SPRU
Science and Technology Policy Research

SEWPS

SPRU Electronic Working Paper Series

Paper No. 144

Are Co-Active Researchers on Top of their Class? An Exploratory Comparison of Inventor-Authors with their Non-Inventing Peers in Nano-Science and Technology.

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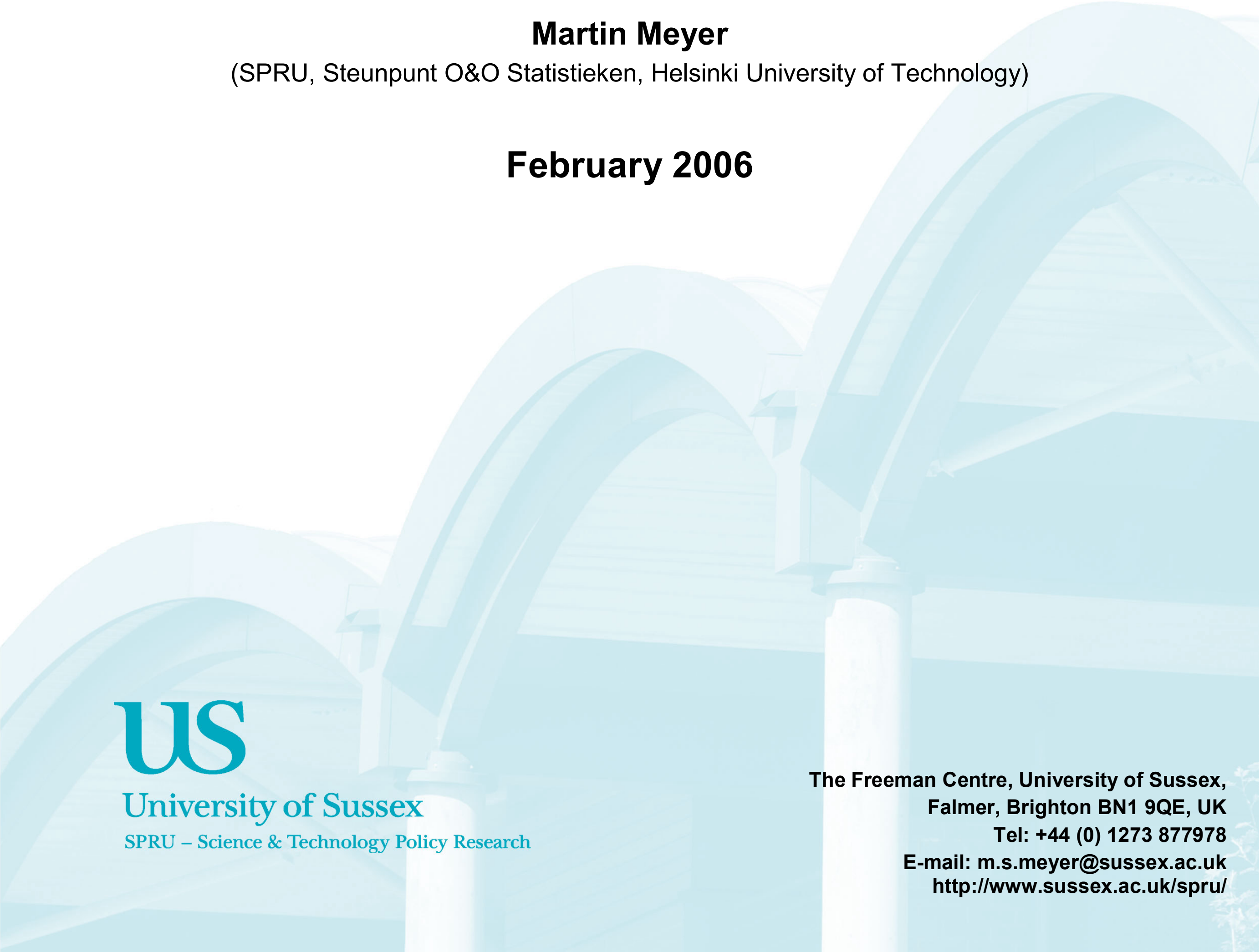
February 2006



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Are co-active researchers on top of their class?
An exploratory comparison of inventor-authors with their non-inventing peers in nano-science and technology

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This paper explores the relationship between scientific publication and patenting activity. More specifically, this research examines for the field of nanoscience and nanotechnology 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 nanoscience publications and nanotechnology patents of a small set of European countries. While only a very small number of nanoscientists appear to hold patents in nanotechnology, a considerable number of nano-inventors seem to be actively publishing nanoscience 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 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 one notable exception. A policy-relevant conclusion is that, generally speaking, patenting activity does not appear to have an adverse impact on the publication and citation performance of researchers.

Introduction

Science and technology were originally viewed as autonomous, at times interacting systems. This division of labor has become increasingly blurred. Work on a new mode of knowledge production (Gibbons et al., 1994), the entrepreneurial university (Clark 1998, Etzkowitz, 1983), and the Triple Helix of university-industry-government relations (e.g. Etzkowitz and Leydesdorff, 1997; Leydesdorff and Meyer, 2003) point to a greater focus on 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 quality of the science they do. Other observers refer to instances where 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 nanoscience and nanotechnology the role of co-active knowledge producers who both publish and patent. 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, over- or under-proportionally prolific and cited in comparison to all authors in their community of practice? Are co-active knowledge generators strong in terms of publication activity or do they resemble weak links between science and technology?

Background & Purpose of this Study

Science, 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 autonomous, at times interacting systems. De Solla Price (1965), as well as Toynbee before him, saw science and technology as ‘dancing partners’ and thus as unlike, yet interacting constructs (Rip, 1992). Based on citation analysis of science and technology journals, de Solla Price developed a two-stream model that reflects much more the autonomy of science and technology as cognitive systems and the reciprocal nature of their interplay. Tracing citations in science and technology journals, he found separate cumulative structures with scientific knowledge building on old science and technology on old technology. He also detected a weak but reciprocal interaction between the two.

Since de Solla 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 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 even 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 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 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. Etzkowitz and Martin, 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 observed that 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. 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 between private-public divide. This concurs with Stokes' (1997) argument that a considerable share of R&D activity is to be located in 'Pasteur's quadrant' – being basic research 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 the co-mingling of researchers in scientific and technological activities further by employing one particular quantitative approach – inventor-author analysis. The next section will put this approach in the broader context of science-technology linkage indicators.

Approaches to Track Science-Technology Interaction

There are several approaches to trace science/technology links (e.g. Meyer, 2002, 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. Another form of science and technology linkage is the lexical approach (Bassecoulard and Zitt, 2004).

Finally, there are a variety of ways to connect scientific and technological activity through personal links. More recently, 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 were linked to researcher names from personal 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 author names. The analysis of co-active 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 with 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 was used by Schmoch (2004) and colleagues (Noyons et al., 2004) to identify patents that are not owned but - by the inventor's workplace - related to public research organizations. The authors used publication data in a similar way as above mentioned studies drew 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 was to use author affiliations to trace university related patents, the present study aims to use inventor-author data to explore the impact of co-activity 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, 2002).

Previous Research

While much attention has focused on the industrial exploitation of scientific research, there has also been growing concern about the impact application-driven research may have on the conduct of science. Geuna and Nesta (2004) distinguish five possible impacts of increased university patenting:

1. Substitution effect between publishing and patenting. Particularly important is the possibility of different impacts depending on the seniority of researchers.
2. Threat to teaching quality (as senior faculty members focus on patenting rather than teaching in the light of changing structures).
3. 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, etc.
4. Diverting research resources (researchers' time and equipment) from the exploration of fundamental long-term research questions.
5. Threat to future scientific investigation from IPR on previous research. In theory, patent law provides a research and experimental use exception from patent infringement 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.

While there are some qualitative studies investigating the issue, there are relatively few quantitative studies. As Kumaramangalam (2004) points out, 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, on the quality of scientific output is still missing. Gittelman and Kogut (2003) explored 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) explored the question whether formal intellectual property rights hinder the free flow of scientific knowledge. More specifically, Murray and Stern tested 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 used 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 to 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, 3-4).

Many studies exploring the science-technology connect and the quality or value of the resulting scientific and technology output draw 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 and (small) national innovation systems.

Ranga et al. (2003) explored the case of one Belgian university, the Flemish Catholic University of Leuven (Katholieke Universiteit Leuven, KUL). Looking at aggregated data for the period 1985-2000, the authors found that basic research publications still exceeded applied publications in terms of both publication frequency and publication growth. Furthermore, the authors have not been able 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) confirmed that both activities do not hamper each other and that engagement in entrepreneurial activities coincides with increased publication outputs, without affecting the nature of the publications involved.

In their survey of university faculty members in Norway, Gulbrandsen and Smeby (2002, 2005) found 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, 2004).[1]

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 observed that laboratories with greater institutional recognition tended to patent more. While the authors warn of drawing too strong conclusions from this particular observation and point to the need for much more detailed data, their findings do point in the direction that development activity geared towards patenting does not necessarily have a negative effect on traditional research leading to scholarly publications.

Scope of this Research

This paper aims to explore the extent to which co-active researchers over- or under-perform in comparison with peers who exclusively publish research. While most studies were focused on biotechnology and subfields or limited to a particular university environment, this study seeks to explore activities in an emergent field that is to some extent different from biotechnology in its innovation logic but still an area of strong exchange between science and technology.[2]

As the literature review indicated, there is relatively little quantitative work on possible impacts of patenting or other 'entrepreneurial' activity of academics on their scientific performance.[3] Some studies addressed the basic/applied continuum; others focused on citation

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

[2] 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 co-active individuals who link as bridges between nano-science and nano-technology (e.g. Meyer 2001; Noyons et al., 2004).

[3] So far relatively few studies have been published. However, there is a growing number 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), or Stephan et al. (2005).

rates of papers before and after patent grants. 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 analysts to formulate strong expectations. However, earlier studies, such as Zucker and Darby’s (1995, 1996) work on star scientists, would suggest that high performers will 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 perform who are not ‘star scientists’.

Therefore, the aim of this study is at a more general level to learn more about how scientists fare who both publish and patent (“co-active knowledge generators”) addressing questions, such as the following: Is there a trade-off between scientific and technological activity? Are co-active researchers equally, over- or under-proportionally prolific and cited in comparison to all authors in their community of practice? Are co-active knowledge generators strong in terms of publication activity or do they resemble weak links to technology on the science-side? These questions are explored with respect to high performers – the ‘super-excellent’ or ‘star scientists’ – but 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.

Methodology

This paper presents the results of a pilot study that compares publication and inventive activity of researchers in nanoscience and nanotechnology for a small set of European countries (United Kingdom, Germany, Belgium). Nanotechnology and nanoscience 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 nanosciences and nanotechnology (e.g. Budworth, 1996; Malsch, 1997, 1999; Meyer et al., 2002). Attempts to come to a generally acknowledged characterization of nanotechnology 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 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 nanotechnology is reflected and matched by the number of search strategies bibliometricians and patent analysts have developed to capture the field. Hullmann and Meyer (2003) as well as Schummer (2004) present more detailed discussions of the topic.

This study 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, 14-18). More specifically, the study exploits a publication database of nanoscience publications retrieved from the SCI-Expanded by ISI Thomson-Scientific and a database of nanotechnology patents granted by the US Patent and Trademark Office. The publication database contains more than 100,000 SCI indexed papers topical to the nanosciences while the patent database comprises about 4,000 US patents that can be related to the area of nanotechnology. Both cover the time period 1992-2001. Table 1 provides an overview of the databases and presents publication and patent data for selected countries.

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 in 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) assumed 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	29574	1	2043	1	14.5	2
Japan	16437	2	1200	2	13.7	1
Germany	**13427**	**3**	**326**	**3**	**41.2**	**8**
France	7909	4	168	4	47.1	10
PR China	7688	5	12	16	640.7	17
United Kingdom	**6671**	**6**	**107**	**5**	**62.3**	**13**
…	…	…	…	…	…	…
Belgium	**1128**	**20**	**34**	**11**	**33.2**	**6**
World	**100593**		**3969**			

Source: Steunpunt O&O Statistieken

Restricting the publication and patent universes in a narrow manner may lead to the exclusion of important links. Figure 1 attempts to illustrate the challenge in the context of this study. Using two given search strategies to delineate nanoscience papers from other scholarly publications and nanotechnology 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 nanotechnology (#2). Conversely, inventors who are not identified as nanotechnology 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-nanoscience topics (#5). Apart from these links, researchers outside both the fields of nano-science and nanotechnology may engage in both patent and publication activity (#6).

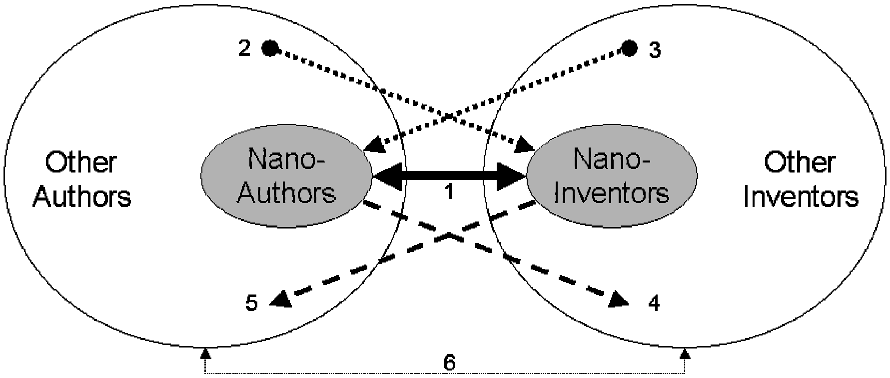

Figure 1: Choices in linking publication and patent data.

To ensure that the amount of 'noise' and 'silence' is kept at a reasonable level this study only proceeds with a matching procedure between nano-authors and nano-inventors (which was depicted as type #1 linkage in Figure 1).[4] Other studies illustrated that tracking even this link can lead to a considerable number of unclear and possibly 'false' links.[5] A matching procedure at the level of the entire databases would not have been feasible. 100,000 papers with multiple authors matched with 4,000 patents with an average of 2-3 inventors would have led to a vast number of (often 'false') matches.

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[4] 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 nano-sciences. Their inventive work, however, lies outside the boundaries of 'nanotechnology'.

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

Therefore, (standardized) inventor and author names were matched on a within-country basis to further reduce the number of irrelevant matches.[6] Moreover, the number of countries was restricted to a set of three countries (Belgium, Germany, and the UK) in which the author is well acquainted with the networks and actors. This allowed for a more effective validation of the matches and was aimed to reduce homonym bias as much as possible. 'Full matches' where last name and initials of the inventor/author pair were identical were generally accepted as such, unless they were very common names in the respective countries. Partial matches with matching surnames but only partly matching initials were traced further (by affiliation/address/research theme). A rather conservative approach was adopted: if in doubt, partial matches were not considered valid.[7]

After this, publication and citation frequencies were calculated to determine the position of co-active knowledge producers in the national nanoscience community. Publication counts were calculated on the basis of full and fractional counts. Authors were then 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)

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[6] 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).

[7] More specifically, the following 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.

authors. The representation of inventor-authors in the different frequency classes was then compared to the overall pattern. Data for the most active and most frequently cited class of authors (the first quintile) was examined in more detail. Authors in this first performance class were ranked again by publication and citation frequency. Then the position and performance of the most prolific (cited) author was compared to the most prolific (or cited) co-active authors. Particular attention was paid to identifying possible performance differences between co-active and non-inventive authors.

Results

This section gives an overview of the findings. First, basic data on the results of the matching procedure are presented. Then co-active researchers' 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.

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, co-active inventors 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. Klitkou et al. (2006) found that around 27% of the 54 Norwegian fuel-cell inventors were also active as authors of scientific publications. The co-activity level can be quite different from field to field. For instance, Blauwhof (1995, 45-46) identified only one inventor-author link at the individual level (199 authors, 147 inventors) in her study of the teletraffic field.[8]

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[8] An interesting observation is that co-activity can vary considerably if the unit of analysis is changed. Blauwhof (1995, 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

The situation on the science (publication) side appears completely contrary. Co-active researchers seem to be a marginal group. In the three countries studied, co-active authors account for 2% or less of all nano-authors. Due to technical reasons[9] 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 co-active 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 comparatively 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 co-active share of authors must be even more marginal, reflecting the overall level of activity.

While the relatively small share of co-active authors is not surprising, the observations with respect to the comparatively high share of co-active 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 nanotechnology (e.g. Schmoch, 2004; Heinze, 2004). While the current data set 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.[10]

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to 40% of the 30 organizations engaged in publishing organizations and around 31% of the 39 that were active in patenting.

[9] 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 twofold: 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.

[10] 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 the UK.

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, 2002). 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 co-active researchers might be persisting skepticism of established firms towards an emerging technology field.[11] 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.

Table 2. Basic data on authors and inventors.

	Belgium	**Germany**	**United Kingdom**
#Authors	2,652 [a]	22,242 [a]	13,235 [a]
#Inventors	44	890	185
#Inventors/#Authors	1.7%	4.0%	1.4%
#Coactive	12	301	75
Share of Coactive Authors	0.5% [b]	1.5% [b]	0.6% [b]
Share of Coactive Inventors	27.3%	33.8%	40.5%

Notes: [a] This count also includes foreign-based authors collaborating with domestic authors since the SCI does not allow personalized assignation of author addresses. [b] Indicates the share of coactive amongst all nano-authors (see also note 9)

Research Productivity and Citation Performance

This section compares the publication and citation performance of co-active researchers with their non-inventing peers. All in all, the findings suggest that co-active knowledge producers 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. Co-active researchers are also over-

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[11] 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).

proportionally represented among highly cited authors. Figure 2 and Table 3 present the findings in detail.

As the distribution of author and inventor types across performance classes illustrates (Figure 2), co-active 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 co-active researchers are in the top performing class while only slightly more than 1% of their non-inventing peers are in this category.[12] Similar observations were made when examining publication frequencies on the basis of fractional counts. About 7% (Germany) to 20% (UK) of all co-active 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 directions even though they are less pronounced. About 4% (Germany) to 9% (UK) of all co-active 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 co-active authors being in the top category compared to 0.8% of their non-inventing peers. So far the data seem to suggest that co-active inventor-authors are over-represented in the better performing classes. Table 3 illustrates this point more clearly by presenting the co-active researchers' 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 co-active researchers' share in a given performance class in relation to the overall share of co-active researchers.

Across all performance categories (publication frequencies based on full and fractional counts as well as citation frequencies) in the two large countries studied, co-active researchers seem to be over-represented in the top performance class by a factor of 6 to 15. Inventor-authors are also strongly over-represented in the second-highest performing class (by a factor of 3 to 4) while they are under-represented in the lowest performance class (the factors vary between

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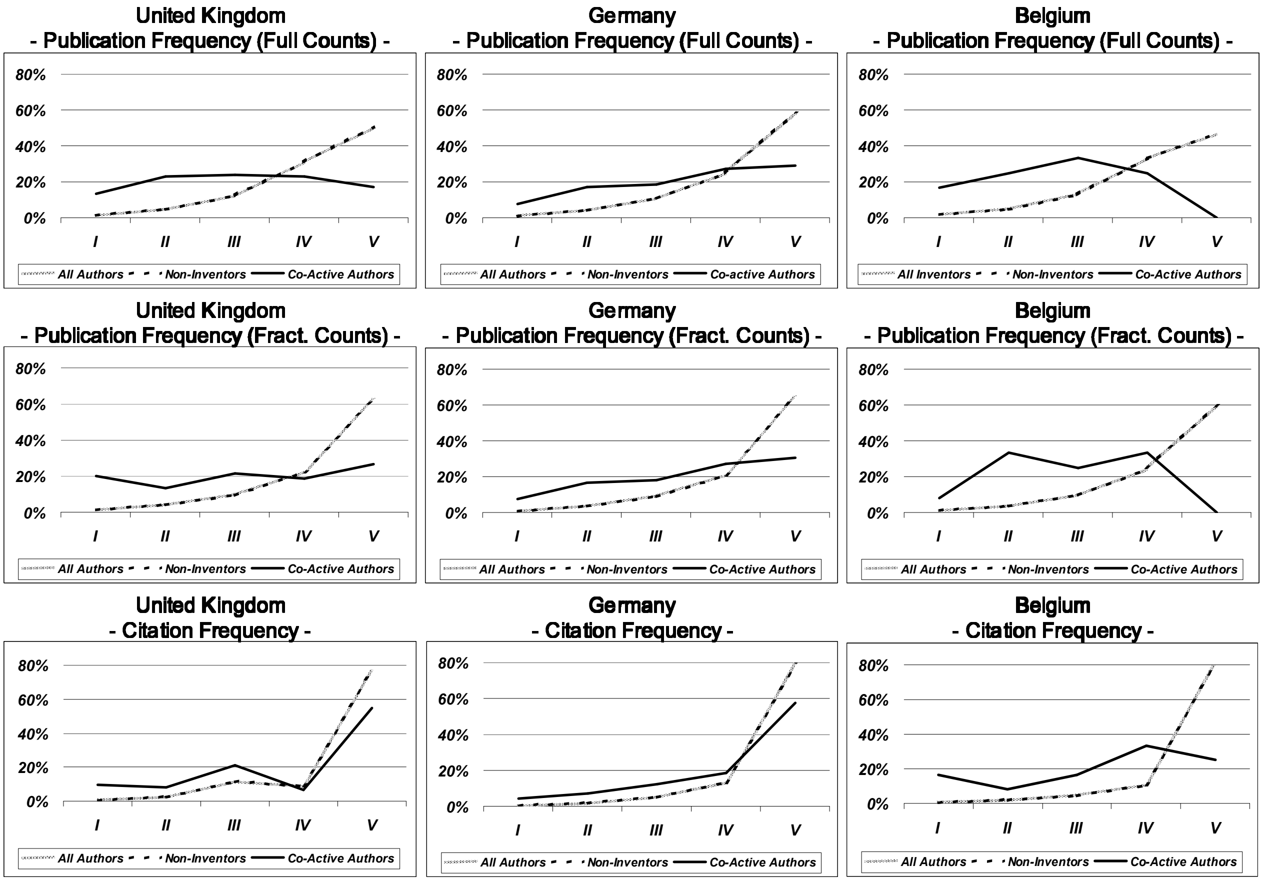
[12] The Belgian observations correspond to this but the overall number of observations is low, which needs to be borne in mind when interpreting the results. Only 34 patents in total could be identified for the country, with 12 of the inventors being co-active.

0.4 and 0.8). The Belgian data again point in the same direction as the observations for Britain and Germany.



United Kingdom - Publication Frequency (Full Counts) -

Germany - Publication Frequency (Full Counts) -

Belgium - Publication Frequency (Full Counts) -

United Kingdom - Publication Frequency (Fract. Counts) -

Germany - Publication Frequency (Fract. Counts) -

Belgium - Publication Frequency (Fract. Counts) -

United Kingdom - Citation Frequency -

Germany - Citation Frequency -

Belgium - Citation Frequency -

Figure 2: Cross-country comparison of researcher productivity and citedness: co-active 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 (co-active, non-inventing and all authors) in a given quintile. As the share of co-active authors is very small and non-inventive authors account for almost all publication activity, the distribution curves for all and non-inventive authors are almost congruent.

Table 3: Share of co-active amongst all authors in performance classes.

Country	Full Counts		Fractional Counts		Times Cited Counts	
Quintiles	Co-Active Share	Over/Under-Representation	Co-Active Share	Over/Under-Representation	Co-Active Share	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%

A closer look at high performers

While co-active authors apparently outperform their non-inventing peers in terms of both publication and citation frequencies, the question still remains as to whether co-active researchers are really 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 capture 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 co-active researchers’ standing within this broad class seems appropriate.

This section explores the question as to where co-active researchers stand within the top performance classes. Such an examination of the highest performing class only points to a slightly different view on co-active researchers (see Figure 3). In the case of the UK and Belgium, the data indicate that co-active researchers 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 co-active researcher 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 co-active researchers 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. 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 co-active researcher 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 nanotechnology R&D. These academic-led centers (networks) of competence around technological themes with obligatory industry participation may have resulted in an extension of activities of '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 5,500 citations this co-active 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.[13]

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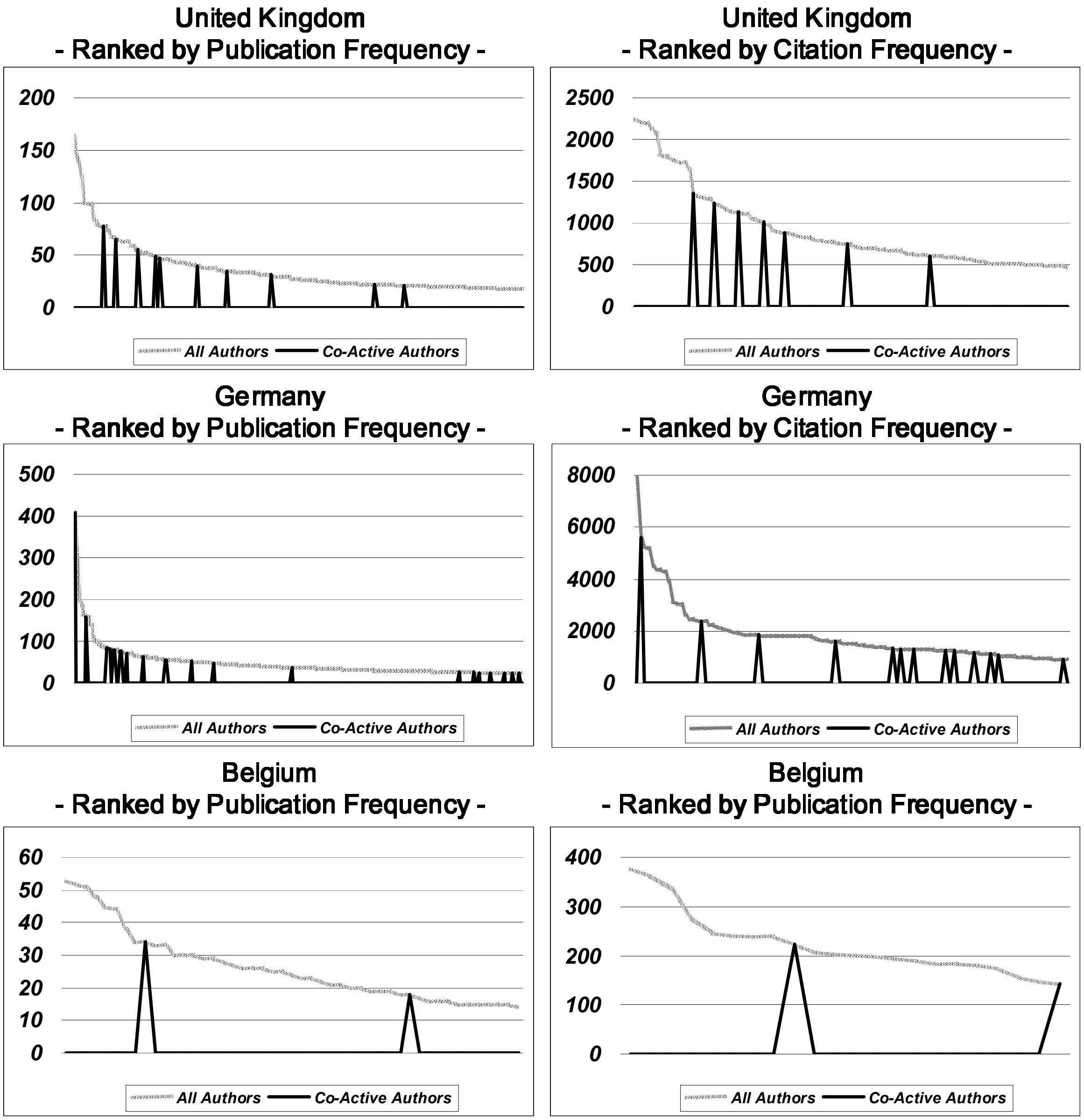
[13] The initial research design was in part inspired by Zucker and Darby's (1996) notion of 'star-scientists'. The authors observed that a small minority of researchers accounting for a high share of publications (with a productivity of more than twenty times above the average) had an intellectual capital 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.

Table 4. Highest and lowest ranked (co-active) authors in top performance class.

	Highest ranked author	*Highest* ranked *co-active* author	*Lowest* ranked *co-active* 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* *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%*

Note: *The next highest ranking co-active author published 159 papers which amounts to 39% of output by the most prolific author.



United Kingdom - Ranked by Publication Frequency -

United Kingdom - Ranked by Citation Frequency -

Germany - Ranked by Publication Frequency -

Germany - Ranked by Citation Frequency -

Belgium - Ranked by Publication Frequency -

Belgium - Ranked by Publication Frequency -

Figure 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.

Conclusions

This research illustrated that inventor–authors, or co-active knowledge generators, can play an important role in both scientific research and technological development. Co-active researchers tend to be both over-proportionally active and comparatively highly cited. The findings indicate that combining scientific with technological aspects of research and development activity does not 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 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 are a very small minority among their publishing peers. In this sense, it would be misleading to speak of techno-science on the nano-scale. The dancer metaphor which can be traced back to Toynbee and De Solla Price still seems to be adequate in the context of nano-science and technology. This observation is not that surprising if one compares the relatively small overall number of nano-inventors to the large number of nano-authors. What seems noteworthy, however, is that inventor-authors account for between almost 5% and more than 12% (depending on country and indicator) of the top-performing authors (i.e. authors in the first performance class).

On the patent side, co-active inventors even seem to 'drive' technological development if one looks at the considerable share they have among all inventors across all countries studied. While co-active authors remain a marginal group in terms of scientific publication activity, author-inventors feature prominently among nano-inventors with shares in the three countries ranging between 27% and 40%. 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) pointed to lower rates of commercial utilization of these types of inventions.

While patenting researchers are clearly over-proportionally represented in higher performing classes of authors, there remains some ambiguity with respect to their share among the 'super-excellent' or top-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 co-active researchers achieve between 48%-70% of the performance levels of the highest ranked researchers, with the notable exception of a German co-active inventor who accounted for the highest publication frequency overall.

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 illustrated, there is also a relatively strong second-tier of co-active top-performers in German nanoscience and nanotechnology. A closer inspection of the data indicated that many of these author-inventors headed nanotechnology 'centers of competence'. These academic-led centers (networks) of competence that are built around technological themes with obligatory industry participation may have resulted in 'super-excellent' researchers extending their activities into the technological domain.

Social network analysis may also be a fruitful avenue of future research. This paper does not address the centrality of co-active individuals in the different worlds of science and technology: Do inventor-authors play a central or marginal role in both networks of scientific communication and the technology community, or do they achieve prominence only in one of the two? This research so far indicates that patenting researchers are among the more prolific authors and also tend to achieve considerable visibility in terms of citations. Based on these observations, it seems likely that patenting researchers would be frequent co-authors and play relatively central roles in their networks of scientific communication. A closer examination of inventor data is required to see whether the high scientific standing is met 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 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 co-active and non-patenting organizations would be the logical next step to follow up on this research. In addition to identifying organizations that employ co-active 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.

Nanotechnology is a heterogeneous and diverse field and so is nanoscience. Both integrate knowledge from a variety of disciplines and sectors. Future research should address the question as to whether the sub-fields that resemble 'nanotech' follow different innovation and co-activity patterns. In addition, one should explore the extent to which differences between countries and their specializations matter in this context.

Finally, this study addressed measured citation performance by times cited counts. These counts capture citations received from all papers in the Science Citation Index and are thus embedded in the universe of all (indexed) science but do not recognize the community of nano-scientists and technologists. It would be interesting to explore to what extent results differed if one looked at the community level only. A high standing in the overall community of science may not translate into high visibility amongst nano-scientists.

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), 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). The author is grateful for comments from workshop and seminar participants. He also wishes to thank Annika Rickne, Linda Butler, Margherita Balconi, Wolfgang Glänzel, Hildrun Kretschmer, Erkko Autio and Michel Zitt for helpful suggestions. Tom Magerman's assistance in data processing was much appreciated. The author is grateful for financial support from the Gatsby Charitable Foundation.

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