Science and Technology Redesign Project

Projet de remaniement des sciences et de la technologie

RESEARCH PAPER

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THE STATE OF SCIENCE AND TECHNOLOGY INDICATORS IN THE OECD COUNTRIES

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THE INFORMATION SYSTEM FOR SCIENCE AND TECHNOLOGY PROJECT

The purpose of this project is to develop useful indicators of activity and a framework to tie them together into a coherent picture of science and technology in Canada.

To achieve the purpose, statistical measurements are being developed in five key areas: innovation systems; innovation; government S&T activities; industry; and human resources, including employment and higher education. The work is being done at Statistics Canada, in collaboration with Industry Canada, and with a network of contractors.

Prior to the start of this work, the ongoing measurements of S&T activities were limited to the investment of money and human resources in research and development (R&D). For governments, there were also measures of related scientific activity (RSA) such as surveys and routine testing. These measures presented a limited and potentially misleading picture of science and technology in Canada. More measures were needed to improve the picture.

Innovation makes firms competitive and more work has to be done to understand the characteristics of innovative, and non-innovative firms, especially in the service sector which dominates the Canadian Economy. The capacity to innovate resides in people and measures are being developed of the characteristics of people in those industries which lead science and technology activity. In these same industries, measures are being made of the creation and the loss of jobs as part of understanding the impact of technological change.

The federal government is a principal player in science and technology in which it invests over five billion dollars each year. In the past, it has been possible to say how much the federal government spends and where it spends it. The next report, to be released early in 1997, will begin to show what the S&T money is spent on. As well as offering a basis for a public debate on the priorities of government spending, all of this information will provide a context for reports of individual departments and agencies on performance measures which focus on outcomes at the level of individual projects.

By the final year of the Project in 1998-99, there will be enough information in place to report on the Canadian system on innovation and show the role of the federal government in that system. As well, there will be new measures in place which will provide a more complete and realistic picture of science and technology activity in Canada.

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INTRODUCTION

What efforts is a country making in the sphere of science and technology? What results are those efforts yielding from a scientific, economic or social standpoint? How is a country positioning itself in relation to other countries in terms of its scientific and technological development? What is the situation of science and technology in Canada? These are all questions that *scientometrics* seeks to answer.

Scientometrics is the science of the *measurement of science*. The methodology that it draws on is based on the use of indicators (Lazarsfeld, 1965). An indicator is a measure of a given dimension of a phenomenon, an event, an entity or a concept. There are three key elements to this definition: concept, dimension, indicator. Consider an example:

We are interested in measuring science: that is our *concept*. We see this concept as having several dimensions, but we will deal with only two of them: inputs and outputs. Science is characterized by the resources assigned to research (inputs) in order to produce certain results (outputs). These are our two *dimensions*. How, then, will we measure those dimensions? By defining each of them in terms of *indicators*. For example, an input indicator might be the monetary investments made in research and development (R&D), while an output indicator might be the number of innovations produced by researchers.

It should be noted that the indicators that we have selected in our example are partial and limited. However, this is the case with all indicators. An indicator is partial because we can always increase the number of indicators in order to obtain a better measurement of the concept considered. For example, we could have added other types of inputs: the personnel assigned to research, the equipment used in research projects, etc. It is in this sense that any indicator is only partial. In another sense too, we say that an indicators is always limited: an indicator, and the model on which it is based, is always a partial reflection of reality. It measures only one facet of reality, a quantitative one at that, and reality cannot be reduced to this one indicator.

In general, two lines of questioning can help us assess the quality of the measurement that we are obtaining with an indicator. First, we must from the outset question the theoretical validity of our indicator. By theoretical validity, we mean that it must be possible to answer yes to the following question: does the indicator properly measure the concept identified? Second, we must question the technical reliability of the indicator: does the indicator yield coherent and consistent results? If the answer to both these questions is yes, we have an indicator which, while imperfect, is satisfactory.

The undeniable value of indicators becomes clear once we accept that there is no optimal measure of the level of science and technology that a country should seek to attain. For example, should a country invest 1%, 2%, or 10% of its resources in R&D? This is a normative question, and there is no objective answer to it. We can, however, compare ourselves to other countries, to see whether, at a given level of R&D, we are producing the same results or whether, for a higher level of R&D, the results are sufficiently attractive for us to increase our R&D to the level of the other country. Indicators, developed and regularly collected, allow for such comparisons between different jurisdictions or time periods, and these comparisons aid in decision-making.

This paper takes stock of the state of the indicators used in the main OECD countries. The principle indicators currently used in the science and technology sphere are reviewed, defined and described, then briefly evaluated.

In an appendix, we have grouped together those indicators which are currently available to governments and which are sufficiently systematized to be considered in this paper. This list is based on the analysis of a number of national and international statistical inventories. The inventories selected basically had to meet two criteria: they had to cover a fairly large group of indicators, and they had to be produced on a systematic and regular basis. Four series of inventories meet these criteria, namely those of the Organization for Economic Co-operation and Development (OECD), the European Economic Community (EEC), the National Science Foundation (NSF), and the Observatoire des sciences et des techniques (OST).[1] For purposes of comparison, we have added to this information (last column of appendix) the indicators currently compiled by Statistics Canada.

We did not, however, want merely to take stock of what exists. It was necessary to go further and take note of current developments. We will therefore also deal with a few new indicators, either because their potential is recognized or because there is a demand for them on the part of governments. As we will see, these new indicators add an additional dimension to science and technology, namely the question of systems and synergies, in short, interrelations between the players in a national system of innovation.

The first section provides a brief historical overview of the development of indicators in the OECD countries to the present. The second section reviews the main indicators currently available, namely those that are sufficiently standardized to be used by the governments of the OECD countries. In the conclusion, we take stock of recent developments and the challenges currently facing governments in the measurement of scientific and technological activity.

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1 OECD (1995), Main Science and Technology Indicators *1995* (1), Paris; OECD (1995), *Research and Development Expenditure in Industry: 1973-199*2, Paris; OECD (1995a), *Industry and Technology: Scoreboard of Indicators 1995*, Paris; Observatoire des sciences et des techniques (OST) (1996), *Science et technologie : indicateurs 1996*, Paris; National Science Foundation (NSF) (1993), *Science and Engineering Indicators : 1991* (10th edition), Washington; CEE (1994), *Rapport européen sur les indicateurs scientifiques et technologiques*, Bruxelles; CEE (1995), *Recherche et Développement : statistiques 1995*, Luxembourg *:* Eurostat.

Historical overview

Scientometrics is now thirty years old, since it has been just over thirty years that the Western countries, notably via the OECD, have had indicators by which they can follow the development of national science and technology systems. It was in 1963 that the OECD first published the *Frascati Manual*, which proposed a "standard practice for surveys of research and experimental development." The Manual standardizes the way governments collect information on investments in research and development (R&D). While as we noted in the introduction, that there is no optimum measure of investments in R&D, the data thus gathered enable the different countries to assess their efforts by comparing themselves with each other, or by comparing their current situation with a recent past.

Since 1963, the *Frascati Manual* has undergone numerous revisions and improvements. Of special note are the refinements made to the measurement of R&D activities in the higher education sector (OECD, 1989). The Manual is now in its fifth edition (OECD, 1993).

The Manual distinguishes between three sets of *scientific and technical activities* (STAs) for which indicators are developed. First there is *research & development* (R&D), defined by the various creative projects whose purpose is to increase knowledge and the applications of knowledge (OECD, 1993 : 31). Second there are *educational and training activities,* encompassing educational activities at the undergraduate and graduate levels. Lastly there are *related services*, consisting mainly of information, diffusion and standardization activities.

The *Frascati Manual* is based on a well-known theoretical model called the "input-output" model (Figure 1). Investments (inputs) are made in various scientific and technical activities (STAs) which translate — potentially — into knowledge and applications (outputs). Until recently, most studies, projects and indicators produced by the OECD and Western countries related to inputs as just defined. [2] This situation may be explained by historical circumstances. Input indicators are directly linked to the needs of the science and technology policies of the 1960s, and more especially with the emergence of science and technology policy. In the 60s and 70s, governments began to get involved and started developing policies on science and technology. The primary objective at that time was to participate in the *funding* of R&D activities. Input indicators thus served to shed light on where there was investment and where less research was being done. Governments therefore had measures which, they hoped, would indicate the areas of investment on which public funding should be focussed.

However, as a result of the increasing complexity of the science and technology phenomenon, various indicators used in the past are no longer very well suited to reality, or at the very least they are insufficient to adequately measure this reality. For example, from a situation where R&D performers were few in number and therefore easy to identify and survey, we have moved to situation characterized by great diversity, with, for example, small firms working alongside large firms. Technological levels have also changed: it is no longer sufficient to know, as our current indicators often tell us, that a firm has a given technology, such as computer equipment and computer-controlled machinery; it may be necessary to know whether the firm has two or more such pieces of equipment, or whether it possesses those of the latest generation.

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[2] For example, Statistics Canada regularly produces, at least at present, only statistics on industrial R&D and government R&D.

Figure 1 — Input-output Model

Inputs	➔	Research activities	➔	Outputs

In a parallel development, governments in the 1980s became more interested in innovation. This is moreover the imperative under which the recent federal science and technology strategy operates (Industry Canada, 1996). These policy considerations are now being formalized in new indicators. Along these lines, the OECD recently developed what is known as the *Oslo Manual* (OECD, 1992b). This focusses on the portion of R&D which is directly concerned with the creation of new products and processes, and which is called innovation. Following the example of the Frascati Manual, the Oslo Manual defines the OECD standards for collecting information on this subject (OECD, 1992b). We will come back to this later.

At the same time as they were beginning to be interested in innovation — and perhaps because they were beginning to do so — governments were also becoming more directly aware of the need to measure research results. And to measure them, it became clear that the many input indicators that had been available for some time were inadequate. What was needed now were output indicators and impact indicators. To be sure, the OECD had long been publishing indicators based on patents, and academic researchers had been developing a number of bibliometric indicators (focussing on publications) for some years. A couple of countries, namely the United States and France, were even producing statistics on this subject on a regular basis. However, unlike the input indicators, very few output indicators were yet standardized. For this reason, the production of such indicators varied enormously from one country to another, and governments' use of them within a policy framework was still quite limited. It was for this reason that in 1992 the OECD, with its *TEP* program — *Technology-Economy-Productivity* (OECD, 1992a) took on a new challenge: to set up a program whose objective was to develop new indicators, especially innovation indicators and output indicators.

To these goals, however, the program added another, which would be fundamental to all future measures: to operationalize the concept of a *national system of innovation* (NSI), a concept that has since been embraced by the OECD. Thus governments now turned their attention to analysing the dynamics of national systems of innovation, focussing in particular on the flows and transfers between the various performers. A national system of innovation is defined as a set of players who interact and whose activities are oriented toward the development of new products, processes and services (Niosi et al., 1993; Lundvall, 1992; Nelson, 1993).

At this point, the indicators specific to this new dimension of science and technology are nearly nonexistent. This, then, is the challenge associated with this new concept: how is the idea of a national system of innovation to be operationalized? With the specific goal of obtaining a better understanding of the dynamics of NSIs, the OECD now offers a set of recommendations relating to science and technology indicators in particular (OECD, 1992a) :

- integrate science and technology statistics more effectively with industrial, educational and employment statistics;
- define new indicators on:
  a) innovation and its diffusion;
  b) intangible investment and its various components;

- improve the data on human resources, and in particular the data on the training of scientists and engineers, and on the supply of and demand for their services;
- expand the indicators on firms, in particular multinational firms;
- improve the indicators on long-term (basic) research, especially in the higher education sector.

Box 1 — Main OECD documents on the measurement of science and technology

1963	*Frascati Manual* (first edition)
1989	Supplement on R&D in the higher education sector
1990	Proposed standard practice for the collection and interpretation of data on the technological balance of payments
1992	*Oslo Manual* (first edition)
1992	The *Technology-Economy-Productivity (TEP)* program
Other documents :	
	The use of data on patents as science and technology indicators
	Recommendation for the development of indicators of human potential in science and technology
	Measurement of high, medium or low technology products and sectors
	Recommendations for the use of indicators based on statistical studies of science and technology publications (bibliometrics)
	Manual on international educational indicators

Input indicators

Of all the science and technology indicators, input indicators are undeniably the most developed. They are supported by a standard method of collection and classification that goes back to the 1960s and is recorded in what, as noted above, is commonly known as the *Frascati Manual* (OECD, 1993).

In this section, we will describe the three major input indicators: monetary investments, human resources and equipment. The first two are relatively well-documented, the third much less so.

Monetary investment

Monetary investment in R&D is the most widely used indicator. As an indicator, it offers at least three advantages (Stead, 1992; Averch, 1991). First, monetary expenditures lend themselves to direct comparisons with the other types of expenditures undertaken for other purposes. Thus it is easy to compare the importance assigned to science and technology in relation to government spending on, say, health or education, or in the case of a firm, in relation to other operating expenditures. Second, and for the same reason, the monetary data on R&D lend themselves to ready comparison between countries. Since a society's optimum level of investment in R&D is yet to be determined, the only way to assess such expenditures is through comparison. Lastly, since the data have been available for several decades, they lend themselves to trend analyses, which are essential to science and technology policy.

Investments are usually presented by means of the indicator known as Gross Domestic Expenditures on R&D (GERD). GERD represents the *absolute* amount invested in R&D in a country by the different national players, on different objects of research. Monetary investments are grouped and presented, as the Manual suggests, under the following three main headings:

- Objectives:
  - government missions;
  - scientific fields;
  - industrial sectors;
- Performing sectors and funding sectors:
  - industry;
  - government;
  - university;
  - private non-profit institution (PNP);
  - foreign;
- Type of research:
  - pure;
  - applied;
  - development.

Because GERD is an absolute amount, it is hard to compare countries of different sizes using this indicator: a small country will always have smaller investments than a large country, but this does not mean that it is making less effort. To assess this effort, a *relative* measure must be used. This is what is done when GERD is placed over a denominator such as Gross Domestic Product (GDP) or population size. If GERD is taken as a percentage of GDP, for example, comparisons can be made between countries, and the latters' efforts in science and technology can be assessed.

Like any indicator, monetary investment in R&D has certain limitations that have to be taken into account in order to make proper use of the indicator. Unfortunately, some of these limitations are often underestimated, overlooked or ignored. The methodological notes to OECD-designed tables, for example, must be read with care in order to appreciate how significant these limitations are. It is appropriate at this point to point out several of them.

First, it must be kept in mind that despite the standardization suggested by the *Frascati Manual,* there are major differences in the way different countries classify data, and this sometimes makes comparisons difficult. Among other things, sub-national levels of government are not always well-covered;[3] the definition of sectors, especially the university sector, varies greatly from one country to another,[4] and owing to national differences in education systems, the data on university R&D do not always include the humanities; data on missions or objectives are treated differently by different countries.[5]

A second set of problems concerns users' needs for detailed statistics. First, under current classification systems, it is not possible to isolate the largest component of R&D (accounting for approximately 75%), namely development (Averch, 1991). The same is true for so-called strategic research and pre-competition research. Next, small and medium-sized firms, the number of which often serves to characterize a country's industrial structure, are very poorly sampled, and their contribution to the national R&D effort is considerably underestimated (Kleinknecht and Reijnen, 1991; Campbell and Wehrell, 1992). Still on the subject of industrial R&D, it is also worth noting that the latter is assigned to a given industry on the basis of the firm's main component by which it belongs to the industry, and not on the basis of the technological focus of the R&D. As a result, research conducted in the firm's secondary branches, that is, research that may be conducted in any of various technological fields, is underestimated, sometimes significantly. Lastly, in the case of Statistics Canada more specifically, it is sometimes hard to obtain *regionalized public data*[6] on industrial R&D, or disaggregated data on government laboratories, such as those of the *National Research Council*.

The above observations are not intended to discredit statistics on monetary inputs. Instead, they show that caution must be exercised in interpreting such statistics, and that the best approach is perhaps to combine monetary data with other, more varied indicators in order to obtain a true picture of efforts invested in R&D.

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3 The coverage of government spending is often limited to spending at the level of the central or federal government, as in the United States, overlooking expenditures by states and local governments. In Canada, the Atlantic provinces are not systematically included in the data; their contribution is based on estimates.

4 The same is true for the definitions of the services sector, research personnel, PNPs, and foreign.

5 This is the case with the advancement-of-knowledge objective in the United States, owing to the fact that expenditures relating to this objective are distributed among other missions, such as defence.

6 At the subprovincial level in the case of Canada.

Human resources

Indeed, one additional indicator that serves to give a picture of the magnitude of research efforts is the amount of human resources assigned to R&D :

- administrators;
- researchers;
- professionals and technicians.

For the user of these statistics, two major questions arise at the outset: what is being measured, and how? For example, what is the definition of a researcher (OTA, 1991: 36)? Two methods are used. A researcher may be defined by his/her occupation, that is, the job or occupation of researcher. Another option — and this is the one most often used, although it is less precise — is to settle for employees' level of qualification, that is, the degree that they hold. The first method is the preferable one, since it provides a better measurement of the dimension to be measured (as noted above, theoretical validity is a criterion for assessing the quality of an indicator). However, many countries merely provide information based on the second option, and in most cases the information relates only to researchers holding a university degree.

A second major issue relating to human resources is whether they are counted in terms of individuals or FTE (full-time equivalence). The problem is that an individual may be assigned to R&D but spend only a part of his/her time on it. The second measure takes this into account. Here again, the practice varies from one country to another. Therefore caution should be exercised in reading and interpreting the data.

The data on university personnel come up against another category of well-known problems (OECD, 1989) owing to the fact that research is not a separate activity but rather an integral part of the work of many academics. The research done varies depending on teaching responsibilities, and it is not necessarily conducted within the educational institution or during working hours. Hence the considerable difficulties involved in measurement: it is hard to measure the amount of time that academic researchers devote to R&D.[7]

Equipment

In theory, a final set of input indicators serves to round out the picture of the efforts and resources devoted to R&D. These are capital expenditures, especially those undertaken to obtain the equipment and technologies used to conduct research activities. The amount of such equipment required in certain areas of physics — particle physics, for example — is well-known. For this reason, such fields are usually described as "big science."

However, and despite the important role of equipment in research activities, especially in the experimental sciences, there are very few if any data on this subject in statistical inventories of science and technology indicators. Of course, equipment purchases and expenditures are included in the amounts invested and recorded as R&D inputs. But figures showing the portion devoted to these investments, which would serve to provide a precise breakdown of the amounts spent on equipment, are not yet publicly available. In fact, only the United States

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[7] Another question also arises: what about the research activities of students and assistants, which are an integral part of the research conducted by professors?

(NSF) publishes specific data on equipment. However, these data concern only equipment in university facilities. In addition, the data are available only in the form of depreciation.

Having said this, we will close by noting that information on this subject may be obtained from another type of survey. Some of these indicators are available from surveys on the diffusion of technologies, as we shall see below. However, these surveys concern only business enterprises, and they focus on only certain technologies.

Output indicators

Until recently, as noted in the introduction, the measurement of outputs was the poor relation of other science and technology indicators. However, the situation is changing. Various attempts are currently under way, both in government and in the university sector, to provide governments with output measures. Here we will merely identify the most widely accepted indicators — firstly, technological research indicators (innovations, patents), and secondly, scientific research indicators (publications) — and conclude with a little-used indicator, namely the number of graduates.

Innovations

Until recently, surveys on innovation were all ad hoc studies conducted by university researchers (Smith, 1992). Noteworthy in this regard are the surveys conducted by the SPRU, dating back to the 1970s. However, this type of survey concerns only the most significant innovations or those considered the most important. Furthermore, there are a number of criteria for determining the importance of a technology, and they vary from one researcher to another. The principles according to which innovations are classified extend from historical considerations to their role in specific sectors of national economic production (materials, energy); they include the principles of technical construction inherent in innovations. The importance of an innovation is also defined in various ways: according to sales figures, contribution to profits, reduction of costs, interindustry diffusion,[8] or the degree of novelty (major-minor).

In order to better measure the innovation process and to fill a gap that we identified earlier in connection with the inadequate picture of R&D that results from classifying it very generally into three types of research (basic-applied-development), the OECD recently published the *Oslo Manual* (OECD, 1992). In it, innovation is defined very broadly as including any new concept, product or process, whether major or minor, and any new market. It also includes different inputs other than research activities as such, including intramural activities related to design and market studies, and outside acquisitions of technologies. The following dimensions and information would be collected by a survey conducted according to the Oslo model:

- prevalence of the innovation (number of firms , industries);
- types of innovation (products, processes);

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8 The distinction between product and process that is used for this purpose is not yet fixed in the surveys, nor is it understood or defined in the same way by all concerned. Indeed, the understanding of it varies depending on who is responding to the survey (Simonetti et al., 1995).

- goals of the innovation (new function, performance, automation, production);
- benefits (quality, technological capabilities, working conditions, expanded product line, increased profits, new markets);
- sources of innovation :
  - internal (R&D units: research, development, engineering; sales and marketing; management; production);
  - external (suppliers, clients, competitors, consultants, public laboratories — government, university— and publications);
- innovation intensity (ongoing, occasional);
- impact on workers (number of employees, productivity, skills);
- obstacles to innovation (skilled personnel, information on markets, regulation, collaboration);
- practices for protecting innovations (patents, trademarks, trade secrets, industrial designs, copyright).

It is still too soon to evaluate the Oslo Manual. Countries are only beginning to conduct such surveys. The EEC countries and Canada, for example, have only recently, for the first time, conducted a survey based on the Oslo methodology. The Statistics Canada survey, conducted in 1993, covers manufacturing enterprises of all sizes. Its universe consists of all firms with a manufacturing establishment that are included in Statistics Canada's Business Register: (1) establishments (plants) that are divisions of large firms, (2) the corresponding head offices, and (3) small firms that have their management and plant at the same location. The 1993 sample consists of 5,729 units in all: 1,595 head offices and 1,954 plants for a total of 3,549 units representing large firms (62%), and 2,180 units representing small firms (38%).

The survey of innovation has several advantages over those concerning R&D. First, unlike the latter, it openly addresses for the first time, with regard to intentions at least, the question of outputs. Second, the survey of innovation opens the black box on activities specific to innovation. Whereas current science and technology indicators, based on the linear model of innovation, measure inputs and outputs, they leave out what happens within the firm. Third, one of the goals of the survey is to obtain measures of impacts.

However, a critical comment is in order here. As currently designed, the survey of innovation unfortunately does not yield any measure of the *volume* of technological outputs, nor does it yield a measure of impacts. The questions asked are intended less to quantify innovation activity than to shed light on the actual processes of innovation and the factors that influence innovation: firms are invited to check whether or not they engage in a given type of innovation and where they believe the impacts are felt. The objective of shedding light on innovation processes and activities is highly laudable in itself. However, the information obtained from this survey is basically qualitative. In addition, once the patterns of behaviour are identified, this type of survey should not be repeated annually, unless there are indications that these patterns are changing from year to year. In short, then, the survey cannot yet, at least as currently designed, serve as the much-awaited basis for output indicators.

Patents

Thus the survey of innovation does not really yield a measure of the amount of outputs produced by firms. It is therefore necessary to use statistics available elsewhere, namely the indicator consisting of the patent, to measure the amount of innovation activity. For this purpose, there are now a number of databases on patents, since in recent years governments have computerized the patent information that they hold. This information is similar to what is contained in the bibliometric databases that will be discussed below: patent title and number, name and address of inventor, date of issue, abstract, citations, key words. Among these databases, there is one that is widely used, namely the US patent database, because most countries file patent applications in that country.

As an indicator of innovation, patents offer a number of advantages, owing to the fact that:

- all or nearly all countries have a national patent system;
- all countries are represented in the major systems such as the USTPO (US Patent Office) and/or the EPO (European Patent Office);
- patents cover the vast majority of technological fields and a great number of industrial sectors.

However, as an indicator, patents also have some well-known disadvantages (Archibugi and Pianta, 1996; Archibugi, 1992; Pavitt, 1985; Basberg, 1987). First, not all inventions are patented (since trade secrets continue to be very important), nor are they necessarily patentable, as in the case of software. Patents are therefore more a measure of invention and inventiveness than of innovation. As such, however, patents allow for useful international comparisons. Second, patents are not all of equal value, nor do they all have the same impact: on the basis of them, it is impossible to judge the market value of the technologies. It should finally be noted that the propensity to patent differs from one industry to another, small businesses have a much lower propensity to do so (mainly owing to cost considerations), and nomenclature systems vary from one country to another.

Nevertheless — that is, despite these limitations — patents as an indicator can yield more information than they do at present, since they are currently merely counted. One need only think of the flows between science and technology as measured by citations in patents (a subject that we will return to later), the sectors from which patents originate (increasingly the academic sector is submitting patent applications), and the technologies patented. In this sense, the indicator is still very underexploited.

One final point: while various inventories have been compiling patents for some time, trade marks, models, industrial designs and copyrights are seldom considered in statistical inventories on science and technology. Since the bodies responsible maintain such statistics, they could be used and included in science and technology inventories, thereby providing additional indicators of inventiveness and innovation.

Publications

Unlike technological production, scientific production is very well covered in some S&T inventories — in the natural sciences, in engineering and in the biomedical sciences at the very least. Statistics on publications, called bibliometric statistics, draw on bibliographic databases on publications; such databases have been developed for documentary purposes since the early 1970s. Each article is indexed with a series of fields or variables: (author(s), address, journal, field, year, abstract, citations, key words.

Two databases deserve mention: The first, the *Science Citation Index* (SCI) of the Institute for Scientific Information (ISI), has been tracking 3,500 journals and 400,000 articles annually since 1945 (Garfield, 1972; 1990). The documents identified range from simple research notes to more substantive articles. However, since the SCI has an obvious bias for literature in English, a second database is sometimes used: the French database PASCAL, a product of the Centre national de la recherche scientifique (CNRS). PASCAL tracks more than 7,000 journals annually.

The coverage of different countries' scientific production varies slightly depending on which database is used, but on the whole, the ranking of the countries is maintained. However, each database has its advantages. The SCI is the only database to provide the citations appearing in each article. Owing to these citations — and this is something that we will return to below — the impact of an article can be measured by calculating the number of citations received during a given period. On the other hand, PASCAL is the only database to index articles by key words. The latter can be used to identify articles concerning a specific topic.

Bibliometrics is the use of databases for statistical purposes. In bibliometrics, there are basically two methods: the counting of articles, and network analysis (which we will deal with below). Counting is basically a method that focusses on calculating the volume of production of articles: accordingly, it measures the number of articles produced by a given performer in a selected field (NSF, 1993; OST, 1996; MESS, 1994). The level of aggregation may be an institution, a sector or a country. The field may be a given scientific discipline, a technology or a specific technological niche.

Bibliometric indicators, which are now fairly well-developed, are used increasingly as a factor to be taken into account in evaluating academic research. Moreover, unlike investments in R&D, they have the advantage of not being subject to confidentiality constraints: the databases are public, as is also the case with patents, discussed above.

Despite these advantages, very few countries systematically produce bibliometric indicators. In fact, only the United States and France regularly produce and publish such indicators. In Canada, only Quebec produces bibliometric indicators; it has done so since the mid-1980s.

This lack of popularity cannot be explained by the poor reliability and validity of bibliometric indicators. There may have been a time when the need to standardize bibliometric indicators limited their use, but this is no longer the case. To be sure, these indicators have various limitations, in particular the fact that they usually cover only the natural sciences, engineering and the biomedical sciences. It should also be noted that obvious linguistic biases largely limit the coverage of the scientific production measured to the literature in English.[9] Lastly, it is worth repeating that publishing is only part of the work of researchers.

Notwithstanding these limitations, bibliometric indicators are one of the main research output indicators, in addition to being very applicable — contrary to what is commonly believed — to research conducted by other types of performers (Godin, 1995). For this reason, they deserve to be included in science and technology inventories.

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9 For the actual methodological limitations of bibliometrics, see Leydesdorff, 1989; Anderson et al., 1988; Callon and Leydesdorf, 1987.

Number of graduates

We will briefly conclude this section on outputs by pointing out that human resources are often identified as a crucial variable in the innovation process. The human resources specifically associated with the R&D process are already accounted for, as we have seen. However, statistics on graduates (enrolments, degrees granted) — one of the main outputs of the education system — are generally not included in science and technology inventories. Of course, all governments have data on these matters, and they appear in numerous publications. But they are not yet shown alongside the better-known science and technology indicators.

The importance that the OECD assigns to human resources in its studies on national systems of innovation (OECD, 1992; 1996) should shortly be reflected in new indicators on this subject. At this point, the only competence indicators used in science and technology relate to personnel *directly assigned to* research activities. Indicators on science and technology workers' training and skills, on supply and demand and on graduates will soon be standardized in the *Canberra Manual* recently designed by the OECD (1995d) in order to provide a more accurate measurement of the state of knowledge.

Impact indicators

The preceding sections have identified the main science and technology indicators available today. However, there are others, and while they are as yet not systematized in governments' statistical inventories, they deserve mention.

As we noted in our introduction, for some years governments have been sending out a clear message that it is now necessary to measure investments in science and technology in terms of their performance (Science, 1995; Industry Canada, 1996). Therefore attention is now being given to impacts. The impacts of science and technology may be of different types:

- economic: increased profits, productivity, market share and exports;
- intangible: improved manpower skills, product quality, etc.

As their name indicates, intangibles are hard to measure, and in fact they are very seldom measured (see section on innovations). As to economic indicators, they are often available in national statistical agencies' publications other than those specific to science and technology. However, these statistics are highly aggregated, and they do not deal specifically with technology, but rather, for example, with the productivity of an industry as a whole. In general, impact indicators call for specific evaluation studies (e.g., Mansfield, 1991). Of course, the Oslo-type survey tackles the issue, but as we have already noted, the information obtained is essentially qualitative.

Diffusion

One impact indicator for which we possess some historical data is the one relating to the diffusion and use of technologies. In 1989 and again in 1993, Statistics Canada conducted a survey on the diffusion of technologies in Canadian manufacturing enterprises.[10]

The information obtained in Canada in the survey on diffusion addresses and sheds light on the following aspects of the diffusion of advanced technologies:

- use:
    - frequency and intensity;
    - diffusion time;
    - origin of the technology;
- investments in acquisition;
- diffusion processes;
    - source;
    - advantages;
    - obstacles;
    - factors.

The advanced technologies selected for inclusion in the survey are the following: design and engineering, manufacturing and assembly, automatic handling of materials, inspection and communications, manufacturing information systems, integration and control. One of the challenges of the coming years will undoubtedly be to update this list. If a technology has been around for a few years and is used by a majority of firms, should it still be considered an advanced technology? This is a question that arises in particular in the case of inspection and communications technologies (72.9%) and design and engineering technologies (62.5%). Another challenge will be to construct appropriate indicators. Since the technologies do not have the same technological weight, a mere count of them is only a partial evaluation. If a firm is using several design and management technologies, is it more important from a technological standpoint than one using a single numerical control production technology? In general, the more proven technologies exhibit a higher rate of adoption than the more recent ones.

Similar problems are encountered in measuring firms' technological significance. This measure is based on the number of technologies present in relation to the value of shipments. Considering that the ratio of the technological quality of the firm's activities to the value of its shipments is not always clear, the evaluation of the technologies should perhaps instead be based on value added.

In conclusion, it is worth noting that Canada is one of the few countries to systematically conduct such a survey. Elsewhere, indicators of technological diffusion are not included in science and technology inventories. At most there are measures of technology purchases, which are developed on the basis of cross-tabulation matrices, as we will see in the next

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[10] In 1993, the data on diffusion were incorporated into the survey of innovation.

section. As to the diffusion of technologies in the home (such as the computer, for example), data on this subject are collected to some extent through broader surveys, but here again they are not incorporated into scientific and technological inventories.

The technological balance of payments

The most commonly used impact indicator relates to the technological balance of payments (TBP). The latter measures transfers of technology according to financial flows relating to two types of transactions:

- transactions concerning different types of intellectual property (patents, licences, techniques, processes, know-how, designs, models);
- transactions concerning services with technical content and intellectual services (engineering studies, technical assistance, R&D services).

The measurement of technology flows and transfers is based on the following methodology: a distinction is made between the technology developed in a given industry and the technology acquired through purchases of intermediate goods and equipment. Clearly, technological intensity is measured on the basis of R&D expenditures, and diffusion is measured through inter-industry flows.

Considering that the flows recorded must be both international and commercial in nature, the limitations of these statistics are obvious: transfers without associated financial flows, such as transfers between corporations within the same group and intramural transfers are not taken into account; nor are transfers involving non-commercial methods of payment, nor are indirect costs (goods and associated services).

A second impact indicator associated with the technological balance of payments is the trade balance. However, while statistical agencies have data on this, such data are seldom incorporated into science and technology inventories. When they are, it should be added that what is generally measured are the exports of a so-called high-tech industry as a whole, and not exports of the products with technological content that are specific to this industry. This is because a high-tech firm is defined according to whether it has a certain percentage of R&D, a definition that is moreover widely contested.

The impact factor

To conclude this section, a final impact indicator should be noted: the impact factor. In bibliometrics, the analysis of citations is considered an impact measure for publications. The citations received by a scientific publication are already widely used by researchers in the sociology of science and by evaluation researchers as a means of measuring the impact of scientific journals. By counting the citations made to the articles published by a given journal, they measure its impact; the more citations a journal receives, the greater the impact it is considered to have.

One can apply this method to institutions or countries rather than journals and thus compare the impact of the research published by them. Unfortunately, the impact thus measured is limited to the scientific impact alone. To measure the impact of research on, say, the economy, the patent method must be used. CHI Inc. pioneered this bibliometric approach applied to citations in patents in particular (Carpenter, 1983; Narin, Carpenter, and Woolf 1984). By searching patents and identifying the scientific articles cited in them, one can obtain a measure of the impact of these articles on technological development and also a measure of flows between science and technology.

Apart from the NSF, no country publishes bibliometric data on the impact factor, applied either to scientific publications or to patents. Of course, as we noted with respect to bibliometric data in general, caution must be exercised when interpreting such data. In the present case, the practice of citation — the functioning of which is still not well understood — varies from one field to another; citations have a life cycle, and they include self-citations; and the indicator is based entirely on the SCI database. These limitations definitely contaminate the value of the indicator, although they do not completely invalidate it.

Flow indicators

We have reached a point at which it is useful to summarize what we have seen thus far. Figure 2 sums up our current understanding of national systems of innovation and the indicators used to monitor and measure them. For the two main components of an NSI, namely research and innovation, four major sets of indicators are identified: input indicators, output indicators, impact indicators, and a new series, namely flow indicators. Flows exist within each of the two major components and also between them.

Along with output indicators and impact indicators, flow indicators are a priority for the coming years. For some time now, flow indicators have been described in the literature. Thus far, however, most of them are based on measures relating to inputs. This is the case with flows of research funding toward different performing sectors, such as from industries to universities, for example, or with purchases of technologies between firms. In other cases, the flows are measured on the basis of the performers' activities: joint projects, or alliances between firms.[11] Considering that the concept of a national system of innovation primarily emphasizes the outputs dimension, flow measures focussing on outputs are probably one of the main challenges of flow measurement.

[11] A. Rose, *Alliances stratégiques de R-D*, Statistics Canada, 1995.

Figure 2 — A Few Indicators of National Systems of Innovation (NSIs)

	Research		Innovation
Inputs	$ Human resources Equipment		$ Manpower Equipment Information
Outputs	Articles Graduates		Inventions Innovations (patents)
Impacts	Impact factor		Diffusion Markets Exports Productivity Profits
Flux	Cosignings Citations	U-I relations Cosignings Citations in patents Mobility of individuals	Alliances Purchases of technology

The applications of bibliometrics in this regard are already known. Bibliometric analysis of networks is an analysis that seeks to identify the relationships between the performers in a given system. Thus, some analysts study the citations that authors make of each others' work. They thus identify what is called a network of co-citations (Small and Griffith, 1974) or produce mappings of performers who constitute the core of a field (Callon, 1993). Contrary to what is commonly believed, however, these applications are not confined to measuring the flows between academics (Hicks and Katz, 1995; Godin, 1995; 1996).

Along the same lines, the bibliometric indicators on international collaboration as measured on the basis of cosignings are well known. These are also indicators of networking. It should be noted, however, that bibliometrics has not yet been used to truly describe or measure *national* collaboration, and this can yield measures of various aspects that are of interest for purposes of setting priorities for science and technology policy:

- flows between sectors;
- flows between regions;
- flows between fields;
- flows between institutions.

This work on measuring flows, particularly with respect to outputs, must be continued. It must also be continued with respect to other aspects, notably innovation. In light of the policy directions of the OECD's TEP program, the concept of a national system of innovation offers the possibility of achieving a convergence of the research conducted on output indicators, impact indicators and flow indicators.

CONCLUSION

In concluding this paper, we would like to draw up a general balance sheet of the state of indicators. It will be recalled that at the outset we suggested that we have gone from input-based indicators, which originated with science policies oriented toward the funding of research, to indicators relating to innovation. Accordingly, the demand since the early 1990s has tended to focus on the development of output indicators, impact indicators and indicators of flows (and thus transfers) between players in national systems of innovation. From our analysis, it thus appears possible for us to make several general observations:

- the *needs of the users* of science and technology indicators — namely government departments and public agencies — must be the primary motivation for producing these indicators; among the expectations of these users, the following stand out:
    - better representation of small firms,
    - better coverage of the *services* sector,
    - more disaggregated data, notably at the (sub)regional level,[12]
    - *output* indicators,
    - information on R&D content, that is, on specific *fields* of activity: the objects of research in the case of universities, and technologies in the case of business enterprises;
    - better use of existing surveys,[13]
- if *science and technology indicators were brought together in a single document,* this would serve to give the indicators greater visibility and ensure that better use was made of them by those concerned.

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[12] Such data are produced for industrial R&D in the United Kingdom, and for inputs by the EEC and France (which also produces data on outputs by region).

[13] This responsibility is already recognized by Statistics Canada, which has plans to use census data to obtain information on training, and tax forms to obtain R&D figures.

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APPENDIX

MAIN SCIENCE AND TECHNOLOGY INDICATORS

INPUTS

	OECD	EEC	NSF	OST	STATCAN
EXPENDITURES ON R&D (GERD)					
Total GERD	x	x	x	x	x
Civil/military GERD	x		x		
GERD by performing sector	x	x	x	x	x
GERD by funding source	x		x	x	x
Current domestic expenditures on R&D by type of activity	x				x
GERD by R&D category (basic research, applied research and development)			x		
GERD by type of expenditure	x				x
Performance of GERD by main scientific field	x				x
Performance of GERD by institution				x	x
Government budget appropriations or outlays for R&D (GBAORD)					
Total GBAORD	x	x	x		
Civil and military GBAORD	x	x			
GBAORD as % of current and capital expenditures of central governments		x			
GBAORD by budget function			x		
GBAORD by government agency and by research topic			x		
GBAORD by socio-economic objective	x	x	x		
GBAORD by government program		x	x		
GBAORD by government program and by type of activity		x			
GBAORD for basic research by budget function			x		
General university funds (GUF)	x				
Government R&D					
Federal expenditures on R&D and R&D programs, by agency and by R&D category			x		x
Federal expenditures on R&D by performer and by R&D category			x		x
Government expenditures by R&D category and by field of science			x		x
Federal expenditures on academic research			x		x
Budget impact of federal tax credits for research and experimentation			x		x
Academic R&D					
Performance of HERD by academic institution			x	x	
Performance of HERD by scientific field	x		x		x
Current expenditures on research equipment in academic institutions			x		
Government financing of academic research by field and by academic institution			x		
Cost of new construction for academic R&D by field			x		
Total square footage of new construction and renovations for HERD			x		
Industrial R&D					
BERD by funding source	x				x
BERD by type of costs	x				
Performance of BERD by industry	x				x
Performance of BERD by size of firm				x	x
Funding of BERD by object				x	
R&D intensity by industry (BERD/gross output)	x	x	x		x
R&D of other origins					
GERD funded by PNPs	x				x
GERD funded from abroad	x		x		x

GERD funded from abroad by industry and by country of origin			x		
GERD funded by national subsidiaries of foreign parent corporations			x		x
R&D-RELATED PERSONNEL					
Total R&D personnel	x	x	x	x	x
Total R&D personnel by employment sector	x	x			x
Total R&D by occupation	x			x	x
Total R&D personnel by major scientific field	x			x	x
Total R&D by level of qualification	x				x
Total R&D personnel in higher education	x	x		x	x
Total and R&D employment of subsidiaries abroad by country/region			x	x	
Total and R&D employment of subsidiaries abroad by industry			x	x	
Experts and volunteers		x			
Support staff	x				
Unemployment rate by occupation			x		
Doctoral scientists and engineers employed in R&D by S/E field and R&D category			x		
Number of researchers and engineers employed by field and type of employer		x	x		
Researchers in higher education (or university graduates)	x	x		x	
Academic position and active in S/E research: by field, racial/ethnic group and sex			x		
Academic position and active in S/E research: by number of years since doctorate obtained and by field (those active in research as proportion of total academic positions)			x		
Doctoral scientists and engineers in academic institutions and proportion of the total who do R&D by field and sex			x		
Type of activity on completion of thesis - distribution between humanities/social sciences and exact sciences				x	
Sector worked in on completion of thesis for doctoral degree holders reporting occupation				x	
Distribution of fields of study by sector worked in on completion of thesis, for exact sciences				x	
Doctoral scientists and engineers employed in academic faculties: by field and primary responsibility (teaching or research)			x		
Number of doctoral researchers funded by the federal government: by field of employment and number of federal funding agencies			x		
Full-time graduate students in S/E			x		
Government sector researchers (or university graduates)	x	x		x	
Business enterprise researchers (or university graduates)	x	x		x	
Business enterprise researchers (or university graduates) by industry	x			x	x
EDUCATION/TRAINING					
Higher education					
Number of students by academic level and by origin (in numbers enrolled)			x	x	
Graduates in all fields, broken down by sex		x			
Graduates in natural and applied sciences, broken down by sex		x			
Students holding Diplôme d'études approfondies - distribution between humanities/social sciences and exact sciences				x	
Students holding Diplôme d'études approfondies - distribution by scientific field in exact sciences				x	
Defence of thesis - distribution between humanities/social sciences and exact sciences				x	
Defence of thesis - distribution by scientific field in exact sciences				x	
Distribution of research grants by field for students preparing a thesis				x	

OUTPUTS

PRODUCTION

Scientific publications					
Scientific publications by field		x			
Scientific publications by performing sector					
Scientific publications by scientific specialization				x	
Specialization indices by field				x	
Patents					
Number of national patent applications	x	x	x	x	

Number of resident patent applications	x		x	x	
Number of non-resident patent applications	x		x	x	
Number of external patent applications	x	x	x	x	
Dependency ratio (number of non-resident patent applications/resident patent applications)	x				
Self-sufficiency ratio (number of resident patent applications/national patent applications	x			x	
Self-sufficiency ratio by sector				x	
Inventiveness coefficient (number of resident patent applications per 10,000 inhabitants)	x				
Diffusion rate (number of foreign patent applications/resident patent applications)	x				
Number of patent applications by industrial sector		x		x	
Number of patents: by type of inventor (individual, industry or government), by country of origin, by country of destination and by year of issue			x		
Number of patents: by class of technology, by sectoral activity index	x		x	x	
Number of patents: by citation rate, citation ratio			x		
Number of patents granted to academic institutions			x		
Number de patents granted to academic institutions and by technology class			x		
Share of patents held by domestic subsidiaries of foreign corporations				x	
Relative contribution to total by sector				x	
Comparative export advantages, technological and in R&D				x	
IMPACTS					
Scientific output and impact compared					
Impact of scientific and technical publications (citation rate)				x	
Impact indices by field				x	
Balance of payments					
Technological balance of payments (TBP): revenues, payments and balance	x	x			x
TBP: coverage rate	x				
TBP: total volume of transactions	x				
TBP according to nature of transfers	x				
Balance of payments on royalties and licences generated by trade in industrial processes abroad: by region (geographic zone) and by country			x		
Balance of payments on royalties and other rights of affiliated or non-affiliated foreign residents			x		
Rate of coverage in international trade by industry	x				
Diffusion					
Use of advanced technologies					x
Current and planned use of advanced technologies					x
Use of functional technologies					x
Type of current and projected main technologies					x
Number of technologies used, by type of industry					x
Rate of utilization of technologies, according to functional group and by industry					x
Utilization of functional technologies, according to size of firm					x
Utilization of advanced technologies, by size of firm					x
Utilization of advanced technologies by region					x
Growth in utilization of technologies					x
FLOWS					
Scientific co-operation					
International scientific co-operation		x			
Distribution of strategic alliances in technology between economic blocs by technology			x		
Distribution of partnerships established by regions with other countries in the framework of international research projects				x	
Regions' affinity for partnership with other countries				x	
Indicators of technology transfer (originating from government laboratories)					
Number of co-operation agreements entered into by government agencies			x		
Mobility of R&D personnel (potential and active)					
Foreign participation in the industrial sector			x	x	
Foreign participation in the manufacturing industry by origin				x	
Student mobility: distribution of scholarship recipients by country		x	x		

National research personnel abroad				x	
Resident and foreign students holding the Diplôme détudes approfondies, distribution by scientific field			x	x	
Defence of doctoral thesis by resident and foreign students, distribution between humanities/social sciences and exact sciences				x	
Geographic origin of foreign students enrolled in thesis programs, distribution between humanities/social sciences and exact sciences				x	
Flows of students from countries of the South				x	
Direct international investment (DII or DFI)					
Distribution of the stock of direct investment in foreign countries				x	
Comparative evolution of market production, international trade and direct international investment (DII) flows				x	
Manufacturing industry's share of DII stocks in major OECD countries				x	
Stocks of direct foreign investment (DFI) by industry				x	
Stocks of DFI in industry by country of origin				x	
Joint publications					
International joint publications by field, number and percentage			x		
Indus./Univ. joint publications as a proportion of articles published by industry: by field			x		
Indust./Univ. joint publications as a proportion of articles in the industrial sector			x		
Affinity for joint publication				x	
Affinity for joint publication by field					
Joint filing of patent applications					
Distribution of joint filings of patent applications				x	
Distribution of joint filings of patent applications by field				x	
Affinity for joint filing of patent applications				x	
Affinity for joint filing of patent applications by field				x	
Trade in goods embodying technology					
Flow of goods embodying technology				x	
Structure of trade in goods embodying technology				x	
High tech commercial flows c.o.f.		x			
High tech commercial flows f.o.b.		x			