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# The Changing Positions of Patenting and Publishing in Basic and Applied Modes of Organized Research

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# Abstract

During the last several decades, patents have increasingly been applied for and granted to academics while researchers in the private sector have increasingly published in journals. In addition, evidence from both patent- and bibliometric-analyses has attested to greater collaborations between the two spheres. The traditional boundaries are thus being redrawn with respect to the two main directions organized research activities take. The purpose of this report is to explore the changing roles publication and patenting play for the way applied and basic research treat their results. Its contribution is mainly explorative.

*Keywords: Applied research; Basic research; Bibliometric analysis; Patent analysis; Triple Helix*

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# The Changing Positions of Patenting and Publishing in Basic and Applied Modes of Organized Research

## 1. Introduction

Organized research activity is often characterized as a tale of two cultures: the fundamental or basic science of academia as against the applied, problem-solving R&D of industry. Although the two cultures have certainly never been as isolated from each other as the label 'pure science' would suggest, they have traditionally demonstrated fundamental qualitative differences. An archetypical conception portrays academic and industrial modes of research as essentially different cultures: they differ in what they research, how they do so and why.

The most pronounced difference however is associated with the question of motivation: it involves the way the two cultures treat their results. In this environment, the predominant rule has been that academic science treats its important results by publishing, industrial R&D basically either through secrecy or (apparently increasingly) through patenting. In this, the logic of patenting (direct and indirect costs, patentability requirements, etc) and that of publishing (peer-reviews etc) have reinforced the cultural disposition. One symptomatic result of this state is that patents and bibliometrics have become attached as 'indicators' for the respective fields.

However, the last 20-30 years have witnessed to a mounting tendency for the two roles to intermingle: patents are being sought and issued to academics while companies are publishing in journals. In addition, evidence in each has attested to greater collaborations between the two spheres. The traditional boundaries are thus being redrawn for these very much separate proxies associated with the two main directions organized research activities take. The purpose of this report is to explore the changing roles publication and patenting play for the way applied and basic research treat their results. It explores generally how the use of the bibliometric- and patent-based proxies or indicators is changing to describe the changing research environment and what difficulties these uses can involve. Before focusing first on bibliometrics and then on patenting, several relevant conceptual and practical aspects of the changing research environment will be discussed.

## 2. Conceptual Issues

Modern research policy seems to be based largely on the hypothesis of a changing knowledge system in which the boundaries between 'basic research' and other types of knowledge production are becoming blurred. Several attempts have been made to systematise and conceptualise this transition. In this section, we explore the elements of three notable approaches.

In *Prometheus Bound: Science in a Dynamic Steady State*, John Ziman introduces the hypothesis that *science* is facing a future within a fixed or slowly growing envelop of resources after growing exponentially for almost 300 years. According to Ziman, this *steady state* implies long-lasting and serious changes in the way science is organized. Current changes he sees include:

- more management of research activities
- more evaluation of research activities
- career structure with less permanence
- more dependency on sophisticated instrumentation
- more networking and collaboration
- more internationalisation
- more specialisation and concentration of resources
- more emphasis on application

Another notable work is The New Production of Knowledge (Michael Gibbons et al. 1994), which has become something of a classic in calling attention to transitions in the modern production of knowledge. The authors present a description of the main features of what they see as an apparent and fundamental transition towards new modes of knowledge organisation. In the New Production of Knowledge, new structures of knowledge-production (Mode 2) supplant traditional modes (Mode 1), familiar from an era of basic-applied dichotomy. Mode 2 displays the following four attributes:

1. *Transdisciplinarity* characterised by problem solving efforts that necessitate multi-directional cumulative development of knowledge and that challenge research activities in several scientific disciplines.

2. *Heterogeneity and Organisational diversity* characterised by the increased number of potential sites where knowledge can be created, linking together sites in a variety of ways and the simultaneous differentiation, at these sites, of fields and of areas into finer and finer specialties.

3. *Social accountability and reflexivity* characterised by growing awareness about the variety of ways in which advances in science and technology can affect the public interest. This awareness has increased the number of groups that wish to influence the outcome of the research process. Social accountability is reflected not only in interpretation and diffusion of results but also in the definition of the problem and the setting of research priorities.

4. *New dimensions of quality controls* characterised by the preservation of scientific quality but in more multidimensional and composite research.

A third approach that illuminates the transitionary situation of formal knowledge production is the Triple-Helix Model. In this formative model, Leydesdorff & Etzkowitz decompose the changing research environment into its industrial, its university as well as its governmental components, thus introducing a third element into the tale of two cultures above. Research-related activities involving each make up the three strands of formal organized research or the three strands of the helix model. One premise of this work is that as research activities in each strand develops, they interact in news ways such that where they, "formerly operated at arms’ length (they) are increasingly working together, with a spiral pattern of linkages emerging at various stages of the innovation process." (Leydesdorff & Etzkowitz, 1998)

The model plays on the 'chain-linked model' of Kline & Rosenberg (1986) and implies that, together, the helices contain the genetic material of the innovation system. This material can be different for different countries. It is however not unchangeable, as with the double-helix namesake, but can adapt. A major idea is that the triple-helix has undergone a marked transition from a post-war scenario in which the university, industry and government relations were characterized by a clear division of labour between basic and applied research and imbued in the V. Bush spirit (Triple Helix 1), through a second stage, to the present situation (in the US), characterized by greater interaction and considerably less reverence to the old dichotomy.

Important to the presentation of the changing roles which patents and journals play is the emphasis placed on the comprehensive and dynamic nature of the change. There are four related dimensions to the development;

1. changes within the individual institutional domains (e.g. university funding),
2. significant influences between the different strands (such as the effect on universities of US regulation concerning the use of publicly-funded research results: see below);
3. the advent of inter-institutional centers to coordinate/facilitate interruption between the different helices (such as the industry-academic Cooperative Research Centers) and ;
4. a 'recursive effect' through which the whole structure evolves in interaction with society as a whole.

## 3. Contextual Aspects

If we look at each of the three helices in turn, prima facie evidence emerges which tends to support the proposition that the production of knowledge is indeed undergoing a transition. In the US, changes in the governmental, industrial and academic levels of analysis are most pronounced and arguably most instructive in this context, as it is here that changes have tended to emerge first, affecting other (especially, developed) countries. [1]

### 3.1. Government

The question of research support—i.e. funding—is at the core of the changing relationships. Two tendencies of US policy during the past couple decades have fundamentally affected the orientation and role of academic, 'basic' science. The first tendency has involved the stimulation of university-industry relations. During the 70s, this grew out of the perception that the US was losing market-shares in fields in which it had been dominant to countries like Japan and Germany. In this context, academic science was seen as a potential and under-exploited competitive advantage for American firms. Thus, various agencies in the government set about to try to strengthen university-industry relations and by this means encourage research synergies between the two.

Several policy-measures were instrumental:

[1] This section relies considerably on Brooks & Randazzese, 1998

1. In 1978, the National Science Foundation (NSF) expanded and formalized a program at the federal and state levels of university-industry research centers (UIRC). In 1980 only three states had such University-Industry Cooperative Research Center programs as against 26 states in 1990.
2. In 1980, the legislative branch introduced new laws that fundamentally affected the question of ownership of results which came out of federally supported research. The Bayh-Dole Act (Public Law 96-517), together with the Stevenson-Wylder Technology Innovation Act and amendments including the Federal Technology Transfer Act of 1996 (FTTA), served to standardize the different practices of universities etc on the question of who should control the economic results. In effect, the Bayh Dole Act, "requires US universities to put into use the intellectual property rights generated from their federally funded research. The various forms this use has taken include the filing of patent applications and the formation of new firms based on rights that the law transferred from the federal government to the universities." (Leydesdorff & Etzkowitz, 1998)
3. In 1984, the NSF's Science and Technology Centers (STCs) stipulated funding on university-industry partnerships.
4. As well as a general restructuring of governmental labs in the twilight of the Cold War.

Such changes have obviously affected both the orientation of university-industry relations and particularly the way research results are treated. The trend towards increased university patenting surveyed below is directly related to these changes.

The second major tendency has involved a relative decline in federal research funding. It is reported that between 1979 and 1991, federal funding per full-time searching academic scientist fell 9.4% according to Brooks & Randazzese, 1998 . This drop in funding has sent universities looking for funding elsewhere.

## 3.2. Industry

Industry has at the same time increased its funding of university research significantly. Funding through contract-research but perhaps primarily collaborations (cf. Meyer-Kramer & Schmoch, 1998) has in fact become the fastest growing component in university funding. It grew from a modest 2.6% of the university budget in 1970 to a total of $1.5 billion, or 6.9% in 1995. This support has of course varied by field of research and by university.

Simultaneously, industry has *__reduced__* its support to its own research labs:

> "although industry in general has increased its contribution to university-based R&D , many firms, including those that have increased support to universities, have actually begun to cut back on their internal R&D expenditures. This phenomenon has been most visible among the large central R&D labs of such corporate giants as AT&T, General Electric, General Motors, DuPont, Xerox, Eastman Kodak, and IBM." (Brooks & Randazzese, 1998)

This interesting combination acts to bring university-industry into a more interdependent relationship.

### 3.3. University

Faced by relative declines in federal funding, absolute increases in industrial interest and new guidelines and infrastructure to facilitate university-industry relations, some American universities are indeed becoming more 'entrepreneurial'. Etzkowitz (1998) describes the change in universities not only in the US but in developed countries more generally as a 'second revolution'. This 'revolution' involves an expansion of the general role of universities from research & teaching institutions to ones that embody 'economic and social development' via the exploitation of R&D results. It builds on the earlier 'revolution' whereby universities added research to their original raison d'être of teaching. A South African professor observes the same change more generally; "Especially in the developed countries, the concept of the 'community' which the university tends to serve has been expanded to also include industry, the manufacturing world and commerce."(Viljone, p 1)

The reorientation towards propagating R&D results has entailed for academia a 'capitalization of knowledge'. The university has, in connecting its research more directly with 'users', become itself an economic actor. This change has coincided with, "the development and maturation of several scientific fields with direct applications to commercial products, including biotechnology, micro-electronics, materials and polymer science, software, computer-aided design and robotics."(Brooks & Randazzese, p 368)

The capitalization of knowledge production with this sort of commercial potential has underlined the need for universities to effectively manage their intellectual property. To address this need, universities seem to increasingly mimic industrial R&D. The first resemblance has been the mushrooming of university technology transfer offices. In line with the Bayh-Dole Act, 34 out of 35 universities who received funding from the NIH and the NSF in 1990 had such offices responsible for applying for patents and other intellectual property rights, for licensing arrangements, overseeing spin-offs etc. The second resemblance is that universities have begun actively to seek patents for their R&D output, in addition or instead of publication.

This presentation opens for a discussion of how the role is manifesting the output of organized research of different descriptions and how such change is made visible through bibliometrics, patent analysis and a cross between the two.

## 4. Bibliometrics and changing patterns in "Basic research"

In the area of research policies, the concept of science is still equated with the concept of 'fundamental or basic research' as opposed to industrial development, despite growing, although not formal evidence such as that reviewed above. But what empirical evidence exists to support *the hypothesis of transition*?

This section reviews a small number of *bibliometric studies*[2] in order to provide and discuss empirical data relevant to the *transition* discussion. There are some inherent difficulties to note before preceding. One main difficulty is that most bibliometric studies focus on quantitative issues of traditional disciplinary research (Mode 1). There

[2] For a short introduction to bibliometric research see Okubo Y., 1997.

are relatively few bibliometric studies that focus directly on evidence for or against the transition hypothesis[3]. One reason is that the most common use of bibliometric data today either involves the production of general statistics about disciplinary output of countries (or sectors within countries), or methodological issues in the evaluation of academic science.

Another implicit question is how relevant bibliometric data and methods actually are in this matter. Research activities in 'Mode 2' do not necessarily exhibit the same propensity to publish in international scientific journals did those of *basic science* in 'Mode 1'. Analysis of scientific publication trends may very well run the risk of underestimating the magnitude of any shifts in the modern research landscape. Furthermore, there are no standard models describing how exactly 'Mode 2' knowledge can be articulated to the traditional research sphere. Does 'Mode 2' mean the intensification of 'tacit knowledge' production? What are the interdependencies between 'tacit' and 'formal' knowledge? Does these interdependencies change from 'Mode 1' to 'Mode 2' and how? To our knowledge, there are no unequivocal answers to these questions and, therefore, bibliometric data can at best provide some general indications about the plausibility of the hypothesis of transition towards a new knowledge regime.

In approaching the transition hypothesis via bibliometrics, we look for three basic types of evidence:

- The first is evidence for whether there is an increase in scientific publications involving private firms and non-academic research institutes.
- The second is evidence for denser patterns of interaction between sectors, institutions and research groups (cf. *Heterogeneity and Organisational diversity of Mode 2*)
- And finally, evidence for an increased body of more 'applied' research including more multidisciplinary research. (cf. Transdisciplinarity *of Mode 2*)

### 4.1. Increase of non-academic sites generating scientific publications

Our first assumption is that increasing numbers of publications in the Science Citation Index (SCI) that involve non-academic research sites supports the plausibility of the transition hypothesis. To approach it, we should consider some aspects about why research is published in scientific journal and about why firms might publish.

Publication in scientific journals by firms initially seems counter-intuitive. In terms of the knowledge product space described by David and Dagsputa (1992), this is because scientific articles represent a form of knowledge production which is highly codified, disclosed and publicly available while firms would tend to produce applied, private and often tacit knowledge. Scientific articles are of course more geared to the traditional logic ascribed to university research of Mode 1.

Diana Hicks (1995), on the other hand, argues that in order to understand why firms produce scientific publications one should not presume that there is a 'natural' and 'clear' distinction between different knowledge types. The issue is how and why

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[3] The empirical data on which this study is based on are, by large, taken from the bibliometric analysis of UK publications made by the Science Policy Research Group in th period 1993-1996.

academic and industrial researchers construct and negotiate the divides between tacit-formal knowledge, between technological-scientific knowledge and between public and private knowledge in such a way as to provide themselves with the maximum advantage.

If the only reason firms perform research is to create appropriable knowledge, their publication activities would indeed be difficult to explain, since publication is a codified and public form of knowledge. However, there are other reasons for firms to perform and publish fundamental research. These other reasons seem to concern:

- The interdependencies between public-codified and appropriable-tacit knowledge[4]. There is a tension between establishing oneself in new knowledge areas *and* protecting competitive advantages in core knowledge areas. In the barter exchange of knowledge networks, firms has to be attractive to other research institutions in order to further their aim of accessing technical opportunities produced in science base. Therefore, firms publish about their long-term research projects and about their resources while simultaneously trying not to reveal information essential to their competitive advantages.

- The maintenance or even the increase of absorptive knowledge capacity of the firms[5] by doing and publishing research. This mechanism helps industrial researchers to maintain and develop their abilities in recognising, understanding and absorbing new technical opportunities (emerging either inside or outside firm's boundaries) in an economically successful manner.

- The need to make visible original research in the firm's core competencies. This also facilitates the maintenance and development of linkages with other important actors in the knowledge areas where firms are active.

Such reasons increase the plausibility of the hypothesis that sites other than universities produce scientific knowledge and, hence, scientific publications. The question is whether these number and the variety of the sites publishing 'basic research' increase over time as the transition hypothesis predicts.

Unfortunately there are few studies that have investigated whether non-academic sites are increasingly publishing in scientific journals. Katz et al's. (1995) bibliometric analysis of UK Science is however a rare and important source. In terms of this survey, *The Bibliometric Evaluation of Sectoral Scientific Trends* is important because:

- it presents for first time series of sectoral publication trends for a whole country.
- it also provides a new classification system which helps us to distinguish, however crudely, between publications in the so-called *basic* and *applied* research.
- it presents bibliometric data on *sectoral trends*.
- It can be argued to be indicative of global tendencies because of the position of the UK.

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[4] For a thorough discussion on the dynamics of tacit and codified knowledge see Saviotti P.P, 1998.

[5] For a more detailed discussion of this point see also Rosenberg N., 1990.

Katz et al. classified a standardized set of institutional address in 9 different sector categories and tallied the annual number of publications per sector. Table 2.1. presents the sectoral distribution of UK publications according to these sectors, including the sectoral shares of UK publications. The table illustrates that it is not only universities that produce scientific publications in the British science system. Private firms (industry and privatised laboratories), in particular, (co-)published about 8 per cent of all UK publications. Hospitals co-produced more than 20 per cent of all UK publications.

*Table 2.1: Lists and publication performance of eight sectors performing research in UK.*

| Sector Name | Notes on Definitions | # Articles | Share |
|---|---|---|---|
| Universities | "Old" universities excluding university hospitals | 217441 | 57,8 |
| Hospitals | Including university hospitals | 81719 | 21,7 |
| Research council | Intra-mural laboratories, excluding 'groups' at universities but including 'units' at universities | 42814 | 11,4 |
| Industry | Industry including all government laboratories privatised during the 1980s | 28088 | 7,5 |
| SHA & BPG | Special Health Authority and British Postgraduate Medical Federation Research Institutes | 17448 | 4,6 |
| Government | Departmental laboratories and local government laboratories | 15597 | 4,1 |
| Non-profit | Laboratories as opposed to research funded by charities | | 2,4 |
| Polytechnics | Sector became universities in the 1990s | 8008 | 2,1 |
| Other | Comprising other educational, other medical and unknown, each of which produces less than 2 per cent of UK output | 9832 | 2,6 |
| Total | All UK publications in SCI, period 1981-1991 | 376226 | 114.2* |

*Source:* Hicks and Katz, 1996, pp. 383, 385.
*) The sum of shares exceeds 100 per cent because of the inter-sectoral collaborations

About 5000 different UK institutions produced scientific publications between 1981 and 1991. The number of private firms represented in the set of UK publications in surprisingly high. More than 2000 firms published at least one paper in the period 1981-1991. The Katz et al. study shows also that the number of private firms identified in UK publications of 1991 increased dramatically compared to that of 1981 (32 per cent increase). The respective increase in the number of hospitals was about 11 per cent.

Based on this evidence, *Hicks and Katz* conclude:

> The increasing number of institutions housing authors of journal articles lends support to the idea that research production is becoming more dispersed. [....] The weight of evidence favouring dispersion (of the knowledge production sites) reinforces the point

> that academic research accounts for only half of the research system in the United Kingdom today. In fact, it form the static half. The number of institutions of other types that produce journal articles, such as companies and hospitals, has grown. (Hicks and Katz, 1996: parenthesis added)

Norway demonstrates some similar tendencies. Using SCI data for the period 1990-1994, Kaloudis (1999) found that private firms (co-)produced about 7 per cent of the total Norwegian publications. About 3950 authors from a variety of Norwegian and foreign institutions contributed to co-author the 1238 Norwegian publications involving at least one institutional address from private firm. Among the private firms, Kaloudis identified 145 Norwegian companies and about 200 foreign companies. As expected, a small number of large companies were represented with a high output of publications.(7 companies published more than 50 per cent of the identified publications during the 5 years) However, small and medium size enterprises from a variety of branches were surprisingly well represented with small numbers of articles.

In the context of Netherlands and USA, Hicks D., 1995 presented some more statistics of company publishing On average, between 1980 and 1989, companies produced 6 per cent of Dutch publications. In the USA (1991), companies produced 9 per cent of science and engineering publications. In addition, Hicks presented some interesting statistics about the *citations company publications* receive. Hicks reports that in the biological sciences nine corporations have citations per paper that rank them among the top 25 US universities. The same in the physical sciences with six companies ranking alongside the top 25 US universities. In a world ranking of institutions in electrical engineering for the period 1986-1990, nine companies had average citation scores equal to those of the top 25 US universities.

In another work, Hicks et al., 1995, found that Japanese chemical-pharmaceuticals publishing grew by 68 per cent over a period of nine years (1980-1989), European pharmaceuticals publishing grew by 73 per cent and Japanese electronics by 84 per cent. (Hicks et al., 1996) Furthermore, large European and Japanese firms in the pharmaceuticals, chemical-pharmaceuticals and electronics sectors published 23 per cent of their papers in the most basic category of journal classification, first introduced by CHI Research, 41 per cent in the second most basic category and 26 per cent in the two most applied categories.

All in all, this survey indicates that there is a growth of heterogeneity of institutions publishing scientific research both in large (UK) and in small (Norway) countries. It also seems that the private firm sector tends to publish 6-10 per cent of all publications of national publication outputs in many OECD countries. Big companies and hospitals seem to substantially increase their publication output in journals of ‘basic research’ in 80's and 90's. These publications tend to get cited as much as other ‘pure’ academic publications.

### *4.2. Increase of the number and of the complexity of scientific interaction patterns*

Our second assumption is that ‘basic research’ knowledge (as codified in scientific articles) is increasingly *co*-produced as scientific knowledge reorganizes towards more heterogeneous and flexible networks. We would therefore expect to find increasing interactions both between the knowledge sectors in a country and between countries.

Data covering co-authorship capture some of the main trends in 'scientific collaboration' world-wide. [6]

There is rich enough bibliometric evidence from several studies indicating that the number of interactions in increasing and the patterns become more complex. *First,* the rapid growth of multi-authored publications[7] and the relative stagnation of single-author and two-author papers suggest that interaction patterns have intensified. During the period 1990-95, the proportion of Norwegian articles with one author clearly declines, those with two and three authors slowly declines, while articles with four authors slightly increases and the share of publications with 5 to 10 authors strongly increases. Similar patterns are also observed in many other national publication outputs. [8]

*Second*, international co-authorships have strongly increased word-wide during the last 15 years. In the Norwegian set of SCI publications, the number of international co-authored papers[9] increased by 78 per cent from 1990 to 1995. In comparison, the total number of Norwegian publications increased by 35 per cent. That is, internationally co-authored papers grew twice as fast as the number of Norwegian publication in a period of five years. In 1995, 39 per cent of all Norwegian publications were international. In the case of the Netherlands, the share of international publications was 34.5 per cent in 1995 compared to 19.5 in 1985, in US 17.5 in 1995 compared to 9 per cent in 1985, in UK 26 per cent in 1995 compared to 14 per cent in 1985 and in Japan 14 per cent in 1995 compared to 7 per cent in 1985. (*Second European Report on S&T Indicators*, 1997) These figures indicate clearly the intensity of internationalisation in world science.

*Third*, the sectoral patterns of collaboration within national systems also seem to intensify. Katz et al., 1995, documents that in 1991, 41 per cent of UK papers involved some type of collaboration between authors in *different* institutions. Over the period 1981-1991, non-collaborative papers declined or remained level, while collaborative papers increased for all eight sectors in the SPRU study. At the end of the period 1981-1991, all sectors produced at least 40 per cent more collaborative papers than at the beginning. It is indicative that about 60 per cent of all industry papers involved institutional collaboration in 1991 compared to 36 per cent in 1981. The share of institutional collaborative papers in universities rose from 31 per cent in 1981 to 46 per cent in 1991.

Kaloudis, 1999, found similar trends in collaboration patterns of Norwegian researchers in Norwegian publications from industry. First, there is a significant increase of company publications from 1990-1994 (about 20 per cent). This increase is mainly caused by multi-authored publications which is an indication of increasing collaboration. The share of international publications remained stable, but it is significantly higher to that of UK industry. More than 35 per cent of all company

[6] For a discussion on the methodological problems emerging from the measuring of scientific collaboration by co-authorship counting see Katz S.J. & B. R. Martin, 1997.

[7] These are publications by more than 3 authors. Single-author publications decreased over the period and to-author publications increased in a slower pace compared to the multi-author publications.

[8] See Melin G., 1997, p.24 and Hicks D.M., S.J. Katz, 1996, pp. 391-392.

[9] An international paper is defined as the paper involving at least one institutional address from from two different countries.

publications were co-authored with an institution from another country in Norway, while, according to Katz et al., 1995, less than 20 per cent of UK industry publications were co-authored with institutions from other countries. Of course there are some bench-marking problems if a comparison of data from the two studies.

When it comes to inter-sectoral collaboration, Norwegian industry relies on the national universities almost as much as UK industry does. Table 2.4 shows these inter-sectoral collaboration patterns.

*Table 2.4: Inter-sectoral collaboration patterns of Norwegian publications from private companies.*

| *Distribution of Industry's co-authorships with other institutions. SCI 1990-94* | | |
|---|---|---|
| | No. of publ. | % |
| Industry SCI publications with at least one UNIVERSITY (Norwegian or foreign) | 619 | 50 |
| Industry SCI publications with at least one COLLEGE (Norwegian or foreign) | 58 | 5 |
| Industry SCI publications with at least one HOSPITAL (Norwegian or foreign) | 283 | 23 |
| Industry SCI publications with at least one RESEARCH INSTITUTE (only Nor.) | 153 | 12 |

Source*: SCI, 1990-1994.*

Universities and university hospitals from Norway and other countries are the institutions with which companies collaborate most frequently. Industry in UK and in Norway collaborate in about half of their publications with universities. This demonstrates also how important the role of universities is in connecting the private sector to science.

### *4.3. Evidence on the increase of transdisciplinary research*

Our third assumption in this section is that greater thematic indicates increasing transdisciplinarity of Mode 2 knowledge-production. However, capturing trends of changes in the cognitive organisation of modern research has been one of the most challenging questions in bibliometric research. Several methodological developments and new mapping techniques have been introduced in recent years in order to study the dynamics of particular research areas (such as neural networks, plant biotechnology etc.) or research specialties.[10] To our knowledge, however, there are few relevant bibliometric studies which address macro-trends in transdisciplinary research. One of the main explanations is the enormous amount of work related to this task and the lack of a robust methods and techniques which can capture shifts of thematic focus in scientific areas.

By changing degrees of transdisciplinarity, we understand in this study the following:

1. Significant quantitative changes in research *collaboration patterns between researchers and institutions from different disciplines* and *from different*

[10] There are many interesting developments in bibliometric research related to studies of science dynamics, some of which are surveyed in Section 4 of this article. Leydersdorff L., 1995 (a), Leydersdorff L., 1995, (b), Leydersdorff L., 1994, Noyons, E.C.M. , A.F.J. van Raan, 1998, Noyons E.C.M., et al. , 1994, Small H., (1998), Small H., (1997) give an idea of the bibliometric innovativeness on this question.

*knowledge sectors* in different research fields. Often, this kind of collaboration patterns emerges in the boundaries of emerging fields.

2. Significant changes in the research profiles of academic research groups, measured as an increase in dispersion of publication outputs to journals belonging to different research areas, and particularly to more ‘application’ oriented journals.

3. The emergence of new fields, or rapid reconfigurations of established research areas, which attract the attention (and contribution) of young researchers with background from different disciplinary domains. These fields have to be “generated and sustained in the context of application and not developed first and then applied to that context by a different group of practitioners.”( Gibbons et al., 1994)

The bibliometric evidence related to these 3 points, remains inconclusive and is open to different interpretations. Here, we shall particularly refer on two macro-studies which provide some rudimentary data on points 1-2. Evidence available on Point 3 is presented in several bibliometric studies of specific areas of research which we only shall mention rapidly.

We return to the original classification system of Katz et al (1995) in order to try to identify changing publication activity in inter-disciplinary journals. Again, this new classification system builds on the ‘traditional’ classification system of the *Institute of Scientific Information*, but it also makes possible the distinction between *disciplinary journals* (‘pure’ journals belonging to either natural or life or applied sciences), *journals in inter-field areas* (journals overlapping several research areas in inter-field natural, inter-field life and inter-field applied sciences) and *interdisciplinary* journals.

Katz et al. address transdisciplinarity by investigating the distributions of publications produced by knowledge sectors in a country (or institutions, or even academic departments) against journal fields. It reveals inter alia that universities produce 38 per cent of all UK publications in Medical and Health Sciences, 82 per cent of all UK publications in Chemistry 93.4 of all UK publications in Mathematics etc. Industry produces only 1.8 per cent of all UK publications in Mathematics, but 25.1 per cent of all UK publications in Engineering and 23.8 per cent of all publications in the Inter-field applied.

Along one axis, their analysis provides a measure of scientific specialisation of 8 knowledge sectors in UK. Along the other, it provides sectoral profiles of each of the 17 classification categories. Combining this sectoral profiles with scientific specialization could be used as a crude indicator of the degree of transdisciplinarity in a field. Their results for scientific specialization show that universities dominate the Natural Sciences. However, there are sectors of this field where the academic orientation is less pronounced. Industry publication is significant in chemistry (13.1 %) while intra-mural laboratories or the Research Council sector is important in Physics (15.8%). In the ‘Applied Sciences’, industry publishes about 20 per cent of all UK publications. Further, the UK data provide a weak indication that hospital and industry research is increasing somewhat faster than research performed without institutional connections.

In terms of research profiles, Katz et al. creates a basket of six SPRU journal categories that they define as more applied: agriculture, medical, engineering, ICT, Material science and inter-field applied. UK data support the hypothesis that the UK system is moving towards more applied research. The group of all applied journal categories together grew faster than the more 'basic' journal categories in the UK data. Particularly, medicine and material sciences were two of the fastest growing areas in UK science in the period. However, not all applied categories showed increases in publication outputs. The picture is much more complex than that. For example, the categories of agriculture and ICT declined in the 80's, while engineering papers remained stable.

Another relevant study is Bourke & Butler (1998).This study compared the departmental profiles of Australian universities with their publication profiles and documented a tendency towards increasing thematic disparity in the publication profiles of the university departments. Their method is quite similar to that of Katz et al., 1995. It examines about 44000 publications registered in SCI from Australia's 37 universities in the 5-year period 1990-1994 and thus uses more current data. The study indicates, for example, that Mathematics departments only publish 37 per cent of their papers in mathematical journals while 25 per cent of their published output appears in journals classified in 'Physics' category. Bourke & Butler (1998) also study the change over time of the departmental publication profiles. They observed a trend towards increased interdisciplinarity in fields, such as Chemical, Biological and Agricultural Sciences. Conversely, they observe a reduction of interdisciplinarity in Mathematical, Physical and Earth Sciences while in Medical and Health Sciences remained unchanged. Thus, this study also indicates that the question of transdisciplinarity is more complex and that it deserves more thorough and careful investigation.

A distinct and exciting avenue to approach transdisciplinarity involves studying the emergence of new fields of research and their characteristics. There are several bibliometric methods used to identify and investigate features of emerging fields. One avenue uses co-citation patterns of individual publications to attempt to identify cognitive interdependencies between disciplines. Small & Garfield (1984) is one early example of this approach which describes how to investigate the evolution of such interdependencies on a macro-level.

The approach of Leydersdorff et al. (1994) is somewhat different. It attempts to produce literature-based indicators for tracking emerging few-fields, fast-changing areas and areas of growth (or decline) using journal-to-journal citations. Like many other studies in the area, it focuses on case studies: *AIDS, superconductivity and oncogenes*. Leydersdorff et al., studied particularly how the inclusion of new journals can be used as an indicator of structural change in research. In a further study, van den Besselaar & Leydersdorff (1996) investigated the *journal dynamics* in the area of *Artificial Intelligence (AI)*. Their analysis shows that AI emerged as a set of journals with the characteristics of a stable field since 1988. The interesting finding related to transdisciplinarity is that, after 1988, both fundamental and applied AI journals are identified in the complex citation patterns of those journals. These citation patterns reveal also that specialties, such as, *pattern analysis*, *computer science*, *cognitive psychology* are related to AI journals.

Another interesting finding in this study is that *Neural network research*, which many would expect to be related to AI research, is neither a part of AI nor of its direct citation environment. Based on advanced co-word mapping analysis, Noyons & van Raan (1998) explored the structure of *Neural network research*. The bibliometric techniques developed in this study are relevant to those that investigate the cognitive aspects of transdisciplinarity in new emerging research areas.

Interdependencies between public knowledge, i.e. scientific publications, and appropriable knowledge, i.e patents, has also been investigated in an increasing number of studies. Noyons et al., 1994, studied inventor-author relations in laser medicine research, that is, the complete set of SCI-publications of all patent inventors in this specialty for the period 1980-1989. This study, demonstrates the close ties, the overlapping of individuals and the cognitive dynamics between application and production of knowledge in *laser medicine research*.

### 4.4. Section conclusions

In this section we presented bibliometric evidence which, we believe, supports the hypothesis of transition as stated in the work of M. Gibbons et al., 1994, Ziman (1994) and Eztkowitz H, (1998) whatever the reasons of this transition maybe. This bibliometric evidence shows that:

- There is an increasing number of non-academic actors publishing research results. These non-academic actors produce increasingly more scientific publications.
- There is an increasing complexity in the interaction patterns between scientists producing scientific publications both in ‘basic’ and ‘applied’ areas of research.
- There are indications of increasing cognitive dispersion in ‘academic research’.
- Several emerging research areas seem to be transdisciplinary, as is the case of laser research, nanotechnology, material sciences, neural networks, biotechnology etc.

Based on these conclusions, the interesting research policy question is not whether a transition is taking place or not. The interesting policy question is what type of knowledge we need to develop for managing this transition. When it comes to the question of what kind bibliometric methods we need for a further and a more subtle investigation of the hypothesis of transition, one of the challenges is to develop bibliometric databases which could enable us to extract quantitative data and qualitative information designed for this purpose.

## 5. Patenting and changing patterns of “applied research”

The evidence from patent-analysis supporting the transition-hypothesis, while prevalent at the general level, is somewhat less easy to find at the detailed level of patent-statistics. However, there are several tendencies that are associated with the changing relationship between ‘basic’ and ‘applied’ research which involve- and become visible-through patenting. For example, there seems sufficient, general evidence to support the statements;

- That university-research increasingly seeks patent-protection (field-dependent)
- That patent-protection is becoming more relevant for university research, both in terms of what is patentable and what the universities want to accomplish.
- That the link between patents and 'science bases' is reported to be becoming stronger.
- And that there is increased collaboration between academic and industrial research.

In this section, we explore evidence of the spread of patenting-especially in certain countries and for certain fields of research- to universities, government (even the US DOD) and non-profit labs. We will associate these changes with the wider set of changes in the way organized research takes place, where it takes place and what it produces. These include changes in the type of technological innovation, changes in the regulatory environment, changes within the university itself and the emergence of overlapping organizations.

### 5.1. Patents and Industry: The traditional role of patenting

For almost all intents and purposes, patenting has traditionally been associated with industrial research. This was no coincidence. The logic of patenting (in most countries), the commercial logic of applying for a patent as well as a certain cultural factor has made patenting the domain of industry. [11] In terms of the logic of the patent regime, patentability caters to technology rather than science in a traditional sense. A patent can be granted for devices or process which demonstrate a 'inventive step' while discoveries and phenomena of nature cannot be patented (see biotech, below). In this, it seems that the patent-regimes of the US or the UK type especially intended for entrepreneurial and industrial R&D and not academic science.

In extension to its technology focus, patentability requires that an invention not only prove novelty and non-obviousness but also demonstrate 'utility'. The concept of utility implies that the invention has a potential for commercial application. Further, this potential is expected to be 'exercised' or actively pursued in order to maintain protection. In a typical case, the 'exercise' of a invention means that active development of a product.

Thus, the requirements for applying and maintaining a patent are clearly favor the products and process of entrepreneurial or industrial actors. This bias is made even more pronounced by the cost of applying for, maintaining and enforcing a patent, which costs thousands of dollars at least. Even in cases where the basic science of university research do meet the patentability requirements, an economic incentive is needed to outweigh the costs associated with patent protection. Since, "the outputs of basic research rarely possess intrinsic economic value," (David, Steinmueller & Mowery, 1995) and since the traditional research university is not geared to developing and marketing any technological innovation that might arise, patenting has doubly not been considered generally relevant for the fundamental research of universities and other nonprofit R&D institutes.

[11] See eg Machlup for a discussion. It should be noted that different technologies in different industries have always had an uneven propensity to patent. Patenting should thus not simply be equated to industrial R&D output, either now or historically.

Patenting, then, is typically biased towards the applied nature of new technical knowledge. On its side, it can be said that 'basic research' is typically biased against the idea manifest in the patent regime, that knowledge can be owned by someone and that others can be excluded from using it. Thus a more fundamental obstacle dividing university-research from patenting has been cultural: monopolizing the fruits of research simply has gone against the academic culture that championed 'open science' and the ideal of 'communalism'.

Patent-counts certainly support the predominance of companies in patenting, especially in certain sectors of the economy. In the case of Norway, only two non-commercial entities figured in the top 18 of those that received patents in the US (1990-96): one a military research institute (FFI) and the other a technology transfer center for the quasi-academic setting of SINTEF. (cf. Iversen 1998) [12]

## 5.2. Changing Environment

The transition of the Triple-Helix of research means that both the way patents and the way patent-statistics get used are changing. There are several general aspects to consider before going on to discuss increased patenting at universities, the reputed strengthening of technology's science-base, increased collaboration between academic and industrial research, plus other factors.

Focusing first on changes involving the patent-regime part of the governmental helix, there are several aspects to note. First, there is a marked increase in the overall demand for patent protection. There has been a 10% increase in first-filings of patents worldwide, from 624,493 in 1992 to 683,874 applications in 1996. [13] The most dramatic change however is in the internationalization of patent-applications, through which one application is filed in other countries. In 1992, a single application led on average to 2.1 filings in other countries. In 1996, this had risen to 4 filings in other countries. This means that the total demand (first and subsequent filings) has increased some 90% in the course of 5 years. Although many of these are retracted even before grant, and many of the remaining are not granted, there are nevertheless a strong tendency towards international patent demand.

There are also notable structural changes taking place within the patent framework. These are becoming important to the way patenting is used whether by industry, governmental labs or universities. A major structural change taking place is the attempt to standardize the considerably different types of patenting systems that exist in different countries. There are for example fundamental differences between the patent regimes in France and Britain, though the European Patent Office (EPO) is trying to accommodate such differences, towards creating an EU-wide patent. [14]

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[12] It should be noted that in Norway, the university generally does not apply for patents. The researchers at the universities do. This effectively hides the 5 large universities and the polytechnics.

[13] Numbers for worldwide applications used here are from the trilateral Statistical Report. 1997. Published jointly by the European, US and Japanese patent offices.

[14] See issue C-366 of the Official Journal dated November 26, 1998. Page 12.

In addition to such regional efforts at institutional standardization, there is the even more ambitious attempt to bring the European, the US and the Japanese patent-systems into phase. There is some evidence of convergence, for example in the terms of patenting. It is only recently that the duration of US and European patents were brought into line (at 20 years). One challenge being faced, however, is not only the terms of patenting, but, crucially, what fulfils the patentability requirements.

**5.2.1. Patenting software and biotechnology**

The way emerging or less-mature types of 'technologies' are approached by the different patent offices fundamentally affects particularly patenting at universities. Two main areas where this is evident involves computer software and biotechnology.

The blanket concept of software cannot be consider either the fruit of completely 'pure' or completely 'applied' research: 'software' is a multi-billion dollar industry but it is also both an input and output of academic research, for instance theoretic mathematics. Whether it qualifies as technology ('device') in terms of patentability is also contested by different patent regimes. Software is not a technology in a traditional understanding of the word and has long fallen almost totally under the purview of copyright protection. During the 80s, however, the US gave software patents greater leeway and since then there has been something of an explosion of software patents granted there. According to Aharonian (PATNEWS, !19981018), 6,100 such patents issued in 1995, as against only 1,300 in 1990. For 1997, he estimated 13,000 to issue. If these estimates are correct, the 44% increase in this type of patent between 1996-1997 far outpaced the 2% increase in all patents granted in the US. (Trilateral Statistical Report, 1998) Other countries have remained much more circumspect and conservative, in keeping with their own patenting traditions. As a result, it is much more difficult to get a software patent in Germany than it is in the US.

In other less mature types of knowledge, analogous types of problems also appear. Biotechnology is an area very much in growth, for which even a more modern understanding of the term 'technology' does not quite feel comfortable. In terms of the patentability criteria reviewed above, biotech borders closely on that which is understood as 'discovery' (for example gene markers or 'tags') or a natural phenomenon (for example, a laboratory mouse). This has led to confusion in what is patentable and at what stage of biotech research. Again, the US has a more liberal policy in this area than many of its counterparts. This has caused friction, not least with less-developed countries (eg. Costa Rica) that have rich plant and animal resources and thus a great diversity of DNA-sequences and rich traditions in isolated useful medicines etc. They are therefore understandably concerned that these resources can be owned by outsiders.

Novel types of patentability have also sparked controversy which pit different elements of the research community against one another. Controversies have arisen concerning patenting of what can be called biotechnological 'intermediate goods' or potential 'instrumentalities'. Signals that the US would allow the patenting of genetic tags (ESTs)- a common ingredient in many types of biotech research, theoretic and applied-raised alarm especially at universities. Another case that apparently goes against the restriction that natural phenomena cannot be patented, involves the case of a live mouse. The CreloxP mouse was patented by DuPont for use in laboratories but where its use is conditioned by licenses. Licensing conditions, which are at the heart of the controversy, can affect the academic community's access to such experimental material. Apparently, there are many other examples, some of which originate in universities.[15] Theoretically, such cases raise the questions of whether patenting could ultimately influence the university's ability to experiment and, if so, what would happen if someone were granted monopoly rights to a mode of experimentation that turned out to be an *instrumentality.* [16]

The development and use of software and biotech have to a large degree germinated in the traditional research university and are very much at home there. In this sense patenting is coming to universities and other research institutes, both in terms of the technology they produce and that which they use. It is in the questions that these fields raise that one glimpses a continuing, underlying tension between proprietary science and the 'open science' ideal.

### 5.3. Research in academia and other non-profit institutes: transition

Patent-regimes are therefore undergoing a series of changes that unevenly affect what qualifies for protection and where. Such issues affect whether academic and other non-profit research might apply for patents and how. The implication here is that what qualifies for patent-protection is opening itself up to a certain degree to include research results that are typical of 'basic' research and thus of academia, and that this is especially the case in the US. This entails, then, that academia can successfully apply for patents for an increasing section of its research production. It does however not indicate why they are increasingly active in applying for patents, not only in the fields of computer and biotech, and not only in the US.

There is much anecdotal evidence demonstrating that patenting is increasingly utilized for university and the nonprofit, R&D institute sector. One problem that is faced however is that reliable quantitative evidence is not immediately available. A major factor here is that universities and the public research sector are not immediately identifiable in the official patent statistics of many places in the world. It is not common, for example, in countries like Norway and Germany to assign Intellectual Property Rights to the university, but to the researcher. Since universities do not have a IPR policy, patents do not turn up as originating at universities except under special circumstances.

The Bayh-Dole act and the related changes involving US universities that were surveyed above mean that US universities tend to be the relevant patent applicant. Here many if not all research universities, like MIT, have developed infrastructure (technology transfer departments) that is specialized in stimulating, collecting and developing knowledge developed at the university (or universities, eg. the University of California system) that can be capitalized on (via patents) . This responsibility spans from the patent application, through licensing to enforcement in case of infringement.

[15] The HCG based foetal test for Down's Syndrome, developed by Bogart at University of California (SD). The university refused to seek a patent for him.

[16] See de Solla Price (1984) on 'instrumentalities' or new types of instruments or ways of experimenting that can lead to revolutionary findings. The question arises, what happens when someone holds monopoly rights on such an *instrumentality*.

One advantage that these transfer university departments generate for the observer is that are keen on publishing how many patents universities are responsible for and what they earn on licensing this technology, how many spin offs and jobs they generate etc. This is of course is not the case for industry. The Association of University Technology Managers (AUTM) is a nonprofit umbrella organization for such transfer programs, both at universities and institutes which carry out nonprofit research.[17] The AUTM put together the basis for Table 3 based on the responses to a survey of 175 U.S. and Canadian universities, teaching hospitals, research institutes, and patent commercialization companies. The figures in table 3.3 are for university entities (n=127) only.

***Table 3.3. Technology transfer from US UNIVERSITIES, fiscal years 1991-95. (1995 = 87% of "top" 100 research universities. Cumulative change based on a "representative sample of 75 universities which have participated in the survey over five years")***

| Activity | 1995 | Cumulative % Change : 91-95 |
|---|---|---|
| Total US Patent Applications Filed | **5,100** | **+127%** |
| New US Patent Applications Filed | **2,373** | **+53%** |
| Licenses and options executed | **2,142** | **+66%** |
| Licenses and options generating royalties | **4,272** | **+72%** |
| Adjusted Gross Royalties | **$274 M** | **+108%** |
| Total Sponsored Research Expenditures | **$17,212 M** | **+29%** |
| Research Expenditures: Federal Govt. Funds | **$11,381** | **+23%** |

*Source: Association of University Technology Managers*

If the figures are accepted as bona fide, the number of new patents rose 53% to 2,373 during the 5-year period. This is five times the total number of patents the Norwegian economy applied for in the US during the same period. (N=475) An additional 499 patent applications were reported by 46 nonprofit research institutes in the US and Canada. These numbers tend to indicate that patenting among universities is growing rapidly and that the tendency is not that old. Notice too that the number of patents, licenses and the size of royalties are growing much faster than is governmental research funding (one reason they are keen to publish these statistics is to encourage continued government funding).

The growth in the number of patents granted, both to universities and nonprofit research in fiscal 1997, corroborates the impression that the trend is reasonably new, although Henderson et al. (1995) showed that academic patents increased 15-fold between 1965 and 1988. The number of grants- which lags behind applications by at least 18 months, and generally 2 to 5+ years (depending on invention complexity, etc)- increased by 23% in 1997 over the previous year to 2,645, according a more recent AUTM survey. Together, 5,290 patents issued in those two years, which is more than half the number for the 5-year period.

[17] http://www.crpc.rice.edu/autm/

This tendency, although certainly distinct in the US for reasons made clear above, is not unique to it. In spite of considerable differences in their institutional and regulatory frameworks, highly industrialized countries other than the US also indicate strong growth in patenting involving universities. Meyer-Kramer & Schmoch (1998) refer to a study of the German case which identified and examined patent applications made by professors during a twenty year period, "…and found-comparable to industrial funds at universities-a considerable increase, between 1974 and 1994 by the factor 2.5, between 1984 and 1994 still by a factor of 1.5." [18] By 1993, the volume of such applications was over 1,000 a year.

The study referred to indicates two interesting aspects about these university-related patents. The first aspect concerns the background of these patents and indicates that they tend to be based on direct collaborations between universities and industry. The second aspect is that university patents are far from crowded into a couple high tech areas. This interesting study showed that the linkages are not first and foremost contract research as one might expect. Instead, collaboration was reported to be a considerably more important form for university-industry interaction. This paper emphasized the importance of the two-way nature of these collaborations, that the patents do not represent one off examples of technology transfer, but express a more organic, long-term relationship between university and industry.

The second interesting aspect is that patenting by university professors involves a variety of disciplines, spanning faculties of mathematics, biology, chemistry but also agriculture and engineering. Of the 14 disciplinary fields registered in the study, the field with the greatest number of patents was mechanical engineering (24%) and the lowest mathematics. (with only a couple patents) It should be noted that the shares were shown to be closely correlated to the budgets of the different university faculties. Nonetheless it is interesting to note that the patenting activity of computer scientists (1%) and pharmacists (2%) ranked low while that of fields of electrical engineering, agriculture and material sciences were considerable. Chemistry and Biomedicine were also highly ranked. (23 and 15 % respectively) This evidence indicates that university patenting is increasing over a fairly broad spectrum of fields and that it is doing so in collaboration with industry.

Universities and nonprofit R&D institutes thus appear to be moving towards more extensive patenting not only in the US and not only in the expected fields of IT and biotech. In fact, many university patents, at least in Germany, involve engineering. Together, the evidence from the US and Germany point to increasing innovativeness of science, both in terms of own patenting and collaboration with industry.

## 5.4. Section summary

Until only recently patenting had largely been irrelevant for academic researchers, for a combination of reasons. Primarily, the inherent fact that basic research by and large does not beget patentable results (novel devices, processes with economic potential) has meant that patent-protection has simply not been an option. In addition, there has been a deep-seated cultural aversion to patenting. The ideal of 'open science' that has pervaded

[18] This work refers to a German report, Becher et al 1986. It is not know whether these are solely first-filings

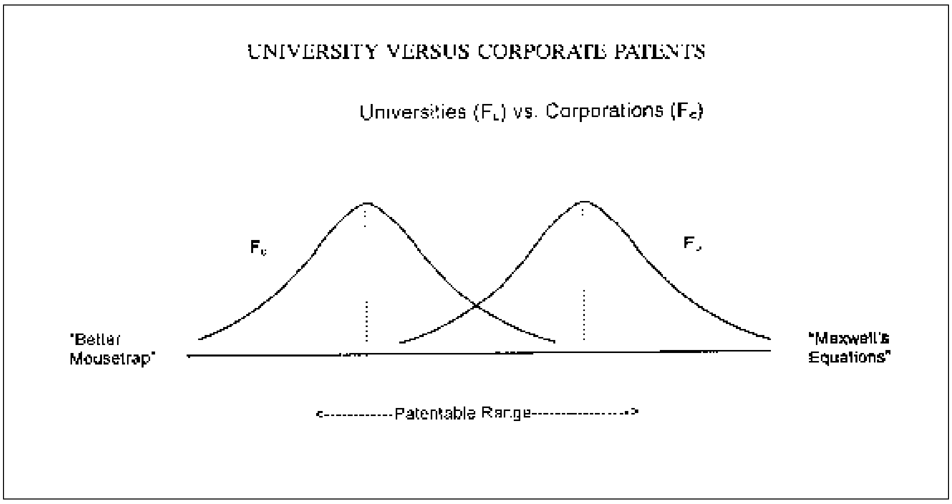
academic research has meant that the researcher generally was not been inclined to pursue this option when feasible. On top of these two fundamental factors, a practical set of reasons has kept academic research from seriously considering patent-protection as an option. A lack of clear guidelines for university patenting combined with a lack of practical support in effectively managing 'intellectual property' (applying for and capitalizing on patented inventions) has made the prospects of recouping the investment in the patenting process remote indeed for university research.

The discussion illustrated that, as part of a comprehensive set of changes in the Triple-Helix of research, patenting has become relevant for universities and nonprofit research institutes.

- The regulatory framework (in the US) has actively encouraged university-industry relations;
- The regulatory framework has made the university actively interested in financially exploiting the results of university research;
- Universities and nonprofit labs have developed strategies and the infrastructure for the active application of IPRs;
- Several fields of university research have matured to a point where many potentially marketable products are appearing;
- University researchers see patenting as a way to make sure that their results will be developed and at least not suppressed;
- The realm of what qualifies for patent-protection is broadening.

The changes in the volume and orientation of patents surveyed here can be summarized through Figure 4.1. The volume of patents is growing, most remarkable for research universities. The base-line of what is being patented is also widening. In a schematic sense, corporate and university patenting are each stretching what is patentable both in the direction of the applied and basic. In the middle, there is growing overlapping of university and corporate patenting, increasingly through collaborations between them. Simultaneously, the fringes spread, apparently allowing increased patenting into the realm of basic science (incidentally, where both universities and corporations are active, often in tandem) but also in the other direction through an apparent weakening of the non-obviousness criterion.

*Figure 4.1: Schematic portrayal of university vs. industry patenting, from M. Traitjenberg, Henderson, Jaffe (1996)*




*Source: M. Traitjenberg, Henderson, Jaffe (1996)*

But what of the quality of these patents and the changing climate's effect on academic science? Henderson et al. (1995) showed that academic patents increased 15-fold between 1965 and 1988. These patents were shown to generally be of a more basic cast than other patents (in terms of the technologically diversity of the citing patents) and of a higher standard of quality (in terms of number of patents that referenced them). The explosion of university patents however has accompanied a peaking of this quality-measure during the mid-80s, suggesting, "that the rate of increase of important patents form universities is much less than the overall rate of increase of university patenting in the period…" (Henderson et al., 1995)

This raises the question of whether the apparent fascination in patenting has not affected the way universities conduct research. Indications are mixed on whether or to which degree academic science is being drawn away from its basic research agenda towards a more commercial orientation. It should be noted first that , 'Fundamental research has always been interested in scientific questions originating in practical problems. One characteristic is that that they do not necessarily stop when the problem is solved." (Brooks & Randazzese, 1998) Another characteristic is that academic science has fundamentally been dedicated to disclosure of one's results. There are some indications that the new orientation of university-industry relations is affecting this dedication. In a series of survey-based studies referred to in Brooks & Randazzese (1998), indications were found that industry often asks university to delay, and sometimes suppress, research results from collaborations while some universities allow information to be withheld from publication.

Such evidence indicates that the apparent trend towards the capitalization of knowledge at research universities does affect the way research done there is disclosed. Altered disclosure-patterns do not however mean that the universities are simply mimicking the behavior of companies in this respect. In general, one is talking about delaying rather than suppressing results.

## 6. The Bibliometrics of Patents

In this section, arguments that commercial innovation is itself become more directly ‘scientific’ will be considered. In an often-cited survey of US industry, Mansfield (1991) indicated that 11% of new products (9%, new processes) launched during 1975-85 “could not have been developed (without substantial delay) in the absence of recent academic research”. These results indicate the scientific intensity of industrial products and processes and therefore tells us something about markets. Patents indicate more broadly the active knowledge-bases of industry and offer something of a look into the future of markets, as they typically precede products by 5-10 years. The scientific intensity of patents also provide an interesting avenue via which to view the relationship between industry and science.

A major approach to the scientification of innovation therefore involves identifying the scientific basis of patented technologies. Since the early 80s, this has been done by examining how patents cite scientific articles. In general, patents cite other publications in order to establish the novelty of the technology in question relative to its prior-art. Primarily, patents cite other patented technology. On the front page of the patent application, patent-examiner cites other patents which the relevant ‘technological frontier’ is defined and the invention’s claims to novelty tested. In cases where that which helps define novelty is found not in patented technology but published scientific articles or conference proceedings, there is a strong suggestion that the technology builds directly on work from the scientific community and thus that this indicates a close relationship between industry and universities. As a result, “the best-known technology/science linkage indicators are patent citations of scientific papers.” (Patent Manual, 1994 p 52)

The basis of such an approach was pioneered by Carpenter, Cooper & Narin (1980) in identifying science intensive areas of technology, and followed up notably by the Narin et al. and by the ISI group.[19] Following parts of this literature, the assumption of this section is that the way patents make reference to Non Patent Literature (NPL), especially scientific journals, can indicate knowledge transfer (i.e.. spillovers) between typically ‘scientific’ knowledge and more typically technical applications. Accordingly, a central issued which this approach has been used to investigate is whether ‘Technology is becoming Science’. Behind such studies is the familiar conception that technology is becoming more complex and integrating increasingly directly the results of science into technology. The use of lasers in medical instruments is an example. One of the more visible sets of research that utilize patent citations to explore the scientific component in technology has provocatively answered the is question (‘is technology becoming science?’) by saying, “the answer is that if it is not becoming science, it is certainly becoming very close to science, especially in the areas of high-tech growth such as drugs and medicine, chemicals and computing and communications.” (Narin & Olivastro, 1992)

In considering the results of these studies, it is important to be about the difficulties of the method. A central question is what actually motivates the patent examiner to make reference to scientific publications. It turns out that not all such references are made to

[19] For an overview of the field, see e.g. Schmoch, Strauss, Grupp & Reiss (in cooperation with Narin & Olivastro) Indicators of the Scientific Base of European Patents. CEC Monitor EUR 15330 EN. Research Evaluation (1993).

directly establish the scientific lineage of the invention; there are more bureaucratic reasons for such citations.[20] In terms of the use of citations in the analysis of science and technology linkages, one of the most compelling such motivations involves those cases in quickly developing fields. In such cases, the delays of publishing patents (in the US) make it incumbent on the examiner to look in published material (which generally has a shorter period of delay).

Taken this into consideration, patent citations form a unique source of information about the scientific intensity of patenting. Studies of the science base of innovations have been conducted at many levels and for patents both issued by the US and European patent offices. One has examined the involvement of science in innovations in terms of total populations of patents, national level, at the industry level or the firm level. Alternately, different aggregations of scientific articles been studied to see how they have been cited by patents. We will consider some of the results from such studies.

## 6.1. General intensity of scientific involvement in innovation on the increase

An important result in this connection involves the increasing number of non-patent citations on the first page of patents granted in the US. Between 1976 and 1989, non-patent literature citations were reported by Narin & Olivastro (1992) to have tripled from an average of less than one reference per three patents to more than one citation per each patent. In looking only at patents granted to companies in the US, they indicated that this increase in frequency is found across most technologies and across most countries. The trend is most marked in drugs & medicine and, relatedly, to the US (which patents in biomedicine) and least in transport and other types of machinery and least by Japanese (whose US patents emphasize this type of technology).

One question is if it is the number of citation per patent and/or the number of patents that cite NPL that is rising. A look at the citations made by the set of patents granted to Norwegians in the US which we saw above indicates that it is both. The table below presents the citations made by the 634 patents in the population to only the type of publication where a scientific element could be argued (159 citations to trade-literature, Japanese patent abstracts etc have been removed). The result is that 23% of these patents (143) cited such publications in the period, with the majority accruing to scientific papers.(394) Although the data-set is too small to draw any strong conclusion, it can be noted that both the share of patents citing this NPL has increased (sporadically) by a factor of two while the number of scientific papers (which is sensitive to individual patents citing large numbers of papers: one patent cites 46 in the last group.) has grown also much more but also very sporadically. The rise in and the level of the share of patents citing NPL is comparable to Narin's analysis.

[20] For an overview and discussion of the motivations of NPL citations, see Grupp and Schmoch (1992)

*Table 4.1. Distribution of NPL citations from Norwegian patents.*

| Year | 1990 | 1991 | 1992 | 1993 | 1994 | 1995/6* | **Total** |
|---|---|---|---|---|---|---|---|
| Total # patents in population | 82 | 86 | 92 | 95 | 92 | 187 | **634** |
| # patents with NPL | 11 | 17 | 25 | 19 | 19 | 52 | **143** |
| **Percent citing NPL** | **13 %** | **20 %** | **27 %** | **20 %** | **21 %** | **28 %** | **23 %** |
| | | | | | | | |
| Journal articles | 21 | 47 | 28 | 22 | 84 | 192 | **394** |
| Books | 3 | 4 | 19 | 19 | 19 | 30 | **94** |
| Conference proceedings, etc | 5 | 10 | 14 | 5 | 2 | 15 | **51** |
| Reference books | 1 | 6 | 5 | 4 | 8 | 4 | **28** |
| **Citations** | **30** | **67** | **66** | **50** | **113** | **241** | **567** |

*until June

## 6.2. Scientific base for patents has traceable link to public-research

A later study by Narin's group reported a similar rate of growth in citations to scientific-papers alone. In this study (1997), the number of citations to scientific papers originating in US institutions-to which the US data has a bias-escalated from 30,000 to some 60,000 such citations. By looking more closely at the origins of such publications together with their underlying funding, Narin concludes that, "more than 70% of the scientific papers cited on the front pages of US industry patents came from public science-science performed at universities, government labs, and other public agencies."(Narin, 1997)

This result, developed for the National Science Foundation, has been well received by the university complex in the US. Critics close to the US patent system, however, indicate that the number of papers may be inflated in some areas (e.g. biotech), with some patents citing a 100 patents a piece, while other areas may be underciting (e.g. software) non-patent prior art. One question is whether the explosion of citations is related to a general broadening of the scope of protection in US patents: such a situation, suggested by some, would entail that the growth is at least in part ascribable to a changing institutional practice. Another question, is whether the strategies of patent applicants is responsible. It is alleged by some that certain categories of patent applicants include hundreds of citations in the application which the examiner must consider but which might distract him from other relevant prior art. In other cases, patent applicants purposely hide non-patent prior art from their applications, knowing the examiner cannot or will not search the relevant art. Such criticism does however not detract from the proposition that the non-patent prior art that is listed by the examiner on the first page is in fact directly relevant to the claims to novelty made in the application. The question of how direct the relationship is or how much is left out does not reduce the claim that the public-research cited was found to be important in the same field as a patented technology.

## 6.3. Scientific link is technology specific

Another result that arises from studying the non-patent citations of patents is that the degree of scientific link or 'involvement' is specific to the type of patented technology in question. The relationship between NPL citations and science-involvement was the subject of the pioneering work of Carpenter, Cooper & Narin (1980). This question has been followed up more recently by a prominent group of German researchers. Grupp, Schmoch and others at ISI have indexed the citation patterns to the technical area of the (EPO) patents. Their work notably reduces the single country-bias evident in the US set (which cites mostly English-language prior-art), classifies patents according to 30 fields of technical activity, adjusts for those patents that cite huge numbers of articles, but has a certain large-company bias.

One result of this indexing is the conclusion that, “the science connection strongly differentiates between technological sectors and yet tenuously between countries.” (Grupp, 1996)The method indicates, perhaps expectedly, that the greatest degree of ‘science involvement’ is associated with biotechnology, while patents in chemistry, microelectronics and semiconductors also demonstrate above average linkages to a scientific corpus. It is however interesting, that the average level for all increases over time before stagnating (Schmoch, 1997) while especially biotechnology continues to increase.

In all, 13 areas are above and 17 below average in the Grupp et al. 1995. Interestingly, the field reporting least involvement in science (even less than consumer products!) seems to overlap the field (‘civil engineering’) in which a considerable number of professors in Germany were found to be relatively actively in seeking patents! In fact many of the academic fields of active patentees, especially those involving mechanical and electrical engineering in which German professors were highly represented in collaborations with industry, score below average in terms of their relationship to science!

This mechanical engineering anomaly suggests that interpreting evidence for the involvement of science in technology requires care. The authors emphasize factors behind the evidence that German professors in engineering end up patenting in collaboration with industry. They argue on the one hand that academic mechanical engineering tends to be applied because of the cognitive structure of the field, and on the other, that the very breadth of the field opens for more frequent collaboration than others. In other words, this is a field of ‘science’, in the sense of “synonym for research of non-industrial institutions, especially universities”, clashes with the cognitive definition of “technology”, which Schmoch gives as, “the body of knowledge about techniques, their tangible embodiment, and the systematic generation of new knowledge about techniques.” (Schmoch, 1997). In this light, it should be appreciated that this cognitive structure combined with the way examiner’s treat prior art (an expressed bias towards patent prior art), entails that the relationship to ‘science’ is rates low indeed for mechanical engineering.

## 6.4. Studies of individual sets of technologies

The experience that citations to science-like the very propensity to patent in industry-is industry-specific has led to a rash of sector studies. Generally these have involved those technologies that demonstrate greater scientific involvement, such as laser-medicine (Noyons et al, 1994) or nano-technology (Meyer,1998). Another approach tailored to the funding agencies in the US, has been to trace how scientific papers reflecting publicly funded research is cited by patents. The example here is less renowned as involving basic science and is typically regarded as low-tech: it involves agricultural science. (Perko & Narin, 1997)

Analyses of patenting in typically high-tech sectors address the slippery question whether technology is becoming science. In particular, they attempt to analyze the aptitude of patent-bibliometrics to approach this question and illuminate the relationship between the basic and the applied element of technology. The general answer thus far supplied by general patent-bibliometrics has been that, if it is not becoming science, it is certainly becoming very close to science, especially in the areas of high-tech growth such as drugs and medicine, chemicals and computing and communications." (Narin & Olivastro, 1992) What does closer analysis of such areas reveal?

One approach combining traditional bibliometricians with patent-analysists has involved the generic field of nano-technology (Meyer & Persson,1998). This field involves the manipulation of physical phenomena of extremely small dimensions. Nano-technology is a contemporary example of research that until recently has been considered 'basic', but that has matured to reveal application in industry. One aim of the particular was to see how directly related the research in the citations made by a growing number of patents were to the patented technologies. The answer was that the two sets of research were more 'casually than causally linked', meaning that the citing technologies did not directly grow out of the basic research referenced. This supports the working hypothesis of the field that the 'transfer' from science to technology is not to be taken too literally.

Another technology in which the scientific link is laser technologies. In 1996, Grupp confirmed the impression via patent-bibliometrics that indeed lasers are 'strongly based on science': it was one of two together with the larger set (for 1987-88, EPO) of genetics/pharmacy patents that qualified as such. In 1994, Noyons et al. undertook a rather comprehensive study of the relationship between science and technology through patents, their citations and expert opinion. This study examined publications involving inventors and assignees as well as the NPL citations. The study revealed that the relationship between NPL and the citing patent's degree of scientific intensity for laser-medicine is less than clear. They concluded that, "less or no NPL reference is not necessarily an indicator of a lesser science intensity of the individual patents, but an indicator of the more technological nature of individual patents." (Noyons et al, 1994) One important observation was that NPLs, if they are to reveal something about the scientific base, should be differentiated between references to basic and applied classes of journals. Without making allowances for the quality of the journal, not enough "to support the claim that the number of NPL references in a patent represents a measure of science intensity in one way or another." (Noyons et al, 1994) One interesting result involved collaboration. The study found that co-publications involving inventors and assignees, predominantly from universities and industry respectively, grew in front of the patents and culminated around the years of the patent-applications. An observation from expert interviews declared that indeed the entire field is science intensive (75% of patented inventors had published as well). This indicates that the number of citations to NPL is in practice more closely related to the number of claims of novelty posted by each patent-and thus the technical breadth of the technology- than necessarily the depth of scientific involvement.

These observations of the study ultimately lead the authors to conclude that "A technological field or specialty is science intensive as such". (Noyons et al, 1994) Interesting, it was of the authors (Grupp) who went ahead to design the ranking above according to NPLs in order to identify such fields. This is interesting because that ranking assumes that fewer (indexed) NPLs entail a less significant relationship between technology and science. This stands in apparent contrast to the result mentioned above that fewer NPL citations do not necessarily mean lower ‘scientific intensity’.

A different type of study examined patent-bibliometrics from the other end, examining how published research is cited by patents in the traditionally ‘low tech’ and applied field of agriculture. Drawing on the same numbers as Narin & Olivastro (1992) above, this study focused on citations to research supported by the USDA. The study concluded that the tripling of citations from 1987/88 to 1993/94, “probably an indicator of increased reliance on basic research by all of agricultural technology, and also reflects a shift in the technology to areas that are traditionally more science-linked, such as generic engineering.” (Perko & Narin, 1997) Of the USDA sponsored research that was cited by patents, much of the growth was accounted for by university-based research (funding increased as well). Collaborations involving universities increased their percentage from 20-27% of the cited material, while the proportion of “university-only” articles apparently doubled.

### 6.5. Section Conclusion

This survey of the most popular tool for quantifying the relationship between science and technology indicates several things:

1. The frequency of patent-references to NPL is increasing dramatically, suggesting ‘increased scientification of technology’,
2. Patent-bibliometrics can reveal interesting aspects of University-Industry collaborations
3. Citations form a not-unproblematic indicator of the relationship
4. Scientific involvement reflected in the NPL citations supports the intuition that certain technological fields are more ‘science intense’ than are others.
5. Some areas not intuitively associated as being scientifically intense also demonstrate increasing ‘scientification as in the agriculture study.

But NPL citations are not unambiguous in their message:

1. NPL citations do not necessarily provide a measure of scientific intensity,
2. The changing patterns of NPL are influenced by institutional factors. Both the examination routines of the individual patent offices and the patenting strategies of the applicant will affect the intensity of NPL citations, not necessarily having to do with scientific intensity

## 7. General Conclusions

In this report we surveyed evidence that industrial and academic research today utilize each others’ traditional venues for presenting results. That is, the results of industrial research is today found in the same scientific journals as academic research, while academic research is increasingly finding its way into the patent-statistics. In addition, one increasingly finds cases of explicit collaboration between the two. Further, one finds (with some reservations) signs of increasing ‘scientification of technology’ through patent-bibliometrics. We have tried to consider the bias exerted by certain fields on such tendencies. Moreover, we have attempted to examine the changes in terms of systemic changes involving the ‘triple helix’ of research.

To our knowledge, there has been no comprehensive study of the changing significance of publishing and patenting despite the fact that many recognize the research environment is in a period of transition. The report has in this sense aimed at exploring the changing preferences for these two avenues of disclosure in this environment and surveying the way evidence from bibliometric and patent-analyses can be used in studying phenomena connected to the evolution of research. In addition, the report has noted certain short-comings associated with existing bibliometric and patent-analytical approaches. There is little doubt that the study of phenomena connected to university-industry research will continue to grow.

The quantitative evidence presented here supports the plausibility of the hypothesis of a qualitative change in global research. However, our review is by no means comprehensive nor conclusive, but, we believe, that it is indicative. Another and more fundamental critique would be on whether bibliometrics and patent data may capture real phenomena in modern research. Well, the content of this chapter may also be seen as an analysis of how metrics of the world of texts correspond to metrics of the world in which we live.

# References

Association of University Technology Managers. AUTM Licensing Survey FY 1991-95.

Association of University Technology Managers. AUTM Licensing Survey FY 1997.

Bourke P., L. Butler, (1998), Institutions and the Map of Science: Matching Univer-sity Departments and Fields of Research, Research Policy, Vol. 26, pp. 711-718.

Brooks, Harvey and Lucien. P. Randazzese. 1998. University-Industry Relations: The Next Four Years and Beyond. In: Lewis M. Branscomb and J. Keller (eds.), In-vesting in Innovation: Creating a Research and Innovation Policy that Works. Har-vard University Press.

CHI Research Inc.. Industry Technology has strong roots in public science. CHI Re-search Letter Vol. V.1. March 1997.

Dasgupta, P., P.A.David,1994. Toward a new economics of science. Research Policy 23, 487-521.

David, P. A., D.C. Mowery, W.E. Steinmeuller, 1994. Analyzing the Economic Pay-offs from Basic Research. In David C. Mowery (ed.): Science and technology policy in interdependent economies. Boston: Kluwer, 57 – 78.

Etzkowitz, Henry, 1998. The norms of entrepreneurial science: cognitive effects of the new university-industry linkages. Research Policy 27, 823-833.

European Commission, (1997), Second European Report on S&T Indicators 1997, Report EUR 17639, Luxembourg.

European Patent Office, Japanese Patent Office, United States Patent & Trademark Office. Trilateral Statistical Report. 1997 edition.

Eztkowitz H., (1998), The Norms of Entrepreneurial Science: Cognitive Effects of the New University-Industry Linkages, Research Policy, Vol. 27,

Gibbons M., et al., (1994), The New Production of Knowledge, Sage, Beverly Hills.

Godin B, (1996), Research and the Practice of Publication in Industries, Research Policy, 25, pp.587-606.

Grupp, H. and U. Schmoch. 1992. Perceptions of scientification of innovation as measured by referencing between patents and papers: in Grupp, H (ed.) Dynamics in science-based fields of technology, Springer-Verlag, Berlin/Heidelberg/New York, 73 - 123

Grupp, H.,1996. Spillover effects and the science base of innovations reconsidered: an empirical approach: Journal of Evolutionary Economics.6, 175 – 195.

Halperin M.R., (1987), Firm and Industry Charactristics Influencing Publications of Scientists in Large American Companies, R&D Managment 17, No. 3, pp. 167-173.

Henderson, R., A. Jaffe, M. Trajtenberg, 1995. Universities as a source of commer-cial technology: A detailed analysis of university patenting 1965-1988. NBER Work-ing Paper No. 5068.

Hicks D.M., (1995), Published Papers, Tacit Competencies and Corporate Manage-ment of the Public/Private Character of Knowledge, Industrial and Corporate Change, Vol. 4, No. 2, pp. 401-423.

Hicks D.M., S.J. Katz, (1996), Where is Science Going?, Science,Technology &Human Values, Vol. 21, No. 4, pp. 379-406.

Hicks, D.M., P.A. Isard, B.R. Martin, (1996), A Morphology of Japanese and Euro-pean Corporate Research Networks, Research Policy, Vol. 25, pp. 359-378.

Hill, Christopher T. and J. David Roessner, 1998. New directions in federal labora-tory partnerships with industry. Science and Public Policy vol. 25, no. 5, 297-304.

Iversen, E.J, 1997. Knowledge bases and interactions in the Norwegian System: a patent share and citation analysis. STEP-Report. Oslo.

Kaloudis A., (1994), Networking in the Norwegian Institute Sector: A Bibliometric Analysis, paper presented in the Fourth International Conference on Science and Technology Indicators, October 5-7 1995, Antwerp, Belgium.

Kaloudis A., (1999), Private Companies and their Publications in Norway, in K. Smith (ed.), Mapping the Norwegian Knowledge System, forthcoming.

Katz, S.J., (1993), Bibliometric Assessment of Intranational University-University Collaboration, D. Phil. Thesis, Science Policy Research Unit, University of Sussex, Brighton.

Katz, S.J., B.R. Martin, (1997), What is Research Collaboration?, Research Policy Vol. 26, pp. 1-18.

Katz, S.J., et al., (1995), The Bibliometric Evaluation of Scientific Trends: Final Re-port, ESRC Centre on Science, Technology Energy and Environment Policy, SPRU, University of Sussex, Brighton.

Le Pair, Cornelis, 1997 Instruments: Motor of Science, Output of Science and two-way connection with industry. In John Irvine et al. (eds.): Equipping science for the 21st century. - Edward Elgar Pub: 345 – 357.

Leydersdorff L., (1995, a), The Challenge of Scientometrics: The Development, Measurement, and Self-organisation of Scientific Communications, DSWO Press, Leiden University, The Netherlands.

Leydersdorff L., (1995, b), On the ‘Scientometric Decline’ of British Science. One Additional Graph in Response to Ben Martin, in Scientometrics, Vol. 20, No. 2, pp. 363-368.

Leydersdorff L., S. Cozzens, P. van den Besselaar, (1994), Tracking Areas of Strate-gic Importance Using Scientometric Journal Mappings, Research Policy, Vol. 23, pp. 217-229.

Leydesdorff, L., H. Etzkowitz, 1996. The Future Location of Research: A Triple He-lix of University-Industry-Government Relations II. EASST Review 15, no. 4, 20-25. Presented at a conference in New York,1998.

Leydesdorff, L., H. Etzkowitz, 1998. The Triple-Helix as a Model for Innovation Studies (Conference Report). Science & Public Policy Vol. 25.

Mansfield, Edwin,1991. Academic research and industrial innovation. Research Pol-icy 20, 1-12.

Mansfield, Edwin,1995. Academic research underlying industrial innovation: sources, characteristics and financing. The Review of Economics and Statistics. Vol. 77 (1), 55-64.

Meyer, M., Persson, O., 1998. Nanotechnology — interdisciplinarity, patterns of collaboration and differences in application. Scientometrics 42 2 , 195–205.

Meyer, Martin, 2000. Does Science Push Technology? Patents citing scientific literature. Research Policy 29 , 409–434.

Meyer-Krahmer, F., U. Schmoch, 1998. Science-based technologies: university-industry interactions in four fields. Research Policy, 27, 835-851.

Narin F., K. Stevens, E. S. Whithlow, 1991, Scientific Co-operation in Europe and the Citation of Multinationally authored Papers, Scientometrics, Vol. 21, No. 3, pp. 313-323.

Narin, Francis & Dominic Olivastro, 1992. Status Report: Linkage between technol-ogy and science. Research Policy 21, 237-249.

Noyons, E.C.M., A.F.J. van Raan (1998), Monitoring Scientific Developments from a Dynamic Perspective: Self-Organized Structuring to Map Neural Network, Re-search, in Journal of the American Society for Information Science 49, pp. 69-81.

Noyons, E.C.M., A.F.J. van Raan, H. Grupp, U. Schmoch. 1994. Exploring the sci-ence and technology interface: inventor-author relations in laser medicine research. Research Policy 23, 443-457.

Okubo Y., (1997), Bibliometric Indicators and Analysis of Research Systems: Meth-ods and Examples, STI Working Papers 1997/1, OECD, Paris.

Okubo Y., et al., (1998), A Multivariate Analysis of Publication Trends in the 1980s with Special Reference to South-East Asia, Scientometrics, Vol. 41, No. 3, pp. 273-289.

Olsen T.B., A. Kaloudis, Publisering og sitering innen medisinsk forskning: en bibli-ometrisk analyse, NIFU skriftserie nr. 9/97, Oslo.

Organization for Economic Co-operation and Development (OECD), 1994. Using Patent Data as Science and Technology Indicators: Patent Manual. Paris.

Pavitt, Keith. 1991. What makes basic research economically useful? Research Pol-icy 20, 109-119.

Perko, J. S. & Francis Narin, 1997. The Transfer of Public Science to Patented Tech-nology: a Case Study in Agricultural Science. Journal of Technology Transfer Vol. 22 (3) 65-72.

Persson O., G. Melin,1997. Equalisation, Growth and Integration of Science, Scien-tometrics, Vol. 37, No. 1, pp. 153-157.

Rosenberg N., (1990), Why do Firms do Basic Research (with Their Own Money)?, Research Policy Vol. 19, pp. 165-174.

Saviotti P.P., (1998), On the dynamics of Appropriability, of Tacit and of Codified Knowledge, Research Policy, Vol. 26, pp. 843-856.

Schmoch, U., E. Strauss, H. Grupp, T. Reiss, 1993. Indicators of the Scientific Base of European Patents. EUR 15330 EN. Commission of the European Communities.

Schmoch, Ulrich. 1997 Indicators and the Relations between Science and Technol-ogy. Scientometrics.

Small H., (1997), Update on Science Mapping: Creating Large Document Spaces, in Scientometrics, Vol. 38, No. 2, pp. 275-293.

Small H., (1998), A General Framework for Creating Large-Scale Maps of Science in Two or Three Dimensions: The SciViz System, Scientometrics, Vol. 41, Nos 1-2, pp. 125-133.

Small H., E. Garfield, (1984), The Geography of Science: Disciplinary and National Mapping, Journal of Information Science Vol. 11, No. 4, pp. 147-159.

Trajtenberg, M., R. Henderson, A. Jaffe, 1997. University versus Corporate Patents: A window on the basicness of invention. Economic Innovation New Technology, Vol. 5, 19-50.

van der Besselaar P., Leydersdorff L., (1996), Mapping Change in Scientific Specialties: A scientometric Reconstruction of the Development of Artificial Intelligence, Journal of the American Society for Information Science, Vol. 47., Nr.6, pp. 415-436.

van Raan A.F.J., (1997), Scientometrics: State-of-the-Art, Scientometrics, Vol. 38, No. 1, pp. 205-218.

Viljoen, H. Christo, (1998). "Intellectual property at universities and the distribution of royalties". IEDEUS. Conference Paper Presented at MIDRAND South Africa: "Commercializing Intellectual Property at Academic Institutions."

Ziman J., (1968), Public Knowledge: The Social Dimension of Science, Cambridge University Press.

Ziman J., (1994), Prometheus Bound: Science in a Dynamic Steady State, University Press, Cambridge.

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STEP-gruppen ble etablert i 1991 for å forsyne beslutningstakere med forskning knyttet til alle sider ved innovasjon og teknologisk endring, med særlig vekt på forholdet mellom innovasjon, økonomisk vekst og de samfunnsmessige omgivelser. Basis for gruppens arbeid er erkjennelsen av at utviklingen innen vitenskap og teknologi er fundamental for økonomisk vekst. Det gjenstår likevel mange uløste problemer omkring hvordan prosessen med vitenskapelig og teknologisk endring forløper, og hvordan denne prosessen får samfunnsmessige og økonomiske konsekvenser. Forståelse av denne prosessen er av stor betydning for utformingen og iverksettelsen av forsknings-, teknologi- og innovasjonspolitikken. Forskningen i STEP-gruppen er derfor sentrert omkring historiske, økonomiske, sosiologiske og organisatoriske spørsmål som er relevante for de brede feltene innovasjonspolitikk og økonomisk vekst.

The STEP-group was established in 1991 to support policy-makers with research on all aspects of innovation and technological change, with particular emphasis on the relationships between innovation, economic growth and the social context. The basis of the group's work is the recognition that science, technology and innovation are fundamental to economic growth; yet there remain many unresolved problems about how the processes of scientific and technological change actually occur, and about how they have social and economic impacts. Resolving such problems is central to the formation and implementation of science, technology and innovation policy. The research of the STEP group centres on historical, economic, social and organisational issues relevant for broad fields of innovation policy and economic growth.