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# CONCEPTUALIZING AND MEASURING TECHNOLOGICAL INNOVATION

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## ABSTRACT

This report deals with the state of the art of science and technology indicators with particular reference to the most advanced countries. An attempt is also made to identifying future prospects in the measurement of key dimensions of a society and an economy which is increasingly based on knowledge.

In the first section we deal with the nature of indicators. In practice, as things stand we have no explicit model capable of determining causal relations between science, technology, economy and society in a single synthesis; as a rule, reference is made to implicit or partial theoretical schemes such as models of the link between innovative activities and the economy.

In the second section we describe main features of various indicators. These indicators are research and development activities data, human resources, patent data, technological innovation surveys, technological balance of payments, analysis of international trade in high-technology products and bibliometrics. In addition, the paper present a discussion of indicators for which methodologies are still in a development stage.

In the third section we look at the prospects for the future. One of the main challenges for those who are in charge of providing indicators is linked to the timing of indicators building. A decade usually elapses from the identification of the need for an indicator and the availability of internationally comparable data. This makes crucial the ability to identify well in advance users' needs and to build a robust design which can accommodate a moving set of objectives.

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# INTRODUCTION

This report deals with the state of the art of science and technology indicators with particular reference to the most advanced countries. An attempt is also made to identifying future prospects in the measurement of key dimensions of a society and an economy which is increasingly based on knowledge.

The indicators under examination have been divided in two groups.

The first group includes indicators for which a statistical methodology has been developed and data are collected and analysed according to a standardised methodology. They are: statistics on research and development (R&D), patent statistics, survey innovation, the technological balance of payments, the analysis of trade in high-technology products, bibliometrics, indicators of human resources.

The second group includes indicators for which methodologies are still in a development stage and the indicators, where available, cannot be compared across countries and over time. They are: indicators based on information of technical journals, intangible investment, surveys of manufacturing technologies, indicators in the field of information and communication technologies, measurement of organisational change in enterprises, technology foresight, public attitudes and public understanding of science and technology.

This report is divided into three sections: in the first section we deal with the nature of indicators, in the second we describe the main features the various indicators analysed, in the third we look at the prospects for the future.

# SCIENCE AND TECHNOLOGY INDICATORS

Science and technology have become a fully-fledged policy issue both in developed and in less developed countries: the large use of resources to this end is inevitably focusing increasing attention on the efficiency and effectiveness of the innovation system.

In terms of science policy at the national level, governments need a set of tools to assess the qualitative performance of scientific institutions (OECD, 1987). Over the last decade governments have also been keen to use innovation to foster economic performance and competitiveness, and therefore have increased their request for information on technical change (OECD, 1992). Managers in industry making decisions on technological activities are coming up against the need to assess the costs and benefits of technological and trading operations involving high risks and uncertain results.

Administrators assigning public resources to research institutes or projects are constantly seeking tools to assess the "quality" and potential of individual researchers, research groups and institutions, together with the social and economic "value" of research findings and inventive or innovative activities in general.

It is no easy task to assemble the theoretical tools and empirical data to meet this need. However, for some years now researchers and organisations in all the industrialised countries have made efforts to develop a view of the scientific and technological enterprise as a system interacting with other systems - social, economic, educational, environmental, etc. At the same time they have been active in seeking the right indicators to assess the demands and results of inventive and innovative activities (Sirilli, 1985).

Science and technology indicators may be defined as a series of data designed to answer questions about the existing state of and/or changes in the science and technology enterprise, its internal structure, its relationships with the outside world, and the degree to which it is meeting the goals set it by those within or without (Fabian, 1979).

The aim of science and technology indicators is therefore similar to that of social indicators: to obtain a picture of the state of science and technology and anticipate the consequences of scientific advances and technological change.

Statistical data are the basic elements (“atoms”) with which indicators (“molecules”) are constructed; thus, the questions indicators have to answer concern aspects of the more general problems which can be tackled using quantitative techniques (OECD, 1992).

By definition indicators illustrate a particular aspect of a complex, many-sided matter. We therefore need an explicit model that can describe both the scientific system itself and the way it relates to the rest of society. This ideal model would offer the possibility to establish the meaning of each indicator and allow relations to be established among the various indicators themselves (Sirilli, 1993).

The development and diffusion of science and technology is an extremely complicated process due to the multiplicity and intensity of links between the various components of the system (Smith, 1996). What appears as a result from one point of view may represent the starting point from another (Freeman, 1982). While respecting the integral nature of the process, a distinction has traditionally been made between input, output and impact indicators (Freeman, 1987). More recently this distinction has been superseded by a vision of innovation as a process where feedbacks play a crucial role in chain-linked models (OECD, 1992), and national systems of innovation propose a perspective in which science and technology should be analysed simultaneously with organisational, institutional, economic and other factors (Nelson, 1992, Lundvall, 1992).

In practice, as things stand we have no explicit model capable of determining causal relations between science, technology, economy and society in a single synthesis; as a rule, reference is made to implicit or partial theoretical schemes such as models of the link between innovative activities and the economy.

The limitations and short-comings of science and technology models must not, however, be considered an insurmountable obstacle to the devising and application of a set of indicators. On the contrary, they should be considered a natural part of a knowledge-developing process that has already yielded significant results and that promises to live up to the expectations of researchers, the scientific community and the decision-makers in the coming years.

The fact that statistical data on various aspects of inventive and innovative activities have been continuously gathered for over thirty years attests to the interest of the scientific community and the decision-makers, while at the same time demonstrating that there are in fact theories, at least implicit, that can guide the operator in the choice and analysis of certain data, rejection of others and appreciation of the need to acquire further data (Patel, Pavitt, 1995).

National and international organisations have published for many years indicators resulting from ad hoc surveys and data gathered for administrative, accounting, operating and scientific purposes (European Commission, 1994; National Science Board, 1996; OECD, 1994c). These indicators are also available on data bases which are maintained by international organisations (OECD, 1995a and 1995b) and private organisations. Taken individually these data do not yield a full picture of the various aspects of science and technology but, analysed together, they shed light on the multi-faceted aspects of the same phenomenon, providing greater depth and range to the analysis. Finally, we must point out that, at the level of science policy, science and technology indicators must be seen as a useful support for knowledge; they cannot replace, but integrate the assessment and capacity for choice of the decision-makers.

The OECD has played a major role in developing statistical manuals aimed at homogenising at the international level procedures for data collection and analysis of various indicators. Obviously, the guide-lines set forth in the manuals are the recommendations of an international organisation based on the principle of common consensus and are to be observed within the limits of feasibility for the sake of improved international data comparability. Various international organisations - OECD, EUROSTAT, UNESCO - are also active in publishing indicators based on data collected by national organisations on the basis of agreed upon international procedures as well as on data coming from commercial data bases.

# THE MAIN FEATURES OF SCIENCE AND TECHNOLOGY INDICATORS

## Indicators for which data are collected and analysed according to a standardised methodology

*Research and development*

Expenditures and personnel for research and development (R&D) are the first indicators constructed ad hoc for measuring scientific and technological activities. The first attempts at measurement in the field of statistics on research and development date back to the 1930's in the Soviet Union and the 1940's in the United States. However, it was only in the 1950's that the National Science Foundation (NSF) of the US embarked on a regular survey of research and development in the United States. The vast experience acquired by the NSF exerted a decisive influence on the activities of the OECD, which in 1963 led to the adoption of the Frascati Manual on the measurement of technical-scientific activities. Over the years this Manual has been revised four times, reaching maturity with the last revision of 1993 (OECD, 1994a). In the last revision of the Manual no radical modifications have been made to the basic definitions and concepts. Rather, a lot of updating, elaboration and further specification has been introduced in the light of experience acquired both through the collection of data and through research on the various indicators and their use in analysis and policy making. The areas where additions or major changes have been introduced are: R&D in the business enterprise sector, classifications of R&D, R&D in the National Accounts, R&D and software, R&D in the defence sector, research staff, the fiscal aspects, forecasting and projections, internationalisation of R&D.

In the field of industrial research, it has been shown that while R&D is a major means to generate technology (Griliches, 1995), it is also necessary to consider ideas and applications deriving from production activities and from activities of technological nature including design, software, technical testing and quality control. The launching of innovation surveys, which cover all the main innovative activities, represent a step forward in this direction (see section 3.1.3 below).

R&D and innovation have an important regional dimension. Local technological competence influences not only the development of a region but has an effect on the economy of the country as a whole. EUROSTAT has prepared a Manual on statistical indicators for regional activities on R&D and innovation (EUROSTAT, 1995a) which broads the scope to regional aspects of the OECD Frascati manual and Oslo manual.

The two major R&D indicators are personnel and expenditure. Data on R&D are regularly (annually or biannually) collected by national statistical agencies while international organisations like OECD, UNESCO and the EUROSTAT are active in the collection (UNESCO, 1979; OECD, 1994a), analysis and publication of data from an international perspective (UNESCO, 1994; EUROSTAT, 1994).

In the last few years R&D data has become available on individual firms from published balance sheet publications. This has opened up a new stream of economic analyses which correlate R&D with performance indicators at the firm level (Griliches, 1995).

The main features of the R&D indicator are the following:

➨ data are reliable, especially because respondents to surveys have learnt over the years to apply the definitions of R&D;

➨ data are comparable over time and across countries;

➨ the breakdowns by sector of performance and sector of financing, type of R&D, type of personnel, etc. allow a rather detailed analysis;

➨ surveys cover only R&D carried out in institutionalised settings, capturing very imperfectly non-structured and occasional R&D carried out in small units (i.e. small firms);

➨ it is not clear to what extent R&D covers information technology related innovative activities like software;

➨ it is not clear to what extent the recent increase of R&D carried out in the service sector is due to the externalisation from manufacturing firms and to what extent it is due to an increasing involvement of service companies in research and development (Young, 1996b).

*Patent statistics*

Patents are the most widely available indicator of output of technological activities. For many years patents counts have been used as indicators of technological achievement of firms and countries. More sophisticated indicators are being developed to give account of the value of patents, based on econometric techniques, and using information possibly correlated to the value: renewal, international patenting and citations. Patents can also be used for assessing patterns of technical change: science-technology linkage, intersectoral spillovers, competitiveness of countries in various industries.

A patent is a right the state grants to an inventor in return for the publication of his or her invention; for a limited period and with certain conditions, it gives the inventor exclusive rights over the commercial exploitation of the invention. The juridical and legal provisions concerning application for and granting and protection of the patent vary considerably from country to country, although there has been a certain levelling out in the last few years.

Statistics on patents started to be collected for administrative reasons, with no intention of contributing to the analysis of the inventive process or technological innovation. Nevertheless, patents are a valuable source of information of a quite unique type on the developments of technologically with a highly detailed breakdown by technological fields, firms, countries and over long time series.

During the past few years an increasing debate has centred around the use of patents statistics as an alternative or addition to traditional statistics on scientific research in order to highlight inventive activity, innovative activity and technological progress in general (Archibugi, 1992; Archibugi, Pianta, 1996; Basberg, 1987; Griliches 1990; Pavitt, 1988). Patents statistics are more detailed in terms of technological classes and cover longer periods than data on R&D. In some countries the historical patents archives date back to the latter half of the 19th century, while figures on R&D cover only the past thirty years. Moreover, patents reveal inventive activities extending outside the research laboratory including design, quality control, technical services, production and non-structured inventive activities.

The utilisation of data on patents to measure technical and scientific output raises a number of problems:

➨ the requisites for an invention to be patented and the type of examination it is subjected vary from country to country;

➨ the propensity to patent varies according to the industrial sector, size of firm and type of inventor (individual or employed in an organisation);

➨ it is not known what proportion of inventions are patented and thus cannot tell to what extent patenting reflects the entire area of inventive production;

➨ the "quality" and "value" of patents varies greatly (Lanjouw et al, 1996);

➨ insufficient data are available on the extent to which patents issued are in fact utilised (Napolitano, Sirilli, 1990);

➨ a significant proportion of patents are of the strategic type, i.e. applied for in order to forestall potential competitors.

These issues are addressed in detail by the Patent Manual adopted by the OECD in 1994 with the aim of providing users and producers of science and technology indicators basic information on how patent data can be used as indicators, and how they can be linked to other statistics on science, technology and economic activity (R&D, scientific publications, trade and production, etc.) (OECD, 1994d).

As regards to the sources of data on patents, we may distinguish three types of data providers: individual patents offices in the various countries, a number of international organisations, and commercial companies providing data .

Among international agencies we may mention the World Intellectual Property Organisation (WIPO), which has published statistics on patent applications and patents granted all over the world since 1979.

The European Patent Office has published data on patent applications since 1978, and is playing an increasing role in the extension of patents in Europe. A variety of national sources has also been used. In particular patents granted in the United States have been used for cross-industry and cross-country comparisons (Patel, Pavitt, 1991).

The Inpadoc (International Patent Documentation Centre) has built up a data base with more than ten million patents granted by 51 countries which identifies the patent families, i.e. groups of patents covering the same invention in various countries.

Derwent Publications Ltd., a private firm whose main activity is the publication of patent abstracts, has built up an electronic system to process statistics on series of data, including qualitative data, contained in patents documents. CHI Research has built up a data base on patents and patent citations at the level of individual countries and companies.

One of the most interesting possibilities for the utilisation of patents is in the area of technological forecasting: analysis of co-citations can identify groups of patents pointing the way to areas of intensive technological development (Van Raan, 1988).

*Surveys of technological innovation*

Technological innovation is one of the main development factors in our society: thus the acquisition of tools to interpret and control it is a priority in scientific and technological policy. In the past ten years various countries have launched various initiatives to gather statistical data on the subject (Hansen, 1992; Archibugi, Pianta, 1996; Smith, 1989). The data gathering follows two approaches: the first consists in identifying the most significant innovations and then sending survey questionnaires to the firms that have introduced them in the country; the second involves submitting questionnaires to the firms that have introduced innovations during a given period of time (Smith, 1992; Arundel et al, 1995). The first approach therefore focuses on individual innovations (object approach), while the second focuses on the innovating firm (subject approach) (Archibugi, 1988).

Various countries have launched innovation surveys adopting methodologies which are not fully comparable (OECD, 1990b).

Experience to date shows that surveys on innovation are not only feasible but yield extremely interesting and useful results (Evangelista et al, 1996; OECD, 1996e). For example data show that R&D represents only a limited fraction of the innovation expenditures, while other factors, like investment in equipment and machinery and design represent the largest part of firms' financial efforts for innovation. Data show also that the pattern of innovation expenditure changes significantly across industrial sectors (Cesaratto et al, 1991).

The OECD has published the “Oslo” Manual on technological innovation and the first revision has been adopted in 1996 (OECD, 1996c).

The Oslo Manual deals with definitions and methodologies for collecting data on the following issues: corporate strategies, the role of diffusion, sources of innovative ideas and obstacles to innovation, inputs to innovation, the role of public policy in industrial innovation, the output of innovation, the impact of innovation.

The OECD methodology was adopted by EUROSTAT and DG-XIII (European Innovations Monitoring System) within the European Commission, and implemented on a EU-wide basis using a common questionnaire; this survey was known as the Community Innovation Survey (CIS) project. EUROSTAT has now built a comprehensive firm-level database with the CIS data, which contains data on almost 41,000 European firms.

CIS was designed to address two main sets of issues. First, the general structure of innovation processes, at the level of all European industry as well as across main typologies of firms and industries. Second, and the most ambitious one, the way national innovation patterns of European countries differ from each other and the determinants of such heterogeneity.

As any other innovation survey, the CIS data set is characterised by strengths and weaknesses. Some problems have emerged as data collected by various countries are not fully comparable (Archibugi et al., 1994). However, in spite of these problems, the CIS exercise has provided extremely useful, providing a description of the main factors influencing the innovation behaviour of firms (Evangelista et al, 1996). It may be expected that the second CIS survey, expected to be launched in 1997, will yield a fully comparable set of data for the European countries.

The OECD Oslo manual has been revised in 1996. The basic theoretical background of the Manual has not significantly changed. Greater emphasis has been attached to the necessity to orient the collection of data to the relevant policy questions and the increasingly knowledge-based characteristics of technology and innovation. The Manual has also been improved in the definition of technology and innovation, by means of providing borderlines examples aimed at distinguishing between technological innovation from aesthetic improvements of products and purely organisational changes.

The major novelty consists in the explicit inclusion of services as a target of investigation of the innovation surveys (Evangelista, Sirilli, 1995). This implies some revisions in the definition of technological innovation and innovation activities so as to make them applicable both to manufacturing and service firms (Young, 1996a).

*The technological balance of payments*

The technological balance of payments (TBP) records the flow of funds for transactions concerning industrial property rights. It covers invisible transactions in a country's balance of payments concerning the purchase and sale of "disembodied" technology in the form of intellectual and industrial property rights including patents, licenses, know-how and technical assistance (Madeuf, 1984). It is therefore an indicator of technology transfer across countries (Hatzichronoglou, 1996).

The main features of the indicator are the following:

➨ the TBP offers a partial view of the general phenomenon of world technology transfer and may thus be used as an indicator of the diffusion of technology or competitiveness, possibly together with other indicators including, for instance, data on foreign trade and direct investment;

➨ the range covered by the technological balances of the various countries is not uniform: in addition to the flow of funds relating to technological transfer in the strict sense of the term (patents, manufacture licences, technical know-how), in some cases they also include technical services (technical assistance, staff training, consultancy services) while in other cases they may even cover payments for intellectual and industrial property rights not directly connected with technology (management services, film rights, etc.);

➨ international comparability of the TBP indicator is also limited by the different survey procedures (direct survey through agent banks, or indirect ad hoc survey; sample survey or census);

➨ by its very nature, "disembodied" technology, which can be exchanged without financial transactions, gives rise to problems of interpretation; it may occur in the context of cross-licensing agreements, with transfer of know-how to a foreign subsidiary, or in the field of non-commercial international co-operation;

➨ trends in transactions included in TBP are significantly conditioned by the multinationals which, according to the available data, are responsible for about two thirds of the total value of transactions recorded in the technological balance of payments (in the case of the United States these in-company transactions account for 80% of the TBP receipts).

In 1982 the OECD began the systematic collection and publication of member countries' TBP data, and a series of seminars and conferences on the subject have led to the adoption of the Manual for the collection and publication of TBP data (OECD, 1990a) and to later methodological developments in the area (OECD, 1996a).

Here we shall list the operations suggested by the OECD experts for inclusion in member countries' TBP: patents (purchase, sale, licences) know-how (non-patented), trade-marks (including franchising), technical assistance, R&D financed abroad. The manual recommends the omission of the following operations: commercial, financial, managerial and legal assistance; advertising, insurance, transport; films, recordings, material covered by copyright; design; software.

Looking to the developments in TBP statistics of the 1990's, the European market liberalisation has had a significant effect since the public authorities are now obtaining technology transfer data from operators on the basis of the intrinsic merit and usefulness of the statistics rather than merely applying an administrative act (Sirilli, 1991). The abolition of currency controls by many countries has given operators greater freedom in their currency transactions overseas. Residents enjoy the right to open bank accounts in foreign currency in their own and other countries, are no longer obliged to convert currency purchased abroad and may acquire foreign currency whenever they like without having to prove that it serves for the payment of imports. In other words, possession and conversion of foreign currency are no longer tied to or limited by specific trading transactions. This has modified the role played by banks as authorised intermediaries, and thus the function of notifying the central bank on currency operations between resident and overseas operators. Data gathering on TBP in European countries is now carried out through statistical surveys: therefore a break in series has occurred since the beginning of the 1990's. A major problem at present is the linking of old and new series which are based on different statistical populations and data gathering procedures (Prisco, Sirilli, 1995).

*Analysis of international trade in high-technology products*

The analysis of trade in terms of products grouped according to technological content raises a number of methodological issues. The problem is to distinguish the high, medium and low technology products on the basis of criteria that do not always meet with general agreement among the experts (Grupp, 1995; Guerrieri, Milana, 1995).

Most of the studies carried out so far have defined “high-tech” as the fields where the ratio between research and development expenses and turnover or value added is above a certain threshold

This approach has a number of limitations:

- research intensity and technological intensity are not necessarily equivalent concepts;
- the statistical data from which technological intensities are drawn are not uniform;
- the choice of threshold values for high, medium and low technology is arbitrary;
- technological intensity can vary greatly within one group of products;
- the intensity ratios take no account of technologies indirectly acquired with machinery and materials. Moreover, they are intrinsically static (taking no account of the accumulation of scientific and technological know-how with time) and vary according to the firm and the country;
- within sectors there may be products with widely different technological intensity.

Intensities have been recalculated also on the basis of indirect R&D intensity based on input-output matrixes (OECD, 1996b).

Another method is to determine the innovative content of products according to the assessments of the experts in the individual product group - different from the standard aggregation of industrial sectors (OECD, 1988). This approach has the merit of allowing a precise distinction of individual products on the basis of their innovative level, with the possibility to separate them from other products belonging to the same group of goods**.** However, it also has some limitations due to:

➨ the need for a very large team of experts from the various areas involved;

➨ the methodologies used for technological level assessment and thus for the achievement of consensus among the experts;

➨ inevitable concentration on high technology products, due to the huge difficulty of covering the entire range of products included in foreign trade classifications.

As for the differences shown by the findings of analyses carried out using the two approaches, we may observe a reduction in the number of products and related revenue with the second method (in the case of Italy the share of high technology products imported drops from 11-12% to 6%) (Amendola, Perrucci, 1990).

*Bibliometrics*

Bibliometrics is a tool by which the state of science and technology can be observed through the overall production of scientific publications. It may be defined as the application of statistical methods to data on articles in scientific journals, books and other means of communications.

It should be pointed out that scientific activity is much more complex and multi-faceted than what is captured by indicators focusing on publications only. At the theoretical level, what these indicators actually measure is still an open question. To answer the question we need a clear picture of the nature of science and scientific output.

Bibliometric indicators (based on the number of publications, citations and co-citations) mainly refer to basic research, much of which is carried out in academic institutions.

The main problems with these indicators include the following:

➨ the propensity to publish and cite varies in the various disciplines;

➨ works of great importance rapidly become part of common knowledge and are thus referred to in the literature without citation;

➨ citations may be critical rather than positive; however, it has been argued that even contested results make a contribution to knowledge;

➨ the various scientific fields are cultivated by groups of varying size, and thus the probability of being cited varies from sector to sector;

- the number of citations does not follow a linear rate in the course of time;
- the value of scientific work is not always acknowledged by contemporaries;
- available data bases are subject to some bias toward English language publications;
- papers represent only one output of laboratory-based activity. Scientific results related to information and software are not published to the same degree (Hicks, Katz, 1996).

While solutions are being found for some technical problems associated with publications - such as reference to the first name when the scientific and technical publications appearing in the Science Citation Index of the Institute for Scientific Information have more than one author, and the occurrence of self-citation - others remain.

Further problems relate to the expectations of potential users. For example, science policy makers need information on where the scientific work behind the publication has been carried out, the sources of funding, costs, etc. Some of these data which cannot be obtained from existing data bases must be sought in the texts themselves or through direct contact with the authors.

Bibliometric indicators reflect an aspect of the social structure of science, i.e. communication, which takes also place through other channels such as informal interaction between researchers. Thus indicators are used on the assumption that the significant advances in science are adequately represented by bibliometrics, although this assumption has been shown to be valid for a restricted number of eminent scientists only: moreover, it is doubtful whether the same conclusions can be applied, at least without particular distinctions, to all the researchers normally engaged in group activities ranging from study and up-dating to experimental laboratory work, teaching, technical services, advisory services, technology transfer and management (Silvani, Sirilli 1995).

To ascertain whether such generalisation is possible we need empirical verification, which can only be carried out through the parallel application of bibliometric and non-bibliometric, e.g. peer review, indicators.

Various data bases established by commercial companies or institutions are used to construct bibliometric indicators: Chemical Abstracts, Compendex, Embase, Inspec, Pascal, Science Citation Index.

The Science Citation Index, which is produced by the Institute for Scientific Information (ISI) in Philadelphia is the only data base to systematically gather information on the scientific papers published by a large set of journals and therefore bibliometric indicators are primarily based on it. Various data bases and models have been constructed on the basis of SCI data which is working on a data bank on scientific literature with information on publications and citations appearing in a selected group of 2,100 scientific journals; ISI and the Centre for Research Planning have developed co-citation models to describe the structure and dynamics of scientific literature, setting up data bases limited to certain years and identifying some thousands of research areas through the analysis of co-citation between papers.

The Pascal data base is used for analyses of the co-presence of key words (co-word analysis) which reveal the evolution of themes in scientific literature and thus development in the research areas.

The OECD has developed some draft guidelines on the use of bibliometrics as science and technology indicator which covers both scientific literature and patents (Okubo, 1995), and which it is hoped will encourage the standardisation process.

The developments foreseeable for bibliometrics for the next ten years basically follow two directions: closer and more extensive knowledge of the scientific system and relations between its components; assessment of scientific activity as a support for decisions on science policy, particularly in the case of funds for research in the public sector and in the universities.

In-depth studies on the scientific system involve a broad range of analytic aspects, of which we may mention:

➨ "science mapping", i.e. the definition of research areas and their transformation, in order to identify the dynamics of scientific activity and the emergence of new disciplines;

➨ the relationship between developments in the scientific system and technological knowledge, with comparison with technology indicators (especially patents) within specific research areas;

➨ analysis of scientific specialisation profiles in various countries and institutions, with comparison between countries in order to identify the position of national scientific systems in the global context of scientific activity (Archibugi, Pianta, 1992);

➨ the use of bibliometric indicators in overall analysis of national science policy, in order to identify the features and trends of research in a given country.

*Human resources*

Human resources are a key factor for the production and distribution of knowledge. Science and technology indicators reports of various countries increasingly include information about students, teachers, researchers, technicians in the context of analyses of the supply and demand of skilled workers for an increasing knowledge-based society.

The OECD has adopted the “Canberra” Manual (OECD, EUROSTAT, 1994b) with the aim of providing a framework for compiling data on stocks and flows of human resources in science and technology, for analysing profiles and trends and for preparing up-to-date series for policy analysis. The Manual provides guidelines for assembling data using both the series that are already available and the results of special surveys, and for facilitating the exchange of joint use of internationally comparable statistics by OECD, the European Commission (EUROSTAT) and other international agencies, notably UNESCO. The concept of “human resources in science and technology” refers to the human resources actually or potentially devoted to the systematic generation, advancement, diffusion and application of scientific and technological knowledge. The Manual, however, covers only individuals with higher-level skills, in particular those with third-level education or a job requiring similar skills, for which stocks and flows are measured.

The Manual represents a major step forward in the international harmonisation of data available from various sources. However, given the national specificities of education systems and data gathering procedures, data are not fully comparable (EUROSTAT, 1995b).

Social security data bases represent an interesting source of data on employment of scientists and engineers. In some countries this source of data is used to analyse mobility of specialists across sectors (manufacturing as well as services) and firms (large as well as small firms) over time (Stenberg et al, 1996).

**Indicators for which methodologies are still in a development stage**

*Indicators based on information of technical journals*

The "literature-based innovation output approach" consists of the analysis of information about innovations reported in technical and trade journals (Kleinknecht, Bain, 1993; Kleinknecht, 1996). One of the most comprehensive surveys has been undertaken by the US Small Business Administration, which has collected information on 8,000 innovations commercialised in the US in 1982 from technical and scientific journals and magazines (Acs and Audretsch, 1990).

The great majority of new products and services are publicised by firms through technical and trade journals which have an edited section on "new products" compiled on the basis of press releases provided by the innovating firms. The information provided by journals usually consists of a brief description of the new product or service and the address and phone number of the firm. This makes it possible to carry out phone or mail interviews asking firms a number of questions about the innovation itself (degree of complexity, degree of novelty, qualitative properties of the innovation and its description, sector of the economy expected to be the major user of the innovation, etc.) as well as the objectives of and obstacles to innovation, the sources of information used for introducing the innovation, the means used to secure the appropriation of the benefits of the innovation, the link between the innovation and R&D carried out within or outside the firm, the role played by R&D government programmes, etc. Other information regards the major economic features of the firm: sales, employees, location.

This methodology allows to collect information about the individual innovation - product, service or project - (object approach), at variance with the innovation surveys conducted on the basis of the Oslo Manual and the R&D surveys based on the Frascati Manual, which refer to the innovating firm (subject approach).

The advantages of this methodology are the following:

➨ the burden for responding firms to report information is rather limited, and firms are usually willing to provide information, especially if they are approached soon after the announcement of the new product when they expect potential customers to show up;

➨ in principle all sectors of the economy are covered, including services and agriculture;

➨ innovations in small firms are more likely to be included, while innovation surveys cover only firms above a certain size (usually with more than 10 employees),

➨ the data gathered with this methodology may be linked with data from micro-data bases like R&D and innovation surveys as well as publicly available data from balance-sheets.

The major limitations of this methodology are the following:

➨ the statistical universe of innovations is not known. The coverage of the surveys therefore does not allow to use standard statistical sampling procedures. Therefore comparisons of number of innovations is not possible;

➨ since firms have no interest to provide information on process innovations, the overwhelming majority of innovations covered through this methodology regards products and services;

➨ there are problems of double-counting the same innovation once it has been imitated by competitors, and problems in identifying imitations introducing some improvement and differentiation of the product or service;

➨ until there is an international standardisation, the data gathered through this method are not internationally comparable.

At present this approach has been adopted in few countries. After the pioneering work by Kleinchnecht in the Netherlands (Kleinknecht, Reijnen, 1993), a comparative study has been carried out (Kleinchnecht, Bain, 1993) and more specific analyses have been carried out in the UK (Coombs et al., 1996) and in Italy (Santarelli, Piergiovanni, 1996)).

*Intangible investment*

In modern societies the knowledge content of production activities is becoming more and more important, and investment is rapidly evolving towards the acquisition of services and the carrying out of activities that pay off over a long period of time.

Intangible investment may be defined as the costs of intangible products that become available in the period under review and that remain in use for more than one year (Vosselman, 1992). In principle it includes a series of items: R&D, training, software, marketing, as well as goodwill, mineral exploration, development of organisations, rights to use intellectual property or concessions, etc.

Ad hoc studies have been carried out in a few European countries launching special surveys (Finland, Norway and Sweden) and using existing statistical data (France and Netherlands).

Innovation surveys carried out using the Oslo Manual methodology yield, as a by-product, data on various components of intangible investment, even though the coverage of each item may not be the same, i.e. the definition of marketing in the Oslo Manual covers only market exploration, while the one for intangible investment encompasses all marketing expenditure which includes expensive activities such as the building of sales networks.

The OECD has started an exercise aimed at harmonising existing practices in view of the preparation of a statistical manual similar to the others of the “Frascati” family. The core components of intangible investment are:

- research and development;
- education and training;
- software;
- marketing.

Taking the experience of Finland and the Netherlands, these four components make up about 80% of the total intangible investment which, in turn, represents between 20 and 50% of tangible investment (Vosselman, 1992). In Austria it has been calculated that intangible investment is 43% of all business investment (Hammerer, 1996).

The measurement of intangible investment is still in the development stage and the data available in some countries are not easily comparable because of heterogeneity in definitions, coverage, data collection procedures.

In perspective, when a harmonised statistical methodology will be adopted on the basis of an internationally agreed procedure, it may be envisaged that the data on intangible investment will be characterised by the same kinds of problem of similar industrial data: in particular, the estimation of stocks of intangibles on the basis of agreed-upon assumptions about depreciation, conversion of data for international and intertemporal comparisons. These and other problems have to be settled in the context of the System of National Accounts which represents the background on which intangible investment should be analysed.

*Surveys of manufacturing technologies*

Innovation and the application on new technologies have moved into the centre of firm strategies. However little quantitative data is collected, and new analytical tools to measure innovation and diffusion of new technologies in an harmonised context are needed.

Ad hoc surveys have been carried out in a few countries in order to measure various aspects of the use and diffusion of technologies (Northcott and Vickery, 1993): microelectronics, information technology, various manufacturing industries (CAD/CAM, FMS, LAN, robots, etc.). The studies have investigated the objectives and barriers to the introduction of the technologies, their diffusion among firms, public policies toward the adoption of the technologies, the impact of their introduction in the firm (OECD, 1993).

The results of these surveys are quite encouraging and interesting (OECD, 1993); however the surveys are still uncoordinated and deserve a harmonisation of concepts and procedures. In particular it is necessary to categorise qualitative aspects of technologies which evolve quickly, making the statistical codification problematic.

*Indicators in the field of information and communication technologies*

Information technology is changing the very nature of work and society. The convergence of information technology and communication raises a number of policy issues: how to bridge the gap between the “information rich” and the “information poor” within societies, the changes in the number and profile of employees in a continuously adjusting economy, the home based work opportunities, the greater participation of women in the work force, up to the implications of electronic commerce using the Internet for conducting business, the implication of electronic banking.

Building indicators in this area is quite necessary; at the same time there are conceptual and operational problems to be overcome before internationally comparable data can be gathered and analysed. The major problems identified by statisticians refer to the very definition of information and communication technologies, the classification of sectors and activities to be surveyed, the products and services to be covered.

In the last few years statistical agencies in various countries have started surveys of both firms and households addressing issues concerning the generation and use of information and communication technologies (Pattinson, McGeachie, 1996; Statistics Canada, 1996). In a particular case information and communication indicators are published in widely diffused statistical publications (Dutch Ministry of Economic Affairs, 1994). The results appear quite interesting, and it may be expected that activities currently under way at the OECD will make it possible to develop a methodology which does not appear to pose particularly difficult theoretical problems.

*Measurement of organisational change in enterprises*

Technology has a potential of providing new opportunities for expanding the range of goods and services, and for increasing productivity and employment; however, the changes in the organisation of firms and in the institutional context determine the effectiveness and impact of the adoption of new technologies (OECD, 1996d). Firms can reorganise both changing their internal structure, e.g. altering the relationships and responsibilities of employees, and changing their external relationships, e.g. buying more goods and services from external markets.

Changes, which may or may not be directly linked to the introduction of new technologies, regard basically the strategy, the structure, the work-place organisation, the human resource management of the firm, as well as its relationship with other firms.

Over the last few years some countries have undertaken ad hoc surveys: Canada, Sweden, Japan, Germany; other countries are developing new surveys along similar lines (Picot, Wannell, 1996). The main aim these surveys is to describe the features of the new work organisation and, where possible, link these structures and changes to both performance indicators at firm and human resource management (Vickery, Wurzburg, 1996).

Although there are signs of improvement in the number and depth of surveys and indicators, the measurement of the most relevant dimensions of change in organisations still poses a host of conceptual and practical problems. Up to now it has not been possible to put forward proposals for collecting figures on very qualitative phenomena like organisation and strategy, and their linkage with performance and structure variables.

*Technology foresight*

Technology foresight may be defined as a systematic attempt to look into the long-term future of science, technology, economy and society, with the aim of identifying the areas of strategic research and the emerging of generic technologies likely to yield the greatest economic and social benefits (Martin, 1996).

The implementation of this approach has some basic features: the prospection into the future must be systematic; the time horizon taken into account should be a long period, from five to thirty years; the approach should combine the foreseen opportunities offered by science and technology with the expected demands from and compatibilities with society and the economy; the identification of emerging generic technologies which may deserve some type of government intervention both in terms of financing and strategic orientation for firms.

The main objective of technology foresight is to identify potentially important technologies early enough to facilitate their development and utilisation. Governments, enterprises and the general public have all an interest in identifying the new emerging generic technologies which are likely to have a large impact on society, the economy, environment and which, by their very nature, require for their development important advances in the science base.

Technology foresight differs from technology assessment. While the former is aimed at identifying the most promising technologies in terms of socio-economic returns from which to choose (top-down), the latter identifies a specific technology, or a bunch of technologies, and evaluates its overall impact along a set of relevant dimensions (bottom-up). It may be pointed out that the distinction between technology foresight, technology assessment and R&D evaluation (which focuses on the selection and the impact of research projects) are becoming increasingly blurred, and that scholars and practitioners in the field are developing a conceptual and operational framework aimed at unifying the three exercises into a unique approach.

The methodology used for the technology foresight exercises consists of making experts interact by means of different techniques: Delphi surveys, panel discussions, brain-storming, scenarios, commissioned studies, expert networks, etc. In order to acquire the necessary information and an adequate variety of options, a large number of experts should be involved: in most of the exercises carried out until now several thousand experts have been drawn from academia, industry, government organisations, and even journalists, science fiction writes, representatives of the general public.

The countries where government agencies have started or supported foresight initiatives include Japan, Germany, the UK, the Netherlands, Australia, France and Italy (OECD, 1996f).

The questions usually addressed in the exercise are:

- ➨ how social and economic needs can be addressed by the new technology;
- ➨ scientific advancements required to develop the new technology;
- ➨ strengths and weaknesses of the country in exploiting the new technology and in acquiring comparative advantages vis-à-vis other countries;
- ➨ strengths and weaknesses of the country's science base compared with the other countries;
- ➨ cost of the scientific and technological resources required to reap the expected socio-economic returns;
- ➨ time dimension of the development, implementation and use of the new technology.

The exercise envisages that a few areas are identified by a steering group, and that a larger number of topics are dealt with by the field experts (in the last foresight exercise of Japan, 16 areas and 1,070 topics have been identified; the respective numbers for Germany have been 14 and 1,150) (NISTEP and ISI, 1994). As an example, the technological areas covered by the Italian exercise are: advanced materials, microelectronics, advanced technologies for information processing, microsystems, software, biotechnologies, production and management technologies (Fondazione Rosselli, 1996); the areas of the last Japanese-German foresight are: material and processing, information and electronics, life science, space, particles, maritime science and earth science, mineral and water resources, energy, environment, agriculture, forestry and fisheries, production, urbanisation and construction, communication, transportation, medical care and health, culture and lifestyles (NISTEP and ISI, 1994).

The advantages of foresight are the following:

➨ it offers governments and firms a set of options on the basis of which to make strategic choices;

➨ even though technology foresight is comparatively a young field, the accuracy of its results is more than acceptable: in the case of the first Japanese Delphi carried out in the early 1970's, 28% of topics had been fully realised and 40% partially realised in the following 20 years;

➨ experience has shown that the process in itself is a valuable output for participants, on top the expected outputs in terms of priorities for stakeholders in the public and private sectors.

The limitations of foresight are the following:

➨ the procedure is very expensive and resource consuming;

➨ consensus building amongst experts may be problematic and depends on the methodologies used (Delphi, panels, brain-storming, scenarios, etc.);

➨ up to now a different mix of methodologies has been used in various countries;

➨ experts may have a vested interest in the outcome of the process;

➨ the results cannot be compared across countries because different lists of technologies are relevant to each country;

➨ foresight may lead companies to concentrate their innovative efforts on a limited set of technologies expected to have high returns, with the consequence on the one hand of missing out promising opportunities which are not given the highest priority and, on the other, of exacerbating competition on those where efforts are concentrated.

Only a limited number of countries have up to now carried out foresight exercises. This may be also be due to cultural specificities which make it difficult to mobilise a large number of experts working in a project associated to an effort to "building the future" especially in countries where constitutional stipulations stress the concept of the freedom of science.

*Public attitudes and public understanding of science and technology*

Most traditional S&T indicators put the emphasis on the characteristics and impact of science and technology from the point of view of organisations responsible for their implementation. Surveys on public attitudes and understanding of science and technology allow to add a fundamental dimension to this social process: what it the citizens' view about scientific developments, scientific programmes or current problems requiring research efforts. Examples include the atom or DNA, the thinning of the ozone layer or the relative importance of medical discoveries vis-à-vis space exploration and environmental issues, the understanding of basic scientific concepts like molecules, light speed, the moving of continents.

Surveys of samples of citizens are regularly conducted in this field in various countries (National Science Board, 1996) and by international organisations (European Commission, 1993).

## PROSPECTS FOR FUTURE DEVELOPMENTS

Having outlined the main science and technology indicators, it is now possible to look into the future.

Science and technology are now being analysed in a much wider context than in the past. Policy makers are interested in disentangling the relationship between science and technology on the one hand, and growth, employment, the environment, organisation, the institutional governance of the system, on the other (OECD, 1996d). In order to address this issue, it is necessary to develop theories which not only explain the working of ever increasingly complex systems, but that are also amenable to statistical measurement. A case in point is the new wave of analyses of national systems of innovation: the theory is very promising but it has to be turned into more operational and quantitative terms.

Building indicators has become a "big science" exercise. No single organisation or country can go alone: international organisations are likely to continue to play a major role as promoters of methodological advancements and providers of data bases and analytical reports. In the future the OECD is expected to continue to act as a stimulus and "clearing house" for the activities of the various member countries, in particular through the Group of National Experts on Science and Technology Indicators.

The increasing number of dimensions to be investigated and the need for tracing relevant phenomena over time, does not allow to discontinue data collection of any series, even in the presence of stable or even diminishing resources of statistical agencies.

In the last few years firms have been subjected to a demand for information from a growing number of research agencies. They therefore exhibit a natural reluctance to devote further resources to supplying data which are not perceived as a direct advantage to them. However, in the case of statistics on innovation considerable interest is displayed by the firm in collaborating, possibly in view of the fact that the growing attention on "innovation" leads company management to take advantage of this supply of data to carry out an analysis of the firm's innovative strategies.

Data referring to firms' technological and economic activities is increasingly affected by the process of internationalisation, which makes national activities diverge from the technological capacity located within the country's borders.

With reference to the data sources used to construct science and technology indicators, it may be expected that in the future the weight of the databases constructed using information collected for administrative purposes (patents, scientific publications, technological balance of payments, foreign trade, etc.) is likely to be greater than that of ad hoc surveys (R&D, innovations, etc.). In this way more information will be made available without having to turn to firms for further data supplies. Moreover, it may be foreseen that the role of commercial producers of science and technology indicators will increase vis-à-vis the institutional statistical agencies.

The methodologies developed within OECD countries have de facto become the standard also for former socialist and developing countries. This makes the task of building indicators even more challenging: on the one hand data may be compared across almost all countries of the world; on the other, differences in the level of economic development introduce further dimensions and differences in emphasis which make the complete picture even more complex.

The agenda of experts in the field of science and technology indicators is rather full. There is a series of areas which have been identified and for which exploratory work has already been started. The measurement of innovation in service companies, organisational innovation, the various dimensions of information technology, innovation in the environment and in other socially relevant fields, the distribution power of knowledge systems, are the most challenging ones.

One of the main challenges for those who are in charge of providing indicators is linked to the timing of indicators building. A decade usually elapses from the identification of the need for an indicator and the availability of internationally comparable data. This makes crucial the ability to identify well in advance users' needs and to build a robust design which can accommodate a moving set of objectives.

In conclusion, science and technology indicators may be said to be in a period of rapid evolution. In the coming years the efforts of statisticians, researchers and policy makers will have to be concentrated on addressing emerging conceptual and methodological difficulties, as well as on improving the systems of data collection and standardisation. This will make available a powerful conceptual and information system which will allow us to understand better the complex phenomenon of knowledge creation and distribution, the effects of which are increasingly felt on our values and needs and ultimately also on our daily lives.

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