITATIONS AFTER ORGANIZATIONAL CATEGORIES

Exhibit 6 gives an overview of the distribution of the patent citations. Not only is the overall interaction between nano-science and nano-technology relatively weak with 275 citations, but almost two fifths of these citation links are between papers written at public sector & research organizations (PSR, including universities, research establishments, etc) and patents held by PSR exclusively. Less than 30 % of the 275 patent citations actually connect work of a PSR author and an assignee in industry.

A closer look at the data suggests that multinational companies (MNC's) ‘rely’ to a lesser extent on PSR science than do small and medium-sized companies (SME's). Amongst the PSR organizations, universities appear to play the most important part in providing useful scientific contributions. Patents held by both MNC’s and SME’s refer mostly to nano-publications authored by university-based researchers. The other PSR organizations appear to produce information that is mainly cited by

[1] This category includes those patent citations that could not be related to a single industrial sector.

nano-patents within the research sector, and here predominantly by university-held patents.

MNC's are far more than mere receivers of knowledge. They have to be viewed as producers of relevant knowledge as well. In fact, 27% of the patent citations referred to in MNC-held patents are related to scientific publications authored by MNC-based scientists. If one adds those papers with combined MNC-university co-authorships to this, almost 35% of the nano-publications cited in MNC-assigned patents are based on research where MNC's are actively involved in. This does not mean at all that university research is not relevant to MNC nano-patenting. In fact 45% of the nano-patent citations identified in MNC-patents are authored in universities.

SME-held nano-patents have a different citation pattern. 45% of their citations refer to university-authored papers. Almost 18% of the citations is to papers written in non-university research organizations. Another 16% goes to MNC-authored nano-literature. Not quite 4% of the nano-references originated in the SME-sector.

Exhibit 6. Patent citations after organizational categories.

PATENT ASSIGNATION AUTHOR AFFILIATION	UNIVERSITY	MULTINATIONAL CORPORATION	SMALL AND MEDIUM-SIZED ENTERPRISE	INDUSTRIAL ASSOCIATION	Other	**Total**
UNIVERSITY	68	34	23	5	8	**138**
MULTINATIONAL CORPORATION	8	21	8	4	6	**47**
RESEARCH ESTABLISHMENT	13	5	9	5	5	**37**
MULTINATIONAL CORP. AND UNIVERSITY	4	6	3	1	3	**17**
UNIVERSITY AND RESEARCH ESTABLISHMENT	7	2	3		4	**16**
SMALL AND MEDIUM-SIZED ENTERPRISE	1	2	2	2	0	**7**
Other	1	3	3	1	4	**12**
Unknown	0	1	0	0	0	**1**
Total	**102**	**74**	**51**	**18**	**30**	**275**

Patent citations after scientific and technological fields and by organizational categories

The following exhibits present a number of examples arranged by field and organizational category. Thereby we can gain a perspective on how patent citations describe the science/technology interface in organizational terms for a specific subfield.

The case of nano-patent citations in the field of *'other machinery'* (Exhibit 10) illustrates a reference pattern in which nanoscience-citing university nano-patents substantially rely on scientific nano-publications authored in the university system or non-industrial research centers. Similarly, it also shows that respective patents assigned to multinationals chiefly refer to work from their own organizational category. The case of *metal products* (Exhibit 11) points to the universities as the main producer of nano-scientific information relevant to nano-patents. However, it also demonstrates the universities are the most citing assignee organization in this area. This might raise questions as to how 'industrial' academic patents are. The case of *electronics* (Exhibit 12) illustrates the importance of universities as science producers. However, university-held patents cite university-generated research much more frequently than others. Industry, in form of multinational corporations, appears to be an important producer of scientific knowledge and also a major absorber. The case of *nano-instruments* (Exhibit 13) indicates the importance of intermediary organizations in terms of knowledge diffusion. Industrial associations and similar organizations seem to be the second absorber of knowledge in the field. Again, it can be pointed out that university-papers are most frequently cited in university patents.

Exhibit 7. Other machinery

PATENT ASSIGNATION AUTHOR AFFILIATION	MULTINATIONAL CORPORATION	UNIVERSITY	INDUSTRIAL ASSOCIATION	**Grand Total**
UNIVERSITY	1	2	2	**5**
MULTINATIONAL CORPORATION	3			**3**
RESEARCH ESTABLISHMENT	1	2		**3**
MULTINATIONAL CORPORATION and UNIVERSITY	1			**1**
UNIVERSITY and RESEARCH ESTABLISHMENT		1		**1**
Grand Total	**6**	**5**	**2**	**13**

Exhibit 8. Metal products, ex. Machines

PATENT ASSIGNATION AUTHOR AFFILIATION	UNIVERSITY	MULTINATIONAL CORPORATION	SMALL AND MEDIUM-SIZED ENTERPRISE	**Grand Total**
UNIVERSITY	8	1	1	**10**
MULTINATIONAL CORPORATION	3	1		**4**
RESEARCH ESTABLISHMENT	3	1		**4**
SMALL AND MEDIUM-SIZED ENTERPRISE	1			**1**
Grand Total	**15**	**3**	**1**	**19**

Exhibit 9. Electronics

PATENT ASSIGNATION AUTHOR AFFILIATION	UNIVERSITY	MULTINATIONAL CORPORATION	SMALL AND MEDIUM-SIZED ENTERPRISE	GOVERNMENT AGENCY	RESEARCH ESTABLISH-MENT	**Grand Total**
UNIVERSITY	11	4	2	1		**18**
MULTINATIONAL CORPORATION		4	3			**7**
UNIVERSITY and RESEARCH ESTABLISHMENT	2	1		1	2	**6**
RESEARCH ESTABLISHMENT		1		1		**2**
MULTINATIONAL CORPORATION and GOVERNMENT AGENCY				1		**1**
SMALL AND MEDIUM-SIZED ENTERPRISE		1				**1**
Grand Total	**13**	**11**	**5**	**4**	**2**	**35**

Exhibit 10. Instruments

PATENT ASSIGNATION / AUTHOR AFFILIATION	UNIVERSITY	INDUSTRIAL ASSOCIATION	MULTI-NATIONAL CORPORA-TION	SMALL AND MEDIUM-SIZED ENTERPRISE	RESEARCH ESTABLISH-MENT	GOVERN-MENT AGENCY	**Grand Total**
UNIVERSITY	13	1	6	2			**22**
MULTINATIONAL CORPORATION	3	3	1			1	**8**
RESEARCH ESTABLISHMENT	3	3					**6**
UNIVERSITY and RESEARCH ESTABLISHMENT	5						**5**
MULTINATIONAL CORPORATION and UNIVERSITY	1	1	1	1			**4**
SMALL AND MEDIUM-SIZED ENTERPRISE		1		1			**2**
HOSPITAL		1					**1**
MULTINATIONAL CORPORATION and RESEARCH ESTABLISHMENT					1		**1**
Grand Total	**25**	**10**	**8**	**4**	**1**	**1**	**49**

These examples illustrate insights that can be gained from the application of patent citation analysis at the combined sectoral/organizational levels. We could demonstrate that the nanoscale science and technology cluster is very heterogeneous and its different subfields show rather varied patterns of knowledge diffusion and absorption. One overall result is that one should make a clear distinction between science and technology on the one hand and academe and industry on the other hand. The analysis has shown that increased patenting activity in a science-based field does not necessarily mean industry is taking up developments coming from the academic sector, at least not in a manner that could be traced by way of patent citation analysis.

However, we were able to demonstrate that nano-scale science and technology are connected through 275 citations. But what sort of linkage do these references describe? Having looked into the relation between nano-science and technology quantitatively, it is necessary to have also a substantive look into it. This again raises the question as to what is 'relevance' as indicated by a patent citation and what sort of connection between knowledge generation processes is captured by a science reference that is listed in a patent – questions that make a closer look at the individual patent citation link necessary.

The Nature of Patent Citations

Peculiarities of Patent Citations

Sociological studies of the patent system point out that the organizational machinery of the patent system itself "determines what is to count as a patentable 'invention' and how large the extent of the protection should be".[32] Patent citations are the result of a highly mediated process, legally and socially shaped and therefore underlying national differences. There are a number of different reasons that motivate patenting[33] and a number of different actors who exercise their influence on the shape of patents. Based on a literature review and a study of patented inventions, this author identified a number of aspects influencing the shape of patent citations. Amongst others, these include:

- organizational structures,
- the legal context of patenting,
- the strategic nature of the process,
- the controversial nature of the process ,
- the different national practices.

These aspects are illustrated in detail elsewhere[34]. The overall difference between the private process/public face character of academic citation and the essentially social character of patent citations is the result of a highly interactive social process within the triple helix of university-industry-government.

A number of actors exert direct influence on the shape of a patent document. This includes, of course, the inventor who, especially in the case of science-based technologies, might be a university researcher who drafts a first description of his/her invention. Patent attorneys or specialists in patent departments on the industry side draft then the application based on the material they received from their clients. Finally, examiners - on the government strand of the Helix - exert critical influence on the shape of the patent document.

One must be aware that there are two essentially different types of citations in patents, front-page[35] and full-text citations. In a European context, one refers to examiner and applicant citations.[36] Only the examiner citations are used in studies by bibliometricians. One should note that examiner and applicant might cite for different reasons. A patent attorney points out:

> "It could be that connections to a scientific base are more observable in the applicant references since these are in the disclosure and might have been included for reasons other than distinguishing the claims, for example, for the purpose of attribution of earlier work".[37]

This can, but does not necessarily need to lead to considerable differences between the two sets of citations. A good illustration for this is the set of patents that are listed in

Exhibit 11. The table compares examiner citations to applicant citations. Often examiner citations contain all the references given by the applicant (#1-3). In most cases examiner citations outnumber the applicant citations. This is due to the duty of disclosure in US patents, as pointed out earlier. However, this does not mean that examiner citations automatically include all the applicant citations (#4-10). Sometimes not a single applicant citation is taken over by the examiner (#9 and 10).

Exhibit 11. Overlap and Differences between front-page and full-text Citations

	JS Patent No.	ront-Page Citations[2]	hared Citations	ull-text Citations[3]
	5,559,353	6 US patents 3 NPR's	1 NPR	1 NPR
	5,367,274	6 US patents 5 foreign patents 12 NPR's	2 foreign patents 5 NPR's	2 foreign patents 5 NPR's
	5,566,197	3 US patents 2 foreign patents 6 NPR's	3 NPR's	3 NPR's
	5,420,083	8 US patents 1 foreign patent 2 NPR's	3 US patents (all patents by applicant)	3 US patents 1 NPR
	5,543,289	23 US patents 2 foreign patents 5 NPR's	7 US patents 1 foreign patent 3 NPR's	7 US patents 1 foreign patent 4 NPR's
	5,603,958	3 US patents 2 foreign patents 2 NPR's	1 NPR	1 foreign patents 3 NPR's
	5,427,767	16 US patents 9 foreign patents	8 US patents 5 foreign patents	8 US patents 6 foreign patents 5 NPR's
	5,298,760	1 foreign patent 4 NPR's	1 foreign patent 1 NPR	2 foreign patents 1 NPR
	5,500,141	9 US patents	--	1 foreign patent 3 foreign patent applications
	5,590,387	11 US patents 2 foreign patents 3 NPR's	--	1 US patent application 6 foreign patent applications 2 NPR's

Source: Meyer, What is special about patent citations?, op.cit., Tab. 1

The occasionally 'bad' citation manners of examiners[38] and the resulting irregular nature of the front page non-patent references (NPRs) have made certain scientometricians — at least to some extent — question the hypothesis that these articles point to scientific bases of technology as described in the respective patents.[39] However, Narin et al.[40] note the dramatic increase of NPRs in patents in the course of the last few years.

Having illustrated the peculiarities and the essentially social nature of the citation process, it is still not clear what sort of linkage a patent citation of scientific literature actually indicates. The following section will summarize the results of a study that investigated the nature of the citation link in ten cases of patented innovations.

[2] Often also 'examiner citations'.
[3] Often also'applicant citations'.

The Nature of the Citation Link

The data presented in this section is based on interviews with inventors about their inventions and the extent to which the front-page (examiner) citation reflect intellectual input or scientific base of the technology they developed and patented.[41]

The cases show that there are indeed many kinds of links between science and patents. Exhibit 4 lists the observations from the cases with regard to science links. The cases support the idea that (front-page) patent citations of research papers usually establish only a highly mediated link between science and technology, even though, in many cases, inventors did say that science and scientific research papers had played a significant role with regard to their inventions. In five of ten cases, inventors indicated the general importance of science. They stated that their inventions are based on their *general* experience in research and/or teaching. Three inventors characterized scientific research papers as important, but background information only.

Only in one of the ten cases one can draw an 'antecedent' cognitive link between a patent and a particular publication that has stimulated the invention patented. In one of the cases, the inventor hardly recognized some of the examiner citations but was able to remember an article he read in *Physics Today* which initiated work on the invention patented. However, the paper was not cited on the front-page since it was not relevant to the examiner in terms of the three legal requirements for granting a patent.

The most direct connection between patent and a cited paper is to be found in the case of a patent that resulted from a basic research project during which a few scientific papers were also written. The examiner cited one of those as background information. The paper itself is another result of the inventor's work in that particular area that also led to a patent rather than that it shows a direct contribution of science to technology. Another science-link is established by the examiner who finds references in the scientific literature that restrict a claim. The case illustrates the patent examiner's role as "the primary source of references in that he or she develops them in course of searching for prior art".[42] Here, the inventor had to modify his claims after the patent examiner had confronted him with material restricting parts of the original claims. Two other inventors said they used citations of papers in special cases. Here, using NPR's can be seen in context of strategic thinking ('fencing off') and legal character of patents.

Exhibit 12. Findings from the cases: Science links.

Science links	Indicated by NPR's ?	Mentions
Inventions based on general experience in research and teaching	No.	5
Scientific literature important as underlying information to inventors	No.	3
Inventions stimulated by articles in downstream specialist journals	No.	1
Research papers as background information cited in patents	Yes.	1
Science references used to attack, restrict, or modify claims	Yes.	1
Research papers cited in special cases only	Yes.	2

The science link established by patent citations is indirect in the sense that the link is not connected to the invention process and the origin of whatever is patented. A citation link connects patent and cited paper insofar as it tells whether the invention touches an area where there has been no patent before, but a scientist has published something relevant.

Earlier sections of this paper indicated that citation links between patents and the papers they cite are, if not explicitly, at least implicitly viewed as an indication of the contributions of science to technology. Here, the findings from the cases are not in complete accordance with prior work. Exhibit 5 summarizes the observations from the cases.

In our view, the findings do not contest the strong science-relation of the patented technology in question. But they do question the assumed direction of the knowledge-flow from science to technology or, from academe to industry. As observations 1 and 2 as well as 3 and 4 indicate, researchers seem to integrate scientific and technological activities increasingly by working on one subject-matter but generating scientific papers as well as technological outputs (patents). In such a situation, one might find it difficult to judge whether science pushed technology or technology pulled science. It seems to be a much more reciprocal relationship than the linear model suggests. In these cases, patent citations reflect much more than scientific contributions to technology. They also indicate the kind of closeness between the two spheres. For instance, they illustrate a close personal science-technology linkage by individuals working on one subject-matter in both scientific and industrial organizations, as shown in observation 1. They also point at co-occurring simultaneous scientific and technological activities of individuals in hybrid (observation 2), or established organizations (observations 3 and 4). In these cases, science and technology seem to be much more intertwined.

In addition, not all the organizations researchers are working for easily fit into a simple academe/industry dichotomy anymore. Are a university-based corporate research institute (observation 2) and a public research institute (observation 3), both of which generate scientific papers as well as patents, now locations of scientific research or technological development?

Exhibit 13. Findings from the cases: Examples of science-technology interactions.

	Types of science-technology interaction as reported in cases
1.	Close personal science-technology linkage: Individuals active both in academic research and industry (adjunct professorships of industrial researchers)
2.	Doctoral candidate working in university-based corporate research institute. His work on the same subject-matter has led to both scientific results (his Ph.D. dissertation) and technological output (the patent examined).
3.	Public research institute is actively involved in both patenting and publishing. Not infrequently, patents and papers result from the same project.
4.	Invention patented was developed by a scientist who was active in a company and produced both patents as well as scientific research papers based on the same project.

It was investigated how the inventors view the relationship between science and technology in their field of expertise. It is not possible to establish a general tendency in favor of a science-push idea. Quite the contrary seems to be the case. In two cases, the inventors tended to speak rather of a technology-driven science than a science-based technology by pointing out that "people patent before they publish" or "patents in very advanced and modern fields usually do not contain references to scientific research papers" and it is not technology, but science that is lagging behind.

Summarizing the results, one can say that cited papers rarely the key source of the idea that led to the technical invention. Several NPC links actually reflect cases where technology is leading science, or refer to instances of reciprocal relationships where knowledge-generating processes are intertwined.

Conclusions

Employing a framework that is related to the triple helix of university-industry-government, this paper has illustrated the problematic character of patent citations referring to scientific literature. The user of this indicator has to be aware of its shortcomings. In particular, one must be aware of the nature of the connection that a patent citation establishes between citing patent and cited document.

Derek DeSolla Price, Arie Rip and Francis Narin used Toynbee's dancer metaphor to characterize the relationship between science and technology. One important question is whether one can use this metaphor to denote the relationship that is established by way of patent citations. We illustrated that the connection between patented technology and the piece of scientific work is very mediated. The patent examiner selects them in the end. Even though there are many differences between patenting and citation processes of national offices, the examiner has always a central role. In countries, such as the US, the applicant has the duty of disclosure, which forces him to indicate all potentially relevant publications to the examiner. However, patent citation analysts almost exclusively track so-called front-page or data sheet citations. These citations are at least selected, if not found, by the examiner. It appears difficult to refer to this connection as knowledge flow between science and technology. In the particular instance of an individual citation, the patent examiner refers the applicant to a potentially relevant publication that could restrict his or her claims. What takes place here, is a communication, a piece of information is forwarded. In some instances, this might refer to a scientific publication. Does this now indicate interaction between a certain piece of science and another of technology? Only in an extremely mediated, indirect sense. One would need to go to some length to establish a 'communicational' link between science and technology by way of patent citations. However, one might ask whether at the level measures of approximation, patent citations can indicate the potential of exchange between certain subareas of science and technology. In this perspective, the patent examiner could be seen as a highly qualified subject-indexer selecting the relevant citations only (for analysts of literature citations such an intermediary would be a dream-come-true) and thereby establish connections of relevance. Patent citations might not be indications for the dance between science and technology, but they still might give useful pointers as to where the 'dance', or more, takes place. This seems to be supported by findings of patent citation analyses by Schmoch et al.[43] They can relate high citation frequencies to technological fields that are generally acknowledged as closely related to science and significantly linear citation frequencies to fields that are viewed as hardly related to science.

The case examples of patent citations in certain fields of nanoscience and technology indicated there is much difference in the citation profiles of the selected subfields. However, one quite frequent result was that mostly university patents cited university papers. There were also cross-links. But most of the connections were rather intrasectoral than cross-boundary. This is not necessarily in contradiction with the fundamental idea of the triple helix framework, namely that actors in one sector increasingly move into the spheres that were previously considered the domain of others. In particular this has been illustrated for the university. In the

American context, there is much talk about the second academic revolution and the capitalization of knowledge. The advent of the academic entrepreneur is often associated with the university moving into the industrial field. The evidence generated in this study does not contradict this. However, it raises the question, if academics begin and continue to make use of hitherto chiefly industrial forms of intellectual property protection, whether they really pursue commercial motives or see patents as a means to document success in the classical game of novelty hunt. The finding that university patents cite rather university-authored papers than industrially authored papers indicates the difference between the institutions of academic science and industrial technology. Even though science was and is performed in industry and even though academics increasingly patent and might set up companies for a multitude of purposes, the mother institutions of science and technology remain mostly self-referential, in spite of developments crossing the line. In this sense one could still use the dancer metaphor to characterize the way these two central institutions relate to each other. Future research is needed to investigate the extent to which observations at the level of patent citations reflect developments at other levels.

Future research should also deal with the question as to whether the number of patent citations can indicate the degree to which a field of science and an area of technology are interconnected. We found 275 patent citations linking a database of more than 5,000 publications with a database of more than 2,600 patents. We found this to be an indication of little overlap. However, other analysts might wish to contest this perception and might argue that the degree of overlap observed here indicates a substantial amount of interrelation, at least compared with other areas.

Notes & References

[1] German for ‘guiding image’. See also L. Marz and M. Dierkes, ‘Leitbildprägung und Leitbildgestaltung’, in G. Bechmann, T. Petermann (eds.), Interdisziplinäre Technikforschung: Genese, Folgen, Diskurs (Frankfurt/Main, New York: Campus, 1994), 35-72.
[2] We use the term 'developer community' to denote social entities that unite individuals that advance scientific and/or technological knowledge into a certain direction. These communities can be characterized by using similar instrumentation, or have a focus on a certain subject-matter. Analysts find it increasingly difficult to distinguish between 'science' and 'technology' and, instead of those terms, prefer to investigate the dichotomy of 'academe' and 'industry' and efforts to overcome it. Given the terminological confusion, we use the term 'developer community'.
[3] DeSolla Price saw in his 1965 study the closest interaction between science and technology taking place in the period of education when ‘budding scientists read the archival literature in their fields’. In terms of translation of new science into new technology, this would imply a time lag of about ten years (corresponding with the education cycle). DeSolla Price later revised his view of clearly separated entities by developing the concept of ‘instrumentalities’. Instrumentalities are laboratory methods for doing something to nature or to data. These crafts and techniques, which the experimentalist/inventor use, link basic and applied research to technology.
[4] H. Etzkowitz and L. Leydesdorff (eds.), Universities and the global knowledge economy: a triple helix of university-industry-government (London: Pinter, 1997).
[5] S. Hinze, G. Jäckel, N. Kirsch, F. Meyer-Krahmer, G. Münt, U. Schmoch, ‘Constraints and opportunities for the dissemination and exploitation of R&D activities: the R&D environment. Report on CEU project no. GS1 (Sprt Eims-99).’ In Interfaces: Science-Technology-Society (European Commission, DG XIII/D2 Dissemination of Scientific and Technical Knowledge Unit: Luxembourg/Brussels: no date).
[6] The concept of ‘institution’ is not very clear. Many authors in innovation studies use the term ‘institution’ in the everyday sense of the term as referring to ‘rather concrete things’ [C. Edquist and B. Johnson, ‘Institutions and Organizations in Systems of Innovation.’ Chapter 2 in C. Edquist (ed.), Systems of innovation: technologies, institutions and organizations (Pinter: London and Washington); 43] pertaining to the organization and utilization of R&D. Examples are technical universities, public research institutes, industrial laboratories, patent offices, etc. However, institutional economists make a different use of the term to differentiate ”the rules from the players” [D.C. North, Institutions, Institutional Change and Economic Performance (Cambridge UP, 1990).p. 5]. Here, ‘institution’ is understood in a sociological sense and refers to established patterns and procedures of behavior. ‘Organizations’ are ”created with purposive intent in consequence of the opportunity set resulting from the existing set of constraints ... and in the course of attempts to accomplish their objectives are a major agent of institutional change” (North, ibid.). But organizations in this sense are what we usually also describe as institutions (see above enumeration). To make a clearer distinction, various authors in the innovation systems literature have adopted North’s usage of the terms ‘organization’ and ‘institution’. Therefore, in this study North's terminology has been adopted.
[7] Hinze et al., op.cit., p. 16.
[8] H. Grupp and U. Schmoch, Wissenschaftsbindung der Technik. Panorama der internationalen Entwicklung und sektorales Tableau für Deutschland (Physica: Heidelberg, 1992).
[9] Grupp and Schmoch, Wissenschaftsbindung der Technik. Panorama der internationalen Entwicklung und sektorales Tableau für Deutschland, op.cit, 2-3.
[10] They point out that research & development and science are not equivalents. R&D include scientific activities to a considerable extent. However, it also encompasses activities, such as constructing industrial prototypes or test equipment. Hinze et al. add that many statistical studies subsume education and training under ‘scientific’ activities, while these are activities that are not included in definitions of research and development. The definition of R&D used in the Frascati manual, for instance, does not include such activities: “Research and experimental development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society and the use of this stock of knowledge to devise new applications.”
[11] Ibid.

[12] F. Narin et al., 'The Increasing Linkage Between U.S. Technology and Public Science', Research Policy, XXVI (3), (1997), 317-330, and literature therein.
[13] E. Autio, Technology transfer effects of new, technology-based companies: an empirical study (Espoo: Helsinki University of Technology, Institute of Industrial Management, Working Paper #1993|1).
[14] E. Autio, Technology transfer effects of new, technology-based companies: an empirical study, op.cit., 26
[15] E. Autio, Spin-off companies as agents of technology transfer: An empirical study of spin-off companies of the Technical Research Centre of Finland (VTT) (Espoo: VTT, 1993), 15.
[16] E. Autio, Technology transfer effects of new, technology-based companies: an empirical study, op.cit., 26
[17] F. Narin, 'Patent Bibliometrics', Scientometrics, XXX (1), (1994), 150.
[18] Narin et al., The Increasing Linkage Between U.S. Technology and Public Science', op.cit., 318
[19] F. Meyer-Krahmer and U. Schmoch, Chemistry, information technology, biotechnology, and production technology: a comparison of linking mechanisms in four fields (Karlsruhe: Fraunhofer Institute for Systems and Innovation Research, 1997), 8.
[20] A. Rip, 'Science and technology as dancing partners' in P. Kroes and M. Bakker (eds.), Technological development and science in the industrial age (Kluwer: n.p., 1992), 231-270.
[21] Ibid., 139.
[22] I. Malsch, Nanotechnology in Europe: Experts' Perceptions and Scientific Relations between Sub-areas. (Seville: Institute for Prospective Technological Studies, 1997).
[23] A. Franks, 'Nanotechnology', J Phys E: Sci Instrum, XX (1987), 1442-1451.
[24] D.W. Budworth, Overview of Activities on nanotechnology and related technology (Seville: Institute for Prospective Technological Studies, 1996).
[25] The Finnish Nanotechnology Programme, for instance, defines nanotechnology as '(...) an increasing number of methods which are used to build structures smaller than the finest structures in current silicon chips, yet larger than individual atoms. This implies a scale from 1 nm to 1000 nm.' [TEKES and Academy of Finland (Helsinki), Nanotechnology: The Way to the Future, Nanotechnology Programme 1997-1999]
[26] G. Bachmann, Nanotechnology. Technology analysis prepared within the framework of the 'Identification and Assessment of Approaches to Future Technologies' plan (no. NT 2051B) under contract to the Federal Ministry for Research and Technology (Düsseldorf: VDI [Verein Deutscher Ingenieure], 1995); BMBF, Delphi-Bericht 1995 zur Entwicklung von Wissenschaft und Technik - Mini-Delphi (Bonn: BMBF, 1996); M. S. Meyer, Nanotechnology and its industrial applications, (Wuppertal: W.WIS, 1996).
[27] More detailed information regarding the data retrieval can be found in M. Meyer and O. Persson, 'Nanotechnology - interdisciplinarity, patterns of collaboration and differences in application', Scientometrics, XXXXII (2), (1998), 195-205; and M. Meyer, 'Patent citations in a novel field of technology: What can they tell about interactions of emerging communities of science and technology?', Scientometrics, XXXXIIX (2), (2000), 151-178.
[28] Martin Meyer, 'Does science push technology? Patents citing scientific literature', Research Policy, XXIX (3), (2000), 409–434.
[29] One illustration of this is, for instance, a major EU-funded conference on 'Nanoscience For Nanotechnology'; the title implicitly assumes that nanotechnology builds critically upon nanoscience.
[30] It should be noted that the matches we found are patent citations listed in the 'other references' section on the front-page of the patent, referring to scientific papers in our nano-publication database only. This methodology corresponds to current practice amongst patent bibliometricians who track front-page citations of non-patent literature to study the science/technology linkage. The following section on the nature of patent citations will clarify the importance of this practice.
[31] Given the dominance of natural sciences it might be interesting to have a closer look at the level of subclasses. The subfields that were cited ten times or more frequently are: physical sciences (with 108 citations), multidisciplinary sciences (40), interdisciplinary natural-engineering & materials (36), chemical sciences (34), materials science (19), medical sciences (14), and Inter-disciplinary life-natural (10).
The data indicates clear differences in the linkage patterns of the industries investigated. While instruments, electric machinery, and electronics have a strong focus on physical sciences (with 19 out of 49 nano-patent citations, 23/40, and 24/35, respectively), the pharmaceuticals and chemicals industries have different orientations. For instance, with ten out of its 29 citations, the pharmaceuticals industry is linked to the medical sciences much stronger than any other industry. Similarly, it is connected to inter-disciplinary life-natural by 8 patent citations. In terms of nano-science and technology, the chemicals industry seems to put emphasis on inter-disciplinary natural-engineering &

materials and multidisciplinary sciences to a relatively greater extent than instruments, electric machinery and electronics industries. Various combinations of these and other sets of indicators confirm the results presented here. For instance, the distribution of patent citations as measured by Dewey descriptors and IPC classification at the 4-digit level present similar results. Physics/engineering with 66 citations the major 'contributing' scientific domain. The strongest connection has been established with subclass H01L (20 citations). Other links are with H01J (6 citations) and G03F (4 citations). The second biggest contributing 'science' is the field of comprehensive works and general sciences with 37 references, which are much more evenly distributed. With 6 citations, H01J tops the list of technological domains linked to this field of science. Runners-up are H01L and C01B. The scientific field 'physics' holds rank #3 with 25 patent citations. However, there is no technological field more than 3 citations are related to.The Dewey-domain 'engineering/chemical engineering' is the fourth biggest attractor of nano-patent citations, together with 'pharmacology and pharmacy (both 15 references). These two area, however, relate to nanotechnologies in entirely different manners. While (chemical) engineering is referenced just by B32B four times and linked to eight other technological domains with one or two patent citations, 'pharmacy & pharmacology' are clearly linked to subclass A61K (with 12 out of 15 patent citations). There are three further linkages established by individual patent citations (A61F, C07F, B01J; one cite each). The only other 'stronger' link is the connection between the scientific field of instruments and the IPC subclass H01J with 4 references.

[32] H. van den Belt, 'Action at a distance: A.W. Hofmann and the French patent disputes (1860-1863), or how a scientist may influence legal decisions without appearing in court', in R. Smith and B. Wynne (eds.), Expert evidence: interpreting science in the law (London: Routledge, 1989).

[33] B. Campbell, 'Generalists, practitioners, and intellectuals: the credibility of experts in English patent law', in R. Smith and B. Wynne (eds.), Expert evidence: interpreting science in the law (London: Routledge, 1989), 211f. Campbell describes the variety of uses patents have and their effect on patenting: (1) Some parties hold many small patents to cover their production; (2) Other economic actors focus on key central patents; (3) Others prefer not to patent but rather to manage their affairs by means of industrial secrecy; (4) Patents are also taken out as part of employee incentive programs to promote inventiveness, resulting in a large number of not necessarily workable minor parts.

[34] Meyer, 'What is special about patent citations', op.cit.

[35] Another, equivalent term would be 'data-sheet citation'.

[36] 'Examiner citations' refer to the references listed in the search reports that are established for every European patent application by specialized examiners in The Hague, while 'applicant citations' rather refer to those references in the full-text, specification part of the application. Not infrequently, search reports also contain references submitted by the applicant party in the specifications.

[37] Personal communication, G. Jordan to author, summer 1999.

[38] Despite the fact that citations in patents are less likely to be irrelevant or superfluous than references in journal papers, Collins and Wyatt (op.cit.) observe that they are not free of problems either. "Examiners, for example, tend to restrict their reading to a narrow range of specialties and to be relatively unfamiliar with the wider literature. Where they do use the journal literature it tends to be in the secondary form i.e., abstracting journals rather than the primary form."

[39] B.G. van Vianen, H.F. Moed and A.F.J. van Raan, 'An exploration of the science base of recent technology', Research Policy, XIX, (1990), 61-81; V. Rabeharisoa, 'A special mediation between science and technology: when inventors publish scientific articles in fuel cells research', in H. Grupp (ed.), Dynamics of science-based innovation (Berlin et al.: Springer), 45-72.

[40] Narin et al., 'The Increasing Linkage Between U.S. Technology and Public Science', op.cit.

[41] Meyer, 'Does science push technology? Patents citing scientific literature', op.cit.

[42] R.S. Campbell and A.L. Nieves, Technology Indicators Based on Patent Data: The Case of Catalytic Converters - Phase I Report: Design and Demonstration (Batelle Pacific Northwest Laboratories, 1979), 9.63.

[43] F. Meyer-Krahmer and U. Schmoch (1997), 'Chemistry, information technology, biotechnology, and production technology: a comparison of linking mechanisms in four fields', op.cit.