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INVENTOR-AUTHORS: KNOWLEDGE INTEGRATORS OR WEAK LINKS? AN EXPLORATORY COMPARISON OF CO-ACTIVE RESEARCHERS WITH THEIR NON-INVENTING PEERS IN NANO-SCIENCE AND TECHNOLOGY

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Inventor-Authors: Knowledge Integrators or Weak Links?

An exploratory comparison of co-active researchers 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 nano-science publications and nanotechnology patents of a small set of European countries. While only a very small number of nano-scientists appear to hold patents in nanotechnology, a considerable number of nano-inventors seem to be actively publishing nano-science research. Overall, these co-active individuals 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 over-represented in this top category, inventor-authors appear not to claim the top ranks within it in most instances.

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.

There are several ways of measuring this interaction with informetric means, such as the analysis of patent citations, co-publications of industrial firms, or university patenting. Another approach is inventor-author analysis. The purpose of this paper is to explore for the field of nanoscience and nanotechnology the role of co-active knowledge producers in both scientific research and technological development.

More specifically, this paper explores to what extent researchers who both patent and publish 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 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 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 dancers 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 commercialisation in academic research (Gibbons et al., 1994; Etzkowitz and Leydesdorff, 1997). Other analysts 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., 2000; 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 organisation 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,[1] 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 (1998) show that ‘star scientists’ from universities played a key role in the birth and growth of the biotechnology industry by playing dual roles as entrepreneurs and research scientists. Murray (2002) explores the interface of scientific and technological networks in tissue engineering and shows that science and

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[1] For instance, Pavitt (1998) and Grupp/Schmoch (1992) pointed to improvements in data processing technologies and information retrieval techniques as well as a more wide-spread distribution of and subscription to specialized databases.

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. (2000, 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; Basscoulard and Zitt, 2004). These include various forms of patent citation analysis (e.g. Narin and Noma, 1985; Narin et al., 1995, 1997; Hicks, 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. There are various approaches. More recently, patents with university researchers as inventors have been traced in a number of studies (e.g., 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 1980’s and early 1990’s 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, the approach was used by Schmoch (2004) and colleagues 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[2].

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 more related to more recent US efforts using patent-paper pairs (e.g. Murray, 2002; Stern and Murray, 2004) 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.

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[2] Observations by other researchers pointed to a strong specialization of university researchers' inventive activity and thereby to the considerable share of universities and their researchers' in patenting certain technologies (see, for instance, Meyer, 2003)

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 licence 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 162 patent-paper pairs in biotechnology, Murray and Stern (2004) explored the question whether formal intellectual property rights hinder the free flow of scientific knowledge. They find evidence for a quantitatively modest but statistically significant ‘anticommons’ effect. Publications linked to patent grants are associated with a higher overall citation rate. However, the authors observe declining citation rates between 11%-17%. They also observed that the effect increases with the years elapsed from the time of the patent grant, and is particularly important for articles authored by researchers with public sector affiliations.

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; MacMillan et al., 2000; Gittelman and Kogut, 2003; Murray, 2002, 2004; Murray and Stern, 2004). There are relatively few studies that look also 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.

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 are still exceeded applied publications in terms of both publication frequency and publication growth. The authors have not been able to identify evidence that the focus of ‘entrepreneurially oriented researchers’ had shifted towards applied research.

In their survey of university faculty members in Norway, Gulbrandsen and Smeby (2002) found that faculty with external funding carry out significantly less basic research than researchers without any external funds. The survey also indicated that faculty who acquired external industrial funding publish more journal articles than their peers with other external funding and also more than peers without any external funds. As Geuna and Nesta point out, this corroborates findings by Godin (1998) and Blumenthal et al. (1996) in their earlier North American studies.

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.[3]

Scope of this Research

This paper aims to explore the extent to which co-active researchers over or underperform in comparison with peers who exclusively publish research. While most studies were focused on biotechnology and subfields or limited to a particular

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[3] Further analysis of KUL case study data by Van Looy et al. (2004) seems to point to similar results.

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.

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. Some studies addressed the basic/applied continuum; others focused on citation rated of papers before and after patent grants. This paper makes an effort to explore the extent to which patenting is associated rather with ‘good’ scientists or rather with researchers who occasionally publish.

The aim of this study is 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?

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, 2003).

There are many different approaches as to how one can define nanosciences and nanotechnology (e.g. Budworth, 1996; Malsch, 1997; 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 this is the working definition:

> 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 nano particles 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, Meyer, DuPlessis, 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 co-active individuals through a matching procedure based on inventor surnames and in initials. Forming inventor-author pairs poses considerable challenges for the analyst.

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**			

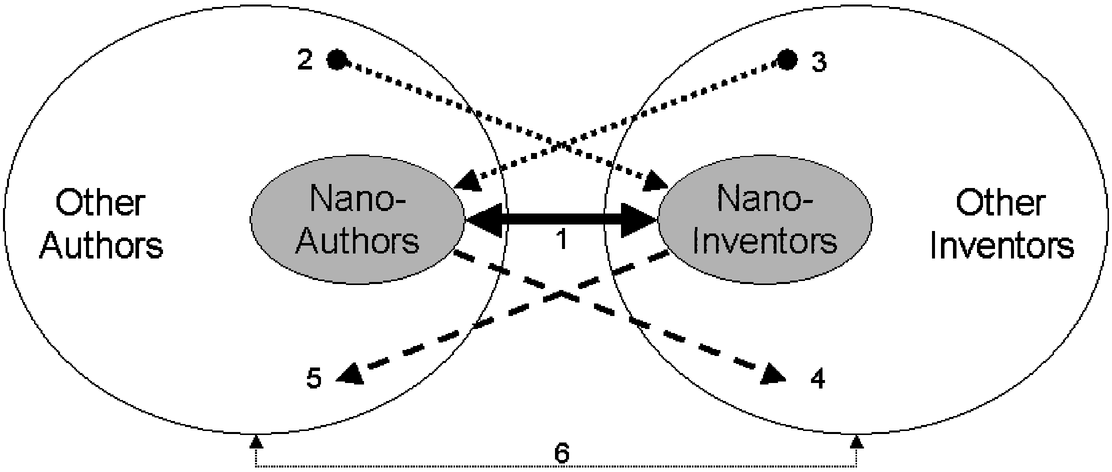
Source: Steunpunt O&O Statistieken

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. The latter expectation holds probably only if co-activity analysis is carried out 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’.

Restricting the publication and patent universes in a restricted 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, researches 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 papers contributions to the field of nano-science (#3). Other inventor-author links include nano-inventors publishing papers on non-nanoscience topics (#4) and nano-authors patenting non-nano inventions (#5). Apart from these links, researchers outside both the fields of nano-science and nanotechnology may engage in both patent and publication activity (#6).

To ensure that the level of '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 let to a vast number of (often 'false') matches.

Figure 1. Choices in Linking Publication and Patent Data.



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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

[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 reduce the number of irrelevant matches further.[6] Furthermore, the number of countries was restricted to initially a set of three countries (Belgium, Germany, and the UK) in which the author knows networks and actors rather well. 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.

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 accounting for the top 20% of the publication counts (or citation counts, respectively). The fifth quintile comprises the least prolific or cited authors. The representation of co-active authors in the different frequency classes was 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.

Results

This section gives an overview of the findings. First, basic data on the results of the matching procedure is 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.

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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).

Relative Importance of Co-activity

First, this section examines the importance of individuals in relation to the colleagues who either only publish or patent. Table 2 presents an overview. On the technology side co-active inventors account for a relative large share amongst the countries' nano-inventors ranging between 27% to 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 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[7] 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-active among all nano-inventors.

Table 2. Basic data on authors and inventors

	Belgium	Germany	United Kingdom
#Authors	2652*	22,242*	13,235*
#Inventors	44	890	185
#Coactive	12	301	75
	(1.7%**)	(1.5%**)	(0.6%**)
	(27.3%***)	(33.8%***)	(40.5%***)

Notes:
* This count also includes foreign-based authors collaborating with domestic authors since the SCI does not allow to personalized assignation of author addresses.
** Indicates the share of coactive amongst all nano-authors (see also fn.7)
*** Indicates the share of coactive among all nano-inventors.

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[7] 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 build 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 includes 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 include other nationals as co-authors.

These observations may invite some speculation as to why the co-active share among nano-inventors is so relatively high. Other studies pointed to the relatively high share of public research organizations in patenting also in other areas of emerging (sub-) fields of science and technologies. Can one observe this high public share because established firms are sceptical about the commercial potential of the inventions? Have they missed out on a technological development? Are different propensities towards risk-taking be an

Research Productivity and Citation Performance

This section compares the publication and citation performance of co-active researchers to 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 were over-proportionally represented among highly cited authors as well. Figure 2 and Tables 2 - 3 present the findings in detail.

As the distribution of author and inventor types across performance classes illustrates (Table 1, 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.[8]

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

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[8] 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.

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 seems to suggest that co-active inventor-authors are over-represented in the better performing classes. Table 4 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 0.4 and 0.8). The Belgian data again points in the same direction as the observations for Britain and Germany.

Table 3 Distribution of Author and Inventor Types Across Performance Classes

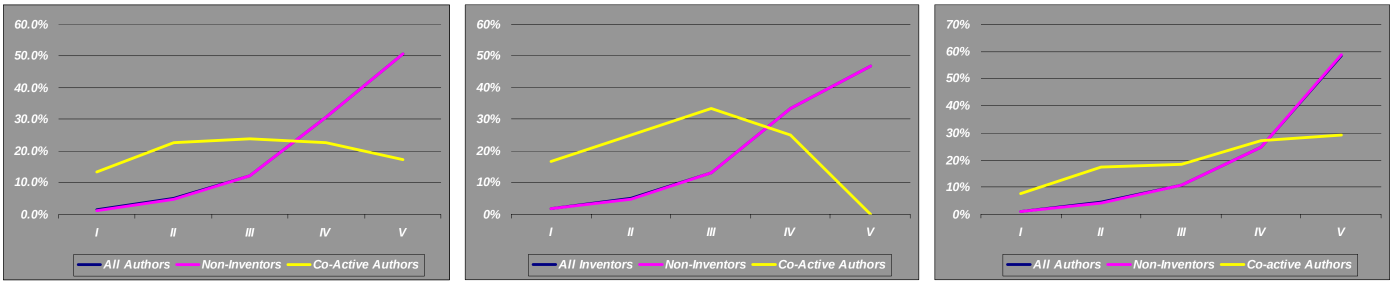
	United Kingdom			**Germany**			**Belgium**		
Full Counts									
Quintiles	All Authors	Non-Inventors	Co-Active Authors	All Authors	Non-Inventors	Co-active Authors	All Inventors	Non-Inventors	Co-Active Authors
I	1.4%	1.3%	*13.3%*	1.2%	1.1%	*7.6%*	1.8%	1.7%	*16.7%*
II	5.0%	4.9%	*22.7%*	4.5%	4.3%	*17.3%*	5.0%	4.9%	*25.0%*
III	12.3%	12.2%	*24.0%*	10.9%	10.8%	*18.6%*	13.1%	13.0%	*33.3%*
IV	30.7%	30.8%	22.7%	24.8%	24.8%	*27.2%*	33.3%	33.4%	25.0%
V	50.6%	50.8%	17.3%	58.6%	59.0%	29.2%	46.8%	47.0%	0.0%
Fractional Counts									
Quintiles	All Authors	Non-Inventors	Co-Active Authors	All Authors	Non-Inventors	Co-active Authors	All Inventors	Non-Inventors	Co-Active Authors
I	1%	1%	*20%*	1.2%	1.1%	*7.6%*	1.4%	1.4%	*8.3%*
II	4%	4%	*13%*	4.0%	3.8%	*16.6%*	4.0%	3.9%	*33.3%*
III	10%	10%	*21%*	9.3%	9.2%	*17.9%*	10.0%	9.9%	*25.0%*
IV	22%	22%	19%	21.1%	21.1%	*27.2%*	24.5%	24.4%	*33.3%*
V	62%	63%	27%	64.4%	64.9%	30.6%	60.1%	60.4%	0.0%
Times Cited Counts									
Quintiles	All Authors	Non-Inventors	Co-Active Authors	All Authors	Non-Inventors	Co-active Authors	All Inventors	Non-Inventors	Co-Active Authors
I	1%	1%	*9%*	0.5%	0.4%	*4.3%*	0.8%	0.8%	*16.7%*
II	3%	3%	*8%*	2.0%	1.9%	*7.3%*	2.1%	2.0%	*8.3%*
III	11%	11%	*21%*	5.3%	5.2%	*12.3%*	4.9%	4.8%	*16.7%*
IV	9%	9%	7%	13.3%	13.2%	*18.6%*	11.0%	10.9%	*33.3%*
V	76%	76%	55%	78.9%	79.2%	57.5%	81.2%	81.4%	25.0%
N	13183	13108	75	22242	21941	301	2652	2640	12

Table 4 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%

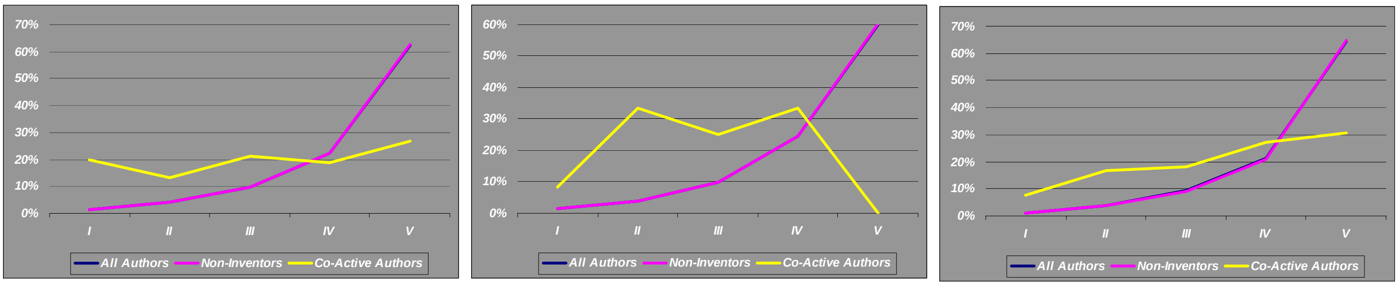
Figure 2 Cross-country comparison of Researcher Productivity and Citedness: Co-active versus non-inventing authors

Full Counts



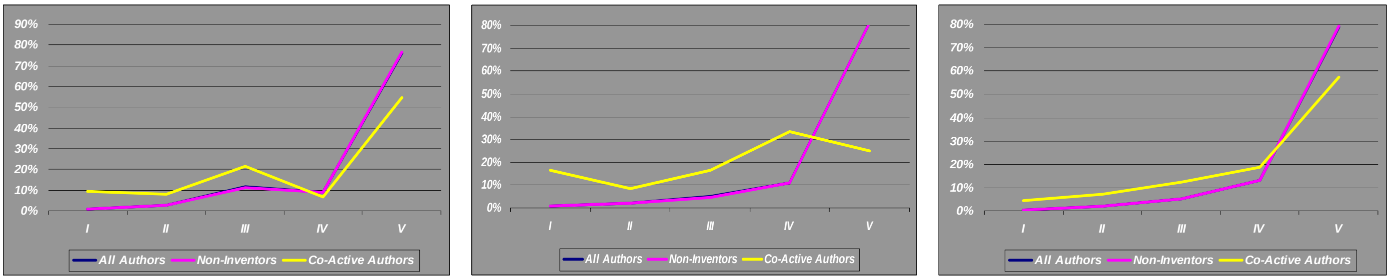
(a) United Kingdom (b) Belgium (c) Germany

Fractional Counts



(d) United Kingdom (e) Belgium (f) Germany

Times Cited



(g) United Kingdom (h) Belgium (i) Germany

Note: Authors are grouped in five performance classes (I: highest performers, V: lowest performance) 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.

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, 2004). As Table 5 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 of the papers the most prolific author has published, respectively. 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) of the most highly cited authors respectively. 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 indicates 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 price.

Data summarized in Table 5 exemplifies 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 points in a similar direction.

However, 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.

Table 5. Highest and lowest ranked (co-active) authors in top performance class

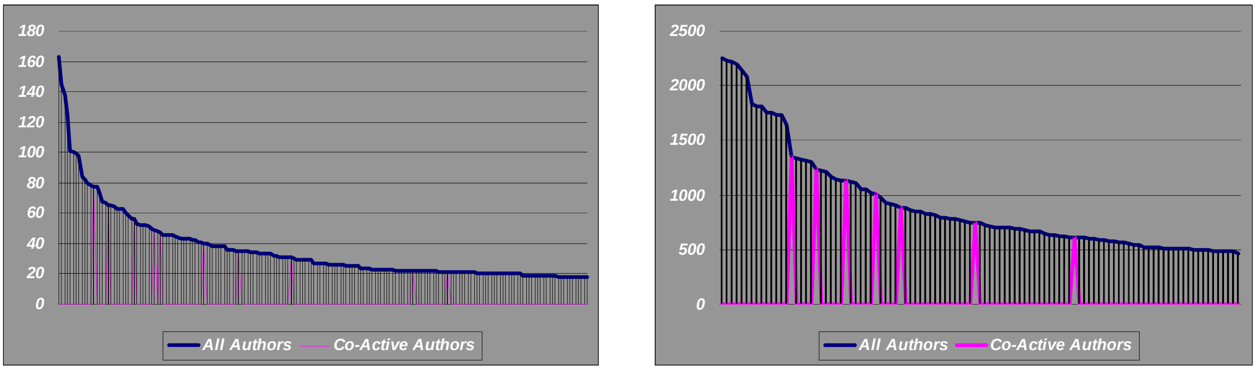
	Highest ranked author	*Highest* ranked *co-active* author	*Lowest* ranked *co-active* author	*Lowest* ranked author
United Kingdom				
Papers	163 *100%*	77 *47.2%*	21 *12.9%*	18 *11.0%*
Citations	2255 *100%*	1349 *59.8%*	608 *27.0%*	469 *20.8%*
Germany				
Papers	408 *100%*	408* *100%**	24 *5.9%*	24 *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 authors

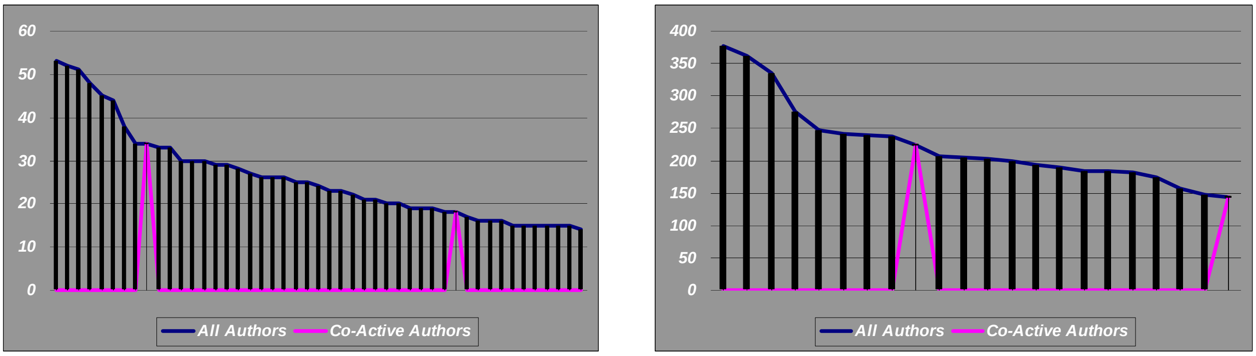
Future research needs to explore possible reasons for this. An explanation may be the specific organizational structure established in Germany for funding nanotechnology R&D. These academic-led centers (networks) of competence around technological themes with obligatory industry participation may have 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.

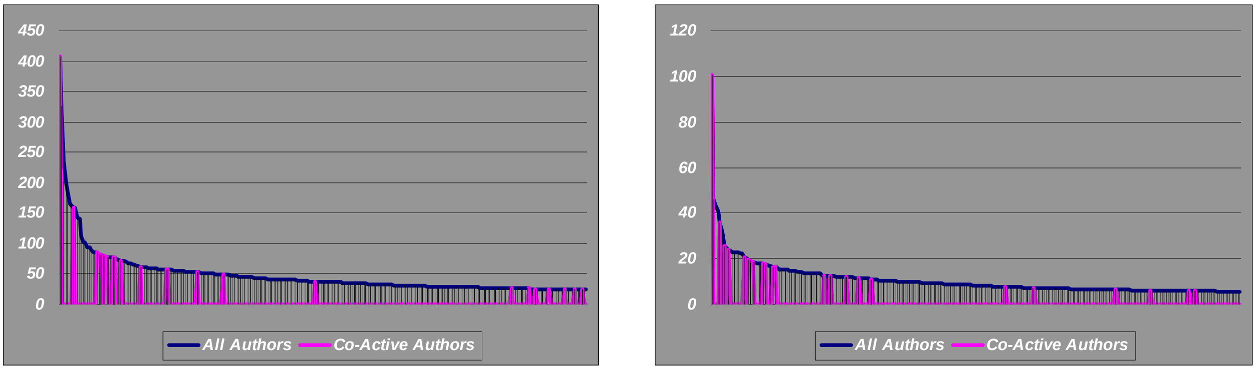
Figure 3 Distribution of Author Categories among Highly Prolific Authors (a-c) and Cited Authors (d-f)



(a) United Kingdom (d) United Kingdom



(b) Belgium (e) Belgium



(c) Germany (f) Germany

Note: Authors are ranked in descending order of their publication citation frequency on the *x*-axis while the *y*-axis points to publication (a, b, c) and citation counts (d, e, f) respectively.

Conclusions

This research illustrated that 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 effect on how co-active scientists perform in terms of publication and citation ratings.

Researchers who are ‘driven’ appear to find another outlet for their work rather than sacrifice science for the sake of technology and commerce. This would support research by others (e.g. Azagra-Caro and Llerena, 2003) who observed in case studies of universities that patenting activity tends to be associated with prestigious groups and labs.

To some extent, 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%.

However, one must beware of strong conclusions in this respect. 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 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, 2004; Meyer, 2004) pointed to lower rate of commercial utilization of these types of inventions.

While co-active 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 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 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 an extension of activities of ‘super-excellent’ researchers into the technological domain.

Nanotechnology is a heterogeneous and diverse field, so is nanoscience. Both nanoscience and nanotechnology 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.

Also more sociologically oriented work may prove insightful. Are there different types of the co-active researchers? Do they follow their invention through the entire innovation process from conception to commercialisation? Are leading (both highly active and cited) scientists ‘co-opted’ inventors? Are less cited author-inventors engineers in development who publish the occasional paper with peers in academe?

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 recognise 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. An overall high standing in the overall community of science may not translate into high visibility amongst nano-scientists only.

Finally, a question this paper did not address regards the centrality of co-active individuals in the different worlds: Do co-active inventors 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 co-active researchers are among the more prolific authors and also tend to achieve considerable visibility in terms of citations. A closer examination of inventor data is required to see whether this high standing is met on the technology side.

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