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Patenting as an indicator of technological innovation: a review

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Patents are an indicator of invention and innovation but, as with other indicators, they have their pitfalls. This paper looks at their use and their advantages and disadvantages. It shows the heterogeneous nature of patents, how they can be compared with other indicators, and offers some international comparisons.

innovation — Always dangerous.
inventors — They all die in the hospice.
Somebody else profits by their discoveries; it is not fair.

Gustave Flaubert,
Dictionnaire des idées reçues

THE PATENT SYSTEM is one of the oldest institutions of market societies (on its origins, see Kaufer, 1989) and it is designed to promote and diffuse innovation. A patent gives the inventor exclusive rights over the commercial exploitation of the invention for a limited period under certain conditions in return for publication of the invention.

The patent system is therefore a contract between the state and the individual: the former grants to the latter a legal and temporary monopoly (in the majority of countries it lasts from 15 to 20 years) on a certain invention against the disclosure of information which the inventor might otherwise keep secret. In practice, neither the legal protection accorded nor the disclosure of the invention is entirely fulfilled.

Patenting as technological indicator

Patents are the outcome of the part of scientific and technological (S&T) activities which have a proprietary nature and are likely to generate business applications; in other words, they are more likely to reflect technological rather than scientific activities.

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Descriptions of patents granted are collected and classified to allow the patent examiners to check that new applications satisfy the requirement of novelty, that is, that they had not already been patented by other inventors. To examine new applications, patent officers need to trace daily a large number of already granted patents. To facilitate the task, patent offices have developed several methods of classification. Patents are classified with systems similar to those used by general libraries — by title, name of the inventor, and, above all, the priority claims they contain.

Patent office examiners are not alone in the use of patent literature; firms also search it for purposes such as:

- to monitor the technological advances of their line of business;
- to identify the inventions made by their competitors;
- to back their legal cases on intellectual property rights (for an overview of the use of patenting for the firm's managerial strategies, see Brockhoff, 1992).

A number of companies (for instance Inpadoc, Derwent and CHI Research) provide on-line information on the patent literature, and several journals and newsletters, such as *World Patent Information*, diffuse information on new methods of patent search.

Since these approaches deal with individual, or a handful of, patents, they do not use the data in their statistical dimension. When patenting is employed to study technological change, a different methodology is used: a number of statistically significant observations is considered. In other words, while patent offices and businesses are mainly concerned to single out individual patent documents, students in the field of technological change are interested in patents in large numbers.

Patents provide a very valuable source of information on the temporal, geographical, sectoral and technological distribution of inventions. Following the pioneering work of Jacob Schmookler, a growing number of studies have employed patenting as a measurement device (Schmookler, 1966; 1972). Several surveys have been published on this vast literature (see, among others, Soete and Wyatt, 1983; Basberg, 1987; Schmoch *et al*, 1988; Pavitt, 1988; Van Raan, 1988; Griliches, 1990; Scherer 1992).

This article is neither intended to substitute for these surveys nor to do justice to the existing literature, but rather to stimulate the readers' interest in the use of this indicator. In particular, those readers interested in the philosophy underlying the data will benefit from Basberg (1987), those on their descriptive use from Pavitt (1988) and those in the econometric applications from Griliches (1990).

Pros and cons of patent indicators

A patent document contains the following information: the title, abstract and full description of the invention; the name, address and nationality of the inventor; the name, address and nationality of the owner of the invention; the technological classes to which the patent belongs at the two, three, four and even five digit level of classification (the United States Patent Office, for example, uses more than 100,000 patent classes); the citations to both the relevant scientific literature and previous patents (for the latter see Narin in this issue). This data is available, some of it even computerized, for most industrialized countries.

As any other available indicator, patenting has its advantages and disadvantages. The main advantages may be summarized as follows:

- Patents represent the outcome of the inventive process, and more specifically of those inventions which are expected to have a business impact. They are a particularly appropriate indicator to capture the proprietary and competitive dimension of technological change.
- Obtaining patent protection is time consuming and costly. It is likely that applications are presented for those innovations which, on average, are expected to provide benefits which compensate these costs.
- Patents are broken down by technical fields, providing information not only on the rate of inventive activity, but also on its direction.
- Patent statistics are available in large numbers and for a very long time series.

But patents also have several disadvantages:

- Not all inventions are patented. Sometimes firms protect their innovations with alternative methods notably industrial secrecy (on the trade-off between patenting and industrial secrecy, see Wyatt *et al*, 1985; Levin *et al*, 1987).
- Not all inventions are technically patentable. This is the case for software, which has an increasingly important role in current technological advance and which, after a long controversy, is now protected in the majority of countries by copy right.
- The propensity to patent (that is, the number of patents registered for each unit of inventive and innovative activity, see Scherer, 1983) greatly varies across technological areas and industries. While in certain fields, such as pharmaceuticals, a large part of the inventions are codified in patent applications, in other equally S&T-intensive fields, such as nuclear physics, only a handful of patents are to be found.
- Firms have a different propensity to patent in each national market, according to their expectations for exploiting their inventions commer-

cially. The size of national markets and the level of integration in international trade affects the number of foreign patent applications received by each country. Moreover, national patent offices receive a large number of applications by domestic inventors and firms, thus they are biased towards the domestic inventive activity (Archibugi and Pianta, 1992a; 1992b).

- In spite of the international patent agreements among the majority of industrial countries, each national patent office has its own institutional characteristics; the attractiveness for applicants of any patent institution depends on the nature, costs, length and effectiveness of the protection accorded.

Shepherd (1979) has argued that

> "patents are a notoriously weak measure. Most of the eighty thousand patents issued each year are worthless and are never used. Many are of moderate value, and a few are bonanzas. Still others have a negative social value. They are used as 'blocking' patents to stop innovation, or they are simply developed to keep the competition out."

All the arguments advanced by Shepherd are partly right, but they do not negate their usefulness as indicator. In detail:

- It is true that many patents are never used, but the same applies to R&D projects since many of them do not result in innovations. In other words, patents also reflect the uncertainty of scientific research.
- It is true that the economic impact of patents is highly skewed (see Sirilli, 1987), but this is due to the uneven economic impact of the inventive and innovative activities.
- It is true that patents are often used by firms to block competitors rather than to introduce innovations, but still they represent a technological capability of the firm.

Patents, invention, innovation

Economists and science policy analysts are not interested in the count of patents as such; they are interested in patents if they provide a measurable yardstick of a much wider phenomenon — inventive and innovative activities. But what is the relationship between patents on the one hand, and invention and innovation on the other?

A large number of inventions are never patented. This does not necessarily prevent them from being innovations, as in the case of firms which commercially exploit new discoveries and rely on industrial secrecy for their protection (such as the Coca-Cola formula, which has been kept secret for many years). In turn, not all the inventions which are patented do become innovations; a large number of them are the so-called 'sleeping patents' which will never be exploited in economic life.

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Some empirical surveys have tried to quantify the share of inventions which are patented and the share of patents which become innovations. Research carried out by Mansfield (1986) has shown that firms apply for a patent for about 66% to 87% of their patentable inventions.

This does not mean that patents account for such a large share of all inventions, since there is an unknown number which are not technically patentable. Moreover, we are aware that a large share of inventions are produced by individuals, universities and research centres; the latter institutions have different aims and attitudes towards their research output, and are more likely to generate papers in scientific journals than patent applications.

The second issue to be addressed is the share of patents which become actual innovations. Old (Scherer *et al*, 1959; Sanders, 1964) and new (Napolitano and Sirilli, 1990) empirical evidence show very similar results: the share of used patents ranges from 40% to 60% of the total applications. The evidence of the share of the inventions which are patented, and that on patents which become innovations, seem to encourage, rather than discourage, the use of patenting.

Heterogeneous nature of patents

Although empirical research has shown that patents are more closely related to innovation than generally believed, this does not solve the problems involved in their use. We can conclude, at most, that patents are a good raw ingredient for quantitative analyses. To provide a satisfactory meal, they should also be well cooked.

One of the main problems is that an aggregation of patents, as well as other measures of technological innovation, includes items of very heterogeneous value: to add up patents implies that inventions with different economic and technological significance are merged. To a certain extent this is due to the heterogeneous nature of technological change. It is very difficult, and often impossible, to give an economic or technological value to each invention and innovation: how is it possible to compare an improved jet engine with a new ball point pen? At the end of the day, the scholar dealing with quantitative indicators will have the impression of adding up apples and oranges (DeBresson, 1986; Smith, 1990).

Impact of individual patents

Several attempts have been made to deal with the different value of individual patents. Townsend (1980) has considered the patents related to coal mining machinery and has rated them according to their importance on a scale from 1 to 4. This commendable procedure, however, is time consuming and requires a specific engineering competence. It might be appropriate for specific case studies but it is difficult to apply to a large number of observations.

A quantitative method to assess the value (or impact) of individual patents is the count of patent citations (see Trajtenberg, 1990a). It is assumed that the greater the number of citations a patent receives, the higher its business impact (which does not necessarily correspond to its quality, see Narin and Olivastro, 1988b). These studies show the very skewed impact of the inventions since only a minority of patents are cited in the subsequent patent literature. The linkage of patents to the previous and subsequent technical literature is explored by Trajtenberg *et al* (1992).

The skewed distribution of the value of patents is confirmed by those studies which have collected data on the annual renewal fees paid by the holder of the invention to preserve the legal validity of the patent (for a survey of this application, see Pakes and Simpson, 1989). Annual renewal fees have to be paid in several countries; therefore the holder of the invention has to decide whether the returns of the patent protection exceed the costs of the renewal fee. In some countries the fee increases each year.

Pakes (1986) and Schankerman and Pakes (1986) have shown that renewal fees are paid until the year of expiration of the validity of the patent for a minority of inventions only. Significant differences are to be found across technological fields, countries of origin of the invention, and national institutions where the patent is registered.

Studies of patent citations show the very skewed impact of the inventions since only a minority are cited in the subsequent patent literature: this skewing is confirmed by collection of data on annual renewal fees

Only a few years ago, data on patent citations and patent renewal fees was time consuming and expensive to collect; not surprisingly, the first papers to use this information considered selected case studies only. The advances in information technology and computer search are making these procedures less costly and more user-friendly. Databases on patent citations are already available, and future studies are likely to employ more refined patent data where quantity will be matched by quality.

These valuable refinements in the use of patenting do not, however, deny the usefulness of patent counts. In fact, these studies have shown that there is a certain relationship between quantity and quality: within a sufficiently large group of 'comparable' patents there is a similar share of good and bad. But what is a comparable group of patents? Significant variations are, in fact, to be found across technological fields, patent offices and countries of origin.

Value across technological areas

Although often underestimated, a crucial constraint on the use of this indicator is the marked difference in the value of patents across fields. Also the value of individual patents within one field is highly variable: to give equal weight to two patents in the same field may be like comparing a pear and an apple. But we can rely on a compensation effect in statistical analyses; within the same class, we might assume the existence of an average value of a single invention.

The same assumption becomes much more dubious when we take into account patents belonging to different classes. Aggregating patents in aircraft with others in metal products may be like comparing a pear tree to a single apple. Griliches (1989) has shown that the number of patents per million US dollars of applied R&D ranged from about 11 in metal working machinery (a class with a high propensity to patent) to 0.01 in guided missiles, a typical class where inventions are better protected by secrecy; with such a variability of 1000 to 1 it is clear that some caution should be taken when patents of different classes are compared.

One of the advantages of patents over comparable indicators arises from the detailed information provided by fields. But to exploit this richness, appropriate statistical methods should be used to compare patents across fields.

What is a patent sector?

When referred to patenting, the concept of a 'sector' (or industry) can be tricky: there are (at least) four ways to aggregate individual patents into a sector (for a formal analysis, see Archibugi, 1988a), according to:

- the technical characteristics of the invention, which is the classification generally provided by the patent offices;
- the product in which the invention is likely to be embodied, which does not necessarily correspond to its technical characteristics;
- the main economic activity of the firm which owns the patent. Firms, and large firms especially, patent in a variety of fields which do not necessarily correspond to their main economic activity;
- the main economic activity of the firms which are likely to benefit most from the invention.

In some cases a patent can belong to the same class according to all four criteria (for example a new chemical entity embodied in a chemical product and produced and used within chemical companies). In other cases the classification of a patent can be different according to each of the four criteria (an electronic device which is part of a machine tool produced by an automobile company and used by aircraft manufacturers).

Matching to other indicators

Patents are often compared to other indicators of scientific, technological or economic activity (Grupp and Schwitalla, 1989).

R&D Not surprisingly, the most natural comparison is between patent data and R&D expenditures. Although the two indicators account for different phases and aspects of inventive and innovative activities, they should be strongly and positively correlated (see Mueller, 1966; Pavitt, 1982; Hausman *et al*, 1984; Bound *et al* 1984; Pakes and Griliches, 1984; Hall *et al*, 1986; Malerba and Orsenigo, 1987).

Surprisingly, the results do not always conform to the expectations, especially at the firm level. There are three reasons for this:

- firms of different business lines innovate in classes with a different propensity to patent;
- data are not always matched according to the same sectoral criteria;
- patents and R&D capture different aspects of the innovation process, and in certain sectors one of the two indicators proves to account for a larger share of inventions than the other.

The validity of patents, as well as of R&D, has also been tested on innovation counts (Comanor and Scherer, 1969; Achilladelis *et al*, 1987) and innovation surveys (see Archibugi, Cesaratto and Sirilli, 1987; Acs and Audretsch, 1989). In some industries, such as pharmaceuticals, both patents and R&D account for the majority of the innovations introduced. In others, such as software, none of the available indicators is able to capture the innovations exploited. The literature cited helps to select the appropriate indicator for case studies.

Bibliometric studies A vast literature documents the relationship between science and technology using scientific publications as indicator for the former and patents for the latter. These studies have explored the interconnections between the scientific and the technological communities (see Narin and Noma, 1985; Coward and Franklin, 1989), as well as the science intensity of the current technological developments (Van Vianen *et al*, 1990. For comprehensive overviews of these developments, see Van Raan, 1988; Van Raan *et al*, 1989).

Stock market value A long-term programme of comparisons between patents and indicators of economic performance, such as the companies' stock market value, has been undertaken by Griliches and his associates at the NBER (see Pakes, 1985; Griliches *et al*, 1988). It is assumed that the stock market reacts to new discoveries and revalues firms' assets before the innovation is profitable in the market, as measured from variables such as productivity or profits. The methodology and the results of this application are surveyed by Griliches (1990).

Innovation and firm size Patents have been employed to explore the relationship between innovation and firm size by Scherer (1965). This research was criticized (Soete, 1979) because, it was argued, small companies have a higher propensity to patent than large ones. However, Mansfield (1986) has shown that the propensity to patent does not change considerably across firm size classes. A comparison of the patenting activity of large firms include Pakes and Griliches (1984), Patel and Pavitt (1991a) and Malerba and Orsenigo (1992).

Multi-technology firms

Industrial economists and management analysts often need to identify the nature of the innovations developed within a firm. The majority of firms, and above all the large ones, are highly diversified and this is reflected in the innovations they create. They often develop technological activities in a larger number of fields than their product lines.

Firms often produce their own equipment and machinery, or the intermediate components of their products. They might also start a number of unsuccessful research projects which will not lead to new products. In other words, a firm's diversification in technological skills and assets is generally

Several studies have considered firms' patent portfolios, either to study their technological diversification, or to identify to what extent firms benefit from innovations carried out by others engaged in similar technological areas

greater than its product diversification.

It is not easy to identify the innovative activities occurring within a firm. Industrial secrecy is often difficult to break. The multi-technological activities of a firm can be identified by patents. The two pieces of information needed are available in a patent document: the technological classes of the patent and the name of the firms (and/or its main business line). Leading technology companies, such as Hitachi and Toshiba, have an annual flow of nearly 1,000 patents, and their distribution across fields makes it possible to identify with a good approximation their innovative projects.

Several studies have considered firms' patent portfolios, either to study their technological diversification (Kodama, 1986; von Tunzelmann, 1988; CHI Research, 1988; Archibugi, 1988b; Niwa, 1992) or to identify to what extent firms benefit from innovations carried out by others engaged in similar technological areas (Jaffe, 1986). These studies have shown that:

- the majority of companies have a wider distribution of technological activities than of product lines;
- patents can be used to identify the economic strategies of companies, often before it is implemented in the market;
- they are a valuable tool to identify the combination of different branches of knowledge into a new technological advance.

Technological interdependence

Technology systems, even more than economic systems, are characterized by strong interdependence. Some innovations might be produced and used within the same firm, but the vast majority of significant innovations interact across firms and sectors. The productivity growth of an industry often depends on the use of innovations developed by up-stream suppliers. Some innovations are applicable to a single-user industry while others may have a more broader impact.

Much work has been done to attempt to understand and measure economic interdependence, and sophisticated techniques, such as input-output tables, have been developed. Only over the last decade growing attention has been paid to technological interdependence (for a review of the issue, see Archibugi, 1988a and DeBresson, 1990). Acquiring information on technological interdependence requires the availability of data on innovations classified according to the sector of production and the sector of use of the innovations.

Thanks to the patient work of Schmookler (1966) and Scherer (1982a), data on the sector of use of groups of patents have been collected, to produce matrices of technological interdependence, in which each cell contains the number of patents sharing the same sectors of production and use. Such a matrix is the technological equivalent of the economic input-output table.

As noted by Scherer (1982a), it would not cost much more for the patent offices to collect systematically the information on the sector of use of the inventions; indeed a growing number of scholars would be grateful to them for it. From 1972 to 1991 the Canadian patent office has provided this information (which has been used, among others, by Séguin-Dulude, 1982 and Ducharme, 1987). To overcome these data constraints, several complex procedures have been developed to estimate the industries which benefit from the innovations produced in a certain sector, often employing the rich data of the Canadian Patent Office (see Evenson *et al*, 1988; Englander *et al*, 1988).

The study of technological interdependence has firstly a descriptive value and it allows, among other things, the identification of these industries with stronger interactions. It also makes it possible to measure the share of innovations used in each sector which are self-produced.

The same analysis can lead to important policy implications: to identify the upstream suppliers of innovations of a specific industry might help to design appropriate innovation policies. Last but not least, it helps to have a better knowledge of the impact of innovation on economic performance, such as its role on employment or productivity growth (Scherer, 1982b).

International comparisons

Since patents are an institutional artifact, their relationship to invention and innovation is strongly dependent on the institutional rules of each country. In centrally-planned economies, for example, patenting serves a different function than in free-market economies, and it has not been an appropriate measure of their internal technological capabilities.

Patents registered in free-market economies are more comparable. Although countries have subscribed to many agreements on industrial property rights which should give equal rights to the

Table 1. World breakdown for patents in 1988

	Domestic applications		Foreign applications		Total national applications	
	No	%	No	%	No	%
OECD countries	483,723	67.7	632,873	89.2	1,116,596	78.1
Africa	5,257	0.7	11,813	1.7	1,707	1.2
Asia except Japan	18,386	2.6	34,442*	4.8	52,828	3.7
Latin America	3,713	0.5	13,435	1.9	17,148	1.2
Eastern Europe	209,595	29.1	16,563	2.3	226,158	15.7
Grand total	720,674	100.0	709,126	100.0	1,429,800	100.0

Note: * Including China, Democratic People's Republic of Korea and Republic of Korea.
Source: Data collated by OECD/STIID from WIPO's "Industrial Property Statistics, 1988".

patented inventions of each nation, there are still basic differences across countries on the costs, form of examination, time of registration and legal protection accorded by patent laws. The propensity to register and, above all, to extend abroad the coverage of a patent is affected by the legislation and practice in each country.

Within the OECD (Organization for Economic Co-operation and Development) area there are remarkable differences between those countries, such as the United States, Germany and Japan, in which applications are examined by experts before they patents are granted and countries such as France and Italy, where patents are easily granted and possible controversies are settled by subsequent legal action. Japan also differs from other OECD economies as it does not allow the grouping together of several claims related to a certain invention into the same application.

Data by geographical area

Table 1 shows data on patenting activity by geographical areas broken down by domestic (the applications presented by residents in their own country) and foreign applications (those presented by foreigners in a given country). Total national applications are the sum of the two. In 1988 nearly one and a half million applications were presented world-wide (data refer to applications rather than patents, and some inventions are counted more than once when the same application is presented in more than one country).

Nearly 68% of all applications were filed by residents of OECD countries. East European countries filed 29% of domestic applications while countries in Africa, Asia (excluding Japan) and Latin America together accounted for about 3.8%. Although these data are not entirely comparable because of major institutional differences in the national legal procedures, they clearly show the geographic concentration in the production of commercial innovations.

Foreign applications registered in the OECD countries account for an even larger share of the total, equal in 1988 to nearly 90%. Patents with a high commercial impact are extended in the markets which are perceived as more lucrative. On the contrary, the number of foreign patents registered in Eastern European countries is very low, and totalled 2.3%.

Changing patterns

The same data can be used to identify the changing pattern of patenting activity and are presented for the OECD countries in Table 2. The average growth rates of domestic patents during the 1980s are reported in column 1, showing that the number of patent applications has not grown significantly. In eight countries a negative rate of change has occurred, while in three other countries growth rates below 2% have taken place.

This steady pattern in domestic patenting should be compared to the rates of change of R&D inputs. In spite of the slowdown after 1985, R&D expenditure has grown at a substantially faster rate than domestic patents. Some authors (Evenson, 1984; 1989) have related the slowdown in domestic patent applications to a decreasing productivity of scientific and technological research (this issue is also discussed in Griliches, 1990).

The decrease of domestic patents, however, may also be related to a growing awareness by applicants of the information that may be obtained from the patent system. In fact, the slow or negative growth rate is generally associated with a decreasing number of applications from individual inventors, which have, on average, a lower probability of becoming actual innovations (see Sirilli, 1987).

Foreign patents also reflect the process of globalization of scientific and technological activities. The greater the resources devoted to R&D, the more we would expect firms to try to appropriate the benefits of their innovations in several markets. In fact, the total number of foreign patents have significantly increased in all OECD countries (column 2 of Table 2).

Japan

Japan is a significant exception to the general pattern: the extensive presence of Japanese firms in

Table 2. Rates of change in domestic, foreign and external patents in the OECD countries

Countries	Rates of change (%) in			Ratio of external to domestic patents[4]	
	Domestic patents 1979-88[1]	Foreign patents 1979-88[2]	External patents 1979-88[3]	1979	1988
United States	2.44	6.30	7.50	1.73	2.67
Japan	8.30	3.85	11.53	0.25	0.33
EEC 12	1.10	9.38	7.49	2.06	3.90
W Germany	0.54	4.87	6.79	2.28	3.93
France	1.16	5.95	7.64	2.41	4.22
United Kingdom	0.64	5.49	8.34	1.37	2.65
Italy	-11.59	10.01	8.50	1.97[b]	na
Netherlands	2.00	10.17	6.91	5.18	7.90
Belgium	-1.05	10.15	6.38	3.65	7.00
Denmark	3.28	7.24	13.47	2.74	6.38
Spain	-0.31	11.77	5.06	0.92	1.48
Ireland	8.39	4.26	14.12	0.81	1.29
Portugal	-6.19	5.33	29.86	0.10	1.94
Greece	-0.18	27.88	8.96	0.07	0.15
Switzerland	-2.21	9.87	3.38	4.60	7.58
Sweden	-2.39	10.12	8.56	2.51	6.52
Austria	-0.75	13.51	7.44	1.66	3.39
Canada	6.28	2.88	8.31	2.83	3.35
Australia	3.26	5.31	17.36	0.70	2.22

Notes: [1] Patents by residents of the country
[2] Patents by foreigners in the country
[3] Patent applications by residents extended in other countries
[4] Average number of patent applications extended abroad for each domestic patent application.
[a] 1980-88
[b] 1980
na: not available

Source: D Archibugi and M Pianta 1992a, elaboration on OECD, *Main Science and Technology Inidcators Data, 1990.*

western patent offices shown above has not been paralleled by an equally widespread presence of western companies in the Japanese system: the growth rate of foreign patent applications has been relatively moderate, and much below the growth rate of domestic applications.

Parallel information on the internationalization of technology markets is provided by the share of external applications (those presented by firms and inventors of each country in other countries), reported in column 3 of Table 2 (a single invention is counted as many times as the patent is extended in different countries). All countries show a rapidly growing effort to patent abroad, with the aim of appropriating the returns from their inventions also in foreign markets. Among the largest countries Japan ranks first. The divergent trends in the growth rates of domestic and foreign patent applications suggest that the reduction in the volume of domestic applications has principally affected those inventions with less certain business potential.

Columns 4 and 5 of Table 2 show the ratio of external to domestic patents for 1979 and 1988. This ratio has considerably increased in all countries. While the trend towards the internationalization of patenting is generalized, significant cross-country differences emerge. In 1988, the ratio was particularly high for R&D-intensive small- and medium-sized countries (the Netherlands, Switzerland, Belgium, Sweden and Denmark). Countries which have a small internal market are to some extent forced to market the results of their innovations in foreign markets. Larger countries, on the contrary, have a weaker propensity to extend their patented inventions abroad.

Japan is the only country which has a ratio below unity: for any three domestic applications, there is only one application abroad. This is partially due to the Japanese patent system which permits only one claim per application, when there may be several claims per invention. On the other hand, it also suggests that, in spite of the fast growth of Japanese patenting abroad over the last decade, this country has still a vast and internationally unexploited technological potential.

Main patent offices

Table 3 reports the share of patents registered during the 1980s in the three main patent offices (the USA, Europe and Japan) according to the country of origin of the applicant. Patent data are aggregated in periods grouping several years in order to avoid random fluctuations. More than

Table 3. Patents registered by advanced countries in the USA, Europe and Japan (percent)

Countries	USA 1979-88 granted	EPO 1980-89 applications	Japan 1979-87 granted
United States	56.31	25.82	7.86
Japan	16.26	15.57	83.67
EEC 12	19.47	47.64	6.09
W Germany	9.41	23.26	2.98
France	3.36	8.98	0.99
United Kingdom	3.55	7.26	0.90
Italy	1.31	3.27	0.30
Netherlands	1.07	3.22	0.70
Belgium	0.37	0.90	0.10
Denmark	0.23	0.33	0.09
Spain	0.12	0.27	0.03
Ireland	0.04	0.09	(1)
Portugal	0.01	0.01	(1)
Greece	0.01	0.03	(1)
Switzerland	1.81	4.46	0.82
Sweden	1.16	1.63	0.32
Austria	0.44	1.07	0.12
Canada	1.83	0.91	0.17
Australia	0.47	0.57	0.08
EPO countries	na	54.66	na
Others	2.24	2.35	0.87
World	100	100	100

Notes: (1): Less than 0%
na: not available
Sources: D Archibugi and M Pianta, 1992a, elaboration on WIPO and EPO data.

45% of patents in the USA were granted to foreigners. In absolute numbers, the US patent office has received by far the largest number of foreign applications. Within the EC (European Community), the largest share of patents in the USA is held by Germany with 9.4%. Great Britain and France have respectively 3.6% and 3.4% of all patents.

The second patent institution is the European Patent Office (EPO), established in 1978 on the basis of an agreement among 13 European countries. This is the only one in the world to be truly international, since a single application can potentially be extended in all its member countries.

Less than half (47.6%) of the applications come from EC countries, while 54.7% come from EPO member countries. The USA has the largest share with 25.8%; however, this figure underestimates the US technological potential as measured by either its share of R&D expenditure or by the inventions registered in the US domestic market. Germany's share at the EPO is close to that of the US at 23.3%. The third country is Japan, which, even in the European market, has a 15.6% share, much higher than France (9.0%) and the UK (7.3%).

The share held by European countries at the EPO is obviously larger than that in the US. However, the ranking based on the shares held by the European countries in both institutions is very similar.

The third database considered here is the Japanese Patent Office, where applications are mainly the outcome of national inventors and firms, which account for more than 83% of the patents granted. This figure shows how much the Japanese patent system is oriented towards its domestic inventions.

National innovative systems

The aggregate data reported above have been used extensively to compare national technological activities across specific fields. National sectoral strengths and weaknesses in each technological field have been identified at the two, three and four digit levels. These descriptive works are often related to policy analysis and policy-making.

One of the main issues encountered by these studies is the selection of the appropriate database. National data do not provide entirely reliable information since they do not allow international comparisons to be made, and they receive a large share of patent applications from their own citizens, often of lesser importance. A truly international database supplying for each patent the markets where it is extended is not available yet.

To overcome these problems, the majority of scholars have used the patents extended by a certain country in a foreign market, and especially in the USA, which is the largest and technologically the most developed market of the world. It is therefore reasonable to assume that the inventions of greatest impact are (also) patented in the USA.

The number of patents registered in the USA by each country has been shown to be positively correlated to resources devoted to R&D (Soete and Wyatt, 1983). While US patents are an invaluable source for comparisons between Europe and Japan, the results they provide for the USA should be taken with a grain of salt. The data of the European Patent Office have been used in recent years, and it is likely that this source will be more regularly exploited in the future to analyse US technological capabilities.

Patent-based studies devoted to the technological activities of specific nations include Narin and Olivastro (1987b); Slama (1987); Grupp and Legler (1989); Patel and Pavitt (1989) for Germany: Patel and Pavitt (1987b); Narin and Olivastro (1987a); Cantwell and Hodson (1991) for the United Kingdom: Pavitt and Patel (1990) for France: Malerba and Orsenigo (1987); Archibugi (1988b); Sassu and Paci (1989); Pianta and Archibugi (1991); Boitani and Ciciotti (1992) for Italy: CHI Research (1988); Narin and Olivastro (1988a) for Japan: Basberg (1983) for Norway: Engelsman and Van Raan (1990) for the Netherlands. International and sectoral comparisons of technological activities include Soete (1987), Patel and Pavitt (1987a; 1991a) and Archibugi and Pianta (1992a).

These comparisons often require the development of statistical elaborations. Appropriate indices have been developed to compare countries across fields (see Soete, 1981; Soete and Wyatt, 1983; Grupp, 1989; Schmoch and Grupp, 1989; Engelsman and Van Raan, 1990; Archibugi and Pianta, 1992a).

Patenting and international economics

For a long time technology has been considered one of the main sources of international competitiveness. However, empirical research in this field was constrained by the lack of internationally comparable data at the sectoral level. At the end of the 1970s, patent data were employed to explore the relationship between technology and trade. In order to test the technology gap theory, Soete (1981; 1987) has regressed data on patents in the US market by SIC (Standard Industrial Classes) classes to countries' export shares. A positive association between exports and patenting in the majority of the sectors emerged although, as expected, the role of technological innovation was less relevant in the sectors where natural resources play a prominent role.

Several scholars have further investigated the relationship between patents and trade (Fagerberg, 1988; Cantwell, 1989; Dosi, Pavitt and Soete, 1990; Amendola, Dosi and Papagni, 1991), and some used a more precise concordance between patent classes and international trade sectors (Amendola, Guerrieri and Padoan, 1991).

More recent research has been carried out both at the Science Policy Research Unit of the University of Sussex and at the Department of Economics of the University of Reading matching data on patenting of the leading world companies to their international production (Casson, 1991; Patel and Pavitt, 1991b). Less than 700 companies are responsible for nearly 60% of patenting in the USA, slightly higher than their share of business-funded R&D. Given this concentration of technological activities, it is understandable that research will focus on the patenting patterns of the large companies.

Other applications

Monitoring technological developments Patents are often used to monitor the technological developments of specific fields. Firms try to appropriate new technological opportunities and to secure market share. In new fields where competition is occurring between rival firms, a growing number of applications is generally presented. A quickly growing patent class often corresponds to original developments in scientific and technological knowledge, but it can also be related to increasing competition on, or diffusion of, already-known inventions and innovations.

Several case studies have proven that fast growing patent classes are generally associated with increasing competition among firms or countries for the leadership in selected technological areas (see, among others, Campbell, 1983; Faust and Schedle, 1983; Walsh, 1984; Wheale and McNally, 1986; Achilladelis *et al*, 1987; Wilson, 1987; Trajtenberg, 1990b). In more general terms, it could be argued that the fields of rapid expansion of patents today are at the technological frontier, and will represent the common technologies of future economic systems (semiconductors, new materials, biotechnology, and so on).

Patel and Soete (1988) have used the rates of change by patent classes to identify firms' and countries' dynamism. A similar methodology was applied by Archibugi and Pianta (1992a) to identify countries' behaviour in the most dynamic fields. This approach has been able to show, for example, that Japan has an above average share of patents in fast growing fields, and Europe, on the contrary, in declining fields.

Regional comparisons Patents have been used to study the geographical distribution of inventive activities within one country as well as its shifts over time (Antonelli, 1986; Suarez-Villa and Vela, 1990; Boitani and Ciciotti, 1990; Jaffe *et al*, 1992). Data at the regional level have been used to assess the economic effects of academic research (Jaffe, 1988).

Research evaluation Since patents are one of the outcomes of research activity, they are also used to evaluate the results of specific research projects (see Schmoch *et al*, 1991). They are often combined with other output indicators, such as bibliometric data. Because of the heterogeneous value of patents, they allow the assessment of the results of research programmes which have generated a large number of applications.

A concluding remark

Patents are a fascinating indicator because they lead the analyst into the process of invention and innovation. They can help to gather information on the intangible phenomenon that is knowledge: a fact which leads a growing number of scholars to optimism about their employment. As any indicator, patents are full of traps, some of which can be avoided by careful use. But it is difficult to persuade the platoons of sceptics on their validity. Their criticism is often bitter, but it plays an important role in preventing the misuse of the indicator and forces the analysts to test and improve the quality of their data. However, in return, they are entitled to ask their critics to provide better measures, if they can.

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