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Sources of inspiration? Making sense of scientific references in patents

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Abstract Scientific references in patent documents can be used as indicators signaling science-technology interactions. Whether they reflect a direct 'knowledge flow' from science to technology is subject of debate. Based on 33 interviews with inventors at Belgian firms and knowledge-generating institutes active in nanotechnology, biotechnology and life sciences, we analyze the extent to which scientific references in patents reflect sources of inspiration. Our results indicate that scientific knowledge acts as a source of inspiration for about 50 % of the inventions. At the same time, the scientific references cited in patent documents and available in patent databases do not provide an accurate picture in this respect: 30 % of patents that were inspired by scientific knowledge do not contain any scientific references. Moreover, if scientific references are present, half of them are evaluated as unimportant or background information by the inventor. Overall, these observations provide evidence that scientific references in patent documents signal relatedness with the implied inventions without necessarily implying a direct, inspirational, knowledge flow between both activity realms.

Keywords Non-patent references · Indicators · Science-technology interaction · Inventor interviews

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Introduction

Basic science contributes to economic growth (Jaffe 1989; Adams 1990) as spillovers can arise from academic research towards private R&D activities (Acs et al. 1992; Mansfield 1995; Cohen et al. 2002). Interactions between firms and scientific actors manifest themselves in multiple ways, including university-industry collaboration and contracting (e.g. Zucker et al. 2002), industry financing of university research (OECD 2006), university spin-offs and licensing activity (Thursby et al. 2001), and mobility of university researchers (Kim et al. 2005). Science-technology interactions have been studied through indicators based on larger datasets of patents, publications, and the implied references: patenting by knowledge generating institutes (universities and research centers), scientific publications by firms, co-application and co-authorship between firms and knowledge-generating institutes of respectively patents and scientific publications, and the citation of scientific literature in patents (or vice versa).

This paper focuses on the interpretation of scientific non-patent references (SNPRs), i.e. references to the scientific literature, cited as prior art in patent documents. These are often conceptualized as reflecting knowledge flows between scientific and technological actors. The number of citations to academic literature in industrial patents in the United States has grown threefold around the mid-nineties (Narin et al. 1997; Van Looy et al. 2007), which is held indicative of growing industry-science interactions over time (Narin et al. 1997; Hicks et al. 2001). Along with the increased recognition of the importance of these interactions for innovation, this has inspired the further development of NPR-based indicators. Examples include the development of science-technology concordance schemes (Tijssen et al. 2000; Verbeek et al. 2002) which allow for analyzing science-technology relations over space and time[1] and for addressing the relation between science-technology interactions and innovative performance, at the level of patents (Cassiman et al. 2008; Fleming and Sorensen 2004; Harhoff et al. 1999), firms (Cassiman et al. 2010; Nagaoka 2007; Subramanian and Soh 2010) and (national) innovation systems (Van Looy et al. 2003, 2007).

At the same time, what scientific NPRs actually reflect- and whether their use for the measurement of science-technology interactions is valid—remains debated. In this regard, some insights from studies about patent-to-patent citations are noteworthy. Trajtenberg (1990) states that patent-to-patent citations reflect spillovers and pathways of innovative trajectories, where downstream patents cite those upstream patents on which they build. He concludes that "citing patents would bear a sort of causal relationship to the cited patent, with citations being the overt manifestation of such a link" (Trajtenberg 1990 p. 185). Likewise, Jaffe et al. (1993 p. 578) argue that "knowledge flows do sometimes leave a paper trail, in the form of citations in patents". Thus, a citation between two patents means that the cited patent represents a piece of previously existing knowledge upon which the citing patent builds. A survey of inventors later verified that the likelihood of actual knowledge spillovers is significantly higher if there is a citation (Jaffe et al. 2000), leading to the conclusion that patent citations signal spillovers and can be used to track knowledge flows. However, Jaffe et al. (1993) also signal issues concerning the validity of interpreting patent citations as knowledge spillovers. Not all spillovers are captured in citations, as the majority of research output is never patented[2]; and not all citations represent spillovers.

[1] For some applications, see e.g. Guan & He (2007), Lo (2010), Ribeiro et al. (2010) and Tijssen (2000, 2001).

[2] By including the scientific non-patent references, this issue can at least partly be addressed.

The authors also warn about differences in citation practice between patents and scientific literature: citations in patents are meant to serve legal purposes, and are the result of a search for and selection of prior art by the examiner, not by the inventor (see also Tijssen et al. 2000). This means that there might be citations referring to documents of which the inventor was not aware, leading to overly optimistic interpretations of patent citations as reflections of direct knowledge spillovers (see also Alcacer and Gittelman 2006; Breschi and Lissoni 2001). Much of the caveats related to the interpretation of citation-based patent indicators stem from ignored differences between the function of references in the scientific literature versus the function of references in patents. References in the scientific literature are added by the author during his/her research, and serve to indicate and acknowledge existing knowledge on which the article builds. References in patents on the other hand serve a legal function, and are added during the granting process for the purpose of evaluating novelty and inventiveness, and for qualifying the claims made in the patent. Indeed, the cited prior art on the front page of patent documents is ultimately selected by the patent examiner and not by the applicant/inventor who might or even should (in the case of USPTO applications) bring relevant references to the attention of examiners. Based on available information in archives and databases, patent examiners ultimately decide which references are relevant to decide on granting, to restrict claims,… The difference (of occurrence) between examiner versus applicant provided references has been part of several studies (Alcacer et al. 2009; Narin et al. 1989; Sampat 2004; Tan and Roberts 2010; Tijssen et al. 2000; Vanderbeke 2006). Whereas for US patents, it has been found that around 20–25 % of all citations in the full texts of US patents (applicant-given) are also listed on the front page (examiner-given), this share is much lower for EP patents (less than 5 %, see Vanderbeke 2006) which might be due to different citation and examination practices in both patent offices (Michel and Bettels 2001).

A limited number of studies explicitly address the role and the meaning of *non-patent* references in patents. When examining a number of nanotechnology patents, Meyer and Persson (1998) observe that most cited articles do not reflect the original source of the patented idea, and that tacit, scientific knowledge plays a more important role in the inventive process. Scientific NPRs therefore do not seem to represent a direct link between the citing patent and the cited article, and scientific literature plays more an indirect role as source of relevant background information. Tijssen et al. (2000) note that NPR-based indicators do not include information about the nature of their contribution to the invention or the knowledge transfer involved; the rationale underlying the selection of citations remains unclear. However, they assume that citations are primarily meant to indicate significant contributions of scientific research to elements of the invention (Tijssen et al. 2000 p. 394) and claim that citations represent genuine, direct, observable links between research and technical inventions (Tijssen et al. 2000 p. 394). Sternitzke (2009) considers the roles of patent references versus scientific references. Based on his analysis of examination reports of rejected European patents, the author suggests that patent references serve as a source for qualifying novelty, whereas scientific references rather qualify the inventive step (i.e. the non-obviousness of the invention). In addition, his study reveals that scientific knowledge constitutes more than general background information that inspires the technical knowledge generation process, as in many cases, it is of commercial relevance. Recently, Roach and Cohen (2013) analyzed relations between knowledge flow characteristics and backward (patent and non-patent) citations in patents at the laboratory level. Combining survey data with quantitative data on backward references, they found that non-patent references are a better measure of knowledge originating from public research. Patent references were less adequate, primarily because they substantially underestimate the impact of public research.

In conclusion, the literature on science-technology interactions tends to conceptualize scientific NPRs as reflecting knowledge flows between scientific and technological actors. In its most far-reaching interpretation, cited articles are represented as sources of inspiration on which the patented invention builds. Few studies however provide an in-depth examination of scientific NPRs and the extent to which these references actually reflect sources of inspiration. This study provides evidence on the role of scientific references as sources of inspiration through interviews with inventors and assesses the relevance of the scientific non-patent references included in the front page of the patent documents.

Data

In order to obtain a more fine-grained insight into sources of inspiration guiding inventive processes and to evaluate the extent to which these sources are covered in the reference lists available in patent documents, interviews were conducted with 33 inventors. Inventors were sampled from 3 Belgian knowledge generating institutes (KGI's: universities and research centers—19 inventors) and from 6 Belgian firms (14 inventors). To ensure the relevance of science-technology linkages and related (NPR-based) indicators, institutes and firms were selected that are active in the fields of Nanotechnology, Biotechnology and Life Sciences—known as 'science-intensive' technologies. For each institute, patents were identified (EPO or PCT applications) that were applied for in the last 10 years (between 2001 and 2011) and that contained one or more references to prior art (patent or non-patent references). Inventors affiliated to the targeted institutes were identified on the selected patents and were contacted and interviewed. Each inventor was interviewed about one specific invention which resulted in a patent. The interviews, which lasted approximately one hour, were semi-structured. The first part implied open-ended questions on the inventive process with a focus on the sources of inspiration. In a second part, questions pertained to the citations referred to in the patent. By means of rating scales, inventors were asked to rate the importance of the cited documents.

In what follows, we first synthesize the inventors' accounts about their sources of inspiration, whereby we distinguish between inventors affiliated to KGI's and firms. We evaluate whether there is a relation between the mentioned sources of inspiration and the cited references in the search report and full text. Second, we report on inventors' assessment of the relevance of the cited references in their patents which allows evaluating to what extent the references, available in patents, represent an accurate picture of the sources of inspiration leading to the current inventions.

Results

Sources of inspiration

This section summarizes the sources of inspiration based on the descriptions of the inventive processes that have led to patents, as provided by the interviewed inventors. The question about sources of inspiration was open-ended and inventors were asked to describe their sources before being shown the extracted reference lists of the patent. In order to report the observations concisely, we relied on the following categorization:

Table 1 Inspiration sources in the inventive process

Unit: inventions ($n = 33$)	Professional background/expertise	Scientific literature	Patents	Firm contacts	KGI contacts	Total
	27	17	4	14	18	80
Share of inventions	81.82 %	51.51 %	12.12 %	42.42 %	54.55 %	

- *Professional expertise* (tacit) knowledge, gained from previous activities and experience inspired the inventive process.
- *Scientific literature* (codified) knowledge obtained from scientific articles or databases inspired the inventive process. This category was only coded as such if a specific document was indicated by the respondent.
- *Patent literature* other patent documents (whether or not invented by the respondent) inspired the inventive process. This category was only coded as such if a specific patent was indicated by the respondent.
- *Firm contacts inspired the inventive process* whether embedded formally (e.g. contract, cooperative project,…) or informally.
- *Contacts with knowledge institutes inspired the inventive process* whether embedded formally (e.g. contract, cooperative project,…) or informally.

For most inventions, more than one inspiration source is mentioned (see Table 1), resulting in an indicated total that is considerably higher than the number of inventions ($n = 33$) under study. 'Professional expertise' was mentioned for more than 80 % of the inventions. This is in line with Meyer and Persson's (1998) observations, where inventors pointed out that their inventions are primarily grounded in specific domain knowledge and experience. Also, Tijssen et al. (2000) observe that inventors mention in-house research as important or very important to arrive at the patented invention (94 % of the cases analyzed).[3] Scientific knowledge was an inspiration source for approximately half of the inventions, as was contacts with knowledge generating institutes. This is in line with the findings from the PATVAL inventor survey[4] (see Giuri et al. 2007), which reports on 9017 patents granted by the European Patent Office (EPO) between 1993 and 1997 and with the results of Tijssen et al. (2000), who found that external scientific knowledge—under the form of co-operation with KGI's or outsourcing of research—was mentioned as important or very important in over 40 % of their analyzed cases. Table 1 shows that patent documents are mentioned less frequently than scientific ones, although contacts with firms appear relevant within the invention process.

Assuming that knowledge spillovers within one's own activity realm are occurring more frequently, inventors from knowledge generating institutes may be more prone to be inspired by the scientific literature and from contacts with KGI's, whereas firm inventors may be more inspired by the technological (patent) literature and by firm contacts. Table 2 summarizes the results of the Chi square test in this respect (sources of inspiration versus firm/KGI affiliation). It should be noted that in our sample, the nature of the 'professional expertise' category is affiliation-dependent: scientific for KGI inventors, and of a more technical nature for firm inventors. As we will be focusing further on the distinction between scientific and technical sources of inspiration, this category is not included in the

[3] Based on a sample of 50 Dutch USPTO patents (1993-1996).

[4] Located in France, Germany, Italy, the Netherlands, Spain and the United Kingdom.

Table 2 Sources of inspiration broken down by firm and KGI inventors

Unit: inventions ($N = 33$)	Scientific literature	Patents	Firm contacts	KGI contacts	Total
Firm ($n = 14$)	5	3	7	7	22
	(7.1)	(1.7)	(5.8)	(7.5)	
Share of inventions	35.71 %	21.43 %	50.00 %	50.00 %	
Knowledge Institute ($n = 19$)	12	1	7	11	31
	(9.9)	(2.3)	(8.2)	(10.5)	
Share of inventions	63.16 %	5.05 %	36.84 %	57.89 %	

χ^2 test: insignificant ($p = 0.34$)—expected values between brackets

Table 3 Sources of inspiration broken down by patents with and without scientific NPRs

Unit: inventions ($n = 33$)	Scientific literature	Patents	Firm contacts	KGI contacts	Total
No scientific NPRs in search report ($n = 15$)	5	0	9	7	21
	(6.7)	(1.6)	(5.5)	(7.1)	
Share of inventions	33.33 %	0.00 %	60.00 %	46.67 %	
Scientific NPRs in search report ($n = 18$)	12	4	5	11	32
	(10.3)	(2.4)	(8.5)	(10.9)	
Share of inventions	66.67 %	22.22 %	27.78 %	61.11 %	

χ^2 test: significant at the 10 % level ($p = 0.07$)—expected values between brackets

following tables.[5] While the figures indeed suggest that inspiration sources from the inventors' own activity realm are more prominent, the overall result is not significant.

If SNPR-based indicators would represent a source of inspiration in the inventive process, scientific sources of inspiration (scientific literature and contact with knowledge institutes) would be mentioned more frequently for patents containing NPRs. This assumption is tested in Table 3.

The results confirm to some extent ($p < 0.10$) that inspiration sources differ between patents with scientific references versus patents without scientific references. It can be seen that scientific literature is mentioned as an inspiration source for 67 % of the patents with scientific references. For patents without scientific references, this share is considerably lower (33 %), suggesting that the presence of scientific references in patents indeed coincides with a higher probability of scientific literature acting as a source of inspiration. At the same time, Table 3 signals that patents containing scientific references appear to be more inspired by the patent literature as well. Finally, the results show that firm contacts figure more prominently as sources of inspiration for patents that contain no scientific references. Tentatively, one could argue from these results that patents containing scientific references are based more on the codified (scientific and technical[6]) literature, whereas patents without scientific references are based more on formal and informal contacts, especially with firms.[7]

5 Including this category does not alter the reported findings.

6 This appears to be additionally confirmed by a positive correlation between the number of patent references and the number of scientific references in patents.

7 An additional check reveals that the patterns observed in Table 3 are similar when the sample is split between firm versus KGI patents.

Table 4 Overlap scientific non-patent references in search report and patent document

Patent authority	Only in SR	Only in text	Overlapping	Total
EPO ($n = 9$)	3	30	2	35
Share	8.57 %	85.71 %	5.71 %	
PCT ($n = 24$)	55	537	18	610
Share	9.02 %	88.03 %	2.95 %	
Total	58	567	20	645
Share	10.42 %	86.56 %	3.02 %	

In the previous part, we showed a weak relation between the sources of inspiration of a patent and the presence of scientific NPRs in the patent's search report. One might argue that the references in the full text of the patent are a better representation of the sources of inspiration than references in the search report: whereas the latter are selected by the patents' examiner, the former were provided by the inventor or the applicant himself. The overlap between both reference lists is limited (Table 4): only 3 % of all scientific non-patent references in the sample appear in the search report as well as in the full text, which confirms previous findings (see Vanderbeke 2006, who found an overlap of only 9 %[8]). Hence, the vast majority of all non-patent references appears only in the full text. The share of overlapping references in the total number of scientific NPRs of the search report depends on the patent authority: 40 % for EPO patents, and 25 % for PCT patents.

In line with Table 3, Table 5 considers the presence of at least one scientific non-patent reference in the full text, in relation to the mentioned sources of inspiration. A χ^2 test indicates that the relation is not statistically significant ($p = 0.27$). However, using full text SNPRs does reduce the false negative ratio—i.e. the share of patent documents without SNPRs while being inspired by science—to 22 % (compared to 33 % when using search report SNPRs). The ratio of false positives—calculated by considering the share of patents including scientific references while no scientific source of inspiration has been mentioned—remains stable at 37.5 % versus 33 %. This leads to the conclusion that considering scientific non-patent references from the full text does not result in a more precise picture regarding the patent's actual sources of inspiration especially in terms of recall. In this respect, it can be noted that the use of applicant-given references is complicated by firms' and KGIs' idiosyncrasies with regard to citation behavior. As Roach and Cohen (2013) argue, patent and citation strategies affect the citations in patent texts, making them less effective for measuring knowledge flows. Likewise, Lampe (2012) found that firms strategically withhold between 21 % and 33 of relevant citations when applying for patents. Citations in the search report can be assumed to be less influenced by such 'strategic behavior'.

Overall, our findings reveal that scientific knowledge is an important source of inspiration for inventors, working for firms and KGI's alike. At the same time, the reported shares show that around one-third of patents that contain no scientific references in the search report are in fact inspired by the scientific literature. Moreover, for approximately one-third of patents with scientific references in the search report, the inventor did not explicitly report on scientific literature having contributed to the inventive process. Considering scientific non-patent references from the full text documents results in a smaller share of false negatives, but a much larger share of false positives. As such, equaling the

[8] Note that Vanderbeke's (2006) sample includes USPTO patents as well.

Table 5 Sources of inspiration broken down by patents with and without scientific NPRs in patent document text

Unit: inventions ($N = 33$)	Scientific literature	Patent	Firm contacts	KGI contacts	Total
No scientific NPRs in patent document ($n = 9$)	2	2	5	4	13
	(4.2)	(1.0)	(3.4)	(4.4)	
Share of inventions	22.22 %	22.22 %	55.55 %	44.44 %	
Scientific NPRs in patent document ($n = 24$)	15	2	9	14	40
	(12.8)	(3.0)	(10.6)	(13.6)	
Share of inventions	62.5 %	8.33 %	37.5 %	58.33 %	

χ^2 test: insignificant (0.27)—expected values between brackets

Table 6 Rated importance of cited scientific non-patent references as sources of inspiration

Calculation unit: cited scientific references[a]	Very important	Important	Not important	Background	Not known	Total
Count	15	12	5	22	1	55
Share	27.27 %	21.82 %	9.09 %	40.00 %	1.82 %	100 %

[a] Note that the proportional distribution of patents over importance categories follows the pattern of shares of references. For the total sample, it concerns 14 patents, 4 of which are firm patents and 10 are KGI patents

presence of scientific references in search reports or patent texts with inventions being inspired directly by science, introduces both false positives and false negatives.

Relevance of references in search report

In this section, we consider the importance of the scientific references that are cited in the search reports, as evaluated by the inventors. Inventors were asked to assess the relevance of these references as sources of inspiration, by rating them on a scale from 1 (very important) to 4 (background). A category 'not known' was added to account for any cited references that the inventor was unfamiliar with. Table 6 presents the distribution of cited scientific references in terms of their importance as perceived by the inventor.[9]

A first observation is that inventors are familiar with most of the scientific references mentioned in the search report (category 'not known' accounts for only 2 %). In a previous study, Jaffe et al. (2000) found that, when submitting the patent application, inventors knew about 70 % of all references contained on the front page of US patents. The difference may at least partly be explained by differences between the USPTO and the EPO patent systems. As Michel and Bettels (2001) point out, the average USPTO search report has the characteristics of a documentary search, whereas the EPO search reports reflect patentability searches. The patentability search is not exhaustive in the same sense as the documentary search in that it should be limited to what is directly relevant to patentability.

[9] In this section, 4 patents are dropped because the inventors were not able to provide us with sufficient information on the individual references. Thus, our results are based on 14 of the 18 patents with scientific NPRs reported in Table 3. The average number of scientific non-patent references wag 3.92 (sd: 2.67, max: 10).

Table 7 Rated importance of cited scientific non-patent references as inspiration sources broken down by references in firm and KGI patents

Unit: cited scientific references[7]	Very important	Important	Not important	Background	Not known	Total
Firm	2	1	2	14	0	19
	(5.2)	(4.2)	(1.7)	(7.6)	(0.3)	
Share	10.53 %	5.26 %	10.53 %	73.68 %	0.00 %	100 %
Knowledge institute	13	11	3	8	1	36
	(9.8)	(7.9)	(3.2)	(14.4)	(0.7	
Share	36.11 %	30.56 %	8.33 %	22.22 %	2.78 %	100 %

χ^2 test: significant at the 1 % level ($p < 0.01$)—expected values between brackets

As such, the volume of references in EPO patents might be lower and more focused than the volume of references in USPTO patents (see also Callaert et al. 2012), implying that the propensity that some of the listed references in USPTO patents are not known to the inventor is higher within the USPTO system. Second, it can be seen in Table 6 that slightly less than half of the references (49 %) were evaluated as 'important' or 'very important' in terms of inspiration, i.e. having directly contributed to the inventive process. The second largest category of cited references is background information (40 %). These references are then not important *as a source of inspiration* per se. The share of scientific references that are rated by inventors as 'not important' amounts to 9 %.

Whether or not inventors from knowledge institutes consider scientific references to be more important than inventors who are affiliated to firms is examined in Table 7. Academic inventors attribute a significantly higher importance to scientific references as sources of inspiration than firm-affiliated inventors: 67 % of scientific references are evaluated as very important or important sources of inspiration, compared to 16 % for firm inventors. For inventors situated within firms, 74 % of the cited scientific references are considered as relevant background information.

The interpretational difficulties implied by these observations could be solved if there were a way to distinguish between those references that qualify as being directly relevant for the inventive process and those that do not. Several researchers consider examiner-assigned 'citation categories' as relevant in this respect (Akers 1999; Criscuolo and Verspagen 2008; Schmoch 1993; Sternitzke 2009). Citation categories that are used by examiners are described in Table 8.

If these categories indeed reflect the importance/relevance of cited source documents not only in the search, but also in the inventive process, then one would e.g. expect X references to represent more important sources than Y references, and A references would be considered as references denoting background knowledge rather than sources having directly led to the development of the patented invention. This assumption is tested in Table 9. The results do not support the validity of citation categories to denote the inspirational relevance of scientific references as assessed by the inventor.

To summarize, our findings suggest that researchers should be careful when interpreting scientific references in search reports as delineating the relevant sources of inspiration of the inventive process. Although almost half of them are indeed deemed 'important' or 'very important', a major share captures relevant background information that did not contribute directly to the inventive process. A considerable 10 % consists of references that are evaluated as 'not important', not even as background information.

Table 8 citation categories

X	Highly relevant documents, prejudicial to the novelty and/or inventive step of the claims, when considered in isolation.
Y	Documents which preclude that a claimed invention can be considered as involving an inventive step, when they are combined with one or more other documents of the same category and when this combination was obvious to a trained person.
A	Documents that define the technological state of the art, without destroying the novelty or the inventiveness.
T	Documents about the theory or principal underlying the invention. Document that can permit better understanding of the principle or theory which lies at the base of the invention, or that can show that the reasoning or the facts underlying the invention are not accurate.
D	Documents that were already cited in the description of the application being examined.

Table 9 Rated importance of cited scientific non-patent references as inspiration sources by citation category

Unit: cited scientific references	Very important	Important	Not important	Background	Not known	Total
Citation category X	8	4	1	12	0	25
	(6.9)	(5.4)	(2.2)	(10.1)	(0.4)	
Share	32.00 %	16.00 %	4.00 %	48.00 %	0.00 %	100 %
Citation category A	4	8	4	8	1	25
	(6.9)	(5.4)	(2.2)	(10.1)	(0.4)	
Share	16.00 %	32.00 %	16.00 %	32.00 %	4.00 %	100 %
Citation category D	4	3	0	6	0	13
	(3.6)	(2.8)	(1.1)	(5.3)	(0.2)	
Share	30.77 %	23.08 %	0.00 %	46.15 %	0.00 %	100 %
Citation category Y	2	0	1	2	0	5
	(1.4)	(1.1)	(0.4)	(2.0)	(0.1)	
Share	40.00 %	0.00 %	20.00 %	40.00 %	0.00 %	100 %
Citation category T	1	0	0	0	0	1
	(0.3)	(0.2)	(0.1)	(0.4)	(0.0)	
Share	100.00 %	0.00 %	0.00 %	0.00 %	0.00 %	100 %

χ^2 test for citation category: no relation ($p = 0.62$)—expected values between brackets. Citations assigned to multiple categories are counted in each category

Discussion and conclusions

Varying interpretations regarding indicators based on (scientific) non-patent references (SNPRs) in patents have been put forward to denote science-industry interactions, ranging from scientific knowledge as inspiration sources to more conservative interpretations suggesting 'relatedness' between the cited science and the citing technology. Within this contribution, we examined whether scientific non-patent references present in patent documents, reflect sources of inspiration from the viewpoint of the inventor.

In a first part, we consider the inventors' point of view on their sources of inspiration within the inventive trajectory. More than half of the inventors mention scientific literature or contacts with KGI's as having directly contributed to the inventive process. Technical literature (patents) inspired 12 % of the inventions covered. Furthermore, KGI inventors are more likely than firm inventors to mention the scientific literature as an inspiration source; the opposite holds for inventors within firms who cite other patents more often as such.

Considering the validity of the presence of scientific non-patent references as indicator for scientific sources of inspiration, we found that patents with scientific non-patent references in the search report are indeed more likely to have been inspired by the scientific literature (but also by the technical literature) than patents without scientific references. At the same time, using the presence of scientific references in search reports for identifying science-based patents implies distortions in two ways. Around one-third of patents that are reportedly inspired by the scientific literature contain no scientific references (cf. Roach and Cohen's (2013) 'errors of omission'). Moreover, for around one-third of patents with scientific references, the inventor did not explicitly report on scientific literature having contributed to the inventive process (cf. Roach and Cohen's (2013) 'errors of commission'). We also considered whether using the presence of scientific non-patent references in the patent full text would be more appropriate to identify science as a source of inspiration, but found no statistical relation. However, errors of omission dropped in this approach.

In a second part, we analyzed the scientific references cited in the patents' search report and their contribution towards the invention. We found that most of the scientific non-patent references in the search report are indeed relevant sources: either as source of inspiration or as background material. At the same time, a considerable share of cited scientific references (10 %) was evaluated by the inventor as 'not important'. Scientific non-patent references in the search reports of patents applied for by KGIs are generally considered to be more relevant by the patents' inventors than those applied for by firms. This suggests that the validity of NPR-based indicators for capturing scientific sources of inspiration may be more straightforward for KGI patents than for firm patents. We also find that 'citation categories' provided in patent systems do not provide a reliable indication to distinguish between important and unimportant references—defined in terms of 'inspiration'—as assessed by inventors.

Within the discussion about the exact meaning of scientific references in patents, our findings provide empirical support to the argument that these references should not be interpreted as signaling direct links between or flows from science to technology (see also Meyer 2000; Tijssen 2001). At the same time, most scientific references are still considered relevant by the inventors at least as background material. Therefore, while the interpretation of the presence of scientific NPRs as indicators of direct knowledge spillovers does not hold, they still allow for the assessment of science-technology interactions in a broader sense, signaling relatedness to science instead of direct knowledge spillovers. The results of empirical studies relating NPR-based measures to technological innovative performance (for example: Cassiman et al. 2008, 2010; Fleming and Sorensen 2004; Harhoff et al. 1999; Nagaoka 2007; Subramanian and Soh 2010; Van Looy et al. 2003, 2007) indeed support the relevance of NPR-based indicators. Our findings urge for interpreting these effects as signaling science relatedness, rather than direct knowledge spillovers.

In spite of our study having a relatively narrow scope and coverage (small number of interviews, only Belgian inventors in science-intensive fields, no USPTO data) it has the advantage of combining interview data with quantitative indicators on a micro-level of analysis. The findings are mostly in line with those of larger scale studies, as discussed above. Future larger-scale studies employing a similar combination of quantitative and qualitative data would be useful to further validate the results.

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