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Nanoscience and Nanotechnology in Europe: Analysis of Publications and Patent Applications including Comparisons with the United States

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ABSTRACT

Europe is investing substantial amounts of money in nanoscience, and nanotechnology is becoming increasingly important in European investment circles. In this article, Thomas Heinze analyzes the development of nanotechnology in Europe and makes comparisons with the United States by studying two basic indicators, publications and patent applications. After a brief overview of the worldwide expansion of nanopublications and nanopatents and the share of different regions, disciplinary and patent specialization patterns of Europe and the United States are examined. Heinze provides a methodology for measuring the contribution of the public research sector to the knowledge base in nanotechnology by linking patent and publication databases. Rankings of the top 15 most productive public research institutions enable the reader to identify active European university and non-university research centers. Finally, a new internet-based search tool is introduced that allows one to download data on European nanotechnology at the organizational level.

INTRODUCTION

Research of nanoscale phenomena has increased over the last decade across the world. Both the fundamental understanding of structures and processes at the atomic and molecular scale (nanoscience) and the utilization and control of nanoscale phenomena for specific purposes (nanotechnology), have progressed considerably in the last years. Not only scientists and technology developers are intrigued by the fascinating opportunities of this emerging field of science and technology,

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but also policy-makers believe nanotechnology to be one of the key technologies of the 21st century that will create new markets and thus prosperity.[1]

Since 2000, the United States National Nanotechnology Initiative ("NNI") has fuelled considerable resources into the exploration of nanoscale phenomena and the development of useful devices and structures. Similarly, several European countries have pursued their own nanotechnology agenda since the late 1980s. Among the first was the United Kingdom in 1986, while France and Germany followed later. In addition, the European Commission funded many research projects in the early 1990s and made nanotechnology one of its research priorities under the current Research Framework Programme (2003-2006).[2]

This article analyzes the overall development of this novel field by studying two basic indicators, publications and patent applications. It describes the development of both nanoscience and nanotechnology in Europe and includes comparisons with the United States. Results partially draw upon data and results of a recent study for the European Commission on nanopublications and nanopatenting across Europe.[3]

After introducing data sources (Part II.), a brief overview about the worldwide expansion of nanopublications and nanopatents is provided, and the share of different regions is discussed (Part III.1.). I also examine different specialization patterns of Europe and the United States in publications and patent applications (Part III.2.). In order to account for the contribution of smaller European countries in this novel field of science and technology, country size is taken into consideration when exploring the relationship between publications and patents (Part III.3.).

In Part III.4., the paper introduces a methodology for measuring the contribution of the public research sector to the knowledge base in nanotechnology developed by Noyons et al.[4] Rankings of the top 15 most productive public research institutions enable the reader to identify active European university and non-university research centers. An analysis of institutional profiles of European universities in nanotechnology sheds light on the European research landscape (Part III.5.). Finally, I introduce a new and freely available internet-based search tool that allows the reader to browse and download data on European nanotechnology at the organizational level (Part IV.).

I. PATENT AND PUBLICATION DATA

In the following, I discuss data and results of a recent study for the European Commission on the *Mapping Excellence in Nanoscience and Nanotechnology across Europe*.[5] Publications were taken as a proxy for basic research and scientific orientation, and patent applications as a proxy for applied research and technology orientation. The publication analysis was performed by the Centre for Science and Technology Studies ("CWTS") at the University of Leiden, the Netherlands. The Fraunhofer Institute for Systems and Innovation Research in Karlsruhe, Germany, was responsible for the patent analysis.[6]

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[1] TECHNOLOGIE AM BEGINN DES 21 (H. Grupp, ed., 1993).

[2] The website http://www.cordis.lu/nanotechnology/src/publication.htm provides useful information about nanotechnology research in the 6th European Framework Programme.

[3] E.C.M. NOYONS, ET AL., EUR. COMM'N, MAPPING EXCELLENCE IN SCIENCE AND TECHNOLOGY ACROSS EUROPE, NANOSCIENCE AND NANOTECHNOLOGY, (Eur. Comm'n, Rep. No. EC-PPN CT-2002-0001, 2003).

[4] *See id*.

[5] *See id*.

[6] The article reports also on patent and publication data outside the context of the European project. The origin of the data is mentioned at the bottom of figures and tables.

Publication data were retrieved from the Science Citation Index ("SCI"), the world's largest publication and citation database in the natural and medical sciences.[7] While the choice of SCI is obvious, there are a number of different patent databases available. Searching patent documents in databases by national or regional patent offices is generally less productive, as the legal requirements of disclosure with regard to titles and abstracts are not very strict. If a search has to be based on keywords to a considerable extent, it should be executed by using Derwent World Patents Index ("DWPI"). The staff of Thomson Derwent prepares new titles and abstracts that describe the technological content of each patent application in more detail and depth. A search of "nano" with right-hand truncation in DWPI titles and abstracts yields about three to four times as many documents as a search in official databases of the U.S. Patent and Trademark Office or the European Patent Office. Therefore, DWPI was chosen as database.

It is not only important to choose the right database, but also the relevant type of patent document. In the European case, the European Patent Office ("EPO") is the first choice for most European applicants. At the EPO, a central examination procedure is carried out that is valid for all member countries of the European Patent Convention ("EPC"). If the patent is granted, the applicant can transfer it to all destination countries to achieve national protection. As the expenses for an EPO application and examination are high, EPO applications represent inventions of high technological and commercial value. Furthermore, the same legal rules apply for all applicants so that a statistical distortion by specific national rules is avoided.

In recent years, foreign applications are increasingly filed as an international application at the World Intellectual Property Organization ("WIPO") or as a Patent Cooperation Treaty ("PCT") application.[8] This is a central application procedure, often including a preliminary examination. However, the relevant examination with respect to legal status is made by the "destination offices." The EPO can be a destination of a PCT application; the respective applications are then called Euro-PCT applications. The article refers to direct applications at the EPO as well as Euro-PCT applications. In both cases, the applications are published strictly 18 months after the priority date.[9]

A major challenge for publication and patent analyses is the proper definition of the fields of science and technology under consideration. Basically, the search strategy for the publication and patent databases should be as large as possible and include as few unsuitable documents as necessary.[10] The standard approach in patent searches is to use appropriate codes of the International Patent Classification ("IPC"), by means of which examiners of the patent office classify each patent application. The delineation of the search strategy for nanotechnology proved to be quite complex, as the specific IPC-subclass B82B for this field was introduced in the year 2000 and does not cover former years. Therefore, the strategy had to be built mainly on keywords including the right-truncated term "nano" but also other nano-related keywords such as "quantum dot," "lithography" or "tunneling." Similarly, a search strategy for the publications was developed because nanoscience is not coded as a field of research in the SCI. This search strategy is built also around "nano" and includes additional terms such as "scanning probe microscopy" or "surface modification." Terms like "wavelength" or "nanosecond" are excluded, as they appear in inappropriate contexts, in particular as "optical wavelength." The terms are combined by

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[7] For details of the patent data see NOYONS ET AL., *supra* note 3, at chap. 2, Appendix B.

[8] See U. Schmoch, *Impact of international Patent Applications on Patent Indicators*, 8 RESEARCH EVALUATION 119 (1999).

[9] This is a decisive advantage compared to an analysis of patents at the United States Patent and Trademark Office ("U.S. PTO"), because only granted patents are published there, and the delay between application and grant is uncertain and can be several years.

[10] For sake of convenience I use "patent" as the equivalent to "patent application" in the following.

intersection (operator "and") in the title and by proximity indicators in the abstract. Experts were involved for a judgement of the terms used. Both search strategies are available in Noyons et al.[11]

II. ANALYSES AND RESULTS

1. Worldwide Nanopublications and Nanopatents

The worldwide rise both in nanopublications and nanopatents is remarkable (Figure 1). Since the discovery and development of the Scanning Tunnel Microscope ("STM") in the early 1980s and later Atomic Force Microscope ("ATM"), research on nanoscale phenomena has burgeoned, particularly since the early 1990s. The number of SCI publications in 2002 is six times the number it was 1992. Over the whole 20-year period, depicted in Figure 1, we find an annual growth rate of 37% in the number of publications. Similarly, the number of EPO patent applications in 2001 has quintupled compared to 1991, amounting to an annual growth rate in nanopatenting of about 25%. Patenting activities start conspicuously early and grow steadily until the mid 1990s when they suddenly shoot to beyond 500 patent applications a year. Publication activities, on the other hand, start in the early 1990s, only when the expensive STM and ATM become available at reasonable prices. The stark increase in publications in the year 1991 has continued ever since and has led to a lagged but similar development in patenting activity. Both curves tend to resemble the developments in other fields of science-based technologies, such as biotechnology or laser medicine.

The results are consistent with other bibliometric studies on nanoscience and nanotechnology published since the late 1990s.[12] In the most recent study, however, Hullmann and Meyer report far fewer worldwide nano patent applications because they use the official EPO database instead of DWPI.[13] Searching with DWPI titles and abstracts proves to be a major advantage for the proper identification of nanotechnology patents.

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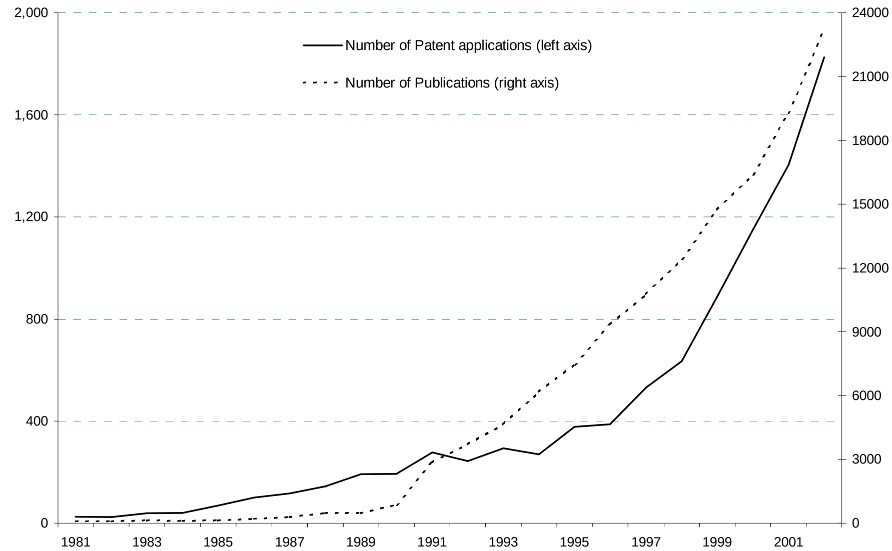
[11] See NOYONS ET AL., *supra* note 3, at 99-101. The appropriate word order and distance was tested by looking at sub-samples of about 50 titles and abstracts in order to verify the linkage to nanotechnology and the reasons why unsuitable documents are included. The aim of this check was to achieve an accuracy rate above 95%. However, this is only correct for the sub-samples selected by chance and cannot be guaranteed for the complete data set. A result of this check of sub-samples was, for instance, that in the abstract, a distance of more than 2 words between the keyword pairs implies a considerable increase of hits, but also an increase of incorrect documents. Obviously, it is not possible to include all documents relevant for nanotechnology without substantial "noise."

[12] T. Braun et al., *Nanoscience and nanotechnology on the balance*, 38 SCIENTOMETRICS 321 (1997); M. Meyer & O. Persson, *Nanotechnology—Interdisciplinarity, Patterns of Collaboration and Differences in Application*, 42 SCIENTOMETRICS 195 (1998); M. Meyer, *Patent Citation Analysis in a Novel Field of Technology: An Exploration of Nano-Science and Nano-Technology*, 51 SCIENTOMETRICS 163 (2001); A. Hullmann & M. Meyer, *Publications and Patents in Nanotechnology: An Overview of Previous Studies and the State of the Art*, 58 SCIENTOMETRICS 507 (2003).

[13] *See* Hullmann & Meyer, *supra* note 12, at 510.

Figure 1: Number of SCI-Nanopublications (publication year) and EPO/PCT-Nanopatent Applications (priority year) on the World Level



Patent applications are projected for 2002.
Source: DWPI and SCI, Online host STN Karlsruhe, computations by author.

2. Europe and the United States: A Comparison

Between 1996 and 2001, there are about 90,000 worldwide publications in SCI, a third of which can be attributed to the European Union Member States ("EU-15"), 26% to the United States, 13% to Japan, 7% to the ten formerly associated European countries (since June 1st, 2004 member of "EU-25")[14] and 22% to other countries including Russia, China, Switzerland and Israel. Hullmann and Meyer report similar numbers.[15]

With about 40% of all scientific nanopublications worldwide, Europe is a major player in the international research community on nanoscale phenomena. Within nanoscience, physics, chemistry and materials science make up the bulk of SCI publications, whereas publications in biology and the engineering sciences are less frequent. Among the worldwide top 5 SCI subdisciplines in 2003, we find Materials Science (13%), Applied Physics (10%), Physical Chemistry (10%), Physics of Condensed Matter (8%) and General Chemistry (6%). The growth rates in Materials Science are 26% between 1999-2000 and 2003, and 61% in Chemistry. Expanding subfields are also Polymer Science (35%), Metallurgical Engineering (29% growth), Chemical Engineering (29%) and Applied Chemistry (24%). So, although nanoscience is a novel science with many fundamental and basic research questions, the growth rates in the engineering subfields point to an increasing attention to more applied problems within the nano community.

In the bibliometrics literature, country comparisons are done with specialization indices. Figure 2 presents a common index, the "relative literature advantage" ("RLA") measuring the specialization of a country (or group of countries) relative to the world output in a given category, here the SCI codes of

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[14] EU-15 includes France, Belgium, the Netherlands, Germany, Greece, Portugal, Spain, Ireland, Luxembourg, Austria, Italy, United Kingdom, Sweden, Denmark and Finland. Ten countries were given member status in June 2004: Poland, the Czech Republic, Slovakia, Slovenia, Hungary, Malta, Estonia, Cyprus, Lithuania, and Latvia.

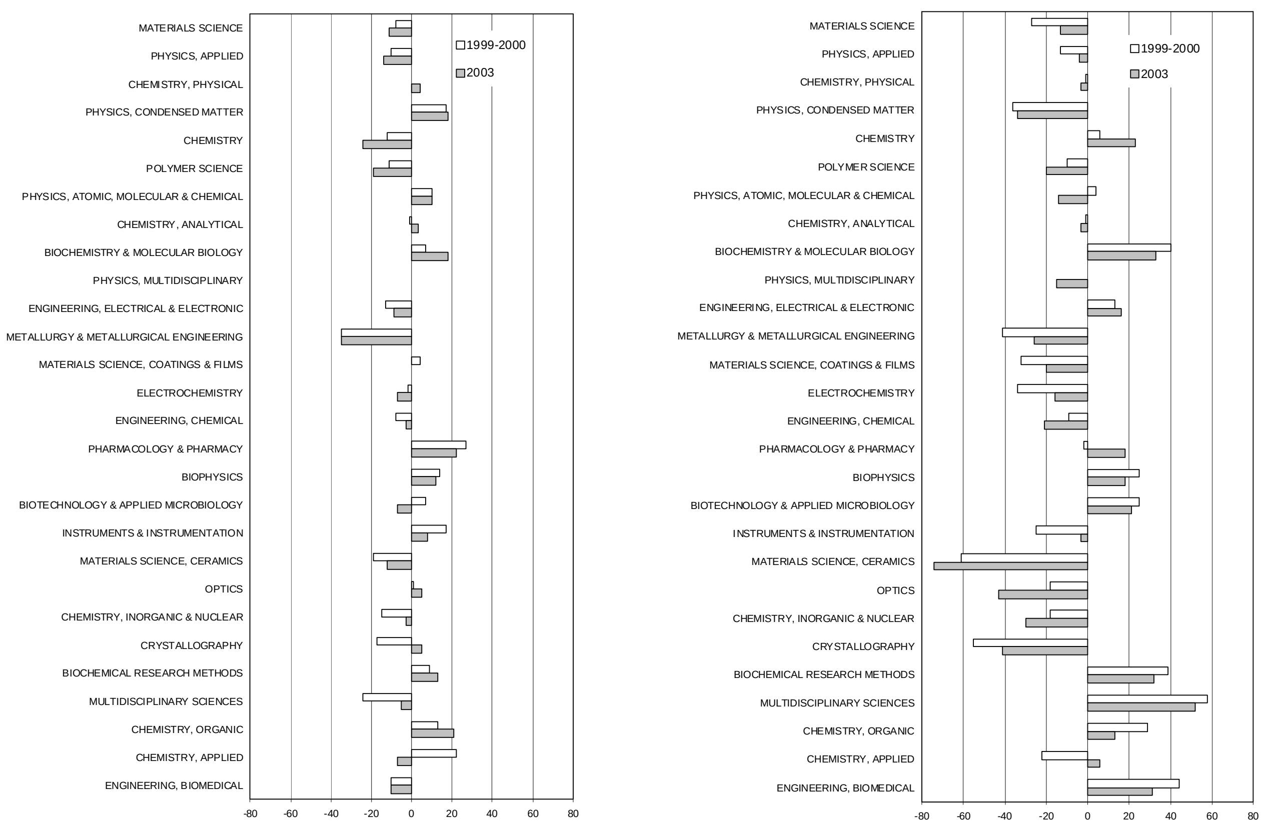
[15] *See* Hullmann and Meyer, *supra* note 12.

scientific subdisciplines. The index's range is from -100 (strong below world average specialization) to +100 (strong above world average specialization). The results refer to the years 1999-2000 and 2003 covering a five year time window. All subdisciplines are displayed in descending order, so the top 10 fields make up 62% of the SCI publication output, the bottom 10 fields just 11%.

The contribution of the EU-15 to nanoscience is relatively even across all scientific subdisciplines, whereas the United States tends to be either over- or underspecialized in many subdisciplines. A closer look at Figure 2 reveals that the U.S. is specialized primarily in fields such as biochemistry, biophysics, biotechnology and biochemical research methods. On the other hand, the U.S. has comparatively fewer publications in materials-related fields including metallurgy, and optics. EU-15 countries have a slight advantage in the physics of condensed matter where the U.S. is rather weak, but in general, they resemble the overall worldwide publication pattern. What cannot be inferred from Table 1, however, is a reversed specialization pattern of Europe and the US.

Figure 2: Disciplinary Specializations in Nanoscience: Europe and U.S. Compared

European Union (15) **United States**



*Source: SCI, Online host STN Karlsruhe, computations by author. Displayed is the Relative Literature Advantage (RLA) measuring the relative specialization of a country (or group of countries) to the world output in a given category, here the SCI-codes of scientific subdisciplines. RLA = 100*tanh (ln ((Pubij/ j Pubij)/(i Pubij/ ij Pubij))). Pub = Publications; i= country, j= subdiscipline (within nanoscience). RLA ranges from –100 to +100 and can be interpreted as follows: -100 to –51: strong below average specialization; -50 to –16: below average, -15 to +15: average; +16 to +50: above average; +51 to +100 strong above average specialization. For details see note 1,* supra.

Between 1996 and 2001, about 5.000 worldwide patent applications were filed using the EPO or PCT process. More than 36% of these applications are from EU-15 countries, particularly from Germany (820), France (299) and the United Kingdom (219), only 4% of all patent applications come from one of the new member states of EU-25. Their technological output remains modest. Similarly, Japan's contribution of 325 applications (or 9%) at EPO/PCT is weaker than its production of scientific papers (13% of all SCI publications). The number of U.S.-based applications amounts to 1549 (or 43%)—a sizeable number when one considers that most U.S. patents are filed at the U.S. PTO. The United States' technological strength is also noteworthy in comparison to their relative scientific output (26% of all SCI publications).

With more than 40% of all nanopatent applications worldwide, Europe adds to its major scientific role one of substantial technological capacity. It is well known that nanotechnology spans sectoral boundaries and encompasses a diverse set of subfields.[16] Figure 3 supports this finding impressively by showing that the most active technological subfields belong to five out of eight main sectors of the International Patent Classification ("IPC").

The classification codes of IPC allow a finegrained analysis of subfields. Figure 3 shows that between 1996 and 2001 most nanotechnology patents are filed in medical applications (i.e., A61K) and the characterization of nanomaterials (i.e., G01N). Europe has a slight lead in the former category, while the United States appears stronger in characterization methods. Semiconductors (i.e., H01L) on the one hand, and measuring devices involving micro enzymes or microorganisms (i.e., C12N, C12Q) on the other hand, are among the second most active fields within nanotechnology. Relative to the U.S., Europe tends to be more active in methods of separating materials (i.e., B01D) and developing new physical or chemical processes or apparatuses (i.e., B01J). In both subfields, the number of American applicants expanded, however, thus narrowing the gap. Furthermore, U.S. applicants file more and more patents in chemical nanotechnology.

Though nanopublications and nanopatents cannot directly be compared, two results seem noteworthy when interpreting both Figures 1 and 2. First, the EU-15 specialization in pharmaceutics tends to be reflected in a relatively high share of patents for medical purposes. Drug delivery is one of the relevant fields where progress has been made in Europe over the course of the last decade. Second, the U.S. specialization in biochemical subdisciplines shows up also in the relative share of patents involving enzymes or microorganisms. Many experts believe that this area will be highly important for nanotechnology as a whole.

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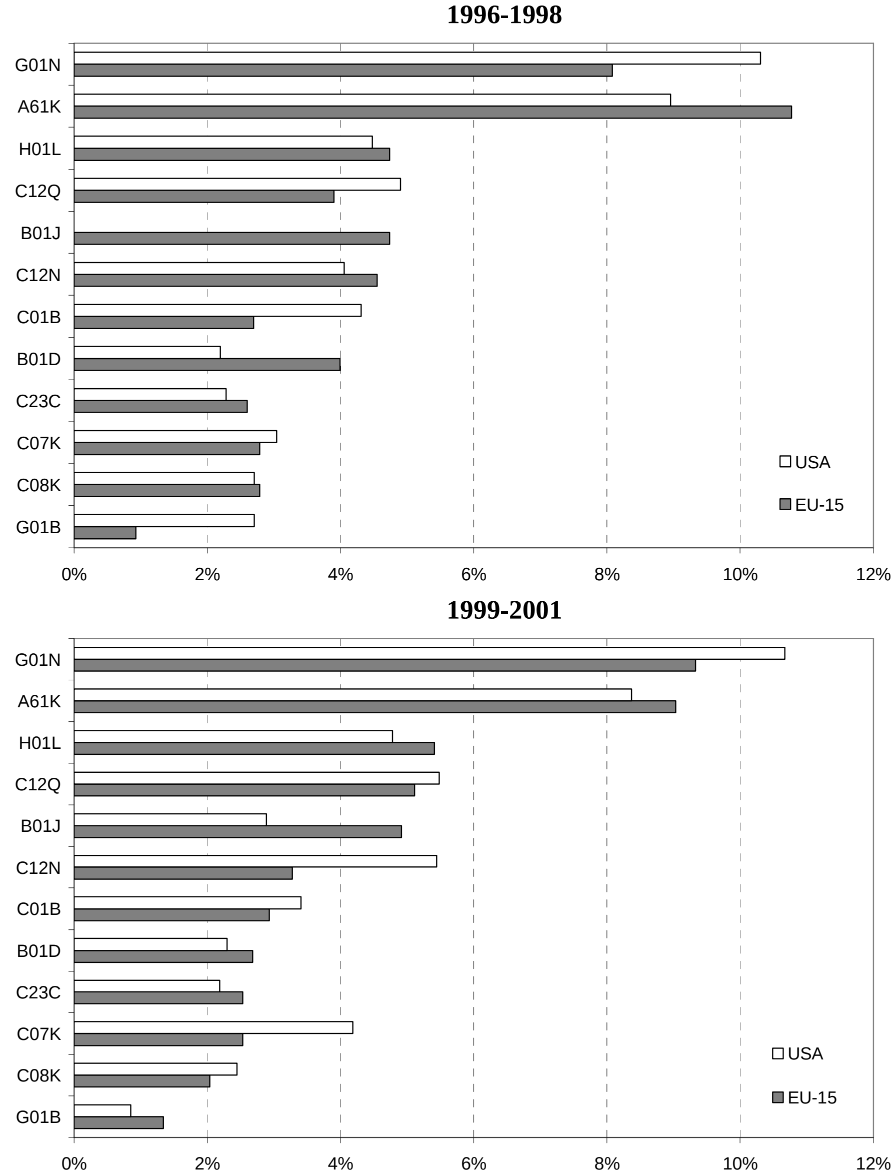
[16] M. RATNER & D. RATNER, NANOTECHNOLOGY. A GENTLE INTRODUCTION TO THE NEXT BIG IDEA (2003); G. Bachmann, *Innovationsschub aus dem Nanokosmos*, Düsseldorf: VDI -Technologiezentrum (1998); *see also* Meyer & Persson, *supra* note 12.

Figure 3: EPO/PCT Patent Applications in Nanotechnology by IPC Classification (4 digit)



G01N = INVESTIGATING OR ANALYSING MATERIALS BY DETERMINING THEIR CHEMICAL OR PHYSICAL PROPERTIES
A61K = PREPARATIONS FOR MEDICAL, DENTAL, OR TOILET PURPOSES
H01L = SEMICONDUCTOR DEVICES; ELECTRIC SOLID STATE DEVICES NOT OTHERWISE PROVIDED FOR
C12Q = MEASURING OR TESTING PROCESSES INVOLVING ENZYMES OR MICRO-ORGANISMS
B01J = PHYSICAL OR CHEMICAL PROCESSES OR APPARATUS IN GENERAL
C12N =MICRO-ORGANISMS OR ENZYMES; COMPOSITIONS THEREOF
C01B = NON-METALLIC ELEMENTS; COMPOUNDS THEREOF
B01D = SEPARATION
C23C = COATING METALLIC MATERIAL; COATING MATERIAL WITH METALLIC MATERIAL
C07K = PEPTIDES
C08K = USE OF INORGANIC OR NON-MACROMOLECULAR ORGANIC SUBSTANCES AS COMPOUNDING INGREDIENTS
G01B = MEASURING LENGTH, THICKNESS, OR SIMILAR LINEAR DIMENSIONS; MEASURING ANGLES; MEASURING AREAS; MEASURING IRREGULARITIES OF SURFACES

Source: EPO and Euro-PCT Patent Applications in Nanotechnology 1996-2001, computations by author. Displayed are the percentages to which each 4-digit subcategory contributes to the overall patent output of either EU-15 or the USA

3. Nanopublications and Nanopatents in Relation to GDP

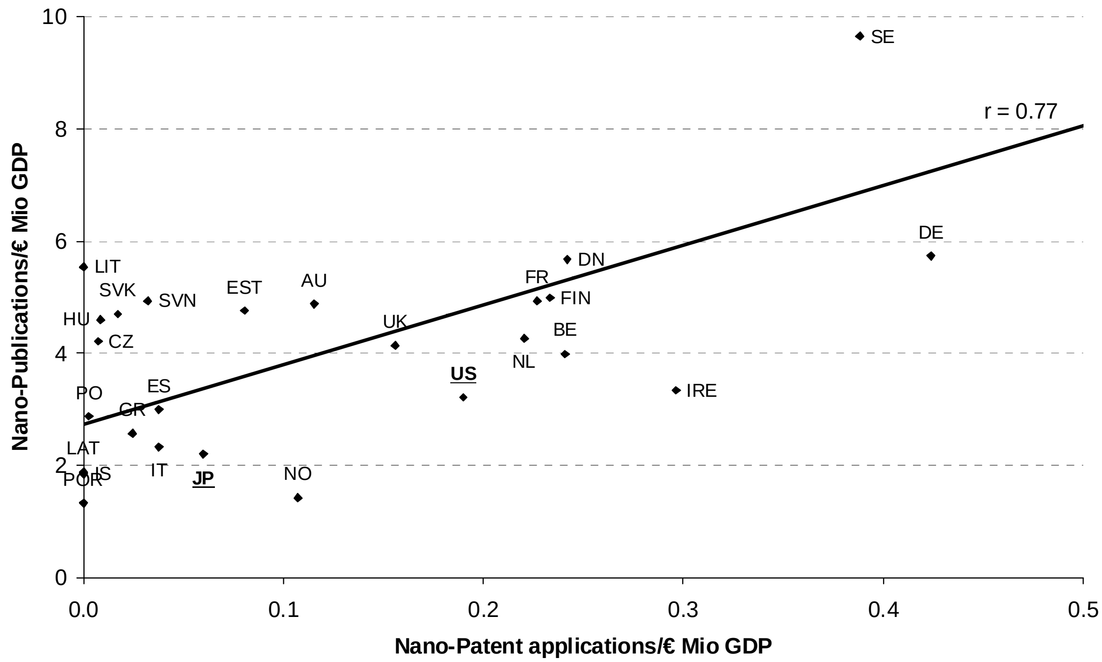
Analyzing publications and patent application in absolute terms only is problematic insofar as differential country size elevates larger countries into the spotlight at the expense of smaller but similarly productive countries. It is also difficult from absolute numbers to give an adequate account of the complex relationship between science and technology indicators.

Figure 4 plots both indicators in relative terms by using Gross Domestic Product ("GDP") in market prices as control variable. The EU-15 average is one patent and 20 publications per € 5 Mio. GDP. France, Finland, Belgium, Denmark, Ireland, Sweden, Germany (and Switzerland) exceed this average on the publication side; Austria, France, Finland, Denmark, Germany, Sweden (and Switzerland) do so on the patent side. Consequently, nearly all smaller EU-15 countries (except for Austria) perform above average in both relative publication and patent output. Switzerland has the relative best record in both dimensions (0.71 on the x-axis and 12.04 on the y-axis), but it is not displayed in Figure 4 because it would distort the scatterplot.

Among the larger countries, only Germany and France have above average performance in nanoscience and nanotechnology, whereas the United Kingdom fails to meet the European average in the technology dimension. Italy, Greece and Spain are lagging behind in both the science and the technology dimension. The United States and Japan, both included for sake of comparison, have relatively low measures and do not achieve the European average. Several of the former EU-associated countries, now member states of the EU-25, perform reasonably in the science dimension but have only modest or no patent output.

The crude relationship between the number of publications and patents is nearly deterministic: $r = .96$ ($p < .000$). Controlling for country size, the correlation coefficient is reduced to $r = .77$, but this is still highly significant. So, including GDP into the analysis reduces the overall correlation, as some countries have relatively low scores in either of the two dimensions. In Figure 4 the association between science and technology is depicted by the correlation line. Below this line and beyond the average value of 0.2 patent/€ Mio. GDP, we find countries with an orientation towards nanotechnology including Switzerland (not displayed), Germany, Ireland, and Belgium. Above the line, and beyond the average value of 4.0 publications/€ Mio. GDP, there are countries with an orientation towards nanoscience, such as Austria or Estonia.

Figure 4: National Contribution to Nanoscience and Nanotechnology in Europe, Relative to GDP, 1996-2000



Source: EPO and Euro-PCT Patent Applications in Nanotechnology 1996-2001, computations by author. DE = Germany, UK = United Kingdom, FR = France, CH = Switzerland, IRE = Ireland, SE = Sweden, NL = Netherlands, FIN = Finland, DN = Denmark, BE = Belgium, AU = Austria, EST = Estonia, LIT = Lithuania, HU = Hungary, CZ = Czech Republic, PO = Poland, SVK = Slovakia, LAT = Latvia, POR = Portugal, IT = Italy, GR = Greece, NO = Norway, JP = Japan, US = United States, IS = Island

4. Nanopatent Output of Public Research Organizations ("PROs") in Europe

In the literature on technological innovation, many authors see the contribution of public research organizations primarily as indirect to the generation of new technologies. Salter and Martin see the impact of fundamental university research on economic growth in the following knowledge transfer mechanisms: (1) increasing the stock of useful knowledge; (2) training graduates; (3) creating new scientific instrumentation and methodologies; (4) forming networks and stimulating social interaction; (5) increasing the capacity for scientific and technological problem-solving; and (6) creating new firms.[17]

With the rise of knowledge-based technologies, such as biotechnology or nanotechnology, PROs are increasingly active in the production of knowledge that might have ramifications in the realm of technology. A growing orientation of public research institutions, in particular universities, on technological applications is reflected in indicators such as external funding by industry or university patenting activities. The interaction of universities with industry is substantial in research-intensive fields of technology,[18] and academic patenting has received increasing attention in recent years.[19]

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[17] A.J. Salter & B.R. Martin, *The Economic Benefits of Publicly Funded Basic Research: A Critical Review*, 30 RESEARCH POL'Y, 509 (2001).

[18] *See* F. Meyer-Krahmer & U. Schmoch, *Science-based Technologies: University Industry Interactions in Four Fields*, 27 RESEARCH POL'Y 835 (R. Mayntz, special issue ed., 1998); *see also* J. Owen-Smith, et al., *A Comparison of U.S. and European*

Patents are generally regarded as output indicators of applied research and technological development.[20] They represent intellectual property rights and are thus legal documents. A patent application has to fulfill various criteria to be granted. First, the described invention has to be new on a worldwide level. It is not sufficient that an invention is new for the company or new in a specific country. Secondly, the new product or process must be distinctly different compared to the state-of-the-art; it must imply an inventive step. So for someone experienced in the state-of-the-art, the solution suggested by the invention must not be obvious. Thirdly, the invention has to be exploitable in commercial terms. Scientific discoveries without a practical purpose are not patentable.

The third criterion implies that most patent applicants are industrial companies. This is reinforced by the fact that patent applications are expensive so that their issuance is only reasonable if a commercial exploitation is aimed at. Against this background, in most areas of technology, the relative number of patent applications individual inventors and research institutes hold are quite small. In standard approaches, institutional analysis of patents covers the patent applicant. With North American universities increasingly filing patents (mainly as a result of the Bayh-Dole Act 1980) in the last two decades, such an approach allows the identification of patenting activity of public research organizations. However, the situation in Europe is different. A recent Organization for Economic Cooperation and Development ("OECD") study concludes that public research organizations are presently not active patent applicants.[21] Traditionally, the ownership has remained in the hands of individual employees (mainly university professors). Although several countries, among them Germany and Austria, transferred the property rights to the universities by modifying their patent law in the last couple of years, until recently universities did not frequently file patents.

It appears problematic to conclude that universities do not patent because, if university researchers are involved in a technical invention, they appear in the patent documents as "inventors." This field, however, is seldom analyzed systematically because it contains the private but not institutional address of the inventors. It is not obvious at first sight where the inventors work and, hence, where the technological knowledge originates from. In order to make a proper estimation about public research involvement in knowledge-based fields of technology, a research group at Fraunhofer ISI developed a methodology to identify the institutional affiliation of the inventors by linking data from patent databases to publication databases. This approach makes it possible to determine the contribution of public research institutions to the development of nanotechnology patents in Europe.[22]

A. Linking inventor data with publication data

For the European study, we determined data sets of patent applications for the priority years 1996 to 2000 and constructed an in-house database, comprising applications directly made to the European Patent Office, and international applications according to the Patent Co-operation Treaty with the EPO as the destination office ("Euro-PCT").[23] The in-house database contains about 2,600 patent applications of

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University–Industry Relations in the Life Sciences, 48 MGMT. SCI. 24 (2002), *available at* http://www-personal.umich.edu/~jdos/ms_penult.pdf.

[19] K. Pavitt, *Do Patents Reflect the Useful Research Output of Universities?*, 7 RESEARCH EVALUATION 10 (1998); *see also* Meyer, *supra* note 12; J. Owen-Smith & W. W. Powell, *The Expanding Role of University Patenting in the Life Sciences: Assessing the Importance of Experience and Connectivity*, 33 RESEARCH POL'Y 1695 (2003).

[20] *See* Schmoch, *supra* note 8.

[21] ORG. FOR ECON. COOPERATION & DEV. "OECD", TURNING SCIENCE INTO BUSINESS: PATENTING AND LICENSING AT PUBLIC RESEARCH ORGANISATIONS, May 28, 2003.

[22] See NOYONS ET AL., *supra* note 3, at chap. 2.

[23] Fraunhofer ISI identified relevant patent numbers in DWPI and transferred them to EPO, which provided the relevant documents. The two steps were necessary, because DWPI documents do not contain country information.

worldwide origin in these five years, of which 1,201 have at least one applicant or one inventor from EU or EU-associated countries.

The institutional affiliation of the inventors was determined by extracting all inventors from E.U. and E.U.-associated countries from the database, all in all several thousand name entries. With the support of CWTS Leiden these inventors' names were matched to authors' names in the Science Citation Index ("SCI"). The rationale of this matching is that nanoscientists and nanoresearchers dispose of knowledge relevant also for developing new technological solutions, and therefore patent applications. The assumption is that, in science-based technologies, those who publish are involved in the patenting process too.

For the names' identification process, several selection criteria were tested. The following ones proved to achieve the best and most reliable yield:

Surname and initial of the first name;

Identical country of the inventor and author;

Comparable technical and scientific fields;

Identical time period of patent application and publication.

Generally, the use of special letters such as the German "ö" or the Danish "ø," both in the patent and publication databases, proved to be the major problem with regard to the match of surnames. Considerable manual cleaning had to be carried out, and all uncertain cases were excluded from the data set. Further, the search had to be limited to the initial of the first name, as only the initials are recorded in the SCI. Therefore, potential sources of error were different first names with identical initials and the unsystematic use of multiple first names.[24]

Problematic inventor-SCI matches occured particularly in the case of countries with the same language (Austria/Germany, Ireland/UK, Belgium/France, Belgium/Netherlands, etc.). In these cases, the identity of the country of the inventor and the country of the author eliminates potential mismatches to a considerable extent. An important step was the restriction of the match to nanoscience. Frequent names appear in many disciplines and would imply many mismatches if the searches had been executed in the SCI records for all disciplines. Similarly, the identical time periods for matching the two databases increased the accuracy of the matching (publications: 1996-2001, patents: 1996-2000).

The validation of the matches comprised several steps and is described in Noyons et al.[25] in more detail. Supported by various software tools, it was primarily based on manual checks of all database entries with regard to inventors and institutions. Of the more than 3,348 inventor names, 1,119 (or 33%) could be matched successfully in SCI; another 184 (5%) name entries were identified as problematic and were excluded from analysis. The remaining names could not be identified in the SCI.

B. Results of the Inventor-SCI Matching Process

The share of non-profit public research institutions is about 30% before the inventor-SCI matching. The high share even before the match is primarily owed to patent applications from non-university research organizations, also from a few universities in some countries. Private transfer offices working on behalf of universities are considered as non-profit, too. Examples are the Technical Services Ltd. of

[24] Owing to the structure of the SCI database, the search had to be limited to first authors in the case of co-publications of several institutions; only in the case of one institution could all authors be included.

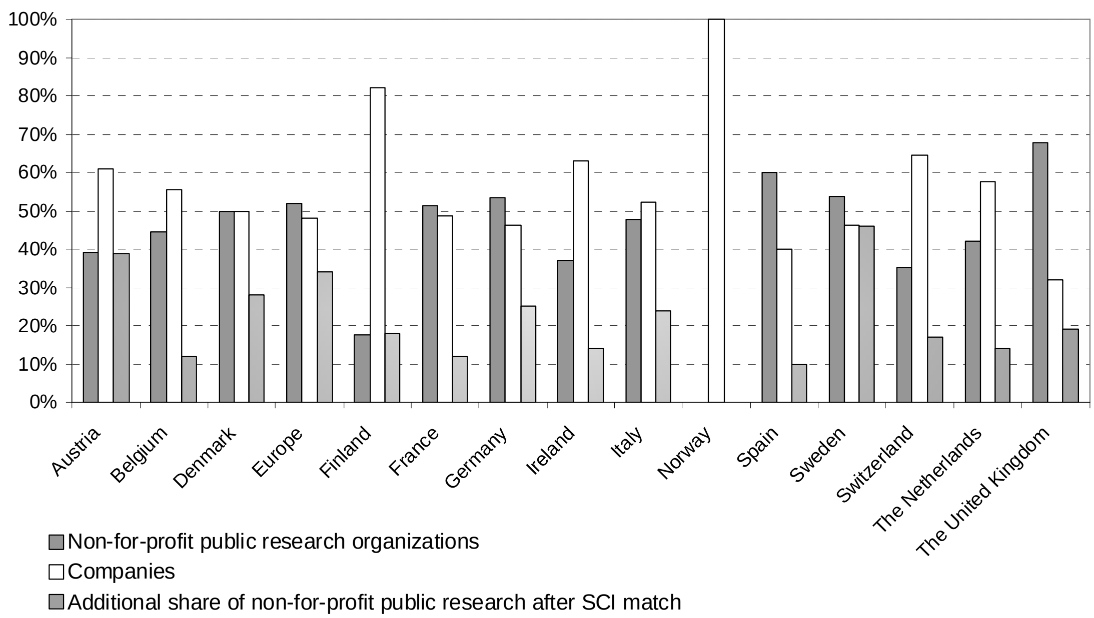
[25] See NOYONS ET AL., *supra* note 3.

Cambridge University or ISIS Innovation Ltd. in Oxford. With the introduction of additional institutions by the SCI-based match of authors and inventors, the share of non-profit organizations climbs to a level of 52%. Thus, the number of non-profit institutions, particularly universities, increases substantially by the matching process.

The share of non-profit institutions depends on the method of counting. In the share of 52% for nanotechnology, the for-profit and non-profit organizations receive one count if they appear as an applicant or by an inventor reference. In the specific case of a firm as applicant and an inventor from a university, both would be counted once. If we assume that such an invention is exclusively based on university research and that the input from the firm is negligible, only the university would be counted. The latter assumption would lead to an even higher share of non-profit public research organizations.

As depicted in Figure 5, the average share of 52% does not apply to all European countries. The United Kingdom and Spain are fairly above this level, whereas Finland, Norway and Switzerland have distinctively lower public research institutions active in developing nanotechnology. Also different is the additional input by the inventor-SCI match by country. The highest yield is found in Sweden, where before the match there were 3 PROs (8%), but after the matching process, 37 PROs (54%). Similarly, the SCI match increases the number of Austrian universities considerably. In this case, the high yield can be explained by an inventor law, valid in the observation period, which allowed university professors to exploit their intellectual property on their private account; whereas the universities did not appear as applicants in the patent documents. The situation in Germany and Italy was comparable.

Figure 5: Share of European Non-Profit Research Organizations and Companies in Nanotechnology Patent Applications



Source: EPO and Euro-PCT Patent Applications in Nanotechnology 1996-2001, computations by author.

In France, the share of non-profit organizations in the applicant information is already quite high due to a high weight of non-university research organizations, and early patent activities of universities. So, here the yield is substantially lower. In the case of the United Kingdom, the difference of the shares before and after the SCI match (49% and 68%, respectively) is remarkable, as the universities have actively engaged in patenting since the eighties.[26] Obviously, the universities often do not lay claim to the inventions of their staff, but allow them to exploit their inventions on their private account; or they directly cede the rights to firms. Even in the United Kingdom, the mere examination of the applicants would be insufficient to reflect the technological orientation of public research institutions.

5. European Nanoscience and Nanotechnology at the Organizational Level

A. Publication and Patent Rankings

The European research landscape in nanoscience consists of several hundred European universities and non-university establishments. Some research units produce only a few publications each year; the biggest and most productive ones produce several hundred publications. A closer look reveals that the bulk of nanoscientific research in Europe is conducted in about a dozen countries. Among the 100 most active research organizations, which make up more than 60% of all nanopublications in the SCI, one finds the following countries in descending order: Germany, the United Kingdom, France, Sweden, Switzerland, the Netherlands, Italy, Austria, Denmark, the Czech Republic, Belgium, Finland and Ireland. When analyzing the top stratum of research centers in terms of publication output, Table 1 shows primarily PROs from Germany, France, the United Kingdom, Switzerland and Sweden, among them several established elite institutions.

As nanoscience spans different scientific disciplines, such as physics, chemistry, materials science, but also biology and engineering, the publication ranking refers several disciplines within one PRO. It would be interesting to know whether, and in which disciplinary field, each university or non-university institute organization is specialized. Yet, a central outcome of the European study was that it is very difficult, if not impossible, to measure publication output and other bibliometric indicators, such as citation rate at the faculty or departmental level across Europe, due to the data noise in the SCI. Therefore, behind the upper organizational level, we might find one or several faculties or departments. In this sense, the ranking of Table 1 is selective in that it displays those universities with several faculties and departments active in nanoscience. Researchers from other universities, that are not displayed here, might be equally productive. In sum, the top 15 gives an overview where a wide range of nano-related scientific research is being carried out.

Table 1: Top 15 Most Active European Research Organizations in Nanoscience Publications, Ranked in Descending Order

PUBLICATION RANKINGS	YEARLY PUBLICATION OUTPUT
U London (UK)	137
U Cambridge (UK)	114
U Paris 06 (FR)	93
ETH Lausanne (CH)	90
U Hamburg (DE)	87
U Oxford (UK)	82
Max Planck Institute Metal Research (DE)	80
Research Center Jülich (DE)	77
Chalmers University of Technology (SE)	77
U Lund (SE)	72
Technical University Munich (DE)	70

[26] See OECD, *supra* note 21, at 25.

U Paris 11 (FR)	68
U Munich (DE)	65
ETH Zurich (CH)	64
U Uppsala (SE)	59

Source: Average Number of Publications in SCI per Year between 1996-2001 in EPO and Euro-PCT Patent Applications in Nanotechnology 1996-2001, computations by author.
U = University of …, DE = Germany, UK = United Kingdom, FR = France, CH = Switzerland, IRE = Ireland, SE = Sweden

It is similarly interesting to see that, out of those top 15 PROs, only a few are among the most active PROs in patenting (Table 2). As was argued before, a considerable share of European PROs is active in the production and codification of technological knowledge (patent applications). The universities in Cambridge, Oxford (UK), Lausanne (CH) and Uppsala (SE), and the Research Center Jülich (DE) belong to both top 15 strata in nanoscience and nanotechnology. The top 15 rankings are, however, by no means identical; and there are conspicuously many German and French non-university PROs in the patenting ranking. The French National Centres for Scientific research ("CNRS" and "CEA") are large established non-university research centers, and the Fraunhofer Society is the major player in the applied sciences and technology development in Germany.[27]

Before more detailed comments on why the publication and patent rankings are not identical for European PROs, it appears noteworthy to look at the company ranking, provided in Table 2. The top 15 stratum covers a substantial part of all company patents. First and foremost, there are companies from France and Germany. The lions' share of all patents are filed by large chemical and pharmaceutical companies, such as BASF, Bayer, Roche, Aventis or Henkel. There are already many medical and cosmetic products involving nanochemistry and nanomaterials, for instance, skin lotions or gels (many of which are developed, produced and marketed by these companies). A61K is the relevant IPC group where these companies file patents (see Part III.2.). In addition, there are companies from the electronics and semiconductor industries, such as Infineon Technologies, Siemens or Vacuumschmelze. H01N and G01N are the relevant IPC-groups here (see Part III.2.). Many of these companies have cooperative relationships to PROs as government, and E.U. funding for industry-academia partnerships has substantially increased in the last decade.

Table 2: Top 15 Most Active European Public Research Organizations and Companies in Nanotechnology Patenting, Ranked in Descending Order

PUBLICATION RESEARCH ORGANIZATIONS	COMPANIES
Leibniz-Institute New Materials (DE)	BASF AG (DE)
U Saarland (DE)	Bayer AG (DE)
Commissariat à l'energie atomique (FR)	Infineon Technologies AG (DE)
U Cambridge (UK)	Henkel KGaA (DE)
Fraunhofer Society (DE)	Vacuumschmelze GmbH (DE)
U Freiburg (DE)	Roche AG (CH)
U Lund (SE)	Elan Corporation plc. (IRE)
U Oxford (UK)	Rhodia Chimie (FR)
Research Center Jülich (DE)	L'Oreal (FR)
U Uppsala (SE)	Cognis Deutschland GmbH & Co. KG (DE)

27 F. Meyer-Krahmer, *The German Innovation System*, *in* RESEARCH AND INNOVATION POLICIES IN THE NEW GLOBAL ECONOMY: AN INTERNATIONAL COMPARATIVE ANALYSIS, 205–52 (P. Larédo & P. Mustar, eds., 2001).

Free University Berlin (DE)	DSM N.V. (NL)
Max Planck Institute Colloids & Interfaces (DE)	Aventis Pharma Deutschland GmbH (DE)
U Tübingen (DE)	Celanese Chemicals Europe GmbH (DE)
Centre Nat. de la récherche scientifique (FR)	Siemens AG (DE)
ETH Lausanne (CH)	Biomerieux S.A. (FR)

Source: EPO and Euro-PCT Patent Applications in Nanotechnology 1996-2001, computations by author. U = University of…, DE = Germany, UK = United Kingdom, FR = France, CH = Switzerland, IRE = Ireland, SE = Sweden, NL = Netherlands

B. Institutional Profiles of European Universities in Nanotechnology

The finding that PROs active in nanoscience are not necessarily active in patenting has to do first with the important role of the non-university research sector in Europe, and second with an institutional differentiation among the universities along the two dimensions of scientific excellence and technological orientation.

The first argument receives support when the normalized citation rate is considered. Among the 15 most productive European research organizations, there are established elite universities such as Cambridge, Oxford, Paris, Munich, and the Swiss polytechnical universities in Lausanne and Zurich. On the impact scale, however, among the most influential research centers, there are several non-university non-for-profit entities, such as the German Center for Cancer Research and the European Molecular Laboratory (both located in Heidelberg). Similarly, publications from the French CNRS, the Karolinska Institute in Stockholm, the Molecular Biology Lab of the British Medical Research Council in the UK and the German Max Planck Society are highly cited. The non-university research sector is not only a major player in European nanoscience research in terms of research budget, but institutes in this sector have attained high scores in scientific excellence measured by citation impact.

For the second argument, consider Figure 6 where the citation impact of European universities (y-axis) is plotted against their ratio of patent applications per scientific publication (x-axis). The analysis includes only universities with at least one patent in the respective time window of 1996-2000. In order to avoid statistical bias towards small numbers, I include only those universities among the 100 most productive research sites in terms of publication output. To measure scientific impact, the normalized citation rate is used, while the patent/publications ratio can be conceived of as a proxy for either an organizational orientation towards science or technology. Abbreviations in Figure 6 indicate the country of origin (e.g., DE=German university, UK=British university, etc.).

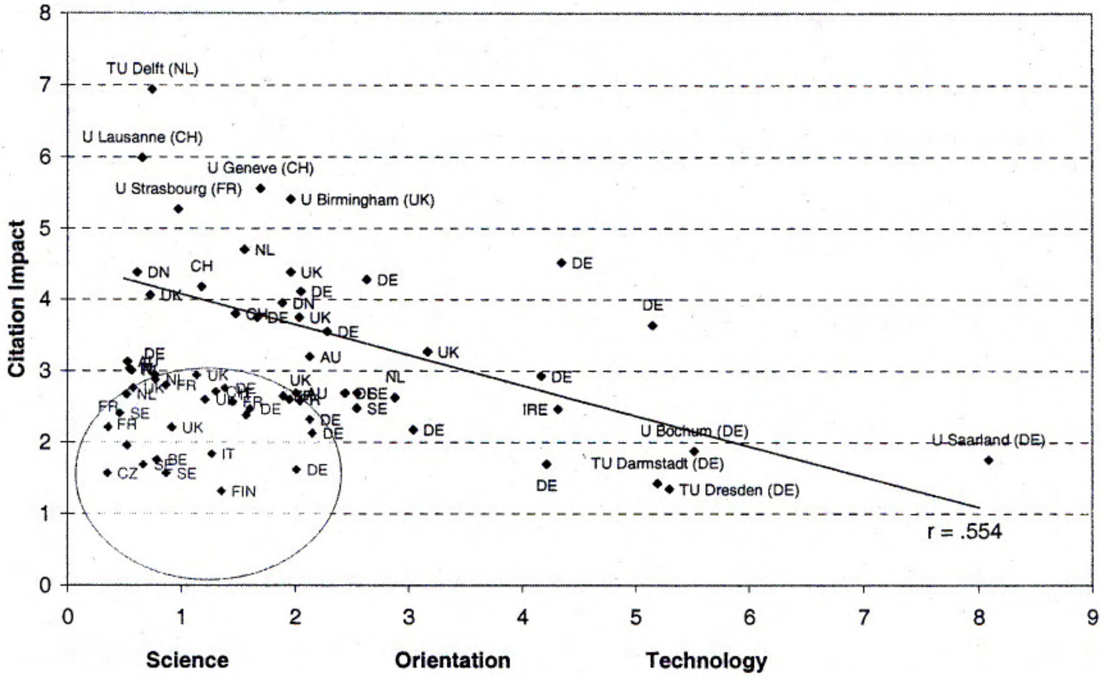
An optical inspection suggests that technologically-oriented universities seem to have a smaller impact than those universities with a stronger scientific profile. However, support for this hypothesis turns out to be weak because the correlation coefficient is low ($r = -.17$) and insignificant. Overall, scientific impact and organizational orientation towards science or technology appear to be independent.

The picture changes when those universities whose profile is scientific, but which have relatively limited impact only, are taken out of the analysis, as indicated by the shaded area.[28] Taking these less influential, science-oriented universities out of the sample gives a relatively high and significant correlation coefficient for the remaining sample ($r = -.55$); the respective correlation graph is depicted in Figure 6. For this sample of universities, the organizational orientation towards science tends to be

[28] Obviously, this segment of university research would deserve more attention as to why the research results of those highly productive universities are less influential in the scientific community. I did not collect data about these universities, and from the bibliometric and patent indicators alone, a proper interpretation cannot be inferred.

positively correlated with the scientific impact of research results, whereas the citation impact covariates negatively with technologically oriented universities. This is to say that scientists from universities with above average scientific impact are relatively less often engaged as inventors than researchers from universities with a clear technological profile. Good cases in point are the universities in Delft, Lausanne, Strasbourg, Geneva and Birmingham. They are far above the average citation level and are only moderately involved in patenting activities. To be sure, researchers from these universities do appear as inventors in EPO and Euro-PCT patents, so their knowledge production has relevance for devising new technological solutions. But their involvement appears limited compared to their overall publication output, and compared to the level of inventor activity found in the technical universities of Dresden and Darmstadt, for example, or Bochum and Saarland. The latter universities are particularly active in cooperating with companies leading to many researchers named in the patent documents as inventors.

Figure 6: Citations Impact and Science-Technology Orientation of Research Universities in European Nanotechnology



Source: EPO and Euro-PCT Patent Applications in Nanotechnology 1996-2001, computations by author.

Citation impact is measured by the unweighted number of citations per publication (CPP). On the metric scale 4 stands for 4 citations per paper on average. Science and technology orientation is derived from the ratio of the number of patent applications (EPO and PCT) to the number of scientific publications (SCI). On the metric scale 2 stands for 2 patent applications per 100 publications. Abbreviations indicate country origin, for instance all data points with "UK" indicate UK universities.

III. INTERNET-BASED SEARCH TOOL

In the context of the European study entitled "Mapping Excellence in Nanoscience and Nanotechnology across Europe," CWTS Leiden developed a complex, web-based search tool that is freely available on the internet (Figure 7).[29]

The design of this tool had to be flexible enough to be used by different types of users. Potential user groups are:

(1) *scientists and researchers*, who want to familiarize themselves with the overall research landscape in nanoscience;

(2) *policy-makers* with a more general interest in mapping research institutions with different institutional profiles across Europe;

(3) *nanotech companies* looking for technologically and scientifically interesting cooperation partners in the science system; and

(4) *venture capitalists* interested in patenting activity of nanotech companies.

The interactive tool enables different users to determine their own criteria and thresholds for identifying research entities of a certain productivity or citation impact. In particular, the possibility of combining bibliometric measures with patent indicators enhances the utility of the tool for the different user groups considerably. It provides data on the main organizational level (i.e., universities, companies or other non-for-profit research institutes) and can be downloaded at different levels of aggregation including the world level, the European level and the national level. For instance, users might first view and download data on universities across Europe with critical mass (e.g., P>20 per year) and a considerable scientific impact (e.g., CPP>5). A more finegrained picture is then available on the national level. Particularly useful in this interactive tool appears the opportunity to display geographically relevant organizations. This enables users to search for entities together with the information of their geographical location.

The possibility of changing thresholds for individual indicators while leaving another unchanged provides the opportunity to identify research organizations with different institutional profiles within the novel and emerging field of nanoscience and nanotechnology. As discussed above, there are research entities with a more "scientific profile" compared to universities and non-university institutes whose considerable involvement in patenting makes them "technology-oriented."

Combining different bibliometric indicators allows one also to control for certain weaknesses inherent in bibliometric data. It is well known, for instance, that the citation per publication ("CPP") is particularly biased towards smaller numbers. This means that smaller institutes tend to reach higher impact. Here, the combination with the number of papers ("P") is available to enable the user to compare institutes with a similar size. By choosing a P of at least 60 (which is 10 papers per year in the time window 1996-2001), and ranking on the basis of impact, a much fairer comparison can be made.[30]

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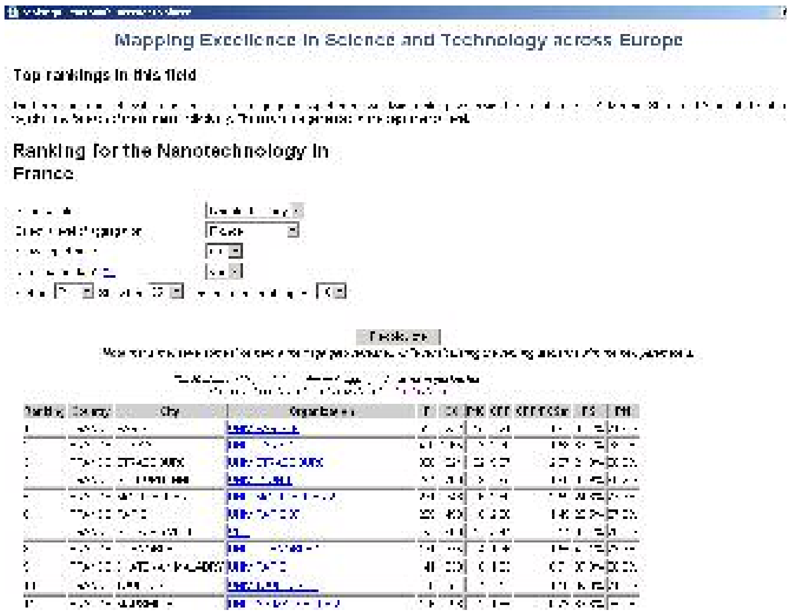
[29] See http://studies.cwts.nl/projects/ec-coe/cgi-bin/izite.pl?show=home. The tool also allows browsing in the fields of Genetics, Immunology, Neurosciences and Bioinformatics.
[30] See NOYONS ET AL., *supra* note 3, at 72.

Figure 7: Interactive search tool for Nanoscience in Europe



Source: CWTS Leiden: http://studies.cwts.nl/projects/ec-coe/cgi-bin/izite.pl?show=publications