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Does science push technology? Patents citing scientific literature

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Abstract

In recent years, there has been a trend towards a science and technology policy that is applied in nature. In times of growing public discontent about high taxation and budget deficits, even basic science needs to document industry relevance. Counting patents apparently related to basic research activities through citations would be one way of measuring the relevance of basic research to industry. This has become especially interesting since Narin et al. [Narin, F., Hamilton, K.S., Olivastro, D., 1995. Linkage between agency supported research and patented industrial technology. Research Evaluation 5 (3), 183–187.] observed an increasing linkage between US technology and public science. The results of Narin et al. indicate a growing relationship between science and technology in a very general way. This idea of an increasingly science-based technology might convey the impression that there is direct knowledge-transfer taking place that is reflected in citations to scientific research papers in patents. A study of front pages of patents in the field of nanoscale technologies suggests that citation linkages hardly represent a direct link between cited paper and citing patent.

Keywords: Science; Technology; Citation; Patents; Nonpatent references

1. Introduction

The study of references in patent documents — a form of linkage bibliometrics — has contributed to the debate about science and technology and how they relate to each other. In this context, one has to mention the pioneering work of Narin et al. They can show an ever closer interaction between science and technology in high-technology areas (e.g., Narin and Noma, 1985). They also claim to have observed an increasing linkage between US technology and public science. Narin et al. (1995) show that the within-country connection between basic science and applied technology is especially pronounced in the highly scientific areas of technology. A more recent study by the same group underpins these findings (Narin et al., 1997). By tracing the rapidly growing citation linkage between US patents and scientific papers, Narin et al. reveal a strong national compo-

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nent, with each country's inventors preferentially citing papers authored in their own country by a factor of between two and four.

How can one interpret these impressive citation data? Is a citation linkage also a direct link? What does it tell us about the nature of the interaction between science and technology? Can this measure indicate the direction of knowledge transfer? Does a patent citation of a scientific research paper indicate an immediate application of science? This paper aims at contributing to a better understanding and interpretation of the data generated by Narin et al. Therefore, it investigates the histories of a number of patented inventions and how the patent citations, especially the science references, are related to the invention process. Firstly, it will place citation analysis in the general debate about the relationship between science and technology. After clarifying definitional issues, different interpretations of Narin's data will be introduced, one based on a basically linear understanding of the innovation process, the other one drawing on a more enlightened perception of the relationship between science and technology. The question will be raised as to whether one can interpret citation linkages as a direct link indicating science-dependence of technology. In the following sections, the role of citations in patents will be discussed in relation to the research issues of the paper. Then a detailed discussion of the case selection follows. Based on findings from the cases and additional interviews with patent experts, conclusions will be drawn. One major point this paper will make is that patent citations do not indicate a direct science link of technology, but illustrate the multifaceted interplay between science and technology. A further point is that one should demonstrate more caution in interpretation even in technological areas with high citation frequencies of scientific research papers and not automatically assume that there is only a linear one-way connection. One should not use a misleading term like 'science-dependence' of technology either. The results from the cases show that there are several ways in which science and technology relate to each other and that even in those fields, technology is more than just a receiver and transformer of scientific results. Therefore, it does not seem appropriate to use the linear science-push model to interpret patent citation data.

2. The relationship between science and technology

2.1. Definitions

The question of whether articles cited on the front page of a patent would be indicators of science bases of the invention described by the patent is widely addressed in the bibliometric literature. Rabeharisoa (1992) notes the heterogeneity of the results of studies addressing this topic. Debates focus not only on practical issues, but also on the very problem of identifying and describing the relationships between science and technology. To capture the relationship between science and technology, citation studies usually establish a link through nonpatent literature cited in patents. This means that patents are considered a representation of technology, while papers and citations to them are viewed as representations of science.

Traditionally, companies patent more than they publish, and university researchers publish usually more than they patent. As Pavitt (1998a) reports, business firms are granted about 80% of all patents, and many of the remaining 20% are granted to individuals who are owners of small firms. Looking at publications, Hicks (1995) has established the reverse pattern. Academics publish more than do their colleagues in industry. In such a situation, with most of the scientific papers published by academics and most patents held by (and originated in) industrial companies, the tendency to associate the academic sector with science and the industrial sector with technology is only natural. This could convey the impression that science and technology are defined organizationally. One might say that due to this pattern, citation studies employ a quasi-organizational definition of science and technology.

2.2. Different interpretations

A debate on the relationship of science and technology without any reference to the linear model is hardly possible. Narin (1994) (p. 150) 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''.

Then again, Narin et al. appear to have a basically linear understanding of the innovation process. This becomes apparent in the rhetoric they use to describe the nature of the science–technology relationship that is established by patent citations to scientific research papers. For instance, they postulate 'science dependence' of certain technologies (Carpenter and Narin, 1983; similarly, Grupp and Schmoch, 1992; p. 123). Another problematic term is 'scientification' of technology (see Grupp and Schmoch, 1992; p. 92ff).

In a way, Narin has pointed to this development himself by indicating the ever closer relationship between science and technology in another context. In his common paper with Noma, he refers to Toynbee's dancer metaphor to describe the relationship between science and technology:

> ...not only are technology and science intimately related as a pair of dancers, but further that much of current high-technology is becoming virtually indistinguishable from science: Toynbee's dancers are today locked in an embrace from which it is virtually impossible to separate the partners (Narin and Noma, 1985; p. 370).

But with dancers dancing an ever closer dance, it also gets increasingly difficult to say who is the partner that determines the direction. This idea is taken up in the two-branched model of innovation suggested by Rip (1992). 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 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''' (ibid., p. 139).

Fig. 1 illustrates the difference between the linear interpretation and the two-branched approach. Basic research, or science, produces a number of scientific research papers, indicated here as copyright symbols (©). Technology is materialized in patents, illustrated here through the symbol for registered trademarks (®). Fig. 1(a) describes one way of interpreting the data of Narin et al. The increasing number of scientific research papers cited in patents documents the growing connection between the areas of science on the one hand, and technology on the other — as indicated by the bold arrow. Fig. 1(b) contrasts this simplified interpretation by a more complex view of the relationship between scientific papers and patents following Rip's model.

Based on the differences between these ideas, one should ask whether it is possible to show a direct link between certain patents and the scientific research papers they quote. To what extent do they

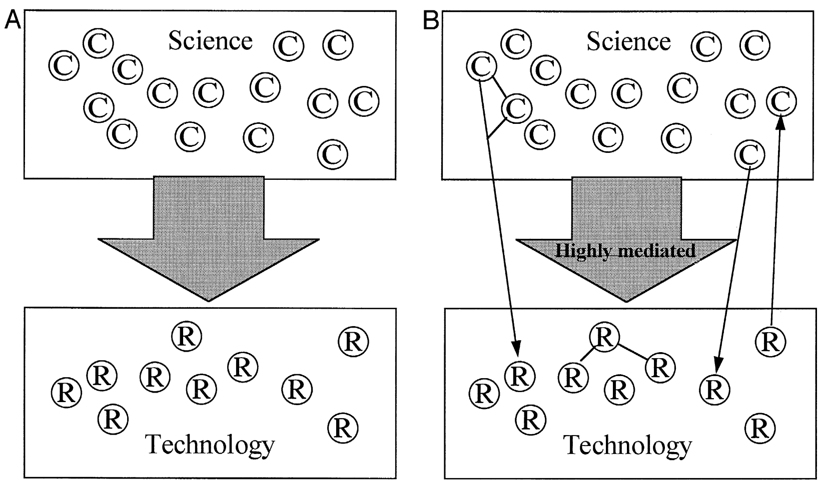

Fig. 1. (A) Linear interpretation (B) Two-way interpretation.

reflect actual input of basic research into a specific invention? Can one draw direct connections between particular papers and particular patents? Fig. 1(b) raises such questions by indicating that there may, in many instances, be an only and highly mediated relationship between science and technology, even though one might find occasionally direct relationships between a patent and a paper it cites.

To answer these questions, one must have a closer look at individual patents to make valid judgements in this matter. In particular, one should investigate why research papers are cited rather than counting them under the assumption that every count makes every penny spent on basic research more legitimate and thus more relevant to industry. To do this, one has to examine the patent-front pages in detail to find out what the inventors cited, how and why.

3. The role of citations in patents

3.1. Patent documents

Before investigating citation studies in more detail, a few introductory remarks on patents and patent citations and their roles seem necessary. Ganguli and Blackman (1995) briefly review the structure of a patent document, which consists of three elementary parts: (1) the title page with bibliographic information, (2) the text, which includes a description of the invention, preferred examples in details as well as drawings, diagrams, and flow charts, and (3) the claims. Given that I want to evaluate citation studies, I follow their focus on the title, or front page. The front page of a patent contains a set of bibliographic data.[2] For the citation studies in question, the bibliographic information available on front pages of patents is most important. There are two sets of references to other patents and literature in patent documents — examiner references on the front page and applicant references embodied in the full-text (e.g., Narin and Noma, 1985). Citation studies just rely on the front page-examiner references since only those are available in the databases the researchers used (Schmoch, 1993). Narin et al. also omit any analysis of references in the body of the patents for a theoretical reason: ‘‘Theoretically, the front page references should be the most important ones on a patent, since they are the ones relied upon . . . by the examiner in establishing the patent’s novelty’’ (Narin et al., 1997; p. 319).[3] However, as one 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’’ (Gary Jordan,[4] personal communication).

To better understand what Narin et al. really do and what function these particular citations have, a closer look at the role of citations in patents is helpful. Narin et al. and other authors make use of certain, so-called nonpatent references (NPRs) on the front pages of US patents. NPRs can encompass references to a variety of nonpatent documents, such as scientific papers, technical papers, conference proceedings, textbooks, disclosure bulletins, abstract services, and so forth. Just a minority of patents contains references citing nonpatent literature. A recent study of the Norwegian knowledge base by Iversen (1998), for instance, shows that only about 30% of Norwegian-originated US patents contained NPRs. This is due to the fact that the stock of prior art references of the Patent Offices predominantly consists of patent literature. For example, the stock of the German Patent Office has about 10% nonpatent literature only (Rainer Bertram,[5] personal communication). Consequently, the official searches

[2] Walker (1995) (p. 135) gives a detailed overview of what is contained on the front page in a standard format: bibliographic information, examination-process information, an abstract of the invention, and a drawing (when applicable), the title, the name of the inventor or inventors, the date of application, the application number, a record of previous applications from which the application stemmed (where appropriate), and the classification number with any applicable cross-reference classification numbers.

[3] Also Narin et al. assume great similarity between front page and text science references. They base this assumption on a brief study by Narin and Olivastro (1988) which indicates that approximately half of the science references are on the front page.

[4] US patent attorney, now associate professor at the Department of Business Studies, Uppsala University, Sweden.

[5] European patent attorney, Grünecker, Kinkeldey, Stockmaier and Schwanhäusser, Munich, Germany.

of the examiners mainly reveal patent literature documents (Rainer Bertram, personal communication). [6]

3.2. Patenting as social process

As van den Belt (1989) (p. 185) establishes, most studies on the working of the patent system have chosen ''a naïve conventional view that the patent system does no more than bestow legal recognition upon what already exists in a well-defined form''. 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'' (ibid.). In other words, patenting is also a social process. There are a number of different reasons that motivate patenting [7] and a number of different actors who exercise their influence on the shape of patents.

As it addresses a number of different readers with different interests, the entire patent document can be seen as ''a compromise between different strategies'' (Rip, 1986; p. 92). Rip (1986) (p. 91f) distinguishes three different kinds of readers: (1) the officials of the Patent Office, who have to grant the patent; (2) the competitors in the field, who are eager for information about new products and processes; and (3) potential licensees, who must be interested in what the patent offers. This readership structure has consequences on the way patents are written (and how citations are selected). On the one hand, one has to fence off, while on the other hand, one must indicate an interesting area. Rip (1986) (p. 92) explains:

> Although patentees may value the patent system in general, in writing their own application they will try to keep the box around their own invention as black as possible while still satisfying the enablement requirement. Penetrability is not in their interest.... Perhaps it would be best to characterise the rhetorical structure of patent applications as a fence of interests.

Following Campbell (1989) (p. 212), one can establish that ''patents are clearly a strategic component in the economic exploitation and development of technology and an important feature of the social dynamics of technical invention''. [8] Rip (1986) (p. 97) emphasizes the legal and thereby strategic character of patents: ''Legal battles may now be fought about interpretations of words or sentences''. [9]

3.3. Patents as legal documents: applicants' and examiners' tasks

Patents are legal documents. Hence, patent citations do not work like citations in papers. Campbell and Nieves (1979) argue that, due to their specific legal functions, citations in patents are likely to be much more carefully selected than citations in journal papers. Due to the wide range of legal requirements, possible loopholes and eventual litigations, ''patent applications are often written by specialist patent advisers and not by the scientists themselves'' (Rip, 1986; p. 91). This section will discuss what the different roles of patent applicant and attorney as well as examiner are and how citations reflect them.

The legal responsibility of the applicant is to describe the prior art. As Collins and Wyatt (1988) (p. 66) explain, ''he or she must set out the background in such a way as to show how the claimed invention relates to, but is innovatively different

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[6] In practice, patent applications which have a closer link to traditional fields of science, for example, chemistry, physics, biology, are more frequently confronted with nonpatent literature.

[7] Campbell (1989) (p. 211f) 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; and (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.

[8] This statement is well underlined by the difficulties Campbell experienced when he tried to get cooperation from corporations involved in patent actions. In particular, their objections included the concern in jeopardizing their legal position in relation to the patent in question (ibid., p. 234).

[9] For the field of biotechnology, Cambrosio et al. (1990) illustrate the strategic character of patents and, furthermore, show that ''while one might expect 'technical' arguments to play a central role...'social', 'historical' 'economic', or 'philosophical' arguments are coextensive with and constitutive of the 'technical''' (ibid., p. 290).

from, what was already public knowledge''. Another legal requirement for patents is their usefulness. Thus, the applicant's task is to identify work ''either related to, but significantly different from, or else a useful step towards, the new invention or a use of the invention'' (Collins and Wyatt, ibid.). The third legal requirement a patent has to meet is novelty.

The examiner's task here is to ensure the novelty of the invention claimed and to identify its limits. Hence, the function of examiner citations is ''to identify the area in which the invention is truly original and therefore merits the granting of a patent'' (Collins and Wyatt, ibid.). Examiner citations usually complement, rather than duplicate the citations by applicants, although ''it happens not infrequently that both examiner and applicant cite the same publication'' (Collins and Wyatt, ibid.).

At this point, some criticism already emerges with regard to the quality of citations. Despite the fact that citations in patents are less likely to be irrelevant or superfluous than references in journal papers, Collins and Wyatt (1988) (p. 67) 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.''

These 'bad' citation manners of examiners [10] and the resulting irregular nature of the front page 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 (van Vianen et al., 1990; see also Rabeharisoa, 1992). However, Narin et al. (1997) note the dramatic increase of NPRs in the course of the last few years. Already in the mid-eighties, Narin and Noma (1985) (p. 373) pointed out that in the early 80s, the examiners had been placing more and more references on the front pages of the patents, and the applicants had been required to be more meticulous in informing the examiner about any references pertaining to the patent.

3.4. Types of patent citations

Further criticism of citation studies is related to the occurrence of different types of citations and their frequency. One can distinguish a number of different citations made in patent documents. As Schmoch (1993) explains, because of the novelty requirement, the examiner has to look for earlier documents (primarily patents) that have the same or almost the same features as the patent application. Only if there are no other relevant documents putting the novelty of the invention in doubt, will the patent application be accepted. Hence, one can find two different types of citations: (1) documents of particular relevance, and (2) references concerning the general background. Documents of particular relevance restrict the claims of inventors. In European search reports, individual documents that, if taken alone, may question novelty or inventiveness of a patent claim are marked with the letter 'X'. Documents which are considered to question inventiveness of a patent claim, if taken in combination with another document, are marked with the letter 'Y'. These letters reflect the opinion of the search examiner, but are not binding in the substantive examination (Rainer Bertram, personal communication). The second type of references (concerning the general, technical background of the invention) is marked 'A' (Schmoch, 1993).

The different types of cited references have different degrees of linkage, or proximity, to the examined patents. While 'X' references have a high degree of linkage, it may vary for 'Y' references, since they are important only with other references. 'A' references usually have a low proximity (Schmoch, 1993). As frequently cited, references are not necessarily technically or economically important, but may be cited for didactic and illustrative reasons in the de-

[10] Collins and Wyatt (1988) also conclude from their observation of occasional repetitions of bibliographic errors that sometimes, examiners have not read the papers they cite. As they sometimes found the use by examiners of the same set of citations in several different patents, Collins and Wyatt also discern an ''occasional tendency to cite by rote rather by relevance'' (p. 67) and speculate that ''some citations are included to demonstrate the examiner's diligence in searching rather than because of their direct relevance'' (p. 67). National chauvinism in examiners' and applicants' citation behavior is another observation by Collins and Wyatt.

Table 1
Motives for citing nonpatent literature (based on Grupp and Schmoch, 1992; p. 79f; and Schmoch, 1993)

Motive	Science link?
1. Prior art is not yet documented by a patent. Examiner thus relates progress in the examined patent application to a scientific publication.	Yes
2. Citations of nonpatentable research results (e.g., formulae, hypotheses, discoveries, etc.)	Maybe
3. Only nonpatent publications are available due to rapid development in a particular technical field.	Maybe
4. Invention published in the company's own journal or disclosure bulletin.	No
5. Citations of patent abstract services (for Japanese language and chemical patents).	No
6. Citations of very simple facts below the threshold of inventiveness so that no related patent exists.	No

scription of prior art, further investigations about the extent 'X', 'Y', and 'A' references occur are necessary. A number of investigations have dealt with this issue (Baré, 1981; Schmoch, 1993). They show that relatively few citations (less than 15% in both studies) are references of the 'X' type. If one sees 'X' and 'Y' references as citations of a high–medium proximity, 29% of all citations can be considered ''linkages to direct knowledge sources'' (Schmoch, 1993). So just about a third of all patent citations have a close relationship to the citing patents. [11]

According to one survey by Schmoch (1993), only 8% of all examiner citations originate from the inventor. His results about citation types and their frequency presented in Section 3.1 referred to references citing to patents only. Although the categories introduced there apply for nonpatent references equally, for database reasons, it is not possible to analyze NPRs automatically in the same manner. This makes a closer look at the motives behind citing to nonpatent references necessary.

3.5. Motives behind NPRs

Interview-based surveys (Grupp and Schmoch, 1992; Schmoch, 1993) could identify a number of reasons for including nonpatent references in search reports. Table 1 gives an overview of the motives and evaluates to what extent they can be used to make judgements on science link.

[11] However, Schmoch (1993) can present some evidence for a more general relationship. He cites an intellectual evaluation study of patent references that has shown for the field of space technology that a large number of references are linked to the citing patents in a very broad sense (Schmoch et al., 1991).

Grupp and Schmoch (1992) and Schmoch (1993) discuss to what extent the various motives are relevant for a citation study that aims to indicate science dependence of certain technological fields. Motive 6 is obviously not science-related. So is motive 5, since it refers to patents just in form of abstracts. Motive 4 refers to cases when the invention seems not important enough to be patented, but competitors should be prevented from applying for a patent on the same subject. Therefore, publications in a company disclosure bulletin are similar to patents. The respective citations then have quite the same character as patent references. Motives 2 and 3 may, but do not need to, relate to a science-intensive field, while motive 1 ''reflects the classic situation'' (Grupp and Schmoch, 1992; p. 80). However, even here, Grupp and Schmoch (1992) warn:

> ...care must be taken to ensure that not every journal is tantamount to a reference to fundamental research. According to a convention (Marquis and Allen, 1966) (p. 80), a journal is only regarded as 'scientific' if it is published by a scientific society. Journals from technical societies...on the other hand reflect the area of applied research.

In the case of technical journals, Grupp and Schmoch (1992) refer to Gibbons and Johnston (1974) (p. 228) who assume that technical literature may also contain basic research reports. In light of this discussion and no quantitative data on the importance of the various motives, Schmoch (1993) concludes that the quota of nonpatent citations as an indicator for the science–technology link has to be interpreted very carefully.

3.6. Research issues of this study

Not all of these criticisms affect the latest work by Narin et al. Although their work is based on an analysis of nonpatent references, which were listed as ‘other references cited’ on the front pages of US patents, they do not use the entire set of references (Narin et al., 1997; p. 318). Narin et al. standardized the NPR data in several steps. [12] To a certain extent, this procedure took care of the irrelevant motives listed by Grupp and Schmoch.

However, as the discussion of previous work has shown, the kind of link a patent citation of a scientific research paper establishes is of a highly mediated nature. Authors use the term ‘science link’ in terms of a prior art and/or claim-restricting relationship. However, if proponents of this method use terms such as ‘science-dependence’ or ‘science-base’ of technology, their readers could form an overly simplistic impression of this mediated relationship. [13] Narin et al. (1997) (p. 317) refer to public science as a ‘driving force’ that stands behind high technology and economic growth. They claim to provide quantitative evidence for the direction of that force. But is it possible to establish such a relationship if one looks at individual inventions? Does science push technology?

As Narin et al. (1997) (p. 319f) point out themselves, their data measure linkages in codified knowledge only. Several writers in the literature of innovation and technical change have emphasized the importance of tacit components of technological knowledge and that information contained in scientific papers often will not suffice to implement the technology in question (David, 1993; Howells, 1996; see also, e.g., Pavitt, 1987; Rosenberg, 1990; Arora, 1991). This suggests that there are more types of linkages between science and technology. One could expect to find a multifaceted interplay between science and technology in concrete situations. If this is indeed the case, one must think about what conclusions one can draw from NPR citation data with respect to the direction of the knowledge flow.

One has to interpret Narin’s impressive data in a different manner given the complexity of the science–technology relationship. To what extent do citation linkages reflect this complex interplay? Could one still speak of the ‘old pusher science’ and science as ‘force’, or would less propulsive metaphors be more appropriate?

4. Method

4.1. Case selection

According to Yin (1994), case studies are particularly useful when complex processes are to be understood. As this study attempts to investigate the reasons for citing scientific literature and shed some light on patent practices, the case study format seems to be most appropriate. However, a study that requires interviews with actors by its nature restricts the scope and scale of an investigation. In this situation, even more attention must be paid to the selection of the patents to be examined. Assuming that there is a higher probability to find direct knowledge links in a young and strongly science-related area, this study of 10 cases investigates citations on data sheets of US patents in the emerging field of nanotechnology. Citation studies dealing with the relationship between science and technology often

[12] First, the data were categorized into different sets, such as science references, abstracts, and books. They identified roughly 242,000 out of 430,226 NPRs as science references defined as ‘‘citations to scientific journal papers, scientific meetings and other scientific publications’’ (Narin et al., 1997; p. 319). Then, Narin et al. formed another subset of the science references, containing citations to papers published in the journals of the Science Citation Index (SCI). The 175,000 SCI science references underwent further standardization and finally, authors’ addresses belonging to the remaining NPRs were linked up with public sources of financial support.

[13] Direct knowledge transfer is meant here as a direct link. Using the terms knowledge or science *link*, not to mention *science dependence*, might confuse even a specialist audience in a field related to ‘linkage bibliometrics’. When an earlier version of this paper was presented to an audience of bibliometricians, a number of them were surprised, if not ‘shocked’, to learn that the citation measure discussed was based on examiner (not applicant) references because they — exposed to linkage rhetoric — automatically assumed a direct knowledge link between the invention and the paper cited. As indicated in Section 3.1, applicant references in the disclosure might be more likely to contain attribution of earlier work.

focus on science-based technologies (e.g., Narin and Noma, 1985; Collins and Wyatt, 1988; Grupp and Schmoch, 1992; Noyons et al., 1994). 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. Collins and Wyatt (1988) (p. 68), for instance, point out that they restricted their research on citations in patents to a field that had to be ''young, rapidly growing and strongly scientific''.

As this study is of an exploratory nature, it employs broad selection criteria. In selecting the cases, Collins' and Wyatt's criteria provided a guideline for this study. The 10 cases are taken from the field of nanoscale technologies. Braun et al. (1997) describe nanoscience and nanotechnology in their bibliometric study as a young and emerging area with hardly any publishing activity in the 1980s and an exponential growth pattern observed in the 1990s. In a later study, Olle Persson and I confirmed the results by Braun et al. and found some evidence for the science-related character of the field (Meyer and Persson, 1998). More than 60% of the nanopapers we found belonged to the category of natural sciences. Just around 20% of the papers belonged to an explicit engineering discipline. [14] In the same study, we were able to identify more than 2000 patents with search terms based on our bibliometric study. If there is any direct link to be shown, one should expect to find it in a field like this, with a total production of around 5000 papers and 2000 patents.

Nanotechnology was also chosen because it constitutes more a cluster of technologies than a single technology (e.g., Budworth, 1996). The term 'nanotechnology' encompasses leading-edge developments in a number of generic technologies that are novel in nature because of the changing conditions and properties of structures at the nanometer scale. By choosing patents from this field, one can compile a selection of patents in a dynamic, novel, and strongly science-related area. Some of the patents belong to the field of nanostructured materials, others are related to opto-electronics and medicine. There are also cases at the borderline with other fields, such as biotechnology or microelectronics.

Previous studies discussed differences in citation patterns between the US and other countries. There was a lively discussion in the literature (e.g., Grupp and Schmoch, 1992) as to whether the differences observed were due to actual differences between the countries or due to language and other biases. Some studies by Narin et al. also pointed out national differences in science dependence within a defined subarea of technology. This is unlikely, and their results can be explained by the fact that the papers cited relate to US data. [15] Findings from interviews with patent experts, which are presented in Section 5, will shed more light on this issue.

This study is meant as an entrance point to studying different patent practices. The debate about whether or not the different citation patterns observed are due to differences in national innovation systems also relates to the question of different patent practices in small economies. Surprisingly, small open economies are not reflected in the studies discussed earlier. Thus, it is interesting to have a few US patents of Swedish inventors in addition to German-originated US patents. Section 5 will point to eventual differences between German and Swedish examining and patenting practices.

[14] In this study, we used data from the Science Citation Index, whose science bias is generally acknowledged. However, our bibliometric results are in line with qualitative data in other studies (e.g., Kuusi, 1994; Bachmann, 1995; Budworth, 1996; Tolles, 1996; Anttinen and Lounasmaa, 1997; Malsch, 1997) pointing out the importance of scientific developments in this field.

[15] van Vianen et al. (1990) showed a clear English language bias causing difficulties in comparing citation data between English and non-English speaking countries. Collins and Wyatt (1988) (p. 67) speak of 'national chauvinism' in applicants' as well as examiners' citation behavior. As for citations to company journals, Grupp and Schmoch (1992) point out that ''similar references to European or Japanese journals are unlikely to be cited because Americans are probably not able to understand the respective languages of the country and the sources required are not available in their card index. This argument too confirms that the above-mentioned independence of the science connection from national technology also applies there despite the contradicting results published'' (p. 92). For a discussion of the effect of different patent law formalities on patent citations, see Grupp and Schmoch (1992) (p. 92f). See also Section 5.3 for a brief discussion.

Table 2
Patent cases selected

Case	US patent no.	Invention patented	Assignee	Inventor
1	5,566,197	Tunable gain coupled laser device	Multinational company	University/PSR[a]
2	5,367,274	Quantum wave guiding switch	Multinational company	University/PSR
3	5,418,197 and 5,420,083	SiC whisker and particle reinforced ceramic cutting tool material and whisker and particle reinforced ceramic cutting tool material	Large firm	University/PSR
4	5,603,958	Pharmaceutical carriers	Foreign company	University/PSR
5	5,427,767	Nanocrystalline magnetic iron oxide particles-method for preparation and use in medical diagnostics and therapy	University-affiliated institute owned by industrial company	University/PSR
6	5,559,353	Integrated circuit structure having at least one CMOS-NAND gate and method for the manufacture thereof	Multinational company	Industrial researchers, in-house
7	5,298,760	Performance of location-selective catalytic reactions with or on the surfaces of solids in the nanometer or subnanometer range	Multinational company	Industrial researchers in-house
8	5,543,289	Methods and materials for improved high gradient magnetic separation of biological materials	Inventor who exploits patent in his firm (SME)	Industrial researchers, in-house
9	5,470,910 and 5,590,387i	Composite materials containing nanoscalar particles, process for producing and their use for optical components and method for producing metal and ceramic sintered bodies and coatings	(i) PSR; (ii) specialist affiliate of multinational company	PSR researchers, in-house
10	5,250,207 and 5,500,141	Magnetic ink concentrate	Multinational company	Industrial researchers, in-house

[a] PSR = public sector research organization.

Grupp and Schmoch (1992), in accordance with Dosi (1988), believe that the various technological fields have a much greater impact on patenting practices. Differences in citation frequencies between technological fields would not be very surprising. US and German patent studies (see e.g., Meyer-Krahmer and Schmoch, 1997) observed that pharmaceutical patents cite scientific papers much more than mechanical and automobile patents. This again is in line with the idea of different patterns of innovation as suggested by Pavitt in his technology-based classification of business firms (Pavitt, 1984; Bell and Pavitt, 1993).

One can even find indications for the notion of different, technology-specific patenting practices within companies. Preliminary research indicates that different patent practices within a firm depends on the division of the company that is applying for a patent. A researcher of a large German multi-technology firm, for instance, describes the patenting behavior of his colleagues in mechanical engineering in this manner who tend to patent processes: ‘‘They apply for a patent when they have found a new way of driving a screw into something’’ (N.N., [16] personal communication). This view makes it interesting to have a look at patents that originated in the same company, but in different technological fields. In broad areas, such as materials, there might be differences within the company even between subfields. This survey includes two patents that originated in the same company, but have applications in two different areas (cases 7 and 10).

The cases reflect the variety of inventors and assignees and the different institutional affiliations of the inventors. Individual assignee–inventors (case 9),

[16] Research manager in a large German multitechnology company.

weaker (case 4) or stronger ties (cases 1–2, 5) of external inventors to their assignees are also included. Table 2 gives an overview. Different patent practices might also exist between inventors who have a background in academic research and industrial researchers. There might be a tendency to include more science references in the specifications with academic researchers than with industrial inventors. This aspect has also played a role in the case selection.

Rabeharisoa (1992) (p. 68) remarks that the existence (or nonexistence) of patents in a field is not a trivial result since ‘‘the existence or nonexistence of patents indicates a certain structuration of the field studied’’. Following this idea and applying it to patent citations, this would mean that existence (or nonexistence) of NPR or science references is not a trivial finding, either. Thus, it is useful to include also patents that — although being in a supposedly science-based field — do not cite to scientific literature, but exclusively refer to other patents.

The selection of patents also reflects the variety of inventors and assignees. The origin of the respective inventors could play a role in their citation behavior, which might be reflected by the examiner references at least to a certain extent. University researchers might refer more frequently to papers than their counterparts in R&D labs of companies — who might be more drawn to patents, for instance. Thus, the sample includes inventors who are academics as well as industrial researchers. On the assignee side, large firms, small and medium-sized companies, as well as research institutes and individuals are included. The focus in this purposive sample is on large firms, since they not only carry out most of the R&D activities, perform and publish most of the basic research based in industry, but also maintain the closest links with academic research (Hicks, 1995; Pavitt, 1998a). Interviews with patent experts suggest that the existence of different organizational structures, e.g., the patent department, might have some impact as well. While independent inventors who are not employed by a corporation appear to be mainly interested in ‘‘showing that their invention is better than the prior art and is so clever that a patent should be granted,’’ the corporate inventors, who have this same motivation, also have been trained over the years by their attorneys to mention the closest prior art in their disclosure documents (Gary Jordan, personal communication).

Table 3
Nonpatent references and citations to patents in cases selected

Case		Nonpatent references							Citations to patents Total
		Journal articles	Books[a]	Company journals[b]	Conference proceedings	Abstract services	Others	Total	
1		1	2	–	1	–	1	6	5
2		8	1	1	2	–	–	12	11
3	5,418,197	1	–	–	–	–	–	1	7
	5,420,083	2	–	–	–	–	–	2	8
4		2	–	–	–	–	–	2	5
5		–	–	–	–	–	–	0	25
6		2	–	–	–	–	1	3	6
7		3	–	1	–	–	–	4	1
8		5	–	–	–	–	–	5	25
9	5,470,910	–	–	–	–	–	–	0	8
	5,590,387	–	–	–	–	1	2	3	13
10	5,250,207[c]	–	–	–	–	3	–	3	8
	5,500,141	–	–	–	–	–	–	0	13
Average		1.9	0.2	0.2	0.2	0.3	0.3	3.2	10.4

[a] Including advanced level textbooks.
[b] Company disclosure bulletin.
[c] Two citations to abstract services for Japanese language patents, one citation to an abstract service for chemical patents.

Table 4
Findings from the cases: science links

Science links	Indicated by NPRs?	Mentions (reported in cases . . .)
• Inventions based on general experience in research and teaching	No	5 (1–2, 4–6)
• Scientific literature important as underlying information to inventors	No	3 (3, 5, 7)
• Inventions stimulated by articles in downstream specialist journals	No	1 (2)
• Research papers as background information cited in patents	Yes	1 (7)
• Science references used to attack, restrict, or modify claims	Yes	1 (1)
• Research papers cited in special cases only	Yes	2 (4, 9)

4.2. Data collection

The focus of this work is on whether there is a direct link between a patent and scientific research papers it cites, which supposedly embody the scientific research relevant to the invention patented. One can only investigate this relationship if one talks to the inventors. Any links established by examiners or patent attorneys are not directly related to the invention process and thereby have to be viewed as a mediated connection between patents and underlying science.

The inventors were contacted to give information on the invention process, the resulting patent, and the connections their invention has to science. Specifically, they were asked to describe the background of the invention, relate the citations in the patent to their invention (if possible), and indicate what impact those references had. Furthermore, it was inquired to what extent the patent citations refer to knowledge sources that had played a role in the invention process and what other factors not indicated by the references had influenced the invention.

The inventors were contacted in a number of ways. Information on the motivational factors of citation behavior as well as on the background of the invention itself was gathered through semi-structured interviews carried out in person, by telephone and e-mail.

Table 3 summarizes the citation characteristics of the patents selected. The patents included in this survey on average contain two times more nonpatent references than the average patent in Narin's sample (3.2 NPRs per patent vs. 1.5 NPRs per patent). One could classify this selection of patents as 'science-based' in Narin's terminology. Considering the cited journal articles and conference meetings as well as the books in the patents of this survey as science references, the average rate is 2.3 science references per patent. [17] The patent cases in this survey have about the same amount of references citing to other patents as does the average patent described in (Narin et al., 1997): 10.4 references/patent vs. 10.5 references/patent.

5. The cases

5.1. Science links

The data from the cases show that there are indeed many links between science and patents. Table 4 lists the observations from the cases with regard to science links. It specifies for each science link whether it is indicated by an NPR and reports how many times this particular link has been mentioned. The numbers in parentheses refer to the individual cases, which are summarized in Appendix A. One proposition derived from the literature review was that patent citations of research papers usually establish only a highly mediated link between science and technology. The cases support this idea, even though, in many instances, inventors did say that science and scientific research papers had played a significant role with regard to their inventions. In five of 10

[17] This is much higher than the average NPR/patent rates given in (Narin et al., 1997). It is still higher than most of the 1995 average science references per patent for particular technology fields as reflected by German patents (Narin et al., 1997; p. 321). This survey includes also three out of 13 patents that do not contain any NPRs; these cases, of course, lower the NPR/patent rate and the science reference/patent relation.

cases, inventors indicated the general importance of science. They stated explicitly that their inventions are based on their general experience in research and/or teaching. The three inventors in cases 3, 5, and 7 characterized scientific research papers as important, but background information only.

Only in one of the 10 cases that one can draw an 'antecedent' cognitive link between a patent and a particular publication that has stimulated the invention patented. In case 2, 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. Case 2 is a demonstration of knowledge transfer between two technological areas that was stimulated by more downstream research news.[18] 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.

While patents actually contain NPRs, they do not reflect the cognitive contribution of a particular paper to the invention. As for reasons behind citing nonpatent literature, the interview data of this study do not contradict the motives given by Grupp and Schmoch (1992) and Schmoch (1993). Most of the patent citations in this study can be categorized accordingly.

The most direct connection between patent and a cited paper is to be found in case 7. Here, a patent that resulted from a basic research project in which a few papers were also written, one of which happened to be cited by the examiner 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 showing 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 (e.g., case 1). 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" (Campbell and Nieves, 1979; p. 963). 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 (4, 9). Here, using NPRs can be seen in context of strategic thinking ('fencing off') and the legal character of patents.

Other cases substantiate the idea of organizational influence on citations and thereby underline the notion of patent citations of research papers as a highly mediated linkage between science and technology. In the present cases, these influences are either the patent departments of large firms (cases 6, 7) or the specialized patent attorneys on behalf of high-technology SMEs who make suggestions for adding references, and thus making the patent 'water-proof' (case 8). These findings clearly confirm the idea that there is no direct, 'antecedent' relationship between cited paper and citing patent. In the cases, the scientific literature cited rarely seems to be the original source of the idea that brought about the invention.

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.

5.2. Direction of the knowledge flow

The second issue this paper deals with is the direction of the knowledge flow between science and technology. Does science really push technology? And to what extent do patent citations reflect this science-push idea?

The review of previous work in the patent citations literature has shown 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. Table 5 summarizes the observations from the cases. Inspired by Rabeharisoa's work in a different theoretical context, an attempt has been made to investigate whether it is at all possible to differentiate scientific from technological activities and actors on an individual as well as an organizational level.

[18] This supports Whitley's view that 'popularized', more downstream knowledge feeds back into research and scientists learn about fields outside their immediate research areas from more popular accounts (Whitley, 1985; see Hilgartner, 1990). This, too, is an example for mediated knowledge transfer.

Table 5
Findings from the cases: examples of science–technology interactions

Types of science–technology interaction as reported in cases	Reported in cases ...
1. Close personal science–technology linkage: individuals active both in academic research and industry (adjunct professorships of industrial researchers).	1–2
2. Doctoral candidate working in university-based corporate research institute. His work on the same subject-matter has led to both scientific results (his PhD dissertation) and technological output (the patent examined).	5
3. Public research institute is actively involved in both patenting and publishing. Not infrequently, patents and papers result from the same project.	9
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.	7

The cases were taken from a field where high science-'dependence' (in Narin's sense) could be expected. 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 (cases 1 and 2). They also point at 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. This interwovenness is much better reflected by Rip's two-branched model of innovation with its emphasis on interconnected processes of exploitation and exploration than limited linear approaches.

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, considered to be locations of scientific research or technological development? Here is where one sees the limitations of a quasi-organizational set of definitions, and the potential usefulness of a cognitive approach.

It was investigated how the inventors viewed 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' (case 8) 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 (case 10).

In addition, in the citations of this survey, there seem to be more differences between various technological fields than between the different assignee–inventor combinations. The electronics-related patents have a higher level of nonpatent references than do the materials-related patents investigated. Different technological fields have different citation patterns. A good illustration of this idea is given in cases 7 and 10. Both cases include patents that originated in the same company. Both inventions were developed at the same site, but in different technological areas. While the first case relies also on NPRs, the other case exclusively reports on citations of other patent documents. If one looks not only at the 'other references', but also at the citations to other patents, one finds at least one strong variation in the citation rate. The biotech-related patent (case 8) was a clear outlier with 25 references to other patents.

5.3. National differences in examining and patenting practices

'Linkage bibliometricians' look at statistical aggregates, not at single cases. If one wants to make the case that there are no direct links between cited publications and citing patent, one has to explain how other prior work can establish a within-country connection between science and technology (Narin et al., 1995, 1997), and in particular, one has to address how other authors could observe local proximity between citing and cited patents (Jaffe et al., 1993). [19] This section will address the within-country link at first and then deal with the local proximity observation.

As for the within-country connections between patents and the scientific articles they cite, an interesting observation is the strong variations in citation frequencies between highly industrialized countries in the same technological field (e.g., see Narin, 1994). If there was a direct link, one could assume that a certain technology is more dependent on science in one country than in another. The idea of a highly mediated linkage would suggest that there are other explanations for the observed differences in citation frequencies.

This study encompasses European-originated US patents only. However, different countries have different patent systems. [20] National patent practices matter even if one looks at US patents only, since most attorneys prepare a first application in the home country and then file that same disclosure in multiple countries within 12 months under the Paris Convention on patents priority (Gary Jordan, personal communication). A number of interviews with patent experts suggest that nationally different patenting practices might affect citation frequencies measured (Kristiina Grönlund, [21] Gary Jordan, Leif Karlsson, [22] Hans-Hermann Zitt, [23] personal communications).

Higher citation frequencies in US-originated patents as compared to European-originated ones might be a consequence of the way how patent applications are examined generally. In Germany, for instance, at first the main claim is examined (Rainer Bertram and Hans-Hermann Zitt, personal communications). The dependent claims are rather briefly examined, mostly with one or two prior art documents disclosing the respective features. Many times, the dependent claims are objected to without a detailed reasoning why these claims were patentable or not (Rainer Bertram, personal communication).

Regarding the examination at the European Patent Office, the main claim and the dependent claims are examined, but ''we try to have one single claim that functions as an umbrella'' (Leif Karlsson, personal communication). The examining practice is rather similar to the German one. Most important is that the main claim meets the three criteria for granting a patent — novelty, nonobviousness, and industrial applicability (Rainer Bertram, personal communication).

By contrast, in the US, all claims — including dependent claims — are examined (Leif Karlsson and Hans-Hermann Zitt, personal communications). The US examiners are obliged to examine each claim thoroughly and to provide a detailed reasoning about patentability of each claim in the first Official Action (Rainer Bertram, personal communication).

However, the most important reason for different citation frequencies in US-originated and European-originated patents is the so-called 'duty of disclosure' in the US. In Europe, it is up to the applicant to

[19] I would like to thank one of my referees for this annotation. It has initiated another set of interviews, which has just further confirmed my strong opinion about the mediated nature of citation linkages.

[20] This section chiefly reports on differences between US and European patent practices, since this study deals with US patents of European inventors. The situation in Japan is so different. A corporate researcher there is required to deliver one to two inventions per month. To meet these targets, Japanese inventors have to submit patent applications that would not qualify for granting patents elsewhere. According to a German patent examiner, ''60% of the new patent applications would not be granted in Germany'' (Hans-Hermann Zitt, personal communication).

[21] Head of Consulting, PRH National Board of Patents and Registration, Helsinki, Finland.

[22] Patent attorney, Groth and Company, Stockholm, Sweden.

[23] Deutsches Patemtamt — German Patent Office, Munich, Germany.

introduce prior art known to him in the examination procedure or to refrain from doing so (Kristiina Grönlund, personal communication). By contrast, US law stipulates that the applicant has to cite any prior documents known to him to the USPTO as long as the application is under examination. Noncompliance with this requirement is considered as fraud by the USPTO and can be used as a grounds for invalidating the patent (Rainer Bertram, personal communication). To practitioners, ''it is only logical that this leads to different practices how patent attorneys prepare the applications'' (Rainer Bertram, personal communication). Therefore, this difference can be seen as one chief reason why citation frequencies in US-originated patents are higher than in European-originated ones (Leif Karlsson, personal communication). A good illustration of this observation is case 8, an invention that was German-originated, but whose patent application was handled by US-based specialist patent attorneys from the beginning. With 25 references to other patents (plus five NPRs), it is the clear outlier in this survey.[24] One US patent attorney reports:

> Some years ago, we used to talk about 'continental-practice' type disclosures when dealing with European origin patents. Specifications (the disclosure portion of the patents) written in the 'continental' style were much shorter than those in the strictly U.S. style. The European patent attorneys seemed to be writing the specifications in a very pointed manner to a single new technical point. Most of these specifications did not have citations of literature at all, but when that was done it was only one or two references. The U.S. practice has been to write much more detailed specifications and this usually meant commenting on 5 or 6 pieces of prior art (Gary Jordan, personal communication).

Drawing a comparison between US and continental (especially German) patent practices, one of the patent experts states:

> the U.S. was regarded as a much tougher legal environment. There had to be as much background information as reasonably possible to convince the patent examiner that the prior art was studied closely before filing the application, there were very good distinctions between the claims drawn and the prior art disclosures, and in the event of future litigation there would be good, meaningful distinctions that could be relied upon in a legal battle (Gary Jordan, personal communication).

For patent-to-paper citations, a localized pattern of citations to papers probably means that problem solvers 'enter' world science through local scientists. Using patent citations, Schild (no date), however, cannot observe such a pattern in her study of inventiveness in the Swedish region of East Gothia.[25] This leads to the question of how to interpret highly aggregated statistical regularities with regard to single regions. The most likely explanation might be found in national examining practice.[26]

Swedish patent examiners prefer to cite a corresponding English-language patent to a Swedish or other-language patent because of a potential later disclosure in multiple countries. Anticipating that a Swedish applicant might wish to file the Swedish

[24] This patent happens to be the only one in this study that was processed by US specialists from the beginning.

[25] Inspired by the work of Jaffe et al., Schild used a similar method to study the impact an individual university has on the region. The idea was ''to identify the degree to which Linköping University research was cited in East Gothia'' (Schild, no date; p. 38). For the 1996 set of East Gothia patents, she identified 106 citations (including NPRs) and 163 cited patent inventors. But only seven of the 163 cited inventors had addresses in Sweden, and of these, only one had an East Gothia address. Most of the citations were to US inventors, with Japan and Germany trailing behind the US.

[26] Another possible explanation could be based on data presented in the Second European Report on Science and Technology Indicators (European Commission, 1997) (Chap. 7, in particular, p. 359ff). The report suggests distinct differences in science, technology, and innovation variables between regions. Referring to the Boston Consulting Group product mix matrix, the report distinguishes between sleeping birds[!], question marks or wild cats, cash cows, and stars amongst the regions in Europe. This would explain the difference in findings, assuming East Gothia is a region with a low science, technology, and innovation profile. However, this assumption is problematic given the nonpatent citation data compiled by Schild (no date) and the fact that the fastest growing science park in Europe is situated in this region.

disclosure in multiple countries, Swedish patent examiners prefer to cite an English-language patent to a Swedish or other-language patent. Only if they have to choose between a Swedish or other non-English language reference, would they prefer the Swedish reference (Leif Karlsson, personal communication). This is different in Germany though. Here, the examiner prefers to cite German-language documents (Rainer Bertram, personal communication). Provided this is the cause for the different results (no local citations in the Swedish study, local proximity in the US research), one could interpret this as a further demonstration of the mediated character of the link patent citations established between science and technology. [27]

6. Discussion

The evidence collected in the study supports the view that there is a general connection between science and technology, but it points out that citation linkages hardly represent a direct link between cited paper and citing patent. This general conclusion does not imply that scientific activities would not be of importance to technological development. The cases show the opposite. Scientific findings are important background knowledge playing an important indirect rather than direct role. The inventors interviewed pointed out that their inventions were often based on general experience in research and teaching. General experience can be seen as one component of tacit knowledge, which is conveyed chiefly through personal interaction in a scientific and/or technological environment. In science-related fields, the ability to absorb tacit knowledge seems to be linked to a certain degree of scientific education. Most of the inventors interviewed had some kind of researcher training. This underlines how important scientific training is for inventive activity in certain fields. Some of the inventors in this survey have intermediary positions between science and technology in the sense that they are employed and financed by an industrial enterprise and have an academic position in the university system. This also emphasizes the significance scientific activities have in supplying human capital. In this context, the cases support prior work by Narin et al., suggesting that patent citations to scientific literature are a general indicator of science-relation of a field legitimizing basic research activities. Patent citations do reflect the degree to which papers are part of the technological state-of-the-art. However, it should be borne in mind that by enumerating publishing and patenting activities, patent citation studies capture just one aspect of knowledge, namely what Nelson (1998) calls the ‘body of understanding’. They do not reflect knowledge about the ‘body of practice’, which is related to the design, development, production, marketing, and use of a particular product model or a specific product line (see also Pavitt, 1998b).

As pointed out earlier, Narin et al. appear to have a basically linear understanding of the innovation process, postulating ‘science dependence’ of certain technologies (Carpenter and Narin, 1983). The cases have shown how to interpret this kind of terminology by pointing to the increasingly intertwined relationship between scientific and technological activities. As some of the cases presented here have shown, technology can drive science, too. Some of the cases have shown that technological developments as indicated by patents take place before their scientific rationalization as indicated by research papers. This is better reflected by the two-branched model of Rip presented earlier, which stresses more the interplay between the ‘scientific’ exploration branch and the ‘technological’ exploitation branch, allowing also for a post-rationalization of technological results by scientific scrutiny and technology setting the research agenda of science. Maybe, it would be more sensible to use another, less ‘pushy’ term to advertise or describe the nature of a citation link. Schmoch (1993) (p. 193) used the phrase ‘science–technology interaction’ which appears to be a much better description of the actual relationship.

‘Linkage bibliometricians’ look at statistical aggregates, not at single cases. Of course, the 10 cases presented here are just an entrance point and by no means sufficient to show any overall effects. However, the interviews with patent experts illustrate the mediated character of the connection yet another

[27] Furthermore, one should note differences even within Europe. The patent offices in Italy, France, and Switzerland are nonexamining and, therefore, provide registration only. Examination was carried out just for certain fields, such as textiles and clock works. Nowadays, there is no examination in these fields anymore, either.

time. They indicate that nationally different patenting practices are a major reason for differences in citation frequencies between countries. The interviews also provide a possible explanation as to why patent citation studies indicate local proximity of citations in one country and not in another (no local citations in the Swedish study, local proximity in the US research). Again, nationally different examining practice is an explanation. One could interpret this as a further demonstration of the mediated character of the link patent citations establish between science and technology. It also shows once more that one should be extremely careful in applying these indicators. The nonexistence of references in patent documents citing 'local' research papers should not be misinterpreted as an illustration of the nonexistence of a link between local science and technology. [28]

7. Conclusions

The cases are consistent with previous work characterizing (or at least implying) patent citation links to scientific literature as being of a highly mediated nature. The cases also show that the citation links do not indicate science-dependence of technology, but should be taken as an indication of the multifaceted interplay between science and technology. This implies that one should not use the linear model to interpret patent citation data. However, such an interpretation does not invalidate the method of patent citation analysis as a policy tool. Policy-makers can still use this method to illustrate the science-relation of technological fields and have a mediated justification for basic research expenditure in certain fields. However, there are many and perhaps better justifications for public funding of basic research (see e.g., Martin and Salter, 1996; Pavitt, 1998a). Patent citation analysis as a policy tool might have more useful applications than an ex-post justification of publicly funded basic research. Its focus should be changed.

Patent citations of NPRs or science references and their frequencies can (at least indirectly) indicate varying intensities of interrelation between science and technology, different from area to area. In some fields, it is stronger (more citations of publications per patent), in other fields, weaker (fewer). This would argue for sector-specific technology transfer policies. Different fields have a different nature of interaction. This might result in different forms of exchange and may require different transfer mechanisms. In combination with other methods, citation analysis may give some hints as to what requirements such a mechanism has to meet in a certain science–technology field. As it also points to fields in which there is little interaction between science and technology, it may induce further investigations as to whether more exchange between academic and industrial research could enhance the further development of a technology.

What one should not do with this method is to make comparisons and draw conclusions about the effectiveness and efficiency of knowledge transfer amongst fields. Even from the limited number of cases presented here, it is possible to see indications for different patterns of citation frequencies according to fields. Other studies confirm this on a broader empirical basis (e.g., Meyer-Krahmer and Schmoch, 1997). In addition, one must bear in mind that not all 'technology' is patented. Software, for instance, has been a field with little patenting. Sectoral trends, such as 'know-how' and 'speed to market' as the preferred method of attaining competitive advantage, may distort a comparison.

Future research should therefore focus on further developing a more enlightened interpretation of patent citations and take the limitations of the data more into account. In addition, future research should concentrate on how to utilize patent citations analy-

[28] Beware also of similar misinterpretations with regard to 'foreign dependence' of technologies. The data from the patent expert interviews indicate that at least in the case of Sweden, patent citations would suggest that technology patented is more foreign-dependent than it actually is due to the aforementioned tendency of patent examiners to prefer corresponding English-language patents to Swedish ones. This finding contradicts to some extent Collins and Wyatt who accuse applicants and examiners of national chauvinism (see [11]). However, Collins and Wyatt have not dealt with patents that originated in Sweden. While the author would not be prepared to deny categorically the existence (or possibility) of Swedish national chauvinism, it has to be said that there is no evidence of it in Swedish patenting practice. To the contrary, Sweden's patenting practice is remarkably cosmopolitan. As there is not such a tendency in Germany, one might speculate whether this situation is a result of Sweden's small country position.

sis — in spite of its mediated nature — as a tool of strategic science and technology policy planning.

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Appendix A. Case summaries

A.1. Case 1: US patent no. 5,566,197 — tunable gain coupled laser device

The basic idea of this patent is to use quantum dot or quantum wire structures to prevent carrier diffusion and enhance gain. According to Olle Nilsson, the inventor, the properties used in the device patented have been well known to specialists for many years. *The inventor stresses the importance of tacit knowledge for this invention* [29] when he says this invention is based on the general knowledge he had acquired in this field by doing research and by teaching for many years. This included reading the scientific literature, visiting conferences, etc. This description by the inventor underlines the idea that scientific activities are important in terms of inventive activity. However, the references Nilsson cited do not reflect the major inputs to the invention at all. As for the patents cited, the inventor was unaware of them during the process of invention. *As he explains, citations are more the result of the examination procedure than they reflect the origin of the invention, as pointed out in the background section.* ''They came up in the screening process for the patent application and imposed limits on what could be included in the application.''

Olle Nilsson's patent has six NPRs. He divides them into three different groups according to type of publication and purpose of the citation: (1) advanced level textbooks: their purpose is to support his description of the general field; (2) journal articles, conference and departmental working papers: Nilsson used them to support his suggestion to use certain, well-known quantum phenomena for carrier diffusion prevention (The inventor knows the authors of the cited papers, but has never collaborated with them.); (3) NPR of restricting character found during the prosecution: it describes a similar pumping and tuning system for dye lasers. Here, no diffusion problem exists. According to the inventor, he was unaware of this when he got his idea to use a similar scheme for waveguide semiconductor lasers.

Nilsson chooses a reference to make writing his patent application easier, i.e., he looks for the most appropriate references to distinguish his claims from

[29] Case studies often rely on interview data. This study is no exception. This section reports on the history of the inventions as seen by the inventors. However, sometimes, it seems appropriate to insert explaining or interpretative remarks. In order to distinguish between reported account by the inventor and interpretation by the author of this paper, *italics* indicate those parts in this section that go beyond a mere depiction of the inventor's views and experiences.

'prior art'. *This indicates that describing the cognitive origins of his invention is hardly reflected in the citations looked at*.

A.2. Case 2: US patent no. 5,367,274 — quantum wave guiding switch

Lars Thylén, the inventor, got the idea leading to this patent during his summer vacation while he was reading an article on waveguides in *Physics Today*, a journal for physicists. He realized that there were similarities to what he was doing in optics. ''I had a look at it just for fun,'' says Thylén nowadays. ''I knew the problems of classical switches.'' The invention patented is basically a transfer of knowledge from one technological area to another. To see what has been published, Thylén did some literature research. He also compiled a number of patents.

He considers papers more important than patents in terms of input to the invention. Thylén remembers just one of the patents cited and this only because it was incoherent. He simply believed what these researchers patented would never work. One reason for this is the motive that inventors have for using references to patent documents, namely to support the inventor's claims for novelty and uniqueness of the invention. In other words, they are citing patents to justify claims. The patents cited, however, ''did not really influence the work we really did''.

Apart from 11 patent documents, Thylén cites 12 NPRs: nine journal articles, two conference papers, and one book. The inventor is acquainted with four of the cited authors. With two of them (Dagli and Datta), there has been a history of cooperation. In the inventor's view, one of the journal articles and the conference paper had given some input to the invention. Thylén found some early references in an article authored by a collaborator, who also functioned as an external examiner. The other paper that contributed some input to the invention was presented by another collaborator. The other authors Thylén cited (Petroff and Sakaki) were known from conferences. According to the inventor, in general, he cited papers to give an appropriate background and to verify his claims. Sometimes the inventor was not able to recognize the other authors and papers in detail anymore.

A.3. Cases 1 and 2: Inventors' history

Thylén and Nilsson know each other. There has been a long history of cooperation and collaboration. As a professor, Thylén has been with the Department of Electronics at KTH — the Royal Institute of Technology in Stockholm — since 1992. Prior to this, he was with Ericsson, the Swedish telecom company, working in the area of optics — in particular, fibre-optic components, digital electronics, and wave guiding. He decided to leave Ericsson after 20 years for KTH, where he was an adjunct professor.

Nilsson is an adjunct professor with the Electrical Engineering Department at CTH — Chalmers Technical University in Gothenburg — as well as at Thylén's department. He was Thylén's predecessor in the professorship before he went to Ericsson.

This brief personal background does not tell anything about how the ideas for both inventions as such were formed and materialized, but it sheds some light on the personal knowledge transfer that has taken place between two academic research institutions — CTH and KTH — and Ericsson. If one is more interested in actual knowledge transfer, looking at assignee–inventor links seems to be a better choice than tracing back citation linkages.

The two cases are also a good example for how difficult it is to distinguish between scientific and technological activities. Both of the inventors interviewed were in so-called adjunct professorship positions. An adjunct professor here means a researcher employed by a corporate R&D organization who spends a considerable amount of time, usually 20%, sometimes 50%, working and teaching at a university department. For this case, it is hard to tell what was science and what was technology.

A.4. Case 3: US patents no. 5,418,197 and 5,420,083 — SiC whisker and particle reinforced ceramic cutting tool material and whisker and particle reinforced ceramic cutting tool material

Both patents deal with whisker and nanosize particle reinforced ceramic cutting tools. The difference between both patents is the use of SiC in one of them. Both patents contain citations of patents as well as of the scientific literature. The patents have five citations of patents and one NPR in common. The general patent contains three further references to patents and another citation of a basic research paper, while the SiC patent has two additional patent references. However, the different patents and papers did not really affect the process of invention.

''The patents are the result of my experience in this field,'' says Gunnar Brandt, the inventor. He works in the R&D department of Sandvik, the Swedish materials company. He has been involved in research on nanowhisker and particle ceramics since the beginning of the 1990s. Though he knows some of the authors and inventors, it is his own prior work that stimulated the invention, *which illustrates the importance of tacit knowledge in the invention process*. His own patents that are cited belong to a related field. ''The inventions have simply grown out of what I was doing then,'' explains Gunnar Brandt. He also states that scientific activities of academic institutions are important: ''We look at what the universities are doing''. Despite the significance of the scientific activities as reflected in research papers, the papers cited do not reflect any input into the invention. He says, ''I found them during my work in this project to compare my invention to what used to be state-of-the-art then''.

A.5. Case 4: US patent no. 5,603,958 — pharmaceutical carriers

This patent deals with the use of a special drug-carrying nanoparticle. The patent cites three patent documents and two articles. *In this particular case, the patent citations could be seen as indicators of familiarity and collaboration*. Two of the cited patents are from inventors known to Bror Morein, one of the two inventors. All of the scientific research papers are by authors Morein knows. One of them is written by his co-inventor, who works in the same lab. The paper by his co-inventor resulted from the same project that led to this patent. The article gives a general overview about the various lipid components involved, while the other paper describes in a more detailed manner the chemistry of certain components important to the invention. The main purpose for citing articles as well as papers was to give an overview of the state-of-the-art in this particular area. *Scientific literature does play a role in this respect. It has the function to support the novelty claim of the patent by describing prior art. However, the importance of NPRs varies from field to field*. Says Morein, ''we are not closely following the drug delivery literature. Therefore, we look more closely at the vaccine papers''. *Here, we actually find a certain kind of relatedness between patent and cited literature. The relationship established by citation indicates personal and subject-related familiarity*.

The patent is completely based on intra-mural research. ''All the work was done in my lab,'' Morein says. Though Morein, based with his group at the Agricultural University of Sweden, is exploiting the patent, the assignee is a UK company — the British Technology Group (BTG). BTG is a company originally founded to take care of UK university-generated inventions. Now they are operating worldwide. With 310 US patents assigned to them, ''they are the leader''. BTG also collaborates with Morein's group in other related fields, namely vaccines. ''They have a broader customer base for carrier systems, and so we let them exploit the patents.''

This case illustrates an interesting situation a small country might face. A leading research group in an advanced field does not seem to have a potent commercial counterpart within the country and feels itself forced to collaborate with a foreign firm. As linkage bibliometric research often neglects small open economies in its coverage, it would be of interest to find out whether there is a higher tendency of small country-originated patents to be assigned to foreign multinational companies.

A.6. Case 5: US patent no. 5,427,767 — nanocrystalline magnetic iron oxyde particles-method for preparation and use in medical diagnostics and therapy

The applicant of the patent is the 'Institut für Diagnostikforschung' (IDF). IDF is a basic research institute funded by Schering, a leading pharmaceutical company in the contrast media market, and since 1990, a so-called An-Institut of the Freie Universität Berlin. The patent is about a method for preparation and use of nanocrystalline magnetic iron oxide particles in medical diagnostics and therapy. The patent contains 25 references citing to other patent documents. There are no citations to the scientific research literature. According to Kresse, there are many scientific research papers as well as patents in this field. In particular, he has more than 600 patents in a personal database. Asked why the patent does not contain any citations to the literature, he pointed out that in this case, the recommended presentation of 'prior art' is most efficiently done by referring to the patents only. ''The patents are already covering the enormous number of scientific publications. This is due to the fact that, although the field is science-based, most of the research is done by companies. Nevertheless, scientific research papers give valuable hints in special cases.''

Kresse divided the cited patents into three classes: (1) standard patents that show the novelty of the invention by referring to prior art, (2) patents of collaborators, and (3) patents of competitors. Eight of the 16 patents belong to the first group of patents, while the remaining eight actually list inventors whom Kresse could identify either as collaborators or as competitors. There are also exchanges of information with competing researchers. Those usually take place at conferences. There, one is informed by others about what they write and publish or patent. Collaborations naturally go further. However, in this particular case, they have not had an effect on the invention. ''On the contrary,'' says Kresse, ''this patent is a real in-house product, where the underlying research work is done by PhD students. Thus, this patent is a good example of a side-line of in-house research.''

This case indicates the tacit knowledge transfer taking place in (post)graduate education between industrial sector and academia. It is indeed a good demonstration for university–industry collaboration. However, it is not to be detected by NPR citation measures. Another problem here seems to be the location of distinct spheres of 'science' and 'technology'. IDF is a university institute, but it is financed by and affiliated to a business firm. It is difficult to draw the line between scientific research and technological development.

A.7. Case 6: US patent no. 5,559,353 — integrated circuit structure having at least one CMOS-NAND gate and method for the manufacture thereof

This patent describes a novel three-dimensional arrangement of MOS transistors leading to higher density. The patent also includes a manufacturing method of the circuit structure by the epitaxal definition of the layer sequences. It resulted from in-house research of Siemens, the German electronic engineering company. According to Franz Hofmann, one of the four inventors, the invention did not involve researchers outside the nanoelectronics group at Siemens Research Center in Munich. The patent contains six references to other patent documents and three NPRs. In this particular case, the various citations document the collaboration of Siemens' researchers and patent specialists.

''When we had the idea for this patent, we went to our patent specialists,'' Hofmann says. Together they wrote the patent application. The patent department did some research to find both patents as well as publications related to the invention. As the inventor explains, the aim was to find examples for the prior state of technology and thereby document the novelty of the invention. According to Franz Hofmann, all of the references to other patents and two of the three citations to scientific research papers were found by the patent specialists and are not related to the invention process. The last reference cites an author who was personally known to the group. However, the invention has been made on the basis of general knowledge and experience and is not so much due to particular inputs of external scientists.

This case illustrates the legal function of patent citation as discussed in earlier sections of the paper. References are cited to meet the special criterion of novelty. An interesting finding is furthermore the strong role the patent department seems to play. This underlines the social nature of the patenting process and shows how important the interaction between inventors and patent specialists are. The case also demonstrates how important local collaboration in R&D is — 'local' here understood as 'in-house' rather than 'extra-mural, but nearby'.

A.8. Case 7: US patent no. 5,298,760 — performance of location-selective catalytic reactions with or on the surfaces of solids in the nanometer or subnanometer range

This patent is about a chemical surface modification in the nanometer and subnanometer range by means of scanning-probe microscopy. The process is used for information storage. Harald Fuchs, nowadays professor at the 'Physikalisches Institut' in

Münster, Germany, is one of the two inventors. He was then working at BASF. His co-inventor was his assistant at that time. The patent resulted from a basic research project at BASF. It was part of the company's contribution to the 'Ultrathin Films Program' of the BMBF, the German Federal Ministry for Education and Sciences, Research and Technology.

The patent contains one reference to a patent document. There are four further references listed, three of which are scientific research papers. The remaining reference is to a technical disclosure bulletin of another company. Only one of the research papers documents a direct contact to another researcher at BASF. Fuchs holds some other patents and has co-authored a number of articles together with his co-inventing colleague. Fuchs agrees that the citations to scientific research papers document the basic research character of his project at the time it was undertaken. However, the citations themselves were the result of literature and database research done afterwards and independently of the original invention. In Fuchs' view, ''the vision for this invention was the result of my own work. I just had to substantialize and calibrate it against the state-of-the-art.''

This case shows a direct link insofar as science and technology 'happened' in the same project, which is illustrated in a science citation. Here, scientific papers and patented technology resulted from the same effort. Again, this case illustrates the close embrace of science and technology. The same researchers delivered papers as well as technological results. But despite the very close and direct link, citation links do not seem to reflect the cognitive origin of the invention.

A.9. Case 8: US patent no. 5,543,289 — methods and materials for improved high gradient magnetic separation of biological materials

This patent discloses improvements in procedures and materials for high gradient magnetic separation (HGMS) of biological materials. It also contains a method to conduct HGMS. The patent cites 25 US and two other patents. Five papers are cited. As Stefan Miltenyi, the inventor, explains, the usually large number of US patents cited is due to the US patent law that makes it possible to proceed against patents and their claims at any time. ''Everything that could be somehow relevant needs to be included.''

This case also illustrates the influence different areas of technology have on patenting. Miltenyi commissions Californian lawyers to take care of his patenting activities. ''They are specialized into biotechnology.'' The lawyers themselves add references to make the application 'water-proof'. The references cited do not indicate direct input into the invention. They are primarily there to relate the invention to prior art. In this particular field, as much as possible is patented. ''People patent before they publish, if they do so at all.''

This case illustrates the influence special fields can have on patenting. This case is undoubtedly taken from a highly science-based field, and yet our inventor's observation is that with respect to publication and patenting, it shows a reverse chronological pattern. One of the reasons for this particular practice can be seen in the legal implications, as Cambrosio et al. (1990) pointed out. While in other fields, small and medium-sized companies or individual inventors file not infrequently themselves, biotech SMEs seem to rely on specialist patent attorneys. The much higher patent citations may also reflect the different examination practices between Europe and the US. In this case, a German inventor commissioned US patent attorneys instead of contacting German attorneys first and then filing a disclosure in multiple countries, including the US. The much tougher legal situation in both the technological field (biotech) and the country (US) might have had an amplifying effect in terms of patent references.

A.10. Case 9: US patent no. 5,470,910 and 5,590,387 — composite materials containing nanoscalar particles, process for producing and their use for optical components and method for producing metal and ceramic sintered bodies and coatings

Both patents deal with nanostructured materials and their production. While the first patent (5,470,910) discloses special composite materials containing nanoparticles, their fabrication as well as their use for optical components, the latter one is a process patent describing a way of producing metal and ceramic sintered bodies and coatings using nanocrystalline metal or ceramic powder. The first patent exclusively lists references to patents (five references to US patents, three to other patents). The second one also contains 13 patents. It also lists three 'other references'. But even they are related to patents. Patent abstracts, the related Japanese patent itself and a search report of the European Patent Office are included. There are no references to scientific research papers in either one of the two patents. ''This depends on the orientation of the respective research establishment that carries out research on a certain topic,'' says inventor Rüdiger Nass of INM, the Institute of New Materials in Saarbrücken, Germany. According to Nass, applied research — as it is done at INM — is naturally more patent-oriented than university-based research. *Who exploits the inventions patented does not seem to have any impact in this case*. Nass did not point out any differences between the two patents, one of which is assigned to an affiliate of a multinational chemical company, while the other patent is exploited by INM itself, with regard to patenting and citation.

According to Nass, there are basically two categories of citations in patents: (1) citations of patents and papers made by the inventors themselves, and (2) citations due to the examination process. *Furthermore, Nass describes the strategic nature of patents and patent citations by distinguishing two different types of patents*: (1) one works in a certain field and has designed something new, an invention in its original sense — something which has never been made before. In this case, the inventor would not be familiar with the relevant patent literature. He or she would search for related patents after the invention was made. However, patents of this kind occur relatively seldom. (2) More likely is a situation in which the inventor is facing a concrete problem. To solve it, he or she has to know how to evade and avoid existing patents. This, however, requires a rather intimate knowledge of related patents. One has to consider what there is of available literature. Scientific research papers become relevant only when one has to deal with special cases.

A.11. Case 10: US patents no. 5,500,141 and 5,250,207 — magnetic ink concentrate

BASF, one of the large German chemical companies, holds a number of patents in the field of nanostructured materials. Here, I look at a patent (and its continuation) for a magnetic ink concentrate and a process for its preparation. Claudius Kormann, one of the inventors, was given the task to ''make something new out of a 50-year-old area''. The patents are the result of in-house cooperation. Apart from Kormann's superior, the other inventors were members of a different department. They gave valuable input from the application side of superparamagnetic solid particles.

The original patent contains 14 references to other patents. Furthermore, it refers to three NPRs, namely patent and scientific abstracts. The main purpose of the cited patents and abstracts is — not surprisingly — to document the state-of-the-art. Most of the documents referred to were not known to the inventor previously. One of them, however, does illustrate in-house cooperation. Kormann knew about this particular patent since it belonged to the colleagues he collaborated with.

Looking at both patents, the original one and its continuation, show other reasons for which patents and papers are cited. The continuation of the original patent contains two further citations to US patents. They were included because they restrict the original claims made in the older patent. Referring to the 'A–X–Y' classification of the European Patent Office, Kormann says, basically ''there are two kinds of patents: those which summarize prior developments in fields related to the invention, and those which make inventors modify their claims''. Patents also contain references that were found by the patent examiner. They are included to specify the claims and avoid misunderstandings.

According to Kormann, citations made in patents to scientific literature do not reflect any input of basic research related to the invention. The case is quite the opposite. ''Patents in very advanced and modern fields usually do not contain references to scientific research papers.'' *Despite a time lag in patenting of about 18 months,* it is science that is lagging behind.

This case shows again the peculiarity of technical fields by pointing out that technology can guide science in certain areas: first, invention, then scientific rationalization. Another finding one can draw from the case is that differences in sciento-technological practice occur within the firm (see case 7 that follows a different pattern).

From what was reported by one of the inventors, one can see some potential a co-inventor analysis would hold. The list of co-inventors illustrates the collaborative efforts between different aspects (and representatives) of technology that were necessary to achieve the inventive result. Another issue then is the question to what extent one could trace back the co-inventor affiliation down to an intra-organizational level, such as departments.

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