Available online at www.sciencedirect.com
ScienceDirect
Research Policy 35 (2006) 1646–1662
research policy
www.elsevier.com/locate/respol

Are patenting scientists the better scholars? An exploratory comparison of inventor-authors with their non-inventing peers in nano-science and technology

Martin Meyer [a,b,c,*]

[a] SPRU, University of Sussex, Freeman Centre, Brighton, East Sussex BN1 9QE, United Kingdom
[b] Steunpunt O&O Statistieken, K.U. Leuven, Belgium
[c] Helsinki University of Technology, Institute of Strategy and International Business, Espoo, Finland

Available online 27 October 2006

Abstract

This paper explores the relationship between scientific publication and patenting activity. More specifically, it examines for the field of nano-science and nano-technology whether researchers who both publish and patent are more productive and more highly cited than their peers who concentrate on scholarly publication in communicating their research results. This study is based on an analysis of the nano-science publications and nano-technology patents of a small set of European countries. While only a very few nano-scientists appear to hold patents in nano-technology, many nano-inventors seem to be actively publishing nano-science research. Overall, the patenting scientists appear to outperform their solely publishing (non-inventing) peers in terms of publication counts and citation frequency. However, a closer examination of the highly active and highly cited nano-authors points to a slightly different situation. While still over-represented among the highly cited authors, inventor-authors appear not to be among the most highly cited authors in that category, with a single notable exception. One policy implication is that, generally speaking, patenting activity does not appear to have an adverse impact on the publication and citation performance of researchers.

Keywords: Patent-publication trade-off; Science–technology linkage; Star scientists; Bibliometrics

1. Introduction

Science and technology were originally viewed as autonomous, at times interacting systems. Over time, this division of labor has become increasingly blurred. Work focusing on a new mode of knowledge production (Gibbons et al., 1994), on the entrepreneurial university (Clark, 1998; Etzkowitz, 1983), and on the Triple Helix of university–industry–government relations (e.g. Etzkowitz and Leydesdorff, 1997; Leydesdorff and Meyer, 2003) points to a greater emphasis on the application and commercialization in academic research. At the same time, analysts observe that firms rely increasingly on external sources of scientific knowledge. Both trends appear to have resulted in an increase in science–technology interaction, which raises questions about the consequences for scientific and technological activity, respectively.

One such issue relates to the patent-publication trade-off. At this stage, it is not yet clear how these developments have affected the work of university scientists. The debate is still quite open. Some observers fear adverse effects that might also have a negative impact on the

* Correspondence address: SPRU, University of Sussex, Freeman Centre, Brighton, East Sussex BN1 9QE, United Kingdom.
Tel.: +44 1273 877978/678177; fax: +44 1273 602324.
E-mail address: m.s.meyer@sussex.ac.uk.

0048-7333/$ – see front matter
doi:10.1016/j.respol.2006.09.013

quality of the science they do (e.g. see the review by Geuna and Nesta, 2006). Following Zucker and Darby (1995, 1996), one could argue that entrepreneurial or technological activity, on the one hand, and scientific excellence or productivity, on the other, are mutually reinforcing.

The purpose of this paper is to explore for the field of nano-science and nano-technology the role of 'inventor-authors' who both publish and patent.[1] More specifically, this study explores the extent to which these researchers measure up to their non-inventing peers in terms of their publication and citation performance. Ultimately, the question this study addresses is whether there is a trade-off between scientific and technological activity. Are patenting authors equally, more or less prolific and cited in comparison to all authors in their community of practice? Are they equally strong in terms of publication activity or does their scientific performance lag behind that of their non-patenting peers?

2. Background and purpose of this study

2.1. Science and technology, and changes in their relationship

The relationship between science and technology has long been (and still is) subject to debate. Science and technology were originally viewed as largely autonomous, but at times interacting, systems. Price (1965), as well as Toynbee before him, saw science and technology as 'dancing partners' and as different but interacting constructs (Rip, 1992). Based on bibliometric analysis of science and technology journals, Price (1965) developed a two-stream model that strongly reflects the autonomy of science and technology as cognitive systems and the reciprocal nature of their interplay. Tracing references in science and technology journals, he found separate cumulative structures with scientific knowledge building on old science and new technology on old technology. He also detected a weak but reciprocal interaction between the two.

Since Price first introduced this notion, much has changed in the study of science and technology. A number of observers believe that the differences between science and technology are becoming ever smaller, if not irrelevant. Work on a new mode of knowledge production and on the Triple Helix of university–industry–government relations point to a greater focus on application and commercialization in academic research (Gibbons et al., 1994; Etzkowitz and Leydesdorff, 1997). Other scholars go further and declare the advent of 'techno-science' (see e.g. the discussion in Rabeharisoa, 1992).

At the same time, analysts observed that firms rely increasingly on external sources of scientific knowledge. Increasing knowledge specialization appears to push firms, and also other organizations, to increase their reliance on a combination of in-house and contract R&D (Brusoni et al., 2001; Granstrand et al., 1997; Langlois, 1992). Firms maintain relationships with autonomous external sources, such as suppliers and universities, that enable them to sense changes in technologies, not necessarily only in areas in which they do business. This notion of 'loose coupling' suggests that an organization maintains not only a network of core relations but also a broader and more varied set of external knowledge relations that are at least somewhat connected to the respective technological trajectory (Bhattacharya and Meyer, 2003).

Both trends appear to have resulted in an increase in science–technology interaction (e.g. Narin and Noma, 1985; Narin et al., 1995, 1997). There has been a debate – on a more general level going far beyond the indicators literature and addressing the issue from a more organizational perspective – as to whether the newly perceived increased intensity of science–technology interaction is 'real'. A number of observers have made the point that various forms of application-oriented research have existed for a long time already or used to be prominent in earlier periods (e.g. Martin and Etzkowitz, 2000).

While some of the measured increase of science–technology exchange may be attributed to improved technical methods in compiling science and technology indicators, most analysts will agree that the emergence of science and technology fields, such as biotechnology, is also characterized by individuals who both do research and are engaged in developing technology closer to the market place.

For instance, Zucker and Darby (1996) show that 'star scientists' from universities had a key role in the birth and growth of the biotechnology industry by playing dual roles as entrepreneurs and research scientists. The authors observe that a small minority of researchers

[1] While 'co-activity' – as used in Bassecoulard and Zitt (2004) – appears to be the most common term to describe this phenomenon, the literature has not yet converged on a single term to denote the individual engaging in this activity. Alternative phrases have been in use, including 'co-active researcher', 'co-active knowledge generator', 'inventor researcher', 'scientist inventor', or 'inventor-author'. For the sake of consistency, the term 'inventor-author' is adopted throughout this article to signify individuals who both publish and patent. The terms 'non-inventive' and 'non-inventing' authors denote scientists in this study who have chosen not to patent.

who account for a high share of publications (with a productivity of more than twenty times the average) had an intellectual capital base of extraordinary value. Murray (2002) explores the interface of scientific and technological networks in tissue engineering and shows that science and technology co-evolve through interlinked networks of scientists that have the capability to bridge the private-public divide. This concurs with Stokes (1997) argument that a considerable proportion of research activity is located in 'Pasteur's quadrant'—being basic in nature but also of relevance to application. Hicks et al. (2004) support this point with their patent citation data; work in basic journals is the most frequently cited in both patents and papers, with *Science* and *Nature* being the leading journals.

This study seeks to explore further the simultaneous involvement of researchers in both scientific and technological activities (for which we use the term 'inventor-authors') by employing one particular quantitative approach based on inventor-author analysis. The next section will set this approach in the broader context of science–technology linkage indicators.

2.2. Approaches to track science–technology interaction

There are several approaches to the task of tracing science/technology links (e.g. Meyer, 2002a,b; Tijssen, 2004; Bassecoulard and Zitt, 2004). These include various forms of patent citation analysis (e.g. Ellis et al., 1977, 1978; Narin and Noma, 1985; Narin et al., 1995, 1997; Hicks et al., 2001; Oppenheim, 2000; Malo and Geuna, 2000; McMillan et al., 2000; Verbeek et al., 2002; Glänzel and Meyer, 2003), the study of scientific articles authored in industry (e.g. Godin, 1993, 1995), joint publications between industry and academe (e.g. Calvert and Patel, 2003), or university-owned patents (e.g. Meyer, 2003). Another way of studying science and technology linkages is using a lexical approach (Bassecoulard and Zitt, 2004).

Finally, there are a variety of ways to connect scientific and technological activity through personal links. In recent years, patents with university researchers as inventors have been traced in a number of studies (e.g. Balconi et al., 2004; Meyer et al., 2003; Rapmund et al., 2004). Here, inventor names are linked to researcher names from personnel records of universities. This can extend considerably the number of patents associated with the university system.

Another variant of the same approach matches inventor names with scientific author names. The analysis of inventor-authors is not novel. The approach was pioneered in small-scale studies in the late 1980s and early 1990s by Coward and Franklin (1989), Rabeharisoa (1992), and Noyons et al. (1994). Tijssen and Korevaar (1997) used the approach to explore Dutch public/private R&D networks in catalysis research. More recently, Gläser et al. (2004) investigated publication and patent activity of researchers within the Division of Chemicals and Polymers at the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) in their quest for the 'least evaluable units'.

Finally, the approach adopted by Schmoch (2004) and co-workers (Noyons et al., 2004) was to identify patents that are not owned but related (through the inventor's workplace) to public research organizations. The authors used publication data in a similar way as in the above mentioned studies, drawing on personnel registries. Their findings underline the importance of scientists' contributions to technological development in certain fields. While the aim of this line of research is to use author affiliations to trace university-related patents, the present study aims to use inventor-author data to explore the impact of being jointly involved in research and invention on scientists' performance. In this sense, the study is related to more recent US efforts using patent-paper pairs (e.g. Murray, 2002; Murray and Stern, 2003) to trace a potential 'anti-commons' effect that inhibits the free flow of scientific knowledge and the ability of researchers to cumulatively build on each other's discoveries (Heller and Eisenberg, 1998; Lessig, 2001).

2.3. Previous research

While much attention has focused on the industrial exploitation of scientific research, there has also been growing concern about the impact that application-driven research may have on the conduct of science. Geuna and Nesta (2006) distinguish five possible impacts of increased university patenting:

1. A substitution effect between publishing and patenting. Particularly important here is the possibility of different impacts depending on the seniority of the researchers involved.
2. A threat to teaching quality (as senior faculty members focus on patenting rather than teaching in the light of changing structures).
3. A negative impact on the culture of open science, in the form of increased secrecy and a reduced willingness to share data with peers, delays in publication, increased costs of accessing research material or tools, and so on.

4. Diverting research resources (researchers' time and equipment) from the exploration of fundamental long-term research questions.
5. A threat to future scientific investigation from IPR on previous research. In theory, patent law provides an exception from patent infringement for 'research and experimental use' that allows university researchers to use patented inventions for their research without being obliged to pay license fees. However, this exception can be weak if the firm that obtains the exclusive right to exploit a patent decides that the research exception is not applicable to university projects financed by industry.

There are relatively few quantitative studies investigating these issues. As Kumaramangalam (2004) notes, there is a substantial and growing body of literature that points to the increasing value of public–private interaction in the evolution of science and technology and in the performance of firms and industries. Yet research that delves into the effects of this public–private interaction and, in particular, the effects on the quality of scientific output is still lacking. Gittelman and Kogut (2003) explore the question whether good science leads to valuable knowledge in US biotechnology. Examining the publications and patents of 116 biotechnology firms during the period 1988–1995, the authors show that scientific ideas are not simply inputs into inventions but that important scientific ideas and influential patents follow different and conflicting selection logics. Their results point to conflicting logics between science and innovation, and scientists must contribute to both while inhabiting a single epistemic community.

In a study of patent-paper pairs in biotechnology, Murray and Stern (2003) explore the question whether formal intellectual property rights hinder the free flow of scientific knowledge. More specifically, Murray and Stern test for the anticommons effect by calculating how the citation rate for a scientific publication changes after patent rights are granted, accounting for fixed differences in citation rate across articles and relative to the trend in citation rates for articles with similar characteristics. The authors use a sample drawn from articles in *Nature Biotechnology* between 1997 and 1999. The sample includes all articles in this journal during this period receiving a USPTO patent grant (resulting in 162 patent-paper pairs), as well as a matched sample of non-patented articles from the same journal and time-period. Differences in the annual forward citation patterns between those with and without a patent pair are examined. The authors summarize their findings as follows:

> While the average cumulative citations between the two groups is relatively similar, articles linked to a patent have a higher *initial* citation rate which then *converges* with the non-patented article citation rate. Using a differences-in-differences estimator of the change in the citation rate after a patent grant occurs, we establish three key findings. First, we find robust evidence for a quantitatively modest but statistically significant anticommons effect. Across different specifications, the article citation rate after a patent grant declines by 11–17%. Second, this effect increases with the number of years elapsed since the date of the patent grant. Finally, empirical evidence for the anticommons effect in these data is particularly salient for those articles with authors with public sector affiliations (such as a university or government laboratory). While we are cautious in our interpretation, this evidence suggests that while the anticommons effect seems to have an empirical basis, the size of the effect (at least as identified in this paper) may be modest. Some of the strongest rhetoric against the patenting of scientific knowledge may overstate the case. (Murray and Stern, 2003, pp. 3–4)

Many studies exploring the science–technology interface and the quality or value of the resulting scientific and technology output focus on biotechnology (e.g. Zucker and Darby, 1995; McMillan et al., 2000; Gittelman and Kogut, 2003; Murray, 2002, 2004; Murray and Stern, 2003). There are relatively few studies that also look at other fields of science and technology. The studies by Ranga et al. (2003), Gulbrandsen and Smeby (2002), and Azagra-Caro and Llerena (2003) are notable exceptions. However, these studies tended to focus on individual universities or (small) national innovation systems.

Ranga et al. (2003) explore the case of one Belgian university, the Flemish Catholic University of Leuven (Katholieke Universiteit Leuven, KUL). Looking at aggregate data for the period 1985–2000, the authors find that basic research publications still exceeds applied publications in terms of both publication frequency and publication growth. Furthermore, the authors are unable to identify evidence that the focus of 'entrepreneurially oriented researchers' had shifted towards applied research. In another study on KUL faculty, Van Looy et al. (2004) confirm that joint involvement in both activities does not hamper either, and that engagement in entrepreneurial activities is associated with increased publication outputs, without apparently affecting the nature of the publications involved.

In their survey of university faculty members in Norway, Gulbrandsen and Smeby (2002, 2005) find that faculty who acquired external industrial funding publish more journal articles than their peers, confirming earlier results of Canadian and US studies (Godin, 1998; Blumenthal et al., 1996; cf. Geuna and Nesta, 2006).[2]

In a case study of the University Louis Pasteur in Strasbourg, Azagra-Caro and Llerena (2003) investigate the connection between laboratory characteristics and patenting output. The authors observe that laboratories with greater institutional recognition tend to patent more. While the authors warn against drawing too strong conclusions from this particular observation and point to the need for more detailed data, their findings do suggest that development activity geared towards patenting does not necessarily have a negative effect on traditional research leading to scholarly publications.

2.4. Scope of this research

This paper aims to explore the extent to which inventor-authors over- or under-perform in comparison with peers who exclusively publish research. While most previous studies focused on biotechnology and its subfields or were limited to a particular university environment, this study seeks to explore activities in an emergent field (nano-technology) that is to some extent different from biotechnology in its innovation logic (e.g. Meyer, 2000; Darby and Zucker, 2003, 2005) but is nevertheless characterized by a strong exchange between science and technology.[3]

As the literature review has indicated, there is relatively little quantitative work on the possible impact of patenting or other ‘entrepreneurial’ activity by academics on their scientific performance.[4] Some studies addressed the basic/applied continuum; others focused on the citation rates of papers before and after patents were granted. This paper makes an effort to explore the extent to which patenting is associated with ‘good’ scientists or rather with researchers who occasionally publish and tend not to be cited to a large extent. Previous work does not allow us to formulate any strong hypotheses. However, earlier studies, such as the contributions by Zucker and Darby (1995, 1996) on star scientists, would suggest that high performers do not necessarily engage in publication activity exclusively. One could assume that at least some of the more prolific and highly cited authors are also active as inventors. Yet it is less clear how inventor-authors who are not ‘star scientists’ perform.

Therefore, the more general aim of this study is to examine how scientists fare who both publish and patent (‘inventor-authors’) addressing questions, such as the following: Is there a trade-off between scientific and technological activity? Are inventor-authors equally, or more or less prolific and cited in comparison to all authors in their community of practice? Are inventor-authors strong in terms of publication activity or do they constitute rather weak links to technology on the science-side? These questions are explored primarily with respect to high performers – the excellent or ‘star scientists’ – although not exclusively. Attention is also paid to all inventor-authors irrespective of their publication and citation performance. The following section gives an overview of the methodology employed.

3. Methodology

3.1. Field of study and data sources

This paper presents the results of a pilot study that compares publication and inventive activity of researchers in nano-science and nano-technology for a small set of European countries (United Kingdom, Germany, Belgium). Nano-technology and nano-science were selected as fields for analysis since they are perceived as relatively closely related fields of science and technology (e.g. Meyer and Persson, 1998; Meyer, 2001, 2000; Kuusi and Meyer, 2002).

There are many different approaches as to how one can define nano-sciences and nano-technology (e.g. Budworth, 1996; Malsch, 1997, 1999; Meyer et al., 2002). Attempts to come to a generally acknowledged characterization of nano-technology have proven futile. As a consequence, actors in the field adopt working definitions for the task at hand. One of the more broadly accepted definitions is the one proposed by the US National Science and Technology Council:

> Research and technology development at the atomic, molecular or macromolecular levels, in the length scale of approximately 1–100 nanometer range, to provide a fundamental understanding of phenomena and materials at the nanoscale and to create and use

---

[2] However, Gulbrandsen and Smeby (2002, 2005) also reported that faculty with external funding – industrial or otherwise – carried out significantly less basic research than their peers.

[3] Nanotechnology and related science fields can be viewed as a loosely connected, instrument-driven field of science and technology following a somewhat different innovation logic than biotechnology. Previous work has illustrated that there are a number of inventor-authors who serve as bridges between nanoscience and nanotechnology (e.g. Meyer, 2001; Noyons et al., 2004).

[4] So far, relatively few studies on this have been published. However, there are growing numbers of researchers working on this or similar topics. See, for instance, working papers by Calderini et al. (2005), Calderini and Franzoni (2004), Markiewicz and Di Minin (2004), and Stephan et al. (2005).

structures, devices and systems that have novel properties and functions because of their small and/or intermediate size. The novel and differentiating properties and functions are developed at a critical length scale of matter typically under 100 nm. Nanotechnology research and development includes manipulation under control of the nanoscale structures and their integration into larger material components, systems and architectures. Within these larger scale assemblies, the control and construction of their structures and components remains at the nanometer scale. In some particular cases, the critical length scale for novel properties and phenomena may be under 1 nm (e.g., manipulation of atoms at ~0.1 nm) or be larger than 100 nm (e.g., nanoparticle reinforced polymers have the unique feature at ~200–300 nm as a function of the local bridges or bonds between the nanoparticles and the polymer).

Not surprisingly, the diversity in opinion about how to define nano-technology is reflected and matched by the number of search strategies bibliometricians and patent analysts have developed to capture the field. Zitt and Bassecoulard (2006), Schummer (2004), and Hullmann and Meyer (2003) present more detailed discussions of the topic.

This pilot study has adopted a set of search strategies that evolved from consultation processes with domain experts at the European and national levels. Details on search strategy and data retrieval are described in Glänzel et al. (2003, pp. 14–18). More specifically, the study exploits a publication database of nano-science publications retrieved from the SCI-Expanded by ISI Thomson-Scientific and a database of nano-technology patents granted by the US Patent and Trademark Office. The publication database contains more than 100,000 SCI indexed papers topical to the nano-sciences while the patent database comprises about 4000 US patents that can be related to the area of nano-technology. Both cover the time period 1992–2001. Table 1 provides an overview of the databases and presents publication and patent data for selected countries.

3.2. Matching procedure

The purpose of this study is to explore interdependencies between publication and patenting performance of authors and inventors. To this end the study draws on both databases to identify inventor-authors through a matching procedure based on inventor surnames and initials. Forming such pairs poses considerable challenges for the analyst. Bassecoulard and Zitt (2004) compare expected properties of various indicators of science–technology linkage. They assume the silence, i.e. ‘true’ linkages that are not found, to be rather high in comparison to patent citation, subject and category sharing. However, the authors see noise, i.e. linkages that are unduly detected or ‘false’ linkages to be rather low. Bassecoulard and Zitt (2004) assume an efficient matching strategy. One way of ensuring such an efficient matching procedure is to carry out the co-activity analysis within intertwined science and technology communities. Homonyms pose a major challenge in name-based matching procedures (e.g. Noyons et al., 2004, or also Meyer et al., 2003, for a discussion in the context of university-related patents). If one defines the communities of scientists and engineers and the related publication and patenting universes too broadly, the homonym issue will lead to what Bassecoulard and Zitt (2004) call ‘unduly detected or ‘false’ linkages’.

Table 1
Selected Publication and Patent Data

Country	Papers		US patents		Papers/US patents	
	Count	Rank	Count	Rank	Ratio	Rank
United States	29,574	1	2043	1	14.5	2
Japan	16,437	2	1200	2	13.7	1
Germany	13,427	3	326	3	41.2	8
France	7,909	4	168	4	47.1	10
PR China	7,688	5	12	16	640.7	17
United Kingdom	6,671	6	107	5	62.3	13
⋮	⋮	⋮	⋮	⋮	⋮	⋮
Belgium	1,128	20	34	11	33.2	6
World	100,593		3969			

Source: Steunpunt O&O Statistieken.

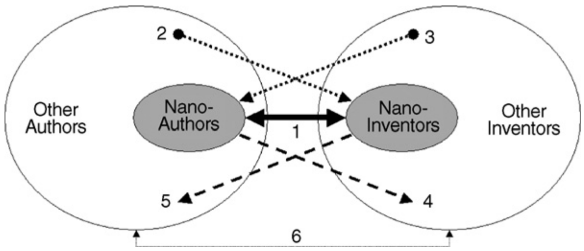

Fig. 1. Choices in linking publication and patent data.

Restricting the publication and patent universes in a narrow manner may lead to the exclusion of important links. Fig. 1 attempts to illustrate the challenge in the context of this study. Using two given search strategies to delineate nano-science papers from other scholarly publications and nano-technology patents from other patents will identify subsets for nano-authors and nano-inventors who can be linked in several ways. For instance, there are nano-inventors who also publish nano-science papers (or vice versa). This establishes a straightforward link between nano-science and nano-technology as depicted by arrow #1. However, researchers publishing papers not defined as nano-science may also become active as inventors in nano-technology (#2). Conversely, inventors who are not identified as nano-technology inventors may just write contributions to the field of nano-science (#3). Other inventor-author links include nano-authors patenting non-nano inventions (#4) and nano-inventors publishing papers on non-nano-science topics (#5). Apart from these links, researchers outside both the fields of nano-science and nano-technology may engage in both patent and publication activity (#6).

To ensure that the amount of 'noise' and 'silence' is kept at a reasonable level this study uses data from a matching procedure between nano-authors and nano-inventors only (i.e. the type #1 linkage in Fig. 1).[5] Other studies illustrate that tracking even this link can lead to a considerable number of unclear and possibly 'false' matches.[6] A matching procedure at the level of the entire databases would not have been feasible. 100,000 papers with multiple authors matched with 4000 patents with an average of 2–3 inventors would have led to a vast number of (often 'false') matches.

To avoid this, the (standardized) inventor and author names have been matched only on a within-country basis.[7] This procedure reduces the number of irrelevant matches. The number of countries in this study has been restricted to a set of three (Belgium, Germany, and the UK) in which this author is well acquainted with the networks and actors, allowing for a more effective validation of the matches to reduce homonym bias as much as possible. 'Full matches' where last name and initials of the inventor/author pair are identical have been generally accepted as such, unless they are very common names in the respective countries. Partial matches with matching surnames but only partly matching initials have been traced further (by affiliation/address/research theme). A rather conservative approach has been adopted: if in doubt, partial matches are to be considered invalid.[8]

[5] Work in progress on the Nordic countries has illustrated that there are hardly any name matches to be traced at the level of nano-inventor and nano-author names. Only if one widens the scope of potential matches to all inventors, can one identify 'inventor-authors' who are related to the nanosciences. Their inventive work, however, lies outside the boundaries of 'nanotechnology'.

[6] See e.g. the discussion in Noyons et al. (2004).

[7] Within-country approach means names of Belgian authors are matched with Belgian inventors, UK authors with UK inventors, etc. This is an approach another group has adopted more recently within a European Commission mapping of excellence exercise in nanotechnologies (Noyons et al., 2004).

[8] More specifically, this procedure was followed: name lists were generated based on inventor and author names as retrieved from the respective databases. After customary cleaning and standardization efforts, a matching procedure was carried out. To be matched in the automated procedure, the last name of the author and inventor had to be identical. Also, one of the initials had to be the same. In addition, a number of other lists were generated that had an auxiliary function containing, for instance, inventors and their cities or authors and their reprint addresses, inventor names with invention titles, authors and their journals, etc. Based on the initial matching procedure, name pairs were excluded that matched the initial selection criteria but where visual inspection pointed to different sets or combination of initials. In another step, lists of the remaining pairs were screened. 'Partial' matches where one or more but not all initials were identical were distinguished from full matches where all initials were shared. Full matches were typically accepted as such, whereas partial matches were scrutinized further. An exception was made in the case of full matches of very common names, such as 'Schmidt'. Here, a similar procedure was adopted as in the case of partial matches. In many instances authors were at least once reprint authors and therefore were unambiguously assigned an address. It was then checked to what extent the reprint address concurred with the other addresses. Where authors had not been reprint authors once, it was attempted to identify re-occurring addresses. Online searches were another means to specify authors' addresses. These addresses were then compared to inventor and assignee addresses as specified in the patent data. In the case where there was a straightforward link, the match was accepted. Often also the content of the scientific and technological work were compared (drawing, for instance, on title or journal information on the science side and title, assignee or classification information on the technological side). Naturally, there is always some ambiguity in making these decisions. Typically, a conservative approach was followed. When in doubt potential matches were not included.

3.3. Performance ranking

After matching the data, publication and citation frequencies are calculated to determine the position of inventor-authors in the national nano-science community. Publication counts are calculated on the basis of full and fractional counts. Then, authors are ranked and grouped into five classes (quintiles) according to the respective frequency measures. For instance, the first quintile contains the most prolific (or the most highly cited) authors who account for the top 20% of the publication counts (or citation counts, respectively). The second quintile comprises the authors who account for the next 20% of publication (citation) counts, and so forth. The fifth quintile includes finally the group of least prolific (or cited) authors. The representation of inventor-authors in the different frequency classes has been compared to the overall pattern. Data for the most active and most frequently cited class of authors (the first quintile) are examined in more detail. Authors in this first performance class are ranked again by publication and citation frequency. Then the position and performance of the most prolific (cited) author is compared to the most prolific (or cited) inventor-authors. Particular attention is paid to identifying possible performance differences between inventor-authors and their non-inventive peers.

4. Results

This section gives an overview of the findings. First, basic data on the results of the matching procedure are presented. Then inventor-authors' science productivity and citation records are compared to those of their non-inventing peers. After this, the performance of inventor-authors among top-ranking authors is explored.

4.1. Relative importance of co-activity

First, this section examines the importance of individuals in relation to the colleagues who only either publish or patent. Table 2 presents an overview. While few authors patent, many inventors seem to publish. On the technology side, inventor-authors account for a relatively large share amongst the countries' nano-inventors, ranging between 27% and 40%. This observation is in line with earlier findings by Schmoch (2004) and colleagues who found that the share of patents linked to the public sector via author affiliations is considerably higher than the share of university patents in overall patenting activity would suggest.

The level of co-activity compares roughly to that observed in fuel cells. In a study of Norwegian fuel-cell research and development, Klitkou et al. (2007) found that around 27% of the 54 inventors traced were also active as authors of scientific publications. The share of inventor-authors can be quite different from field to field. For instance, Blauwhof (1995, pp. 45–46) identified only one inventor-author link at the individual level (199 authors, 147 inventors) in her study of the teletraffic field.[9]

Table 2
Basic data on authors and inventors

	Belgium	Germany	United Kingdom
#Authors	2652[a]	22242[a]	13235[a]
#Inventors	44	890	185
#Inventors/#authors (%)	1.7	4.0	1.4
#Inventor-authors	12	301	75
Inventor-authors/authors (%)	0.5[b]	1.5[b]	0.6[b]
Inventor-authors/inventors (%)	27.3	33.8	40.5

[a] This count also includes foreign-based authors collaborating with domestic authors since the SCI does not allow personalized assignation of author addresses.
[b] The share of inventor-authors amongst all nano-authors (see also text note 10).

The situation on the science (publication) side appears completely contrary. Inventor-authors seem to be a marginal group. In the three countries studied, they account for 2% or less of all nano-authors. Due to technical reasons[10] the national nano-author sets also include international collaborators of the respective country's authors. Therefore, one needs to interpret the observed shares with considerable care. Nevertheless, the share of inventor-authors among nano-scientists is at such a marginal level that one can assume that their share is still considerably lower than the observed shares of co-activity among all nano-inventors. Obviously, this com-

9 An interesting observation is that co-activity can vary considerably if the unit of analysis is changed. Blauwhof (1995, p. 46) observed a substantially higher degree of co-activity at the organizational level. She could identify an 'overlay' of 12 organizations that were involved in both patenting and publication activity. This corresponds to 40% of the 30 organizations engaged in publishing organizations and around 31% of the 39 that were active in patenting.

10 The SCI does not contain address information pertaining to individual authors. This raises problems in assigning nationality to particular authors within an author team. Within the context of this study, the choice was two-fold: either include all authors within a then extended set of national papers or consider building a strictly national set of nano-authors using only addresses of corresponding authors. About 71–77% of the papers had a first author with a national address. The remainder included papers with a corresponding author in another country than the one studied while national authors were included among the other authors. Naturally, also papers with a national corresponding author most likely included other nationals as co-authors.

paratively low share is linked to the differences in size between the nano-author and nano-inventor populations. The size of the entire nano-inventor community in relation to the nano-science community is marginal, never exceeding the 4% mark. Therefore, the share of inventor-authors (in relation to all authors) must be even more marginal.

While the relatively small share of inventor-authors among authors is not surprising, the observations with respect to the comparatively high share of inventor-authors among inventors may invite some speculation. As mentioned, other studies pointed to the relatively high share of public research organizations in patenting in emerging fields of science and technology, including nano-technology (e.g. Schmoch, 2004; Heinze, 2004). While the current data does not help much further because of its focus on individual researchers, it is safe to assume in the light of other studies that universities and other public research organizations play a greater role also here than in overall patenting. Some of the universities in the countries studied launched intellectual property activities quite recently and are undergoing a steep learning process. One could argue that this has led to a patent 'inflation' in which, at times, patent applications were filed for inventions with debatable commercial potential.[11]

The trend in firms, especially in non-core technologies, of accessing knowledge through more 'loose coupling' relationships with universities and other research organizations could be an alternative, complementary explanation. Nano-science and technology is a broad area that can potentially affect a range of industries. However, often the developments are still at an early stage; immediate applications are not necessarily visible (e.g. Meyer, 2001, 2002b). This situation makes it conducive for companies to engage in collaborative research with academic partners, leading to patents as well as joint publications.

A third explanation for the relatively high share of inventor-authors might be persisting skepticism of established firms towards an emerging technology field.[12] Also, firms may choose to follow other strategies than patenting in protecting their intellectual property or securing their freedom to operate in the area. It should be stressed that all these explanations are rather speculative and one should be careful of drawing strong conclusions.

4.2. Research productivity and citation performance

This section compares the publication and citation performance of inventor-authors with their non-inventing peers. All in all, the findings suggest that inventor-authors are typically not at the bottom end of publication and citation rankings. A considerable number of inventor-authors are prolific in terms of publication frequency and have achieved a position of considerable centrality in national networks. Inventor-authors are also over-proportionally represented among highly cited authors. Fig. 2 and Table 3 present the findings in detail.

As the distribution of author and inventor types across performance classes illustrates (Fig. 2), inventor-authors are over-represented in the better performing classes. In terms of publication frequencies (calculated on the basis of full counts), about 7% (Germany) to almost 17% (UK) of the inventor-authors are in the top performing class while only slightly more than 1% of their non-inventing peers are in this category.[13] Similar observations can be made when examining publication frequencies on the basis of fractional counts. About 7% (Germany) to 20% (UK) of all inventor-authors are to be found in the top quintile whereas only 1.0–1.4% of non-inventing authors are in that class. The results for Belgium point in the same direction.

If one includes citation performance as an additional measure, the observations point in the same direction even though they are less pronounced. About 4% (Germany) to 9% (UK) of all inventor-authors are represented among the top cited authors, compared to 0.4% (Germany) to 1% (UK) when examining non-inventing authors. The Belgian results are more skewed with 16.7% of the inventor-authors being in the top category compared to 0.8% of their non-inventing peers. So far the data seem to suggest that inventor-authors are over-represented in the better performing classes. Table 3 illustrates this point more clearly by presenting the inventor-authors' share in the respective performance classes vis-à-vis their over- or under-representation in that class. Over/under-representation is calculated as the quotient of the inventor-authors' share in a given perfor-

[11] A surge in university patenting has certainly been reported elsewhere. See e.g. Saragossi and van Pottelsberghe (2003) on developments in Belgium. Similar developments are reported for Germany at least until 2000 (e.g. Schmoch, 2006).

[12] For instance, recent interviews with field experts in the UK still pointed to a potential 'technology-business disconnect' among certain established firms (Meyer et al., 2004).

[13] The Belgian observations correspond to this but the overall number of observations is low, which needs to be borne in mind when interpreting the results. Only 34 patents in total could be identified for the country, with 12 of the inventors being co-active as nano-science authors.

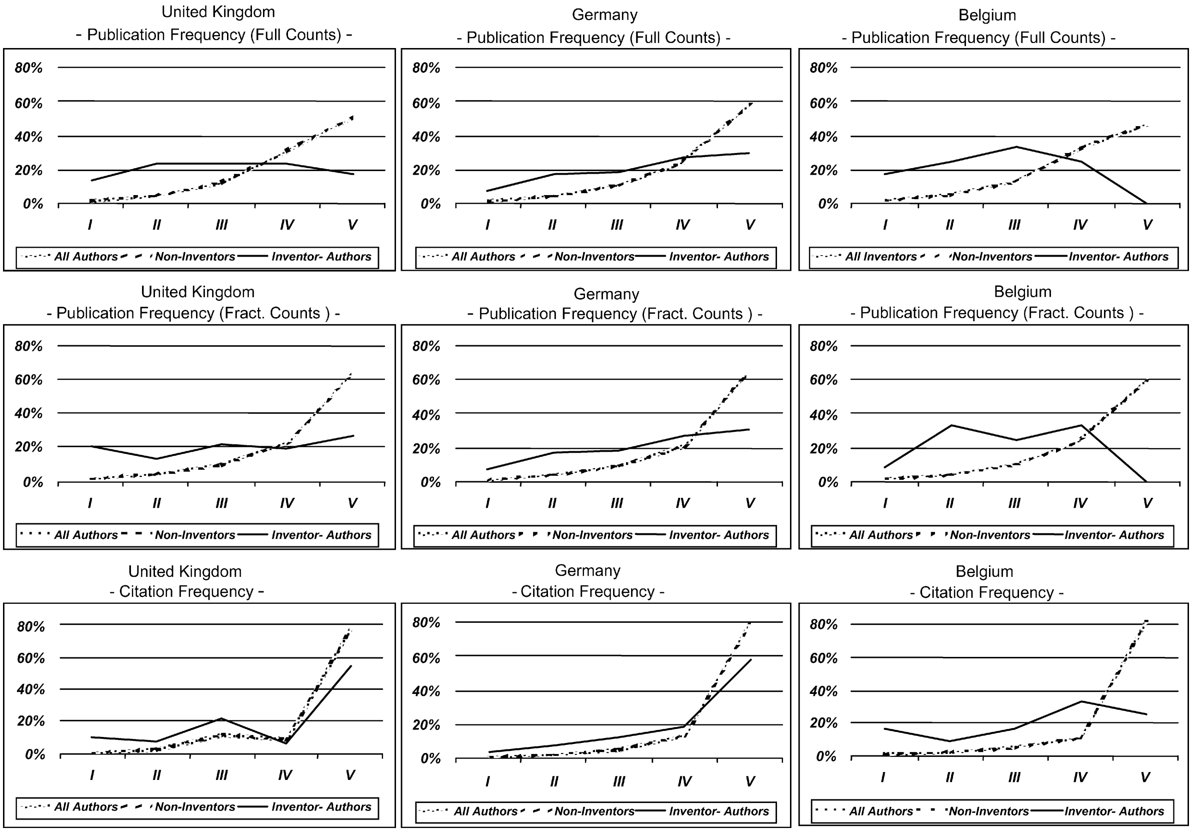

Fig. 2. Cross-country comparison of researcher productivity and citedness: inventor-authors versus non-inventing authors.
Note: Authors are grouped in five performance classes (I: highest performers, V: lowest performers) along the *x*-axis while the *y*-axis displays the share of the respective author types (inventor-authors, non-inventing authors, and all authors) in a given quintile. As the share of inventor-authors is very small and 'non-inventive authors' (who do not patent) account for almost all publication activity, the distribution curves for all and non-inventive authors are almost congruent.

mance class in relation to the overall share of inventor-authors (among all nano-science authors).

Across all performance categories (publication frequencies based on full and fractional counts as well as citation frequencies) in the two large countries studied, inventor-authors seem to be over-represented in the top performance class by a factor of 6–15. Inventor-authors are also strongly over-represented in the second-highest performing class (by a factor of 3–4) while they are under-represented in the lowest performance class (the factors vary between 0.4 and 0.8). The Belgian data again point in the same direction as the observations for Britain and Germany.

4.3. A closer look at high performers

While inventor-authors apparently outperform their non-inventing peers in terms of both publication and citation frequencies, the question still remains as to whether they are really at the top of their league. Performance classes are defined rather broadly in this study. Top-performers are defined as authors who account for the top 20% in terms of publication output and citation counts. This definition is suitable for an overall comparison with the overwhelming majority of non-inventing authors.

However, such a definition may not exclusively capture 'star-scientists' or what some analysts called the 'super-excellent' (Zitt et al., 2004). As Table 4 illustrates, the spread between the best and the 'worst' performer in this class is wide. The lowest ranked among this class of most prolific authors achieves a publication output that reflects about 11% in the UK and just 6% in Germany, respectively, of the papers the most prolific author has published. In terms of citations, the situation is not quite as pronounced. Yet there is still a considerable gap within this class of top performers. The least cited authors in the class get 21% (Britain) and 11% (Germany) respectively of the most highly cited authors. Therefore, a closer look at inventor-authors' standing within this broad class seems appropriate.

Table 3
Share of inventor-authors amongst all authors in performance classes

Country	Full counts		Fractional counts		Times cited counts	
Quintiles	Share of inventor-authors (%)	Over/under-representation (%)	Share of inventor-authors (%)	Over/under-representation (%)	Share of inventor-authors (%)	Over/under-representation (%)
United Kingdom						
I	5.5	961	8.2	1449	6.7	1172
II	2.6	457	1.8	320	1.8	312
III	1.1	195	1.2	218	1.1	186
IV	0.4	74	0.5	83	0.4	75
V	0.2	34	0.2	43	0.4	72
Total	0.6	100	0.6	100	0.6	100
Germany						
I	8.6	632	8.8	654	12.1	898
II	5.2	385	5.7	418	4.9	364
III	2.3	171	2.6	192	3.1	232
IV	1.5	110	1.7	129	1.9	140
V	0.7	50	0.6	47	1.0	73
Total	1.4	100	1.4	100	1.4	100
Belgium						
I	4.3	940	2.6	582	9.1	2009
II	2.3	498	3.8	834	1.8	402
III	1.1	254	1.1	250	1.5	340
IV	0.3	75	0.6	136	1.4	303
V	0.0	0	0.0	0	0.1	31
Total	0.5	100	0.5	100	0.5	100

This section explores the question as to where inventor-authors stand within the top performance classes. Such an examination of the highest performing class only points to a slightly different view (see Fig. 3). In the case of the UK and Belgium, the data indicate that inventor-authors were not to be found at the very top of the most prolific and highly cited authors. This would suggest that combining publication with patenting activity does come at a (small) price. Data summarized in Table 4 exemplify this. For instance, in the UK the most prolific inventor-author achieved less than half the publication frequency than the most active author overall. In terms of citations, the highest-ranked inventor-author received about 60% of the citations of the most highly cited researcher. The Belgian data point in a similar direction.

As for possible explanations as to why inventor-authors are not to be found at the very top, one could argue that at this extreme level there is a price to be paid after all for combining patenting and publication activity. However, one must be careful not to rush to conclusions. Nano-science can be seen as an area of many disciplines.

Table 4
Highest and lowest ranked (inventor-)authors in top performance class

	Highest ranked author	Highest ranked inventor-author	Lowest ranked inventor-author	Lowest ranked author
United Kingdom				
Papers	163 (100)	77 (47.2)	21 (12.9)	18 (11.0)
Citations	2255 (100)	1349 (59.8)	608 (27.0)	469 (20.8)
Germany				
Papers	408 (100)	408[a] (100)	24 (5.9)	24 (5.9)
Citations	7969 (100)	5578 (70.0)	898 (11.3)	897 (11.3)
Belgium				
Papers	53 (100)	34 (64.2)	18 (34.0)	14 (26.4)
Citations	377 (100)	224 (59.4)	143 (37.9)	143 (37.9)

Values in parentheses are in percent.
[a] The next highest ranking inventor-author published 159 papers which amounts to 39% of output by the most prolific author.

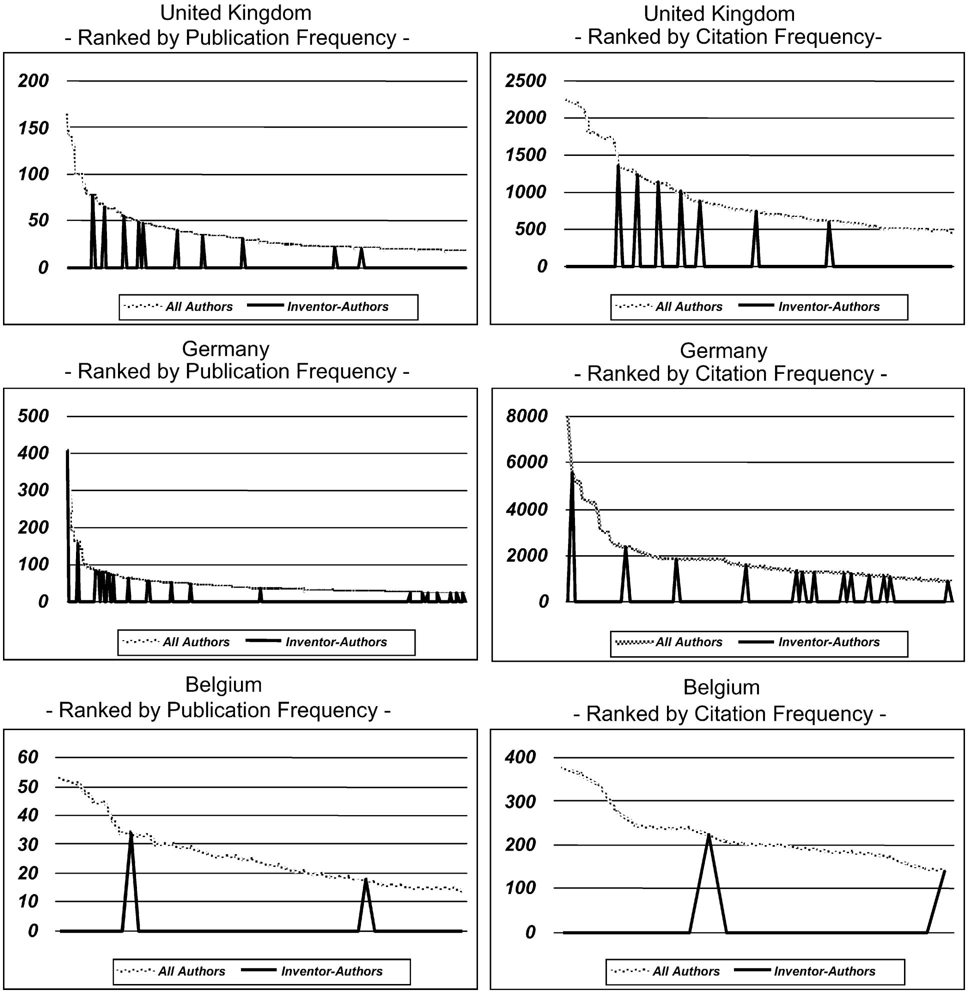

Fig. 3. Distribution of author categories among highly prolific authors and cited authors.
Note: Authors are ranked in descending order of their publication/citation frequency on the *x*-axis while the *y*-axis points to publication and citation counts, respectively.

This means that specialization effects could be at work. Theoretical contributions may be important and highly cited but may not be translated into technological applications.

Also, one notable exception could be observed in the case of Germany where the most prolific author (with a total of 408 publications) is also an inventor. The second-ranked author, a non-inventor, has a total of 325 publications. The next ranked inventor-author has a publication record of 159 papers, corresponding to 39% of the total publication output of the most prolific author or 49% of the most prolific non-inventing author. Future research needs to explore possible reasons for this. An explanation may be the specific organizational structure established in Germany for funding nano-technology R&D. These academic-led so-called ‘competence centers’ and ‘competence networks’ around technological themes with obligatory industry participation may have resulted in an extension of activities of ‘star-scientists’ and ‘super-excellent’ researchers into the technological domain. An alternative explanation could view the top-ranked scientist as an outlier. While he is the highest ranked author in terms of publication frequency, he is not the top-ranking author in terms of citations. However, at 70% or with more than 5500 citations this inventor-author still finds only one (non-inventive) author who is more cited. In any case, it would be interesting to explore in future research whether citation rankings corrected for the publication volume of researchers would yield similar results.[14]

[14] The initial research design was in part inspired by Zucker and Darby’s (1996) notion of ‘star-scientists’. The authors observed that

5. Conclusions

5.1. Are inventor-authors 'star scientists'?

This research has illustrated that inventor-authors (researchers who both publish and patent) can play an important role in both scientific research and technological development. Their publication output tends to be over-proportionally high and they are also comparatively highly cited. The findings indicate that combining scientific with technological aspects of research and development activity does not seem to have any strong adverse effects on how patenting scientists perform in terms of publication and citation ratings. Researchers who are 'driven' appear to find another outlet for their work rather than sacrificing science for the sake of technology and commerce. This would support research by others (e.g. Azagra-Caro et al., 2006; Azagra-Caro and Llerena, 2003) who have observed in case studies of universities that patenting activity tends to be associated with prestigious groups and labs.

One also needs to stress that inventor-authors represent a small minority among their publishing peers. In this sense, it would be misleading to speak of nano-science/technology as 'techno-science'. The 'dancers' metaphor, which can be traced back to Toynbee and De Solla Price, still seems to be appropriate in the context of nano-science and technology. This is not that surprising if one compares the relatively small number of nano-inventors to the large number of nano-authors. What seems noteworthy, however, is that inventor-authors account for between 5% and 12% (depending on the country and indicator) of the top-performing authors. In other words, inventor-authors appear to make a substantial contribution to nano-science even though they resemble only a small minority in terms of all the authors active in this area.

On the patent side, inventor-authors even seem to 'drive' technological development if one looks at the considerable proportion they represent among all inventors across all the countries studied. While inventor-authors remain a relatively small group in terms of scientific publication activity, they feature prominently among nano-inventors, representing between 27% and 40% of the total across the three countries. These observations seem to concur with Zucker and Darby's work on 'star scientists' (Zucker and Darby, 1995, 1996; Zucker et al., 1998).

Having said this, one must bear in mind that patents are an indicator of technological activity rather than a proxy for innovations that are successful in the market place. Not everything that has been patented will be commercialized. Some of the universities in the countries studied have launched intellectual property activities quite recently and are undergoing a steep learning process. To some extent, this may raise questions as to the value and commercial promise of the patented technology tracked in this study. In some instances, individuals rather than companies or other organizations are involved. Research elsewhere (e.g. Whalley, 1991; Astebro, 2003; Meyer, 2005) points to lower rates of commercial utilization of these types of inventions.

While patenting researchers are clearly over-represented in higher performing classes of authors, there remains some ambiguity with respect to their share among the very best or 'star' performers. This study suggests that there may be a trade-off between publication and patent performance but only at the very top. The top-ranked inventor-authors achieve between 48% and 70% of the performance levels of the highest ranked researchers, with the notable exception of one German inventor-author who accounted for the highest publication output overall.

5.2. Future research

Future research needs to explore whether this is an exceptional case or whether other, institutional factors have an impact on the observed pattern. As the data presented here illustrate, there is a relatively strong second-tier of top inventor-authors in German nano-science and nano-technology. A closer inspection of the data indicates that many of these inventor-authors headed nano-technology so-called 'competence centers' or 'competence networks'. These academic-led centers (networks) of competence that are built around technological themes with obligatory industry participation may have resulted in truly excellent researchers extending their activities into the technological domain.

Another issue to be explored further is the relationship between the seniority of inventor-authors and all authors.

a small minority of researchers accounting for a high share of publications (with a productivity of more than twenty times above the average) had an intellectual capital base of extraordinary value. To reflect the cumulative aspect of the knowledge generation and reception, the initial research design of this study included citation counts that were not normalized by an author's publication frequency. This counting method favors authors with a longer publication history – typically eminent scientists – and tends to bias somewhat against 'rising stars'—younger scientists with a (shorter and more recent) publication record that has not attracted quite as many citations. Also note that citations received from across all papers in the SCI (and not just nano-papers) were counted. For a more detailed discussion of this aspect, see the conclusion section of this article.

This study focuses on patterns that can be observed for an entire field. Tracking seniority at this level is a considerable challenge. While an author's overall publication output could conceivably be used as a proxy for age or seniority, one needs to bear in mind that there is anecdotal evidence suggesting that especially in an emerging field, such as nano-science, authors might pursue also other lines of research outside the 'nano-realm'. Here, smaller-scale studies might provide valuable insights.

Social network analysis may also be a fruitful avenue of future research. This paper does not address the centrality of individual inventor-authors in the different worlds of science and technology: Do inventor-authors play a central role in both scientific and technological networks, or do they achieve prominence in only one of the two? The research reported here suggests that patenting researchers are among the more prolific scientific authors and they also tend to achieve considerable visibility in terms of citations. Based on these observations, it seems likely that patenting researchers will frequently engage in co-authorship and play a relatively central role in their scientific networks. A closer examination of inventor data is required to see whether the high scientific standing is matched on the technology side.

Also more micro-sociological work may prove insightful in this context. Are there different types of inventor-authors? Do they follow their invention through the entire innovation process from conception to commercialization? Are leading (both highly active and highly cited) scientists 'co-opted' inventors? Are less cited author-inventors engineers in industrial laboratories who publish the occasional paper with peers in academe?

In particular, it may be worthwhile to explore in more detail in which type of organizations the most science-prolific inventors are based. This would add an organizational dimension to this research, which was concerned only with individual performance trade-offs. A comparative study of the scientific performance of non-patenting and patenting research organizations would be the logical next step to follow up on this research. It goes without saying that such an effort should be combined with a comparative analysis of the organizational context in which researchers are embedded: Are there organizational drivers influencing scientists' performance?

In addition to identifying organizations that employ patenting researchers, future research should also explore organizational networks further. Tracing scientific networks of firms may allow us to develop particularly interesting insights about their knowledge sourcing strategies in this emerging area of science and technology.

Nano-technology is a heterogeneous and diverse field as is nano-science. Both integrate knowledge from a variety of disciplines and sectors. Future research should address the question of whether the various sub-fields that make up 'nanotech' follow different patterns in terms of innovation and science–technology relations. In addition, one should explore the extent to which differences between countries and their specializations matter in this context.

Finally, this study has looked at citation performance in terms of counts of the number of times scientific papers are cited. These counts capture citations received from all papers in the *Science Citation Index* and are thus embedded in the universe of all (indexed) science. Tracing citations received exclusively from nano-papers would be a way to explore the position of inventor-authors within the nano-science community. It would be interesting to examine the extent to which the results differ. A high standing in the overall community of science may not necessarily translate into high visibility among nano-scientists.

One could argue that most current emergent fields, such as the nano-sciences, integrate knowledge from a range of specialties. Some authors may see themselves as contributors to these (more established) areas rather than any field of nano-science. One or more of their papers might touch upon a nano-issue but the focus of their work is outside 'core' nano-science. Exploring these patterns could also provide an avenue for analysts to define the fuzzy boundaries of an emerging area.

Acknowledgements

Earlier versions of this paper were presented at the Academy of Management Conference, the International Conference of the Society for Scientometrics and Informetrics in Stockholm (Sweden), the Nordic Workshop for Bibliometrics and Research Policy at Åbo Akademi, Turku (Finland), and the Science and Technology Indicators Conference in Leiden (Netherlands), as well as seminars at Lund University (Sweden), Dalian University of Technology, Henan Normal University, and ISTIC (Beijing, China). This author is grateful for comments from workshop and seminar participants. He also wishes to thank Annika Rickne, Linda Butler, Margherita Balconi, Hildrun Kretschmer, Wolfgang Glänzel, Ben Martin, Erkko Autio, Ismael Rafols and Michel Zitt for helpful suggestions, Tom Magerman for assistance in data processing, and Susan Lees and Phillips Brooks for editorial advice. Financial support from the Gatsby Charitable Foundation is gratefully acknowledged.

References

Astebro, T., 2003. The return in independent invention: evidence of unrealistic optimism, risk seeking or skewness loving? Economic Journal 113 (484), 226–239.

Azagra-Caro, J., Carayol, N., Llerena, P., 2006. Patent production at a European research university: exploratory evidence at the laboratory level. Journal of Technology Transfer 31 (3), 257–268.

Azagra-Caro, J.M., Llerena, P., 2003. Types of contractual funding and university patents: from analysis to a case study. In: Paper Prepared for the Conference on 'Knowledge and Economic and Social Change: New Challenges to Innovation Studies', Manchester, CRIC, April 7–9, 2003 (Cited in Geuna and Nesta (2006)).

Balconi, M., Breschi, S., Lissoni, F., 2004. Networks of inventors and the role of academia: an exploration of Italian patent data. Research Policy 33, 127–145.

Bassecoulard, E., Zitt, M., 2004. Patents and publications: the lexical connection. In: Moed, H.F., Glänzel, W., Schmoch, U. (Eds.), Handbook of Quantitative Science and Technology Research: The Use of Publication and Patent Statistics in Studies of S&T Systems. Kluwer Academic Publishers, Dordrecht, pp. 665–694.

Bhattacharya, S., Meyer, M., 2003. Large firms and the science/technology interface—patents, patent citations, and scientific output in thin films. Scientometrics 58 (2), 265–279.

Blauwhof, G., 1995. The Non-linear dynamics of technological developments: an exploration of telecommunications technology. Doctoral dissertation, Universiteit van Amsterdam.

Blumenthal, D., Campbell, E.G., Causino, N.A., Louis, K.S., 1996. Participation of life science faculty in research relationships with industry. New England Journal of Medicine 335 (23), 1734–1739.

Brusoni, S., Prencipe, A., Pavitt, K., 2001. Knowledge specialization, organizational coupling, and the boundaries of the firm: why do firms know more than they make? Administrative Science Quarterly 46 (4), 597–621.

Budworth, D.W., 1996. Overview of Activities on Nanotechnology and Related Technology. Institute for Prospective Technological Studies, Seville.

Calderini, M., Franzoni, C., 2004. Is academic patenting detrimental to high quality research? An empirical analysis of the relationship between scientific careers and patent applications. Working Paper no. 162, CESPRI, University Bocconi, Milan.

Calderini, M., Franzoni, C., Vezzuli, A., 2005. If star scientists do not patent: an event history analysis of scientific eminence and the decision to patent in the academic world. In: Paper Presented at the 5th International Triple Helix Conference, Turin, Italy, March 18–21, 2005.

Calvert, J., Patel, P., 2003. University-industry research collaborations in the UK: bibliometric trends. Science and Public Policy 30 (2), 85–96.

Clark, B.R., 1998. Creating Entrepreneurial Universities: Organizational Pathways of Transformation. Pergamon, Oxford.

Coward, H.R., Franklin, J.J., 1989. Identifying the science-technology interface—matching patent data to a bibliometric model. Science Technology & Human Values 14 (1), 50–77.

Darby, M.R., Zucker, L.G., 2003. Grilichesian breakthroughs: inventions of methods of inventing and firm entry in nanotechnology. NBER Working Paper Series, #9825, accessed at http://www.nber.org/papers/w9825.

Darby, M.R.; Zucker, L.G., 2005. Socio-economic impact of nanoscale science: initial results and nanobank. NBER Working Paper Series, #11181, accessed at http://www.nber.org/papers/w11181.

Ellis, P., Hepburn, G., Oppenheim, C., 1977. Patent citation networks. In: Proceedings of the International Symposium on Patent Information and Documentation (No Pagination). Munich, Germany (Cited in Oppenheim (2000)).

Ellis, P., Hepburn, G., Oppenheim, C., 1978. Studies on patent citation networks. Journal of Documentation 34, 12–20.

Etzkowitz, H., 1983. Entrepreneurial scientists and entrepreneurial universities in American academic science. Minerva 21 (2–3), 198–233.

Etzkowitz, H., Leydesdorff, L., 1997. Universities and the Global Knowledge Economy: A Triple Helix of University-Industry-Government Relations. Pinter, London.

Geuna, A., Nesta, L., 2006. University patenting and its effects on academic research: The emerging European evidence, Research Policy 35 (6) 790–807.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzmann, S., Scott, P., Trow, M., 1994. The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies. Sage, London.

Gittelman, M., Kogut, B., 2003. Does good science lead to valuable knowledge? Biotechnology firms and the evolutionary logic of citation patterns. Management Science 49 (4), 366–382.

Glänzel, W., Meyer, M., 2003. Patents cited in the scientific literature: an exploratory study of 'reverse' citation relations in the Triple Helix. Scientometrics 58 (2), 415–428.

Glänzel, W., Meyer, M., DuPlessis, M., Thijs, B., Magermann, B., Schlemmer, B., Debackere, K., Veugelers, R., 2003. Nanotechnology: Analysis of an Emerging Domain of Scientific and Technological Endeavour. Steunpunt O&O Statistieken, Katholieke Universiteit Leuven.

Gläser, J., Spurling, T., Butler, L., 2004. Interorganisational evaluation: are there 'least evaluable units'? Research Evaluation 13 (1), 19–32.

Godin, B., 1993. The relationship between science and technology: a bibliometric analysis of papers and patents in innovative firms. Unpublished D. Phil. thesis. University of Sussex, Brighton.

Godin, B., 1995. Research and the practice of publication in industries. Research Policy 25, 587–606.

Godin, B., 1998. Writing performative history: the new New Atlantis? Social Studies of Science 28, 465–483 (Cited in Geuna and Nesta (2006)).

Granstrand, O., Patel, P., Pavitt, K., 1997. Multitechnology corporations: why they have 'distributed' rather than 'distinctive core' capabilities. California Management Review 39, 8–25.

Gulbrandsen, M., Smeby, J.C., 2002. The external orientation of university researchers: implications for academic performance and management. In: Paper Presented at the 4th Triple Helix Conference, Copenhagen, November 6–9, 2002.

Gulbrandsen, M., Smeby, J.C., 2005. Industry funding and university professors' research performance. Research Policy 34 (6), 932–950.

Heinze, T., 2004. Nanoscience and nanotechnology in Europe: analysis of publications and patent applications including comparisons with the United States. Nanotechnology Law and Business 1 (4), 427–445.

Heller, M., Eisenberg, R., 1998. Can patents deter innovation? The anticommons in biomedical research. Science 280 (5364), 698–701.

Hicks, D., Breitzman, T., Olivastro, D., Hamilton, K., 2001. The changing composition of innovative activity in the US—a portrait based on patent analysis. Research Policy 30 (4), 681–703.

Hicks, D., Tomizawa, H., Saitoh, Y., Kobayashi, S., 2004. Bibliometric techniques in the evaluation of federally funded research in the United States. Research Evaluation 13 (2), 78–86.
Hullmann, A., Meyer, M., 2003. Publications and patents in nanotechnology. An overview of previous studies and the state of the art. Scientometrics 58 (3), 507–527.
Klitkou, A., Nygaard, S., Meyer, M. Tracking techno-science networks: a case study of fuel cells and related hydrogen technology R&D in Norway. Scientometrics 70 (2), in press.
Kumaramangalam, K., 2004. Does collaborating with academia improve industry science? Evidence from the UK Biotechnology Sector, 1988–2001. ASLIB Proceedings 57 (3), 261–277.
Kuusi, O., Meyer, M., 2002. Technological generalizations and leitbilder—the anticipation of technological opportunities. Technological Forecasting and Social Change 69 (6), 625–639.
Langlois, R.N., 1992. Transaction costs economics in real time. Industrial and Corporate Change 1, 99–127.
Lessig, L., 2001. The Future of Ideas: The Fate of the Commons in a Connected World. Random House, New York.
Leydesdorff, L., Meyer, M., 2003. The triple helix of university-industry-government relations: a model for innovation in the 'knowledge-based' economy. Introduction to the Triple Helix special issue. Scientometrics 58 (2), 191–203.
Malo, S., Geuna, A., 2000. Science/technology linkages in an emerging research platform: the case of combinatorial chemistry and biology. Scientometrics 47 (2), 303–321.
Malsch, I., 1999. Nanotechnology in Europe: scientific and organizational dynamics. Nanotechnology 10 (1), 1–7.
Malsch, I., 1997. Nanotechnology in Europe: Experts' Perceptions and Scientific Relations Between Sub-Areas. Institute for Prospective Technological Studies, Seville.
Markiewicz, K.R., Di Minin, A., 2004. Commercializing the laboratory: the relationship between faculty patenting and publishing. Haas School of Business Working Paper.
Martin, B., Etzkowitz, H., 2000. The origin and evolution of the university species. VEST 13 (3–4), 9–34.
McMillan, G.S., Narin, F., Deeds, D.L., 2000. An analysis of the critical role of public science in innovation: the case of biotechnology. Research Policy 29 (1), 1–8.
Meyer, M., 2000. Patent citations in a novel field of technology—what can they tell about interactions between emerging communities of science and technology? Scientometrics 48 (2), 151–178.
Meyer, M., 2002a. Tracing knowledge flows in innovation systems. Scientometrics 54 (2), 193–212.
Meyer, M., 2003. Are academic patents an indicator of useful university research? Research Evaluation 12 (1), 17–27.
Meyer, M., 2005. Independent inventors and public support measures: insights from 33 case studies in Finland. World Patent Information 27 (2), 113–123.
Meyer, M., Morlacchi, P., Persson, O., Archambault, E., Malsch, I., 2004. Continuous Professional Development in Emerging Technology Sectors. A SPRU report for the ETB—the UK Engineering and Technology Board. University of Sussex, Brighton.
Meyer, M., Persson, O., 1998. Nanotechnology—interdisciplinarity, patterns of collaboration and differences in application. Scientometrics 42 (2), 195–205.
Meyer, M., Persson, O., Power, Y., with Nanotechnology Expert Group and Eurotech Data, 2002. Mapping Excellence in Nanotechnologies. Preparatory study for the European Commission, DG Research, Brussels.
Meyer, M., Siniläinen, T., Utecht, J.T., 2003. Towards hybrid Triple Helix indicators—a study of university-related patents and a survey of inventors. Scientometrics 58 (2), 321–350.
Meyer, M.S., 2001. Patent citation analysis in a novel field of technology: an exploration of nano-science and nano-technology. Scientometrics 51 (1), 163–183.
Meyer, M.S., 2002. Between Technology and Science: Exploring an Emerging Field: Knowledge Flows and Networking on the Nano-Scale. Doctoral thesis, University of Sussex, Brighton. Available through dissertation.com at http://www.dissertation.com/book.php?method=ISBN&book=1581122535.
Murray, F., 2002. Innovation as co-evolution of scientific and technological networks: exploring tissue engineering. Research Policy 31 (8–9), 1389–1403.
Murray, F., 2004. The role of academic inventors in entrepreneurial firms: sharing the laboratory life. Research Policy 33 (4), 643–659.
Murray, F., Stern, S., 2003. Do formal intellectual property rights hinder the free flow of scientific knowledge? An empirical test of the anti-commons hypothesis. SPRU Conference in Honor of Keith Pavitt, 2003, Brighton (Cited draft dated November 10, 2003).
Narin, F., Hamilton, K.S., Olivastro, D., 1995. Linkage between agency supported research and patented industrial technology. Research Evaluation 5 (3), 183–187.
Narin, F., Hamilton, K.S., Olivastro, D., 1997. The increasing linkage between US technology and public science. Research Policy 26 (3), 317–330.
Narin, F., Noma, E., 1985. Is technology becoming science? Scientometrics 7 (3–6), 369–381.
Noyons, E.C.M., Buter, R.K., van Raan, A.F.J., Schmoch, U., Heinze, T., Hinze, S., Rangnow, R., 2004. Mapping Excellence in Science and Technology across Europe: Nanoscience and Nanotechnology. Centre for Science and Technology Studies (CWTS), Leiden University, The Netherlands.
Noyons, E.C.M., Van Raan, A.F.J., Grupp, H., Schmoch, U., 1994. Exploring the science and technology interface—inventor author relations in laser medicine research. Research Policy 23 (4), 443–457.
Oppenheim, C., 2000. Do patent citations count? In: Garfield, E. (Ed.), The Web of Knowledge: a Festschrift in honor of Eugene Garfield, ASIS Monograph Series. Information Today, Medford, NJ, pp. 405–432.
Price, D.S., 1965. Is technology historically independent of science? A study in statistical historiography. Technology and Culture 6 (4), 553–568.
Rabeharisoa, V., 1992. A special mediation between science and technology: when inventors publish scientific articles in fuel cells research. In: Grupp, H. (Ed.), Dynamics of Science-Based Innovation. Springer, Berlin, pp. 45–72.
Ranga, L.M., Debackere, K., von Tunzelmann, N., 2003. Entrepreneurial universities and the dynamics of academic knowledge production: a case study of basic vs. applied research in Belgium. Scientometrics 58 (2), 301–320.
Rapmund, A., Gulbrandsen, M., Iversen, E.J., 2004. Academic patenting in Norway. Paper Presented at the 9th Nordic Workshop on Bibliometrics, Informetrics and Research Policy. Abo Akademi, Turku (Finland).
Rip, A., 1992. Science and technology as dancing partners. In: Kroes, P., Bakker, M. (Eds.), Technological Development and Science in the Industrial Age. Kluwer, Dordrecht, pp. 231–270.
Saragossi, S., van Pottelsberghe, B., 2003. What patent data reveal about universities: the case of Belgium. Journal of Technology Transfer 28 (1), 47–51.

Schmoch, U., 2004. The technological output of scientific institutions. In: Moed, H.F., Glänzel, W., Schmoch, U. (Eds.), Handbook of Quantitative Science and Technology Research: The Use of Publication and Patent Statistics in Studies of S&T Systems. Kluwer Academic Publishers, Dordrecht, pp. 717–731.

Schmoch, U., 2006. The role of universities in economic growth: the German situation. Paper presented at the 5th International Congress on Higher Education, Cuba, February 13–17, 2006.

Schummer, J., 2004. Multidisciplinarity, interdisciplinarity, and patterns of research collaboration in nanoscience and nanotechnology. Scientometrics 59, 425–465.

Stephan, P.E., Gurmu, S., Sumell, A.J., Black, G., 2005. Who's patenting in the university? Evidence from the Survey of Doctorate Recipients. Forthcoming in the Economics of Innovation and New Technology. Accessed at http://www2.gsu.edu/∼ecosgg/research/pdf/sgsb_eint.pdf.

Stokes, D., 1997. Pasteur's Quadrant: Basic Science and Technological Innovation. Brookings Institution Press, Washington.

Tijssen, R.J.W., 2004. Science-technology connections and Interactions. In: Moed, H.F., Glänzel, W., Schmoch, U. (Eds.), Handbook of Quantitative Science and Technology Research: The Use of Publication and Patent Statistics in Studies of S&T Systems. Kluwer Academic Publishers, Dordrecht, pp. 695–715.

Tijssen, R.J.W., Korevaar, J.C., 1997. Unravelling the cognitive and interorganisational structure of public/private R&D networks: a case study of catalysis research in the Netherlands. Research Policy 25 (8), 1277–1293.

Van Looy, B., Ranga, M., Callaert, J., Debackere, K., Zimmermann, E., 2004. Combining entrepreneurial and scientific performance in academia: towards a compounded and reciprocal Matthew-effect? Research Policy 33 (3), 425–441.

Verbeek, A., Debackere, K., Luwel, M., Andries, P., Zimmermann, E., Deleus, F., 2002. Linking science to technology: using bibliographic references in patents to build linkage schemes. Scientometrics 54 (3), 399–420.

Whalley, P., 1991. The social practice of independent inventing. Science, Technology and Human Values 16 (2), 208–232.

Zitt, M., Bassecoulard, E., 2006. Delineating complex scientific fields by a hybrid lexical-citation method: an application to nanosciences. Information Processing and Management 42 (6), 1513–1531.

Zitt, M., Ramanana-Rahary, S., Bassecoulard, E., 2004. Relativity of citation performance and excellence measures: from cross-field to cross-scale effects of field-normalisation. Scientometrics 63 (2), 373–401.

Zucker, L.G., Darby, M.R., 1996. Star scientists and institutional transformation: Patterns of invention and innovation in the formation of the biotechnology industry. Proceedings of the National Academy of Sciences of the United States of America 93, 12709–12716.

Zucker, G.L., Darby, M.R., 1995. Virtuous Circles of Productivity: Star Bioscientists and the Institutional Transformation of Industry. NBER Working Paper No. 5342.

Zucker, G.L., Darby, M.R., Brewer, M., 1998. Intellectual capital and the birth of U.S. biotechnology enterprises. American Economic Review 88 (1), 290–306.