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LINKING SCIENCE AND TECHNOLOGY WITH INDUSTRY

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Abstract

In recent years, as the development of science and technology rapidly accelerated, science- and technology-based industries have emerged. Representative examples are the Information and Telecommunications (IT) industry in the late 20th century and more recently the BioTechnology (BT) and NanoTechnology (NT) industries. However, despite the emergence of science- and technology- based industries, industrial policy-makers have suffered difficulties in grasping exactly what kinds of science and technology they should manage. Therefore, in this research, I propose a method of linking science and technology with industry, by adopting the media wherethrough they are delivered. As the media for conveying science and technology, I make use of the scientific articles administered by the Institute of Scientific Information (ISI) and the patents registered in the US Patent and Trademark Office (USPTO). In this way, I identified 750 journals and 84 US patent classes corresponding to the IT industry, 1779 journals and 7 patent classes corresponding to the BT industry and 483 journals and 16 patent classes corresponding to the NT industry. This research is meaningful in that it emphasized the importance and convenience of scientific articles and patents in formulating today's industrial policies and showed how to link science and technology with industry, by using the subject categories of the ISI and the patent classes of the USPTO.

Keywords:

Science, technology, industry, scientific articles, patents

1. Introduction

Today, with the development of science and technology, new industries are emerging. For example, in the late 20th century, the Information and Telecommunications (IT) industry showed high dependency upon science and technology and led economic growth in many countries (OECD, 2000). With the advent of 21st century, it is expected that BioTechnology the (BT)-based (Clark et al., 2000) and NanoTechnology (NT)-based industries (Fleischer et al., 2000) will guide the economic development of the future. Therefore, in theses newly-emerging industries, science and technology have been recognized as an important arena for industrial policy-makers. However, at present, they often face problems in formulating policies because they cannot discern what kinds of science and technology they should deal with. Therefore, in this research, I define science and technology in an operational sense and propose a method of linking science and technology with industry for the purpose of policy making.

Although it is impossible to precisely define science and technology, there have been three major approaches for understanding science and technology.

- Nature-based: Science generally refers to a constellation of systematic activities for the understanding and discoveries of universal truths and principles (Gibbons, 2003). In other words, its research processes and results should be generalizable and re-experimentable and, therefore, objectively proven by a specific research community. Technology, on the other hand, refers to the process of making tools, machines, contrivances and materials in the course of production (Rivers, 2005). Therefore, its development processes and know-hows do not need to be generalizable and re-exprementable and, thus, become product-specific.

- Actor-based: Historically, most scientific discoveries were made by those universities which have a large number of scientists and most technological developments were accomplished by those firms which hold the largest plethora of technologists (Pavitt, 1998). In fact, in the earlier works on the national innovation system (NIS), the roles of universities mainly involved basic research, which again can be dichotomized into pure science such as Physics and Mathematics and applied science such as Computers and Materials, and the roles of firms mainly encompassed commercial developments (Nelson, 1993). However, nowadays, the unique roles of universities and firms have become less emphasized for three main reasons: firstly, the novel and fast-growing fields such as the IT, BT and NT requires a vast scope of research which spans both science and technology and, therefore, who does what cannot be clearly divided (Geuna and Nesta, 2006); secondly, universities and firms autonomously cooperate on numerous projects because of their respective interests – the professors of universities require large-scale funding for their research (Mansfield and Lee, 1996; Cohen et al., 1998; Meyer-Krahmer and Schmoch, 1998) and the industrial practitioners of firms need the academic rationales for their research and acquaintances with excellent scientists for their future recruitment (Hicks, 1995; Hicks et al., 1996; Godin, 1996; Tijssen et al., 1996); and finally, governments encourage mutual research between universities and firms in order to eliminate redundant investment in the case of large and nationally important subjects (Hayashi, 2003).

- Document-based: Since scientific research processes and results have to be publicized and acknowledged by a specific community, scientists need a medium through which to convey their achievements. On the other hand, because technology is directly linked to firms' revenue creation, technologists tend to hide the methodologies they use to achieve product development. Earlier, De Solla Price (1965) pointed out this intrinsic discrepancy between science and technology by using two terms, "papyrocentric" and "papyrophobic." The contrasts expressed by these two terms effectively reflect the phenomenon wherein scientists try to publish their works in order to obtain recognition within their community, while technologists prefer not to reveal their know-hows in order to conceal their production methods from their competitors. Therefore, science has been expressed in document form while technological developments have not been sufficiently exposed in written form. However, nowadays, most countries have adopted a patent system and given monopolistic rights to patent holders in order to encourage innovations in industrial fields. Hence, it has become possible to track technology via patent documents.

Thus far, I briefly summarized the three main criteria permitting to differentiate science and technology. Among these three criteria for distinction, I adopt the last one, i.e. the output-based approach, since the first one is not easily maneuverable because the definitions are too conceptual and the second one is not appropriate because, these days, the actors of doing science and technology are intermingled, thereby making it difficult to grasp who does what.

2. Science and technology in documents

2.1 Scientific articles as science

Science is not private but public knowledge since scientists make their contribution by publishing their work and based on these published articles, they can claim the originality of their work (Merton, 1997). The incentives and disincentives to publishing scientific articles are encapsulated in the following advantages and disadvantages, respectively.

The advantages are:

- Scientific articles are the only medium to show scientific achievements (Wouters, 1998).
- Citation patterns show the direction of scientific knowledge development (Small and Garfield, 1985).
- Despite criticism of paper citations, they are still a good indicator for knowledge flow since they exhibit the general development patterns of scientific fields (Sirilli, 1998).

The disadvantages are:

- The propensity to publish is different depending on each scientific field (Meyer, 2002).
- Papers written in non-English languages are disregarded (Meyer, 2002).
- Papers represent only one output of laboratory activities. Scientific results related to information and software are not published to the same degree (Hicks and Katz, 1996).

Despite some drawbacks, with this publishing mechanism, scientists obtain recognition in a specific community. Therefore, documented articles are the only effective tool for diagnosing scientific fruits. In the 1970s, Eugene Garfield founded the Science Citation Index (SCI), i.e. a database of scientific papers. The SCI not only covered sporadic scientific articles, but offered citation patterns of each article for tracing purposes. Moreover, compared to the other databases, the coverage of the SCI was immense - most of the other databases either only offered information on the first author or encompassed only one or two specific scientific fields. Due to its overwhelming merits, the SCI became the most widely referenced database for examining the patterns of scientific changes. However, the SCI remained difficult to be utilized because the database had to be purchased in the form of CD-ROM and, which made the information it contained outdated until the next edition of the CD-ROM was launched. Therefore, the Institute of Scientific Information (ISI), which now administers the SCI, developed the web-based SCI on the Web of Science (WoS) in order to improve its accessibility and timeliness.

2.2 Patents as technology

Regarding technology, almost every country employs a patent system as a tool to protect and encourage inventions and, thus, can be mobilized as a proxy for technology. The advantages and disadvantages of using patents are as follows.

The advantages are:

- They are a direct outcome of the inventive process, and more specifically of those inventions which are expected to have a commercial impact. They are a particularly appropriate indicator for capturing the proprietary and competitive dimension of technological change (Archibugi and Pianta, 1996).
- Because obtaining patent protection is time-consuming and costly, it is likely that applications are filed for only those inventions which, on average, are expected to provide benefits that outweigh these costs (Archibugi and Pianta, 1996).
- Patents are broken down by technical field and, thus, provide information not only on the rate of inventive activity, but also on its direction (Archibugi and Pianta, 1996).
- Patent statistics are available in large numbers and for a very long time series (Archibugi and Pianta, 1996).
- Patents are public documents and, therefore, all information including the patentees' names is not covered by statistical confidentiality (Archibugi and Pianta, 1996).

The disadvantages are:

- Not all inventions are technically patentable. This is the case of software, which is generally legally protected by copyright (Archibugi and Pianta, 1996).
- Not all inventions are patented. Firms sometimes protect their innovations with alternative methods, notably industrial secrecy (Archibugi and Pianta, 1996) since they do not consider patent protection to be the most important means for the appropriation of innovation (Levin et al., 1987; Brouwer and Kleinknecht, 1997).
- Firms have a different propensity to patent in their domestic market and in foreign countries, largely depending on their expectations for exploiting their inventions commercially (Archibugi and Pianta, 1996).
- Although there are international patent agreements among most industrial countries, each national patent office has its own institutional characteristics, which affect the costs, length and effectives of the protection accorded. In turn, this affects the interest of inventors in applying for patent protection (Archibugi and Pianta, 1996).
- Patent classification does not correspond to economic fields (Griliches, 1990; Kleinknecht et al, 2002).

- Sectoral differences in propensity to patent exist (Arundel and Kabla, 1998). Firms in high technological opportunity sectors tend to have a higher propensity to patent than those in low technological opportunity sectors.
- There is a threshold effect for small firms. Therefore, one patent of a small firm is not equal to one patent of a large firm (Kleinknecht et al, 2002).

As mentioned above, although patents also have several drawbacks, they are, in an overall sense, the most representative of technology in terms of importance and value.

However, since each country not only has a different patent system but also its firms file international patents according to their own strategic motivations, the number and quality of patents vary from nation to nation. Moreover, in a majority of cases, firms tend to patent more in their home countries than in foreign countries (European Commission, 1997; Patel and Vega, 1997; OECD, 2003), which causes a home advantage bias (Faust and Schedl, 1982). Therefore, Dernis and Kahn (2004) maintained the use of patent families, i.e., the patent documents granted in various patent offices, thereby enabling us to have several advantages as well as to remove home advantage bias. However, a large dataset for patent families is not easily accessible (Michel and Bettles, 2001) and, therefore, researchers have used patents granted by the Eupropean Patent Office (EPO; Le Bas and Sierra, 2002), since the EPO uses a patent system agreed to by 27 European countries (Archibugi and Pianta, 1992). Counting the patents registered in the EPO is a reasonable option to remove the home advantage effect, since the applicants have to file a patent in their home country as well as in the EPO (Dernis and Khan, 2004). The OECD (2003), on the other hand, recommends that we should investigate the triadic patent families, i.e. the patents contemporarily listed in the US Patent and Trademark Office (USPTO), the European Patent Office (EPO) and the Japanese Patent Office (JPO), in order to reduce a home-advantage bias. However, the EPO provides annual data in the form of CD-ROM with a limited scope and the JPO does not offer an electronic form of data, which hampers efficient data gathering. Therefore, many researchers have used US patents because the USPTO offered the widest and most up-to-date information.

3. Methods and exemplary results

3.1 Methods

As regards science, since the SCI, at present, holds around 6,000 journals related to science ranging from pure science such as Physics to applied science such as Biotechnology, it becomes a very time-consuming task to allocate each journal to the corresponding industry. Therefore, I utilize the subject categories provided by the ISI. It provides 171 subject categories, each of which is composed of analogous journals. Also, the scope notes explaining each subject category are available at the ISI website, www.isi.com. By referring to the scope notes and the explanations about the journals at the ISI website, we can select and regroup the subject categories relevant to each industry.

As for technology, the USPTO employs over 400 patent classes whereby each patent is classified. However, the USPTO classification cannot also be not perfectly matched to any industry classification since a certain technology can be applied to several industries. Despite this difficulty, there have been many attempts to transform the patent classification into an industry classification because patent information is invaluable when it comes to examining industrial knowledge. Among the various classification schemes, we mainly referred to that of Hall et al. (2001) since it resulted from a large-scale technology-industry matching project using US patents. They firstly aggregated patent classes into 36 two-digit sub-categories and further grouped them into 6 one-digit categories. Since the one-digit categories are too broad to match patent classes to the corresponding industries, I opt for the two-digit subcategories. Then, by referring to the explanation of each class on the USPTO website, www.uspto.gov, I eliminate the patent classes that are not matched to each industry and add those that are matched to each industry from the rest of the sub-categories[1].

3.2 Exemplary results

First, in terms of the grouping of subject categories, 11 subject categories including Automation & Control Systems constituted the IT industry; 24 subject categories including Biochemical Research Methods BT industry; and 11 subject categories including Instruments & Instrumentation NT industry. Since the subject categories are a collective set of analogous journals, we can count the number of journals in each sub-category by referring to the ISI website. Consequently, it was found that the IT industry held 750 relevant journals in 11 different subject categories; the BT industry 1779 journals in 24 idiosyncratic subject categories; and finally, the NT industry 483 journals in 10 heterogeneous subject categories.

Second, with respect to grouping of patent classes, I roughly grouped the sub-categories into the corresponding industrial fields. In this way, in the case of the IT industry, Hall et al. (2001)'s sub-categories 21-24, 41, 42, 45, 46 and 49 were allocated; in the case of the BT industry, their sub-categories 31, 33 and 39 were selected; and finally, in the case of the NT industry, their sub-categories 32, 43 and 54 were assigned. After eliminating the patent classes that were not matched to each industry, by referring to the explanation of each class on the USPTO website, I finally obtained 84 patent classes in 7 different sub-categories in the case of the IT industry; 7 patent classes in 3 idiosyncratic sub-categories in the case of the BT industry; and 16 patent classes in 3 heterogeneous sub-categories.

[1] It is very reasonable to point out that most of countries do not adopt the USPTO classification system in order to classify their national patents, instead opting for the International Patent Classification (IPC) system. Therefore, if researchers or policy-makers wish to study their own country's patents, they should additionally match the USPTO classes to the IPC codes by referring to the USPTO website.

Table 1 shows the matching table of the subject categories and patent classes all together.

Table 1 Science-technology-industry relationship

Industry	Science (ISI subject category)	Technology (Hall et al's sub-category)
IT	Automation & Control Systems (49); Computer Science, Artificial Intelligence (89); Computer Science, Cybernetics (18); Computer Science, Hardware & Architecture (45); Computer Science, Information Systems (97); Computer Science, Interdisciplinary Applications (92); Computer Science, Software Engineering (83); Computer Science, Theory & Methods (78); Engineering, Electrical & Electronic (215); Imaging Science & Photographic Technology (11); Telecommunications (63)	Communications, Computers (12), Computer Hardware & Software (17), Computer Peripherals (2), Information Storage (4), Electrical Devices (14), Electrical Lighting (6), Power Systems (12), Semiconductor Devices (4), Miscellaneous-Elec. (9) and 116, 123, 181, 279 from the Mescellneous-Others (4).
BT	Biochemical Research Methods (58); Biochemistry & Molecular Biology (278); Biology (82); Biophysics (69); Biotechnology & Applied Microbiology (142); Chemistry, Medicinal (38); Chemistry, Organic (58); Cell Biology (159); Critical Care Medicine (21); Developmental Biology (34); Emergency Medicine (11); Engineering, Biomedical (44); Evolutionary Biology (35); Genetics & Heredity (137); Integrative & Complementary Medicine (13); Marine & Freshwater Biology (78); Materials Science, Biomaterials (15); Medical Informatics (19); Medicine, General & Internal (112); Medicine, Research & Experimental (77); Microbiology (89); Pharmacology & Pharmacy (207); Reproductive Biology (24)	Drugs (2), Biotechnology(2), Mescellaneous-Drug & Med (3)
NT	Instruments & Instrumentation (54); Materials Science, Characterization & Testing (26); Microscopy (10); Mycology (18); Nanoscience & Nanotechnology (32); Neuroimaging (13); Optics (58); Radiology, Nuclear Medicine & Medical Imaging (93); Spectroscopy (40); Surgery (139)	Surgery & Medical Instruments (7), Measuring & Testing (4), Optics except 399 (5)

Note. The number of journals and the number of patent classes in the parentheses

4. Discussion

In this paper, I firstly proposed the use of scientific articles and patents in understanding science and technology, due to its concreteness, coverage, accessibility and maneuverability. Secondly, I proposed a method for linking science and technology with industry by exemplifying the IT, BT and NT industries. It should be admitted that because journals are deliberately aggregated into the correponding subject categories, the proposed method may be insufficient in terms of accuracy. That is, considering that this research aims to provide a sketchy snapshot of science- and technology- intensive industries as a preliminary step before earnest analysis, further analyses should be accompanied in the future.

For example, in terms of national industrial policies, which areas among national R&D projects we should place a priority on has become a focal issue. Therefore, as for R&D priority setting, we can measure the amount of scientific and technological knoweldge in emerging industries, by utilizing the proposed method, and actively support those areas which are important but have not attained thresholds. The SCI offers information on authors, authors' institutional affiliations and their addresses and countires, and the USPTO website exhibits information on inventers, assignees, i.e. inventers' affiliations, and countires. Therefore, by collecting data in an emerging industry of interest, we can tally the number of scientific articles or patents by actor and nation, thereby showing the major actors and countries in terms of amount. It is also possible to analyze scientific articles and patents from a perspective of importance by employing various indexes such as citation frequencies and technology life cycle. Secondly, since science and technology are closely related (Gibbons and Johnston, 1974; Narin and Noma, 1985; Jaffe, 1989; Brooks, 1994; Mansfield, 1995; Van Raan, 1998), in order to frame policies related to them, we should, in advance, understand the degree of relatedness. As regards the relationship between science and technology, Brooks (1994) pointed out the effect of science onto technology in six aspects and vice versa in two respects. At present, the most prevalent way of diagnosing the linkage between science and technology is analyzing non-patent citations (NPCs) in patents documents (Verbeek et al. 2002). However, this only represents the dependency of technology onto science, not accommodating that of science onto technology. Therefore, for the understanding of mutual interactions, we need a framework to view science and technology at a glance. Since this research offered an approach regarding how to connect science and technology with industry, the studies about the degree of relatedness will be commenced by utilizing the method herein proposed.

References

Archibugi, D. and Pianta, M. (1992) 'Specialization and size of technological activities in industrial countries: the analysis of patent data', *Research Policy*, Vol. 21, pp. 79-93.

Archibugi, D. and Pianta, M. (1996) 'Measuring technological change through patents and innovation surveys', *Technovation*, Vol. 16, pp. 451-68.

Arundel, A and Kabla, I. (1998) 'What percentage of innovations is patented?', *Research Policy*, Vol. 27, pp. 127-141.

Brooks, H. (1994) 'The relationship between science and technology', *Research Policy*, Vol. 23, pp. 477-486.

Brouwer, E and Kleinknecht, A. (1997), 'Measuring the unmeasurable: a country's non-R&D expenditure on product and service innovation', *Research Policy*, Vol. 25, pp.1235-1242.

Clark N., Stokes, K. and Mugabe J. (2000) 'Biotechnology and development: threats and premises for the 21st century', *Futures*, Vol. 34, pp. 785-806.

Cohen, W. M., Florida, R., Randazzese, L. and Walsh, J. (1998) 'Industry and the academy: uneasy partners in the cause of technological advance', in: R. Noll R (Ed), *Challenges to the Research University*, Washington DC: Brookings Institution Press, pp. 171-199.

Dernis, H and Khan, M. (2004) 'Triadic Patent Families Methodology', *OECD STI Working Paper* 2.

De Solla Price, D. K. (1965) 'Is technology historically independent of science? A study in statistical historiography', *Technology and Culture*, Vol.6, pp. 553-568.

European Commission (1997) *Second European Report on S&T Indicators*.

Faust, K. and Schedl, H. (1982) 'International patent data: their utilisation for the analysis of technological developments', *Workshop on Patent and Innovation Statistics*, Paris: OECD.

Fleischer, T., Decker, M. and Fiedeler, U. (2000) 'Accessing emerging technologies: methodological challenges and the case of nanotechnologies', Technological Forecastging and Social Change, Vol. 72, pp. 1112-1121.

Gibbons, J. H. (2003) 'On the intimate kinship among the methods of science, art, and the humanities', *Technology in Society*, Vol. 25, pp. 1-4.

Geuna, A. and Nesta, L. J. J. 2006. 'University patenting and its effect on academic research: the emerging European evidence', *Researcy Policy*, Vol 35, pp.790-807.

Gibbons, M. and Johnston, R. (1974) 'The roles of science in technological innovations', *Research Policy*, Vol. 3, pp. 220-242.

Godin, B. (1996) 'Research and the practice of publication in industries', *Research Policy, Vol. 25, pp.* 587-606.

Griliches, A. (1990) 'Patent statistics as economic indicators: a survey', *Journal of Econonic Literature*, Vol. 28, pp. 1661-1707.

Hall, B. H., Jaffe, A. B. and Manuel, T. (2001) 'The NBER patent citations data file: lessons, insights and methodological tools', *NBER Working Paper* 8498.

Hayashi, T. (2003) 'Effect of R&D programmes on the formation of university-industry-government networks: comparative analysis of Japanese R&D programmes', *Research Policy* Vol. 32, pp. 1421-1442.

Hicks, D. (1995) 'Published papers, tacit competencies and corporate management of the public/private character of knowledge', *Industrial and Corporate Change*, Vol. 4, pp. 401-424.

Hicks, D. and Katz, S. (1996) 'Systemic bibilometric indicators for the knowledge-based economy', *Conference on New S&T Indicators for the Knowledge-based Economy*, Paris.

Hicks, D. Isard, P. and Martin, B. (1996) ‘A morphology of Japanese and European corporate research networks’, *Research Policy* 25, pp. 359-378.

Jaffe, A. (1989) ‘Real effects of academic research’, *American Economic Review*, Vol. 79, pp. 957-970.

Kleinknecht, A. Van Montfort, K. and Brouwer, E. (2002) ‚The non-trivial choice between innovation indicators’, *Economics of Innovation and New Technology*, Vol. 11, pp. 109-121.

Le Bas, C. and Sierra, C. (2002) ‘Location versus country advantages in R&D activities: some further results on multinationals’ locational strategies’, *Research Policy*, Vol. 31, pp 589-609.

Levin, R. C., Klevorick, A. K., Nelson, R. R. and Winter, S. G. (1987) ‘Appropriating the returns from industrial research and development’, *Brookings Papers on Economic Activity*, Vol.3, pp. 783-831.

Mansfield, E. (1995) ‘Academic research underlying industrial innovations: sources, characteristics and financing’, *Review of Economics and Statistics*, Vol. 77, pp.55-62.

Mansfield, E. and Lee, J. L. (1996) ‘The modern university: contributor to industrial innovation and recipient of industrial R&D support’, *Research Policy* 25, pp. 217-221.

Merton, R. K. (1997) ‘The sociology of science: an episodic memoir’, in: R. K. Merton and J. Gaston (Eds), *The Sociology of Sience in Europe*, Carbondale: Southern Illinois University Press, pp. 3-141.

Meyer, M. (2002) ‘Tracing knowledge flows in innovation systems’, *Scientometrics*, Vol. 54, pp. 193-212.

Meyer-Krahmer, F and Schmoch, U. (1998) Science-based technologies university-industry interactions in four fields, *Research Policy* 27, pp. 835-852.

Michel, J and Bettles, B. (2001) ‘Patent citation analysis. a closer look at the basic input data from patent search reports’, *Scientometrics*, Vol. 51, pp. 795-816.

Narin, F. and Noma, E. (1985) ‘Is technology becoming science?’, *Scientometrics*, Vol. 7 , pp. 69-81.

Nelson, R. (1993) *National Innovation System*, London: Oxford University.

OECD (2000) Science, technology and innovation in the new economy, *Policy Brief*, pp. 1-12.

OECD (2003) *Compendium of Patent Statistics*.

Patel, P. and Vega, M. (1999) ‘Patterns of internationalisation of corporate technology: location vs. home country advantages’, *Research Policy*, Vol. 28, pp. 145-155.

Pavitt, K. (1998) ‘Do patents reflect the useful research output of universities?’, *SPRU Electronic Working Paper Series* 6.

Rivers, T. J. (2005) ‘An introduction to the metaphysics of technology’, *Technology in Society*, Vol. 27, pp.551-574.

Small, H. and Garfield, E. (1985) ‘The geography of science: disciplinary and national mappings’, *Journal of*

Information Science, Vol. 11, pp. 147-159.

Sirilli, G (1998) 'Conceptualising and Measuring Technological Innovation', *IDEA Report* 1.

Tijssen, R. J. W., Van Leeuwen, T. H. H. and Korevaar, J. C. (1996), 'Scientific publication activity in industry in Netherlands', *Research Evaluati*on, Vol. 6, pp. 1-15.

Van Raan, A. F. J. (1998) *Handbook of Quantitative Studies on Science and Technology* Amsterdam: Elsevier Science Publisher.

Verbeek, A., Debackere, K., Luwel, M., Andries, P,, Zimmermann, E. and Deleus, F. (2002) 'Linking science to technology: using bibliographic references in patents to build linkage scheme', *Scientometrics*, Vol. 54, pp. 399-420.

Wouters, P. (1998) 'The signs of science', *Scientometrics*, Vol.41, pp. 225-241.