BIBLIOMETRIC ANALYSIS OF SCIENTIFIC AND TECHNOLOGICAL RESEARCH: A USER'S GUIDE TO THE METHODOLOGY

by
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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 current report, Federal Scientific Activities (Catalogue 88-204), released early in 1997, begins to show what the S&T money is spent on with the new Socio-Economic Objectives indicators. 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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Working Papers

The Working Papers publish research related to science and technology issues. All papers are subject to internal review. The views expressed in the articles are those of the authors and do not necessarily reflect the views of Statistics Canada.

PREFACE

This paper, **Bibliometric Analysis of Scientific and Technological Research: A User's Guide to the Methodology**, by Élaine Gauthier, provides an overview current usage of bibliometric methods and techniques, including an extensive bibliography. It also provides technical specifications on the database of Canadian authors that has been developed, with Statistics Canada support, by the *Observatoire des Sciences et des Technologies.* This working paper is a companion document to two other working papers. The first, **Knowledge Flows in Canada as Measured by Bibliometrics,** uses the database to develop statistical indicators of knowledge flow in the natural sciences and engineering. The second, **The Use of Bibliometric Data to Measure Scientific Production in the Arts, Humanities and Social Sciences: A Methodological Note,** examines the issues involved in the use of bibliometrics for the social sciences, arts and humanities. Both of these working papers are authored by Benoît Godin, Yves Gingras and Louis Davignon of the *Observatoire des Sciences et des Technologies.*

The objective of the Information System for Science and Technology Project at Statistics Canada is to develop useful indicators of activity and a framework to tie them together into a coherent picture of science and technology in Canada. Bibliometric indicators of science and technology provide an important contribution to the understanding of the production of science and technology, as measured by the production of scientific publications, and of knowledge flows within the science and technology system, as measured by co-authorships in scientific publications. Bibliometric indicators can shed light on science and technology production and knowledge flow at the international, national, provincial, sub-regional, municipal and institutional levels and thus constitute a critical component of the information system on science and technology for Canada.

The bibliometric project, supported by Statistics Canada, created a Canadian database of bibliometric information. This involved the cleaning of the 1995 data from the selected indexes (*Science Citation Index, Social Sciences Citation Index,* and *Arts and Humanities Citation Index*) to ensure that all institutional addresses were standardized and assigning a sector code (university, government, business, etc.) to each institution. The three working papers are part of the project. In order to facilitate the use of bibliometric information for policy and decision-making a series of regional workshops is being held to introduce the database and to discuss uses of it.

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ACKNOWLEDGEMENTS

I wish to extend special thanks to Yves Gingras and Benoît Godin, of the *Centre interuniversitaire de recherche sur la science et la technologie* (CIRST), for their comments on the drafts of this document. I also wish to thank Pierre Di Campo, documentalist, for his help in gathering materials, and François Vallières, INRS research professional, who provided essential information concerning the database of the *Observatoire des Sciences et des Technologies*.

INTRODUCTION

With the financial assistance of Statistics Canada, the *Observatoire des Sciences et des Technologies* has set up a database used to generate bibliometric indicators. This database of Canadian authors has been specifically designed to meet the needs of public policy makers and program administrators.

This guide to the methodology is, above all, a complement to *Knowledge flows in Canada as measured by bibliometrics*[1]. It shows how bibliometric studies can help understand the Canadian innovation system. Particular emphasis has been placed on the flow of knowledge in Canada, and more specifically on exchanges between countries, provinces and institutional sectors.

For slightly more than 30 years now, Western countries, notably through the OECD, have had access to indicators that help them monitor changes in national scientific and technological systems. It was back in 1963 that OECD published for the first time the *Frascati Manual*, proposing a "sample method for surveys of experimental research and development".[2] The Manual provided a standard for government measures aimed at gathering information on investments in research and development. The *Frascati Manual* has undergone several revisions and improvements since 1963.

The *Frascati Manual* is based on the well-known theoretical "input-output" model. Investments (input) are applied to various scientific and technical activities that lead—potentially—to both knowledge and applications (output). Until recently, most of the efforts (reflections, studies and indicators) of OECD and Western countries were focused on input. This situation can be explained on historical grounds. In fact, input indicators are linked directly to the emerging scientific and technological policies of the 1960s and 1970s. The chief goal at that time was to take part in research and development funding. Input indicators helped determine where funds were invested and where there was less research. It was hoped that this would provide governments with tools indicating the best possible use of public funds.[3]

In view of the complexities of science and technology, many of the indicators of the past have become less inadequate as a measurement of reality. Furthermore, during the 1980s, governments became more and more interested in innovation and the impact of research. This is in fact the focus of recent federal strategies for science and technology in Canada.[4] In this context, OECD designed the *Oslo Manual,*[5] which deals with aspects of research and development directly linked to innovation, i.e., the creation of new products and processes. OECD also took up a new challenge in 1992 with the *TEP Program (Technology, Economy,*

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[1] Benoît Godin, Yves Gingras and Louis Davignon, *Knowledge flows in Canada as measured by bibliometrics*, Working paper, Science and Technology Redesign Project, Statistics Canada, 1998.

[2] OECD, *Proposed standard practice for surveys of research and experimental development (Frascati Manual),* Paris, 1994.

[3] Leclerc, Michel et Gingras, Y., "Les indicateurs du financement privé de la R&D universitaire au Québec: critique de la méthode", *Revue canadienne de l'enseignement supérieur*, vol. 23, n° 1, 1993, pp. 74-107.

[4] Government of Canada, *Science and technology for the new century: A federal strategy*, Ottawa, 1996.

[5] OECD and Eurostat, *Proposed guidelines for collecting and interpreting technological innovation data (Oslo manual),* Paris, 1997.

Productivity),[6] aimed at operationalizing the concept of national innovation system (NIS). A national innovation system is defined as a set of interrelated actors whose activities are oriented towards the development of new products, processes and services.[7] Nowadays, governments are turning their attention to the dynamics of national innovation systems, notably the flow and transfer patterns between various actors.

Indicators linked specifically to this new aspect of science and technology, i.e. flow patterns, are practically non-existent. The challenge associated with this new concept is to operationalize the notion of national innovation system. Bibliometrics is a tool that can be used for this purpose. But before we deal with flow measurement, it might be useful to briefly describe the principal functions of bibliometric analysis applied to scientific and technological research.

One of the primary goals of scientometrics and bibliometrics applied to public policy is to serve as an information tool for decision making. It is within such a context that the present document was written. The objective is to provide public policy makers with a guide to the use of bibliometric tools currently available. There are many applications of bibliometrics, including the development and evaluation of science and technology programs and policies, the management of private and public research, or technological monitoring and strategic decision making. The following then is a methodological guide to bibliometrics applied to public policy.

This guide deals with bibliometric indicators and methods within specific applications. The author begins with a brief outline of descriptive and relational indicators. This typology is based on a 1997 OECD document.[8] The principal indicators are then described within the broader context of their utilisation. The emphasis is on the three main functions of scientometrics and bibliometrics, i.e. description, evaluation, and monitoring of science and technology. Examples of applications are provided for each topic.

The author provides an annotated bibliography of the various applications of bibliometrics. The bibliography includes reference works on scientometrics and bibliometrics, as well as empirical bibliometric studies. References are listed according to the broad subdivisions of the guide itself, providing readers with concrete information about the applications of bibliometrics. The author has emphasised various national experiences, including several Canadian studies.

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[6] OECD, *Technology and the economy: The key relationships*, Paris, OCDE, 1992.

[7] Niosi, J., P. Saviotti, B. Bellon and M. Crow (1993), National systems of innovation: In search of a workable concept, *Technology and Society*, 15: 207-227; Lundvall, B.A. (1992), *National systems of innovation: Towards a theory of innovation and interactive learning*, Pinter:London; Nelson, R.R. (ed.) (1993), *National innovation systems: A comparative analysis*, New York, Oxford University Press.

[8] Yoshiko Okubo, *Bibliometric Indicators and Analysis of Research Systems: Methods and Examples*, Paris, Organisation for Economic Cooperation and Development, (STI Working Papers 1997/1), 1997.

A — BIBLIOMETRICS APPLIED TO PUBLIC POLICY: METHODS AND EXAMPLES

Scientometrics can be defined as the measurement of scientific and technical research activity. Bibliometrics is a branch of scientometrics that focuses principally on the quantitative study of scientific publications for statistical purposes. Bibliometric methods serve three main functions, i.e. description, evaluation, and scientific and technological monitoring.[9] As a descriptive tool, bibliometrics provides an account of publishing activities at the level of countries, provinces, cities or institutions, and is used for comparative analyses of productivity. The data can then be used to assess the performance of research units, as a complement to standard evaluation procedures. Bibliometric data are also used as a benchmark for the monitoring of science and technology, since longitudinal studies of scientific output help identify areas of research that are developing or regressing.

Table 1 — Grid used for the conceptual analysis of bibliometric studies

level	year	sector	discipline
micro			
meso			
macro			

Table 1 provides a schematic outline of the three levels of analysis of variables, which can be applied to the database of the *Observatoire des Sciences et des Technologies*. Thus, the production of a single researcher can be measured within the framework of an evaluation. This level is mostly used in conjunction with other evaluation methods, since bibliometric tools are not considered a valid method of measuring the productivity of individual researchers. The other two levels (meso and macro) are by far the most often used. At the meso level, bibliometric indicators describe the scientific production of institutions and research groups. They can also be linked to grant programs for program evaluation purposes. At the macro level, bibliometric indicators are used to measure national output by country, province or city. National output is analysed as a means of comparing research systems and determining the links between the various institutions of a given national system.

1 — Bibliometric indicators

In order to make rational decisions, public policy makers need to have a firm understanding of scientific and technological activities. Bibliometric indicators provide the only overall picture of the scientific

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[9] Xavier Polanco, *Infométrie et ingénierie de la connaissance*, in J.-M. NOYER (Ed.), *Les sciences de l'information bibliométrie scientométrie infométrie*, Rennes, Presses universitaires de Rennes, 1995.

output of a country. In a research paper dealing with science and technology indicators, Godin described the present status of bibliometrics:

> *There may have been a time when the fact that bibliometric indicators were standardised limited their usefulness, but this is no longer the case. Furthermore, they are not expensive to produce. They do have their limits, notably because they normally include only the natural sciences, engineering, and the biomedical sciences. There is also an obvious linguistic bias that largely limits the coverage of scientific output to publications in English. Finally, it must be remembered that publishing represents only one of the activities of researchers. In spite of such limits, bibliometric indicators are one of the principal tools for measuring research output, while providing a very good tool — contrary to popular belief — for research conducted by other types of actors. For this reason, they deserve a place in scientific and technological directories.*[10]

1.1 — Descriptive indicators

Bibliometric indicators can be subdivided into two major categories: descriptive indicators and relational indicators having an analytical function. Listings of papers and citations, listings of patents and the citations they contain are examples of the most current descriptive indicators. They measure the volume and impact of research at various levels. When they are used over prolonged periods of time, they provide a means of identifying trends. Enumeration methods are based on calculations of the number of scientific publications that can be attributed to one actor in a given area. This may be an author, an institution, a sector of activity covering several institutions (universities, public laboratories, industries) or even a geographic area (city, province, country). A research area can be aggregated at the level of one scientific discipline or of one sub-discipline, one technology or even one specific technological niche.[11] Descriptive indicators can be applied to publications and patents depending on whether the analysis deals with scientific output or with technological output.

1.2 — Relational indicators

Co-author analysis is the most frequent relational indicator. It helps identify links and interactions between the actors of national and international systems of science and technology. Such interactions constitute the flow of knowledge. The methods known as co-word analysis and co-citation analysis are also relational indicators.[12] They provide a picture of scientific activity based on the content of publications. Such indicators help monitor changes in science and technology and identify emerging research topics and the relevant contributors. Co-citation analysis and co-word analysis are rarely used

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[10] B. Godin, *The state of science and technology indicators in the OECD countries,* Research paper, Science and Technology Redesign Project, Statistics Canada, 1996, 18.

[11] B. Godin, *The state of science and technology indicators in the OECD countries,* Research paper, Science and Technology Redesign Project, Statistics Canada, 1996, 17.

[12] The *Observatoire des Sciences et des Technologies* database of Canadian authors as it now stands does not allow for the use of such indicators because of the lack of data on references and key words.

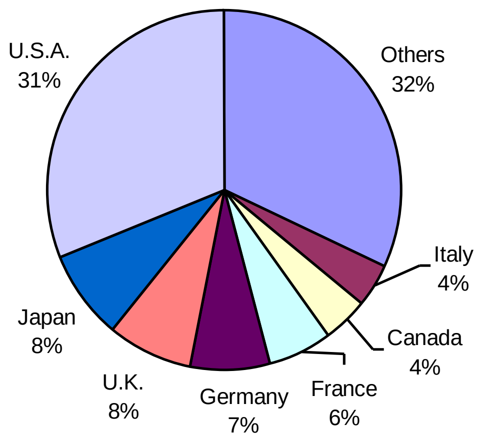
for policy purposes, unlike descriptive indicators and co-author analysis which are currently used in the description and evaluation of research.

2 — Analysis of scientific output

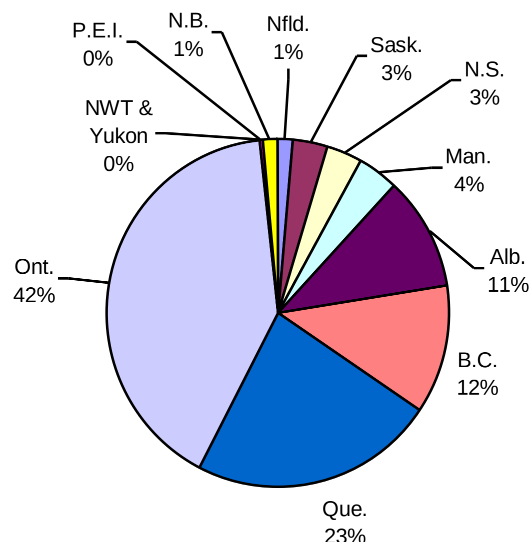
A listing of a country's scientific publications is an indicator that can be used for the detailed analysis of scientific output. Depending on the objectives of a given study, this indicator is used to measure the relative weight of a country, the output of researchers, or the dynamics of a scientific field or an institutional sector. The output of one country can then be compared to that of other countries in a competitive or comparable situation. Comparisons between countries can also be based on disciplines. Example 1 shows three different aspects of the Canadian scientific output.

Example 1 --- Three aspects of Canadian scientific output, 1995

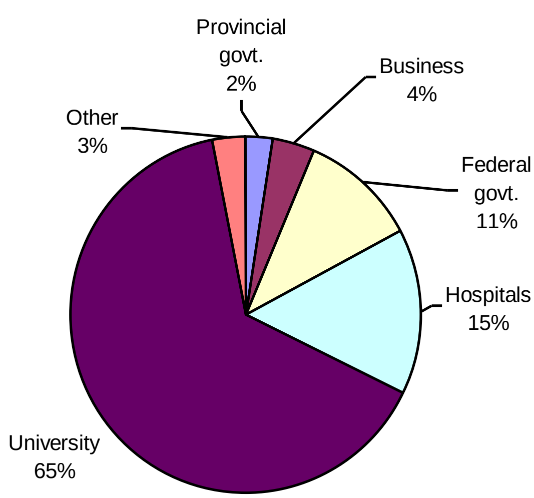
Canadian share of world publications, 1995



Provincial share of publications, 1995



Share of publications by sector, 1995



Source: Observatoire des sciences et des technologies (CIRST), March 1998.

In an effort to measure aspects of national output, a number of countries publish statistics on scientific publications by discipline. A specialisation index has been developed to identify, for a given country, those disciplines that are over-represented or under-represented in terms of world averages for each sector. This index is the ratio of the percentage of a country's publications in a given discipline to the percentage of publications in that discipline at the world level. If the result is greater than 1.0, the index shows that the country in question produces more than its share of the publications in that discipline compared to the rest of the world. The same type of calculations can be applied to provinces, cities or sectors. Example 2 shows the specialisation indices for Canada in the natural sciences, engineering, and the biomedical sciences.

3 — Flow analysis

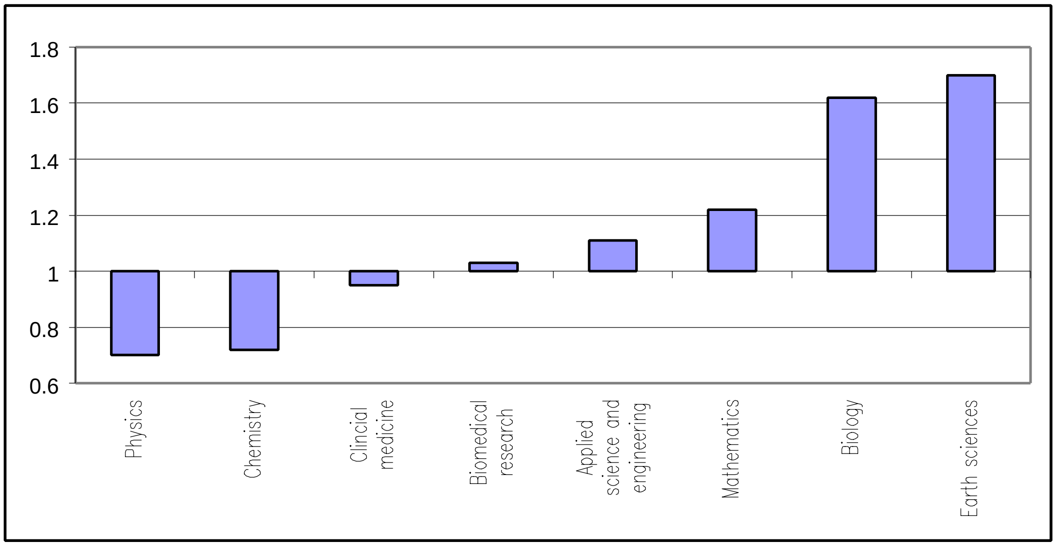
Flow indicators emphasise the relationships between researchers, institutions and research fields. As a result, they are sometimes called relational indicators. Science and technology are the result of exchanges of knowledge and collaborative work among researchers. It is therefore necessary to establish indicators to identify these exchange networks. Flow analysis is an attempt to describe existing relationships among the various actors of a given system. Flow measurements can focus on the relationships between individuals, institutions, targeted sectors of activity, e.g. university-industry relationships, linkages between science and technology, or even collaborative efforts between provinces and countries. Flow analysis provides an important measure of the integration of researchers and of the scope of a national network of collaboration; both types of information help identify the effectiveness of public intervention and its impact.

The database of the *Observatoire des Sciences et des Technologies* was designed specifically to determine the flow patterns in the national innovation system. By breaking down the information contained in the addresses, it is easy to gather the data needed for flow analysis. The database provides information about the flow of international knowledge, the flow of knowledge within and between provinces, as well as the flow of knowledge between institutional sectors.

Co-authorship is the preferred indicator used to describe collaboration and co-operation in all areas of research. Such collaborative efforts, or flow, lead to publications within the formal network of scientific journals. These publications are the raw materials for the database.

Co-author analysis is based on the principle that, when two or more researchers jointly sign a paper, intellectual and/or social links can be assumed to exist between them. Such links are measured by co-author analysis. An institutional or geographic analysis using co-authorships shows the exchanges that occur between various countries or various segments of a national innovation system. Flow analysis makes use of any and all information present in the addresses of authors. Linking such information to the discipline associated with the corresponding journal provides a detailed picture of the many aspects of scientific exchanges. Co-author analysis thus helps identify the principal partners of research activities while providing a detailed picture of the formal network of collaboration within which exchanges take place.

Example 2 --- Specialization indices for Canada, 1995



Source: Observatoire des sciences et des technologies (CIRST), March 1998.

3.1 — International flow patterns

Exchanges between countries are undoubtedly the most best-known form of knowledge flow. To obtain a profile of a country's scientific collaboration with other countries for a given year, the first step is to list all the publications in which the country in question is mentioned in the "address" field. The next step is to compile all the co-authorships with other countries displayed in the "address" field. The countries are identified on the basis of the institutional affiliation of the authors. The indicator itself may be relatively simple, but listing the share of each country taking part in a publication remains a delicate operation.

There are in fact several ways of counting publications having more than one country in the "address" field. The publication can be broken down into as many parts as there are countries involved. For example, each country taking part in a publication might be counted for 1/3 if the "address" field contains three different countries. This is the so-called breakdown method.

A second method consists in assigning the origin of a publication to the country of the first author. This so-called first-author method does not take into account the contribution of the other authors. It is based on the erroneous hypothesis that the first author is the most important one. Moreover, the link between the first author and the first address cannot be identified with certainty.

A third method consists in assigning the publication to each of the contributing countries. Thus, an article by co-authors from different countries will be counted for each of those countries. This means that the total number of publications will exceed the actual number of publications. This method does not take into account the relative contribution of the authors. It emphasises the participation of each country to the production of knowledge.

Example 3 — International scientific co-operation: the example of Canada

A study was carried out to determine Canada's profile in terms of international scientific collaboration. The study showed that "Canada is ranked last among the eight leading OECD countries in terms of the number of international patents, the number of scientists and engineers in relation to the labour force, the number of high technology industries having a positive trade balance, and the amount of research and development financed by industry. Between 1981 and 1986, Canada was ranked seventh among major countries producing scientific publications with 4.3% of all publications surveyed by the Institute for Scientific Information in Philadelphia (ISI). While the contribution of the United States in this respect (representing 33.4% of the world's scientific output in 1990) might appear as an anomaly, the United Kingdom continues to produce 7.4% of scientific information in spite of its declining influence during the last decade, outperforming the Soviet Union, Japan, the Federal Republic of Germany and France. Canada comes next, which in view of its low investment — equal to $10 billion according to 1992 forecasts — is not so bad. What is the explanation for this contradiction between human and financial investments and the apparently good results? While an analysis of the authorship of Canadian articles may not provide an explanation, it does give us a clue. With almost 6% of internationally co-authored articles, Canada is ranked fifth among countries in terms of international co-operation, ahead of Japan but behind Sweden, Italy, France and Germany. Canada invests little, produces a lot in relative terms, and co-operates enormously!"

Canada's international scientific co-operation with its 10 first partners, by discipline and percentage, 1990

	Biology	Biomedicine	Engineering and technology	Clinical medicine	Earth and space	Math.	Chemistry	Physics
U.S.A.	45.8	50.8	38.6	49.6	39.2	39.9	29.7	32.5
U.K.	7.8	8.1	5.5	6.7	13	5.8	9	6.7
France	3.1	9.1	5	7	7.7	5.8	9.4	9.7
Germany	3.8	5	2.7	2.2	5.3	4.9	7.7	9
Netherlands	3.7	3	2.1	4.5	4.5	2.5	4.9	4.5
Japan	2.3	2.7	5.5	3.1	2.5	3.7	4.9	6
Italy	0.8	1.4	1.7	3.1	1.8	3.3	3.3	4
Australia	3.7	1.4	3.6	2	4	2.9	2.3	1.7
Switzerland	1.4	1.4	1.9	2.3	0.9	2.5	2.1	4.1
Sweden	1.7	1.8	1.7	2.5	1.4	0	1	1.7

Source: Leclerc, M., "La coopération scientifique internationale, l'exemple du Canada", *La recherche*, Vol. 24, No. 252, March 1993, 350-357

Each method has its advantages and disadvantages.[13] The method, which assigns a publication to each of the participating countries, is the method most often used to measure national performance. It is the

[13] Much has been written on the subject of counting publications, and the study of national performance. Cf. Schubert, A., W. Glanzel, and T. Braun, "Scientometrics data-files: A comprehensive set of indicators on 2,649 journals and 96 countries in all major fields and subfields, 1981-1985". *Scientometrics*, Vol. 16, No. 1-6, 1989, p.7; J. Anderson, *et al.*, "On-Line Approaches to Measuring National Scientific Output: A Cautionary Tale", *Science and public policy*, Vol. 15, No. 3, 1988, 53-161; L. Leydesdorff, "Problems with the 'measurement' of national research performance", *Science and public policy*, Vol. 15, No. 3, June 1988, 149-152; D. Lindsey, "Production and citation measures in the sociology of science: The problem of multiple authorship", *Social studies of science*, Vol. 10, 1980, pp. 145-162.

method that was used for the database of the *Observatoire des Sciences et des Technologies.* However, to avoid producing percentages of each country's contribution that exceed 100%, the denominator used in the calculations is the sum of publications attributed to each country.

3.2 — National flow patterns

The flow of knowledge occurs not only between countries, but also within countries. In fact, co-author analysis can help to determine links between provinces, cities and institutional sectors. Just as scientific collaboration can be studied internationally, networks of co-operation can be identified between provinces or even between actors within the same province. This type of indicator is established by determining the province in each Canadian address. By compiling the percentage of articles in a given province, written in collaboration with authors from the same province or from another province, it is possible to show, in a given year, the flow pattern within a province, or between actors of different provinces, i.e. inter-provincial flow patterns.

Example 4 — Regional collaboration: the example of the Montreal area

In a bibliometric study of regional scientific collaboration, Godin and Ippersiel prepared a profile of the flow of knowledge between researchers in the Montreal are and the rest of Quebec. They analysed 23,953 articles containing at least one address in the Province of Quebec. The findings indicated that all regions have a tendency to collaborate more at the international level than with Montreal or Quebec City. The collaboration between regions is as follows.

	Articles (A)	Co-authorships between regions (B)	Montreal co-authorships (C)	C/A
Montreal	16,159	924 (5.6%)		
Montreal outskirts	1,318	436 (32.2%)	292 (67.0%)	22.2%
Corridor	1,934	451 (22.7%)	266 (59.0%)	13.4%
Quebec City	3,959	631 (15.5%)	340 (53.9%)	8.46%
Regional outskirts	583	215 (34.7%)	96 (44.7%)	16.47%

Source: B. Godin and M.-P. Ippersiel, "Scientific collaboration at the regional level: The case of a small country", *Scientometrics*, Vol. 36, No. 1, 1996, 63.

The same method can be used to evaluate the flow pattern between institutional sectors. Co-author analysis applied to sectors is based on identifying the sector for each of the institutions contained in the "address" field.[14] The next step consists in counting, for a given sector, all the co-authorships linked to each of the other sectors.[15]

Example 5 — Collaboration within and between sectors in Quebec publications, 1980-1990

Sectors	University	Hospital	Industry	Government
University	8407	1771	179	612
Hospital	-	2374	37	72
Industry	-	-	444	41
Government	-	-	-	982

Godin analysed the publications of Quebec authors between 1980 and 1990 in order to verify the following hypothesis: the proportion of publications from universities is decreasing whereas the share of other sectors is on the increase. A sector of activity was assigned to each publication on the basis of the address. Publications by authors in other countries or in the rest of Canada, as well as publications for which no sector of activity could be identified were assigned to the category "others". Collaboration within a sector corresponds to the co-authorship of a publication by authors in the same sector. Collaboration between sectors corresponds to publications whose authors are from different sectors.

The author concluded that the university sector remains the most prolific with 60% of all publications in 1990 and the share of publications in other sectors is rapidly increasing, at the expense of the university sector. Nevertheless, universities remain the most frequent partners in collaborative efforts between sectors in terms of co-authorships.

Source: B. Godin, "Besides Academic Publications: Which Sectors Compete, or Are There Competitors?", *Scientometrics*, Vol. 33, No. 1, 1995.

4 — Research evaluation

Evaluation, strategic management and futures analysis have become frequent activities within the framework of scientific and technological policy. In this respect, bibliometric methods are aimed principally at the decision-making process. They provide quantitative data to supplement the qualitative evaluation process.

Although, bibliometric indicators were developed in the post-war period, public policy makers have become interested in such indicators fairly recently. As public policy makers came to see science as a

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14 Sectors of activity include different types of institutions. The types of institutions and the ways in which they are classified are explained in detail in the glossary of Appendix II.

15 A detailed list of sectors with specifications is found in Appendix I of this guide.

cultural asset, then as a public asset, and then as an economic asset,[16] the need to measure the results of science became more and more pressing. As a result, the use of bibliometric methods of evaluation became more widespread as an information tool for public policy makers.

Evaluation procedures can be applied to all three levels of analysis identified above, i.e. at the micro level (researchers), the meso level (research programs) and the macro level (provincial and national research systems). Callon *et al.* described three major categories of issues associated with research evaluation.[17] The first category is related to evaluations of the volume of scientific output. The second category deals with the relevance of research in terms of its impact on the development of knowledge or on society and the economy. Evaluations of relevance are aimed at assessing the choice of research topics and of grantees as well as their ripple effects on the dynamics of research. The third category deals with the efficiency of research management. Bibliometric evaluation procedures are directly linked to the first two categories. Whereas output indicators are used to evaluate scientific output, indicators linked to co-author analysis and citation analysis are used to evaluate relevance. Using bibliometrics in evaluating the efficiency of research management requires that research topics be identified specifically so as to "detect possible synergies or pinpoint unwanted duplication."[18] Bibliometric techniques can be used to set up lists of actors and research topics, providing administrators with an overview of the available resources, and allowing for their use in restructuring an organisation on the basis of the structure of research.

4.1 — Impact measurements

One of the problems raised by bibliometric evaluation is how to define and measure the quality of the output. Two major issues have governed the bibliometric procedures used for the evaluation of scientific research, i.e. the notion of quality and that of the impact of research.

In the beginning, bibliometric evaluations attempted to measure the quality of research on the basis of citations. It was felt that the number of citations was an indication of research quality. The more often a document was cited, the higher its quality. The citation indicator was soon criticised. In addition to its partial character, critics had serious doubts about its true meaning. Many researchers raised questions about the reasons why authors chose the publications they quoted. This line of reasoning raised serious doubts about the use of citations as an indicator of quality. Nevertheless, the citation indicator was never totally invalidated.

In an article on bibliometric techniques used to evaluate research programs, Francis Narin, President of Computer Horizons Inc., explained the basic principles of citation analysis applied to research evaluations:

(1) publications, especially scientific articles, are a legitimate indicator of research productivity; and

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[16] John de la Mothe, "The political nature of science and indicators", *Science and Public Policy*, Vol. 19, No. 6, December 1992, 403.

[17] M. Callon, J.-P. Courtial, H. Penan, *La scientométrie.*, Paris, Presses universitaires de France, (Que sais-je? 2727), 1993, 103.

[18] *Ibid.* 110.

(2) references to articles (the number of times reference is made to an article in another article published subsequently) are a legitimate indicator of the quality or impact of the article cited.[19]

Narin maintained that a comparison between traditional evaluation methods and bibliometric methods showed convergent results. There would seem to be a correlation between article citation rates and the formal evaluation of articles by peers; between researcher publication or citation rates and independent measurements of prestige, such as scientific awards; and between the publications of departments and the ranking of these departments by peers.[20]

Nowadays, there is greater focus, in bibliometrics, on measuring the impact of research on the scientific community. The concept of impact is related mostly to the dissemination of knowledge and less to the quality of research. The number of references to an article is interpreted as a sign of influence, or visibility, in the scientific community. There is wide consensus about this new interpretation.[21]

The impact factor is an index used to measure the probable impact of research findings published in a scientific journal. This index is related above all to journals. The *Journal Citation Reports*, published each year by ISI, define the impact factor of a journal as the ratio between the citations and the published articles. The impact factor of a journal, for a given year, is the total number of citations obtained for that year by articles published in the journal during the two previous years, divided by the total number of articles published by the journal during the same two years.[22] The higher the prestige of a journal, the higher the impact factor and the greater the probability that an article published in the journal will be cited. As a result, the impact factor is an indicator of the overall visibility of a journal and of its impact on the scientific community. As applied to articles, the impact factor indicates the number of times an article in a scientific journal will probably be cited, on the average, during a given period of time.

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[19] F. Narin, "Bibliometric techniques in the evaluation of research programs", *Science and public policy*, Vol. 14, No. 2, April 1987, pp. 99.

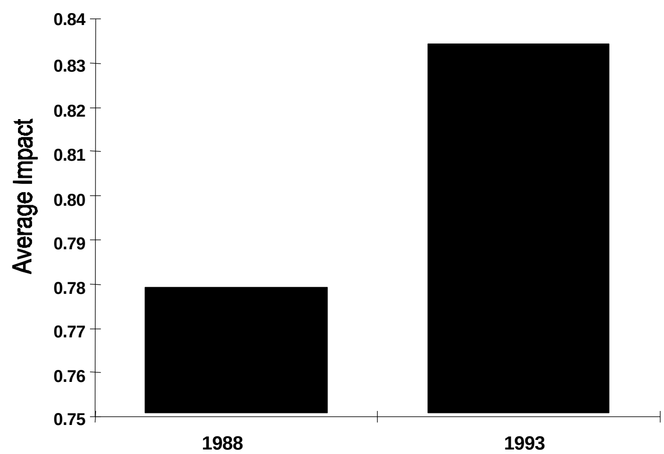
[20] Francis Narin, "Evaluative bibliometrics: The use of publication and citation analysis in the evaluation of scientific activity", Contract NSF C-627, National Science Foundation, March 31, 1976, Monograph: 456, NTIS Accession #PB252339/AS, cited in: F. Narin, "Bibliometric techniques in the evaluation of research programs", *Science and Public Policy*, Vol. 14, No. 2, April 1987, note 3.

[21] Cf. L. Leydesdorff, "The relation between qualitative theory and scientometric methods in science and technology studies", *Scientometrics*, Vol. 15, No. 5-6, 1989, pp. 333-347.

[22] The impact factor was developed by ISI, which still ensures its dissemination through an annual bibliometric publication called *Journal Citation Reports*. There are many ways of calculating the impact factor. This is the ISI definition. For a description of other ways of calculating the impact factor, see E. Garfield, "Citation analysis as a tool in journal evaluation, *Science*, 178:471-79, 1972. A discussion of impact factors will be found in P.O. Seglen, "How representative is the journal impact factor?", *Research evaluation*, Vol. 2, December 1992, pp. 143-149. The problem of standardisation is dealt with in Y. Gingras, "Performance indicators: Keeping the black box open", *Proceedings of the Second International Conference on the Impact of R&D*, Ottawa, 1995.

Example 6 — Average impact of Canadian publications

In a feasibility study carried out for the Natural Sciences and Engineering Research Council, Gingras used impact measurements to compare the average impact of Canadian publications, in the fields of evolution and ecology, to the average impact of international publications in the same fields. The impact measurement was standardised previously. An average impact value of 1.0 means that the Canadian output is equivalent to the international output. A value of less than 1.0 means that the average impact of the Canadian output is lower, or less visible, than that of the world average.



Source: Yves Gingras, *Bibliometric analysis of funded research: A feasibility study*, Report to the Program Evaluation Committee of NSERC, April 1996.

In terms of evaluation, the advantage of the impact factor is that, unlike the number of times an article is actually cited, it is made available each year through the *Journal Citation Reports.* Citation analysis on the other hand requires an interval of about four years between publication of an article and the citation count. If evaluation procedures are to be truly effective, they must be carried out as soon as programs have ended. As an evaluation tool, the impact factor helps solve a number of problems. There is no need to wait a long time for the data; it costs less than a citation count; and finally, sources of error are minimised. Furthermore, for a given discipline, there is an excellent correlation between impact factors and the relative significance of journals as evaluated by researchers.[23] Since there is a specific impact factor for each discipline, and even each speciality, comparative studies are only carried out within the relevant disciplines and specialities.

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23 P.R. McAllister, R. Anderson and F. Narin, "Comparaison of Peer and Citation Assessment of the Influence of Scientific Journals", *Journal of the American Society for Information Science*, Vol. 31, 1980, pp. 147-152. J.T. Wallimack and K.D. Sedig, "Quality of Research Measured by Citation Method and by Peer Review: A Comparaison", *IEEE Transactions on Engineering Management*, Vol. 1, Em-33, November 1986.

Example 7 — Program evaluation: the National Institutes of Health

The grant programs of the American institutes linked to the National Institutes of Health (NIH) have been evaluated using the bibliometric method since 1973. Computer Horizons Incorporated (CHI) have worked under contract with NIH to develop a bibliometric database to evaluate the impact of NIH in terms of publications and citations. The evaluation report, entitled *An Analysis of Research Publications Supported by NIH, 1973-80,* makes the following observations:

- the correlation between research expenditures and the subsequent publication volume;
- the increase in the volume of publications supported by NIH with respect to the total increase of publications in the bibliometric database;
- increases in NIH financial support for basic research as compared to that for clinical research;
- publications supported by NIH in comparison with total publications broken down by specific field;
- the percentage of publications supported by NIH appearing within the upper decile* of articles cited in each field;
- the interaction among researchers according to the field and the source of funding.

The output indicators used in the evaluation procedure are the following:

- publications standardised on the basis of journal impact;
- publications standardised on the basis of author status;
- citations;
- output/input ratio;
- number of citations divided by the number of publications;
- performance of the upper decile.**

* 10% of the most cited articles.

** Percentage of articles published in a given field, by researchers in a given institution, as compared to the percentage of articles appearing in the upper decile in terms of citations.

Source: Henry Small, *An analysis of research publications supported by NIH, 1973-80*, cited in H. Small and E. Smith Aversa, *An Agreement Between The Medical Research Council of Canada and The Institute for Scientific Information*, Philadelphia, Institute for Scientific Information, July 1991.

4.2 — Program evaluation

When scientific and technological activities came to be seen as public assets having an important role to play in the national economy, there was a growing need to evaluate research programs because of their strategic significance. Nowadays, the evaluation criteria are legitimacy and relevance. Traditional program evaluation methods, such as peer assessment or client assessment for public laboratories for example, are not always well suited to the new objectives. The new evaluation criteria must be more objective and rigorous. Moreover, public policy makers need a general overview which a cost-benefit analysis, for example, cannot provide. Institutionalisation of the evaluation process has thus created a need for new evaluation tools and for more suitable databases. This has opened the way to bibliometric methods.

Example 8 — Convergent indicators in universities

Ben Martin and John Irvine have created a model for the evaluation of scientific research that is based on input and output. The method is used to establish a relationship between input and output so that research units can be compared to one other. This evaluation model, based on four elements, uses the method of convergent indicators. Anderson has provided the following summary:

1. Identify and evaluate the input (researchers, financial and technical resources) and the output (contribution to science, technology and education). Establish a relationship between the input and the output.

2. Use the institutional approach. Analysis is based on research units and not on individuals.

3. Use the comparative method and apply it to analytical units that are similar.

4. Combine various indicators which each reflect a different aspect of research performance. Each indicator is partial and imperfect, and reflects part of the relative importance of scientific contributions, and part of the relevant social, institutional, psychological and other factors.

The principal indicators used are: article output, citation analysis, and peer evaluation, along with the number of researchers, and research grants.

Source: F. Anderson, *New approaches to research policy using bibliometrics*, Quebec, Conseil de la science et de la technologie, February 1987; Ben Martin and John Irvine, "Assessing basic research: Some partial indicators of scientific progress in radio astronomy", *Research Policy*, 12, 1983, 61-90.

4.3 — Evaluation of academic research

Traditionally, the evaluation procedure in universities has been based on peer review. However, bibliometric data are a good complement to traditional methods, especially when the evaluation deals with research groups, administrative units such as departments and faculties, or even the institution as a whole. The bibliometric evaluation of individuals, however, remains problematic and controversial because of the methodological limits of bibliometrics.[24] In fact, bibliometric statistics are reliable only for sufficiently aggregated data. That is why bibliometric tools are more robust when they are applied

[24] According to Garfield, citation analysis as an indicator of individual performance is inadequate. The evaluation must take into account publication practices and citation conventions, including self-citation, as they occur in the researcher's environment, as well as his or her age and the prestige of the journals. Eugene Garfield, "How to use citation analysis in faculty evaluations and when is it relevant?", *Essay of an information scientist*, Vol. 6, 354-372. Nowadays, citations are no longer used as an indicator of quality, but rather as an indicator of research impact.

to administrative units (meso level) instead of individuals (micro level). The quality of an evaluation therefore depends on the unit being evaluated.

When an evaluation is carried out on the output of a university as a whole, the objectives and multiple tasks of the institution must be kept in mind. Research cannot be evaluated in the same way as teaching, or the humanities in the same way as hard science. As a university or department becomes more oriented towards teaching and applied research, there is less likelihood that the volume of its publications will be significant. It is therefore important to keep in mind the particular mission of the university before making comparisons between institutions. The same constraints apply to the various administrative units within the institution, as well as to various scientific disciplines. In an effort to adapt to the realities of multi-functional academic institutions, bibliometric research uses convergent indicators to throw light on the multiple activities of administrative units. The principal objective of convergent indicators is to overcome the limits of bibliometric indicators taken individually so as to create a set of partial indicators that are representative of all activities. When several different indicators converge towards the same conclusion, that conclusion is more valid.

5 — Bibliometric monitoring of research

Bibliometric monitoring makes it possible to establish a quantitative profile of the state of research and therefore of national performance. Public policy makers need to be constantly informed about overall research activities at the national level, and about a country's relative position on the world scene, for a given research activity. Descriptive indicators provide such a monitoring at various levels of data aggregation. Bibliometric monitoring is usually carried out at a fairly high level of aggregation such as national scientific output by discipline or by institutional sector. However, bibliometric monitoring can also be used for administrative monitoring, in which case it deals mostly with the activities of universities and research centres.

5.1 — Administrative bibliometric monitoring

The problems which administrators of research institutions have to overcome are different from those of public policy makers. Administrators need to access detailed information about the research activities for which they are responsible. Bibliometric monitoring helps them understand and evaluate research activities taking place within research units. Administrators use bibliometrics for guidance about the future of research, on the basis of existing research in a given field.

Strategic positioning is one of the major applications of bibliometric indicators. This is done by identifying, through the use of databases, the people who are active in a field, the topics on which they are working, and the networks within which they operate. This information is used to identify emerging niches, those that have reached maturity as well as those in decline, along with the actors and partners who are responsible for research output. Research managers use data on the relationships between researchers and the links between research topics to understand their position within the network and to evaluate it in terms of what is going on in a given field of research.

Example 9 — State of nanotechnological research in Canada

In 1996, the National Research Council of Canada commissioned a bibliometric study on the state of international nanotechnological research. The goal was to provide information on the development of research and technology within the framework of its nanotechnology program. Two aspects of research were targeted: a description of the major orientations characterising pure and applied research, and an analysis of industrial research activities in nanotechnology and any links with pure and applied research.

Bibliometric data were gathered from three sources: the INSPEC database which covers among other things physics and electrical engineering, the chemical section of the SCI database, along with *US Patent Search Claims & Abstracts*. The study was carried out using a list of key words defining the field of nanotechnology. The list was provided by experts at the National Research Council. A database of publications containing any one of the key words, either in the title or in the abstract, was established for the period from 1989 to 1996. A similar database was set up for patents.

The report contained the following information:

- frequency lists by key word for scientific publications and patents;
- the structure of the field illustrated by graphs bringing together key words on the basis of their co-occurrence;
- graphs illustrating research fields associated with Canadian research institutions;
- a description of publication and patent trends during the period in question;
- the world distribution of publications and patents;
- an activity index for the major publishing countries as a group;
- an international list of the most active institutions in this area according to the distribution of publications and patents;
- a list of Canadian institutions that have published documents and their area of specialisation;
- a list of Canadian institutions holding patents according to their area of specialisation.

Research managers were made aware of the state of research throughout the world, and of specific research efforts in Canada.

Source: R. Dalpé, É. Gauthier and M.-P. Ippersiel, *The state of nanotechnology research*, Report presented to the National Research Council of Canada, May 1997.

Appreciating the significance of networks, consortia and other forms of association, in the innovation process for example, helps gain a better understanding of how these associations can be advantageous for a business. With better associations, businesses are able to determine the most productive links in the network, in terms of the latest research developments, as well as the people who are best positioned within the network.[25] Thus, research managers can put bibliometric data to good use in order to position a research unit strategically, whether it is a university department, a public laboratory or a business.

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[25] W.A. Smith, "Evaluating research, technology and development in Canadian industry: Meeting the challenges of industrial innovation", *Scientometrics*, Vol. 34, No. 3, 1995, 533.

Let us take, for example, a business operating in a high-technology area such as biomedical research. A bibliometric monitoring of its field of specialisation might help such a business understand different aspects of scientific output, e.g. research topics that have been developed, those that are emerging, as well as the people doing the research. Moreover, analysing scientific publications and patents simultaneously would help the business understand specific scientific and technological developments within its field of specialisation. Information gained through technological monitoring would therefore represent a comparative advantage for the business.

Co-citation analysis and co-word analysis are also tools that help research administrators understand scientific output in a broader context. Co-citation analysis determines the links between articles on the basis of citations.[26] A link is assumed to exist between two articles when they are simultaneously cited by a third article. The strength of the link between the co-cited articles is proportional to the number of articles that cite them simultaneously. This makes it possible to identify networks of articles and authors. Such networks provide clues to the cognitive development of specialities and disciplines. They help pinpoint new research topics, and track links between disciplines and the changes they undergo.

Co-word analysis is applied to the content of articles, and thus provides a more in-depth study of research topics than does citation analysis. Co-word analysis[27] is a method that identifies links between research topics according to the simultaneous presence of key words within documents. The goal is to provide a graphical representation of the structure of scientific output at a given time, in a two-dimensional or three-dimensional space. Such a graphical representation is based on plotting maps showing the position of the content of scientific output as well as the people involved in research. Discipline analysis is one of the applications of co-word analysis. It helps pinpoint the scientific and technological output of researchers within the more limited framework of a discipline.

Co-word analysis and co-citation analysis can serve as a research management tool to the extent that they help monitor the development of research topics within a given institution or program. In the context of an evaluation, they are used to measure scientific and technological output in terms of the stated research priorities of policies and programs.

6 — Representativeness of bibliographic sources

The database of the *Observatoire de la science et de la technologie* provides good coverage of all the fields of knowledge. However, the use of ISI databases as the main source of information for bibliometric studies raises a number of issues concerning the representativeness of the data.Several specialised indices could have been used as a bibliographic source, including Chemical Abstracts, INSPEC, PASCAL to name only the best known. The choice of the ISI databases is justified by the fact that they are the only ones that contain the list of all addresses indicated in the publications. This is the unique characteristic that led to the choice of ISI databases to set up the database. The study of

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[26] H. Small And F. Greenlee, "Clustering the *Science Citation Index* using co-citations I. A comparison of methods," *Scientometrics*, Vol. 7, 1985, 391-409; H. Small And F. Greenlee, "Clustering the *Science Citation Index* using co-citations II A comparaison of methods," *Scientometrics*, Vol. 8, 1985, 331-340.

[27] M. Callon, J.P. Courtial, W.A. Turner and S. Bauin, "From translations to problematic networks: An introduction to co-word analysis", *Social Science Information*, Vol. 2 1983, 191-235; M. Callon, J. Law and A. Rip, *Mapping the dynamics of science and technology*, London, MacMillan, 1986.

knowledge flow patterns between the participants of a given system requires complete data on the institutional affiliation of the authors. However, no direct link can be made between addresses and authors on an individual basis. In fact, the information is not presented methodically. The first address does not necessarily match the address of the first author. Likewise, the number of addresses can be different from the number of authors. The ISI data simply reproduce the information provided by the authors themselves in their publications. The information has value only when it is aggregated, not when it is applied to individuals.

Another advantage of the ISI databases is that they alone contain the complete list of references cited by each document. These references can be used to measure the impact of an article by calculating the number of citations for this article over a given period. The great advantage of the ISI databases is that they provide the complete list of addresses given by the authors, something that is not done by other current databases such as PASCAL, FRANCIS, MEDLINE and INSPEC, which only include the address of the first author.

The ISI databases also provide other advantages in terms of representativeness. According to Garfield, the top 2,000 journals, among the 3,400 that are covered, represent about 85% of published articles and 95% of articles cited.[28] This means that there is a significant concentration effect in the overall scientific literature worldwide. This type of concentration guarantees the representativeness of the SCI database. However, Leclerc feels that the SCI database is only truly representative of mainstream scientific activity, i.e. those scientific currents that feed and determine Western science.[29]

A study based on a sampling of 2,500 periodicals surveyed in 1972 has shown that SCI provides excellent coverage for the United States and the United Kingdom, good coverage for France and Germany, and under-coverage for publications from Japan, the Soviet Union, as well as other countries. Moreover, in terms of disciplines, the coverage was best for research in medicine, biomedical research and the physical sciences such as chemistry, physics and mathematics. On the other hand, SCI provided less good coverage for engineering and technology in general, as well as for the earth sciences.[30] The same reservations are expressed by OECD in its 1997 document.[31]

Such considerations raise the issue of the inclusion of Canadian authors in the ISI databases. The simple comparison shown in the TABLE C responds to this issue. There is a slight variation in the coverage of scientific output for various countries depending on whether the ISI databases (SCI, SSCI, AHCI), or those of CNRS (PASCAL, FRANCIS) are used. Generally speaking, however, the ranking

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[28] These statistics apply to the SCI database (CD-ROM, 1994 edition); cf. Eugene Garfield, "The Significant Scientific Literature Appears in a Small Core of Journals", *The Scientist*, September 2, 1996. A few years previously, Garfield had maintained the same proposition with very similar data. Cf. E. Garfield, "How ISI selects journals for coverage quantitative and qualitative considerations", *Current Contents*, 22, 1990, *pp.* 5-13.

[29] M. Leclerc, *Mesurer la science : Dynamiques et mesures de la coopération scientifique internationale du Québec et du monde, 1980-1990*, Québec, Ministère de l'industrie, du Commerce, de la Science et de la Technologie, September 1995, p. 337.

[30] M. P. Carpenter and F. Narin, "The Adequacy of the Science Citation Index (SCI) as an indicator of international scientific activity", *Journal of the American Society of Information Science*, Vol. 32, No. 6, 1981, pp. 430-439.

[31] Y. Okubo, *Bibliometric indicators and analysis of research systems: Methods and examples*, Paris, OECD, 1997, STI Working Papers 1997/1, 18.

of countries is maintained. TABLE C shows that the SCI database provides good coverage of publications by Canadian and Quebec authors in comparison with the French database PASCAL, which nevertheless surveys more periodicals.

On the other hand, Canada's scientific production in the social sciences and humanities is less well represented in the SSCI and AHCI databases. The research subjects in these disciplines are in some ways an obstacle to proper international coverage. There is in fact throughout the world a certain consensus about the subjects, methods and quality of research in the hard sciences. This consensus internationalises, so to speak, the scientific development of the hard sciences. On the other hand, research in the humanities and social sciences is more contextual. Research subjects depend on the location and the society in which they appear. For this reason, it is more difficult to draw a representative picture of scientific activity in these fields using existing databases. That is why the SSCI and AHCI databases cannot maintain that they provide truly representative coverage of Canadian publications. This is even truer for documents written in languages other than English.

Table C: Comparing two bibliometric databases
Share of principal countries, 1990-1992

	SCI		*PASCAL*	
	N	(%)	N	(%)
United States	480, 626	(36.5)	498,789	(32.5)
Japan	115, 555	(8.8)	124,676	(8.1)
Federal Republic of Germany	98, 664	(7.5)	98,723	(6.4)
France	76, 652	(5.8)	112,213	(7.3)
United Kingdom	9,560	(7.3)	114,202	(7.5)
Canada	**64,528**	**(4.9)**	**61,469**	**(4.0)**
Quebec	**14,237**	**(1.1)**	**12,592**	**(0.8)**
Others	386,809	(29.3)	522,622	(34.1)
Total	1,318,440	(100)	1,532,694	(100)

Source: Benoît Godin, Profil bibliométrique de la recherche financée en sciences naturelles, génie et sciences biomédicales, Research Report Submitted to the FCAR Fund, January 1997.

At the end of the 1980s, a study by Garfield[32] showed that the number of francophone periodicals surveyed by SCI was gradually decreasing. In 1985, SCI was surveying 46 Canadian periodicals, as compared to 41 in 1988. Of these, there were no Quebec periodicals in French. Another study by

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32 E. Garfield, "French research; citation analysis indicates trends are more than just a slip of the tongue", *Current Contents*, 23, 1988, p. 9. Cited in: Leclerc, Michel, Y. Okubo, L. Frigoletto and J.-F. Miquel, "Scientific co-operation between Canada and the European Community", *Science and Public Policy*, Vol. 19,, No. 1, February 1992, p. 16.

Garfield[33] has shown that the probability of being cited, for French and Quebec researchers publishing in French, was between 30% and 50% lower than for anglophone researchers. These observations would tend to confirm that francophone researchers, including Quebec researchers, are underrepresented in the SCI database. Nevertheless, this trend is countered by the fact that a vast majority (95%) of francophone researchers in Quebec universities is now publishing in English.[34]

The types of documents that are compiled also represent an important limit for the ISI databases. In spite of its systematic coverage of periodicals,[35] ISI does not compile documents that are distributed outside existing dissemination channels. Such documents, known as grey literature, include theses, internal reports, research notes, patents and communications that have not been published.[36] Monographs are not surveyed in spite of the fact that they represent a significant part of the scholarly output in the humanities and social sciences. Certain reservations should therefore apply whenever bibliographic data from the ISI databases are used for evaluation purposes. The smaller the analytical unit, the higher the risk that the choice of data will affect the evaluation results. It is therefore very important for users of a scientific publication database to take this kind of limitation into consideration.

In summary, the representativeness of bibliometric data depends on which specialised indices are used as a source. The SCI database has more advantages than disadvantages. In the natural sciences, engineering and the biomedical sciences, articles in English make up the bulk of the scientific output. Furthermore, scientific journals indexed by SCI account for most of the citations, and are thus representative of the bulk of the scientific output. On the other hand, SCI shows significant bias in terms of coverage by country, publications in foreign languages (other than English), as well as coverage of publications in the applied sciences. In spite of these shortcomings, SCI remains a valid bibliographic source.

The SSCI and AHCI databases on the other hand merit a more qualified description. The dynamics of the social sciences, the humanities and the arts are different from those of the disciplines covered by SCI. In fact, a significant share of scientific output is published in the form of monographs. Moreover, since these disciplines are of a more contextual nature: researchers publish more often in their own language. As a result, any bias in favour of English would underestimate a significant portion of the scientific output in these disciplines. That is why SSCI and AHCI are considered to be of little value unless they are supplemented by other databases.

The ISI databases do have certain limits, but they will never completely invalidate the results of a bibliometric study. Experienced analysts always take into consideration the inherent limitations of data

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33 Cited in Leclerc, Michel, Y. Okubo, L. Frigoletto and J.-F. Miquel, "Scientific co-operation between Canada and the European Community", *Science and public policy*, Vol. 19, No. 1, February 1992, p. 16.

34 *Compendium 1996 : Indicateurs de l'activité scientifique et technologique au Québec*, Bureau de la Statistique du Québec, 1991, p. 43. See also: Gingras, Y., C. Médaille, *La langue de publication des chercheurs québécois en sciences naturelles, génie et sciences biomédicales (1980-1988)*, Québec, Ministère de l'Enseignement supérieur et de la Science Direction du développement scientifique, 1991.

35 Cf. E. Garfield, "How ISI selects journals for coverage: Quantitative and qualitative considerations", *Current Contents*, 22, 1990, 5-13.

36 Patents and communications can be found in specialised databases. *Index to Scientific & Technical Proceedings* (ISTP) surveys conference proceedings in the fields of science and technology, and has done so since January 1991. *US Patent Search Claims & Abstracts* has been covering American patents since 1979.

whenever they are interpreting results. The database of *the Observatoire des Sciences et des Technologies* remains a tool capable of providing a general though qualitatively incomplete overview.

CONCLUSION

This document has provided a general description of the bibliometric analysis of scientific and technological research. The conceptual framework presented distinguishes relationships between three data aggregation levels (i.e. micro, meso, and macro) and three major variables (years, sectors, and disciplines). This type of conceptualisation helps differentiate bibliometric analyses according to the needs and interests of users. The principal bibliometric indicators are presented and a distinction is made between "descriptive indicators"- based on publication counts- and "relational indicators" which highlight the links between researchers, institutions and countries. Publication counts and descriptive indicators form the basis of bibliometrics. Possible applications are emphasised.

Descriptive indicators and macro-analysis are described within the framework of the evaluation of national performance. Co-author analysis and various methods used for publication counts enable the analysis of international and national flow of knowledge. The section on research evaluation introduces the issues of quality assessment and impact measurement. The application of bibliometric methods to program evaluation and academic research evaluation are also discussed, along with the method of convergent indicators. Co-citation analysis and co-word analysis are described in terms of the bibliometric monitoring of research.

The great advantages of the use of bibliometric data are availability and flexibility. There are many applications; it is important to remember that bibliometric studies always make use of several indicators, and sometimes of more than one type of data, e.g. when publications and patents are combined. While numerous, applications are, in fact, still recent in terms of evaluation and decision making. In recent years, bibliometric tools have proven their usefulness. The next step is for them to be accepted as a complement to traditional evaluation methods and decision-making techniques.

The great potential of bibliometrics applied to the study of scientific and technological research is only described in general terms here. Readers who wish to know more about bibliometric methods may consult the accompanying annotated bibliography. They will find there a detailed account of bibliometric tools, as well as many examples of applications, in several fields, and many descriptions of national experiences.

In closing, it should be noted that the bibliographic database of *the Observatoire de la science et de la technologie* is now available for the analysis of Canadian scientific output. An analysis of aggregate statistics produced using the database is also available[37].

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[37]Benoît Godin, Yves Gingras and Louis Davignon, *Knowledge flows in Canada as measured by bibliometrics*, Working paper, Science and Technology Redesign Project, Statistics Canada, 1998.

B — BIBLIOGRAPHY

1. General sources on bibliometrics

This section contains sources that deal with scientometrics and bibliometrics. These are in fact manuals for readers who wish to know more about the subject. They provide a good overview of methods and indicators, as well as of the problems raised by the choice and use of information databases. The document prepared by Anderson provides a good introduction; its approach is firmly based on applications to research policy. Although less recent, it remains significant because it is very well documented. Courtial, as well as Callon, Courtial and Penan, provide a general introduction to scientometrics. They give a good overview of co-word analysis. These works are well structured, and they provide a wealth of information. However, they say little about bibliometric studies by non-French researchers. Other works in this bibliography complete the picture concerning American, Dutch and British contributions. Generally speaking, the principal journals in the field of applied bibliometrics are *Scientometrics*, *Research Policy*, *Science and Public Policy* and *Research Evaluation*.

ANDERSON, Frances, *New approaches to research policy using bibliometrics*, Québec, Conseil de la science et de la technologie, (document interne n° 4), February 1987.

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COURTIAL, J.-P., *Introduction à la scientométrie: De la bibliométrie à la veille technologique*, Paris, Anthropos Economica, 1991.

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NOYER, J.-M. (Ed.), *Les sciences de l'information: Bibliométrie scientométrie infométrie*, Rennes, Presses universitaires de Rennes, 1995.

Van RAAN, A.F.J., *et al.*, (Eds.), *The handbook of quantitative studies of science and technology*, Amsterdam, Elsevier Science Publishers B.V., 1988.

Van RAAN, A.F.J., *et al.*, (Eds.), *Science and technology in a policy context*, (Select Proceedings of the Joint EC - Leiden Conference on Science and Technology Indicators, Leiden, The

Netherlands, 23-25 October 1991), Leiden, DSWO Press, (Science Studies Series, No. 8), 1992.

WEINGART, P. *et al.* (Eds.), *Representations of science and technology*, (Proceedings of the International Conference on Science and Technology Indicators, Bielefeld, Germany, 10-12 June 1990), Leiden, DSWO Press, (Science Studies Series, No. 6), 1992.

2. Bibliometric statistics

This section contains directory-type documents. Each one provides statistics on one or several aspects of scientific research. The articles by Braun and colleagues are of particular interest. They are part of a long-term project aimed at documenting various aspects of scientific research throughout the world. The compendium of research in Quebec represents a unique tool, along with the bibliometric study by Leclerc on international scientific co-operation in Quebec. This is an excellent example of the use of bibliometrics for technological monitoring by a provincial government in Canada. This section also contains national statistical works from France (*Observatoire des sciences et des techniques*), the United States (National Science Foundation), as well as the European Union.

BARRÉ, R. (Ed.), *Science et technologie: Indicateurs 1996 Rapport de l'Observatoire des Sciences et des Techniques,* Paris, Economica, 1996.

BRAUN, T., W. GLÄNZEL, MACZELKA, HAJNALKA and A. SCHUBERT, "World science in the eighties: National performances in publication output and citation impact, 1985-1989 versus 1980-1984: Part II. Life sciences, engineering, and mathematics", *Scientometrics*, Vol. 31, No. 1, 1994, pp. 3-30.

BRAUN, T., W. GLÄNZEL and H. GRUPP, "The scientometric weight of 50 nations in 27 science areas, 1989-1993: Part I. All fields combined, mathematics, engineering, chemistry and physics", *Scientometrics*, Vol. 33, No. 3, 1995, pp. 263-293.

BRAUN, T., W. GLÄNZEL and H. GRUPP, "The scientometric weight of 50 nations in 27 science areas, 1989-199: Part II. Life sciences", *Scientometrics*, Vol. 34, No. 2, 1995, pp. 207-237.

BRAUN, T., W. GLÄNZEL and A. SCHUBERT, "Scientometric indicators datafiles", *Scientometrics*, Vol. 28, No. 2, 1993, pp. 137-150.

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GLÄNZEL, W., "A bibliometric approach to social sciences: National research performances in 6 selected social science areas, 1990-1992", *Scientometrics*, Vol. 35, No. 3, 1996, pp. 291-307.

LECLERC, Michel, *Mesurer la science: Dynamiques et mesures de la coopération scientifique internationale du Québec et du monde, 1980-1990*, Québec, Direction des politiques scientifiques et technologiques; Direction générale des politiques industrielles, scientifiques et technologiques; ministère de l'Industrie, du Commerce, de la Science et de la Technologie, September 1995.

MIQUEL, J.F., T. OJASOO, Y. OKUBO, A. PAUL, and J.C. DORÉ, "World science in 18 disciplinary areas: Comparative evaluation of the publication patterns of 48 countries over the period 1981-1992", *Scientometrics*, Vol. 33, No. 2, 1995, pp. 149-167.

MINISTÈRE DE L'ENSEIGNEMENT SUPÉRIEUR ET DE LA SCIENCE (MESS), *Compendium 1996: Indicateurs de l'activité scientifique et technologique au Québec*, Québec, Gouvernement du Québec, 1996.

NATIONAL SCIENCE FOUNDATION, *Science and engineering indicators: 1996*, Washington (D.C.), U.S. Government Printing Office, 1996.

SCHUBERT, A. and T. BRAUN, "International collaboration in the sciences 1981-1985", *Scientometrics*, Vol. 19, No. 1-2, 1990, pp. 3-10.

SCHUBERT, A., W. GLÄNZEL and T. BRAUN, "Scientometrics data files: A comprehensive set of indicators on 2,649 journals and 96 countries in all major fields and subfields, 1981-1985". *Scientometrics*, Vol. 16, No. 1-6, 1989, pp. 3-478.

UNESCO, *World science report 1993*, Paris, UNESCO, 1993.

UNESCO, *Statistics on science and technology*, Paris, UNESCO, October 1991.

3. Indicators

3.1 Indicators in general

The contributions listed in this section deal with bibliometric indicators used as analytical tools as opposed to describing their use in a specific context. They describe the validity and use of various indicators in general. They represent a source of information on scientometric indicators as a whole. The paper by Edge is a review of the principal bibliometric indicators. It also talks about limits and weaknesses. The documents published by OECD provide essential information about the utilisation of indicators. They establish statistical standards for all OECD countries. Other documents dealing with national experiences have been included to provide a broader account of indicators in general. Thus the paper by Zitt and Teixeira discusses the specific experience of the *Observatoire des Sciences et des Techniques*. This institute has been providing scientific and technical monitoring for years throughout France, and it has developed a number of indicators.

BARRÉ, R., "The European perspective on S&T indicators", *Scientometrics*, Vol. 38, No. 1, 1997, pp. 71-86.

CALLON, M., "Les indicateurs des sciences et des techniques", *Recherche et Technologie*, n° 1, January-March 1986, p. 42.

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GALANTE, E. and C. SALA, "R&D evaluation at the Italian National Research Council: The agricultural indicators", *Scientometrics*, Vol. 36, No. 2, pp. 223-236.

GILBERT, G.N., "Measuring the growth of science", *Scientometrics*, Vol. 1, No. 1, 1978, pp. 9-34.

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GRUPP, H., "On the supplementary functions of science and technology indicators", *Scientometrics*, Vol. 19, No. 5-6, 1990, pp. 447-472.

LECLERC, M. and Y. GINGRAS, "Les indicateurs du financement privé de la R-D universitaire au Québec: critique de la méthode", *The Canadian Journal of Higher Education/La revue canadienne d'enseignement supérieur*, Vol. 23, No. 1, 1993, pp. 74-107.

Van der MEULEN, B.J.R., "The use of S&T indicators in science policy: Dutch experience and theoretical perspectives from policy analysis", *Scientometrics*, Vol. 38, No. 1, 1997, pp. 87-102.

MOED, H.F., W.J.M. BURGER, J.G. FRANKFORT, and A.F.J. van RAAN, "The application of bibliometric indicators: Important field- and time-dependent factors to be considered", *Scientometrics*, Vol. 8, Nos. 3-4, 1985, pp. 177-203.

NARIN, F. and K. HAMILTON, "Bibliometric performance measures", *Scientometrics*, Vol. 36, No. 3, July 1996, pp. 293-310.

NATIONAL BOARD OF EMPLOYMENT, EDUCATION AND TRAINING, *Research Performance Indicators*, (Commissioned Report No. 21), Canberra, Government Publishing Service, 1993.

OECD, "Quantifying technological advance: S&T indicators at the OECD, challenges for the 1990's", *Science and Public Policy*, Vol. 19, No. 5, October 1992, pp. 281-290.

OECD, *Manual on the measurement of human resources devoted to science and technology (Canberra Manual)*, Paris, OECD, 1995.

OECD, *Proposed standard practice for surveys of research and experimental development (Frascati Manual)*, Paris, 1994.

OCDE, *R&D statistics and output measurement in the higher education sector*, 1989.

OECD, *Technology-Economy-Productivity Programme (TEP)*, Paris, OCDE, 1992.

OECD and Eurostat, *Proposed guidelines for collecting and interpreting technological innovation data (Oslo manual)*, Paris, 1997.

Van RAAN, A.F.J., N.J. NEDERHOF, and N.F. MOED (Eds), *Science and technology indicators: Their use in science policy and their role in science studies*, (Select Proceedings of the First International Workshop on Science and Technology Indicators, Leiden, The Netherlands, 14-16 November 1988), Leiden, DSWO Press, (Science Studies Series, No. 3), 1989.

Van RAAN, A.F.J. and R.J.W., TIJSSEN, *An overview of quantitative science and technology indicators based on bibliometric methods,* TEP Conference, Paris, OECD, July 1990.

STEAD, H., "Collection of S&T statistics", *Science and Public Policy*, Vol. 19, No. 5, pp. 275-280.

ZITT, M. and N. TEIXEIRA, "Science macro-indicators: Some aspects of OST experience", *Scientometrics*, Vol. 35, No. 2, 1996, pp. 209-222.

3.2 Indicators of scientific collaboration

The documents listed in this section deal mainly with the empirical study of scientific collaboration. There are contributions on international collaboration, as well as on networks bringing together researchers and institutions. They all share a common element: the use of co-author analysis. This provides a good overview of the range of possibilities. Generally speaking, international collaboration is a major topic. The papers by Melin and by Peters and van Raan deal more specifically with the links between academic institutions. There is also an original contribution by Qiu, who uses co-author analysis to study links between disciplines. Subramanyam provides a broader outlook by reviewing the many interpretations of the concept of scientific collaboration in terms of the sociology of science, whereas Katz and Martin discuss the concept of scientific collaboration and its significance within the context of science policy. The paper by Beaver and Rosen describes the history of the phenomenon. These authors maintain that the development of scientific collaboration is linked to the institutionalisation of scientific research. All these bibliometric studies illustrate the persistence and scope of the co-author analysis. The paper by Hicks & Katz provides an interesting perspective on the need to integrate scientific collaboration within the framework of research policy.

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CARPENTER, Mark P. and Francis NARIN, "The adequacy of the Science Citation Index (SCI) as an indicator of international scientific activity", *Journal of the American Society of Information Science*, Vol. 32, No. 6, 1981, pp. 430-439.

DALPÉ, R., "International activities of public laboratories in Canada", *Technology in Society*, Vol. 19, No. 2, 1997, pp. 127-143.

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HICKS D. and J. Sylvan KATZ, "Science policy for a highly collaborative science system", *Science and Public Policy*, Vol. 23, No. 1, February 1996, pp. 39-44.

KATZ, J.S., *Bibliometric assessment of intranational university-university collaboration*, D. Phil. thesis, Science Policy Research Unit, University of Sussex, 1993.

KATZ, J.S. and B.R. MARTIN, "What is research collaboration?", *Research Policy*, Vol. 26, 1997, pp. 1-18.

LECLERC, M. and P. DUFOUR, "International science and technology collaboration", in J. de la Mothe and P. Dufour (Eds.), *Science and technology in Canada*, Harlow Essex, Longman Publishing, 1993, pp. 125-161.

LECLERC, M. and J. GAGNÉ, "International scientific cooperation: The continentalization of science", *Scientometrics*, Vol. 31, No. 3, 1994, pp. 261-292.

LUUKKONEN, T., R.J.W. TIJSSEN, O. PERSSON and G. SIVERTSEN, "The measurement of international scientific collaboration", *Scientometrics*, Vol. 28, No. 1, 1993, pp. 15-36.

LUUKKONEN, T., O. PERSSON and G. SIVERTSEN, "Understanding patterns of international scientific collaboration", *Science, Technology & Human Values*, Vol. 17, No. 1, 1992, pp. 101-126.

MELIN, G. "The networking university: A study of a Swedish university using institutional co-authorships as an indicator", *Scientometrics*, Vol. 35, No. 1, 1996, pp. 3-13.

MELIN, G. and PERSSON, O., "Studying research collaboration using co-authorships", *Scientometrics*, Vol. 36, No. 3. July 1996, pp. 363-378.

MIQUEL, J.F. and Y. OKUBO, "Structure of international collaboration in science: Part 2 Comparisons of profiles in countries using a link indicator", *Scientometrics*, 29, No. 2, 1994, pp. 271-297.

MOED, H.F., R.E. de BRUIN and A. STRAATHOF, "Measurement of national scientific cooperation in CEC-related areas of science during 1985-90", Report EUR14581, Office for Official Publications of the European Communities, Luxemburg, 1992.

OKUBO, Y., J.F. MIQUEL, I. FROGOLETTO and J.C. DORÉ, "Structure of international collaboration in science: Typology of countries through multivariate techniques using a link indicator, *Scientometrics*, 25, No. 2, 1992, pp. 321-351.

PETERS, H.P.F. and A.F.J. VAN RAAN, "Structuring scientific activities by co-author analysis: An exercise on a university faculty level", *Scientometrics*, Vol. 20, No. 1, 1991, pp. 235-255.

QIU, Liwen, "A study of interdisciplinary research collaboration", *Research Evaluation*, Vol. 2, No. 3, December 1992, pp. 169-175.

SUBRAMANYAM, K., "Bibliometric studies of research collaboration: A review", *Journal of Information Science*, Vol. 6, 1983, pp. 33-38.

4. Evaluation

4.1 Research evaluation

The documents listed in this section describe several studies on research evaluation in terms of performance. National experiences are included with papers by Barbarie for Canada and Cozzens for the United States. Kostoff is particularly interested in the evaluation of public research at the federal level. The paper by Helander reviews the experience of northern countries. Evaluation studies also deal with fields of research. Examples are the paper by Frame on basic research and the contribution by Finkenstaedt on research in the humanities, of particular interest since bibliometric studies dealing with the humanities and social sciences are rare indeed. Gibbons and Georghiou provide an overview of evaluation methods, including bibliometric methods. In this context, the paper by Moed compares bibliometric evaluation methods with the traditional technique of peer evaluation. The two methods are often contrasted, but they should in fact be seen as complementary. A contribution by Vinkler deals with the delicate subject of evaluating individual performance.

BARBARIE, A., "Evaluating federal R&D in Canada", in Barry Bozeman and Julia Melkers (Eds.), *Evaluating R&D impacts: Methods and practice*, Boston, Kluwer Academic Publishers, 1993.

COZZENS, S., "U.S. Research assessment: Recent developments", *Scientometrics*, Vol. 34, No. 3, 1995, pp. 351-362.

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GIBBONS, M., and L. GEORGHIOU, *Évaluation de la recherche: un choix de pratiques en vigueur*, Paris, OCDE, 1987.

GEORGHIOU, Luke, *Evaluation of research: Synthesis report*, Ad hoc Group on Scientific and University Research, Directorate for Science, Technology and Industry, Paris, OECD, January 1986.

HELANDER, E., "Evaluation activities in the Nordic countries", *Scientometrics*, Vol. 34, No. 3, 1995, pp. 391-400.

KOSTOFF, R.N., "Federal research impact assessment: Axioms, approaches, applications", *Scientometrics*, Vol. 34, No. 2, 1995, pp. 163-206.

KOSTOFF, R.N., "Performance measures for government-sponsored research: Overview and background", *Scientometrics*, Vol. 36, No. 3, 1996, pp. 281-292.

LINK, A.N., "Economic performance measures for evaluating government-sponsored research", *Scientometrics*, Vol. 36, No. 3, 1996, p. 325.

LUUKKONEN, T., "Bibliometrics and evaluation of research performance", *Annals of Medecine*, Vol. 22, No. 3, 1990.

MARTIN, B.R. "The use of multiple indicators in the assessment of basic research", *Scientometrics*, Vol. 36, No. 3, July 1996, pp. 343-362.

MARTIN, B.R. and J. IRVINE, "Assessing basic research: Some partial indicators of scientific progress in radio astronomy", *Research Policy*, Vol. 12, No. 2, 1983, pp. 61-90.

MOED, H.F., *et al.*, "A comparative study of bibliometric past performance analysis and peer judgement", *Scientometrics*, Vol. 8, No. 3-4, 1985, pp. 149-159.

MOED, H.F., W.J.M. BURGER, J.G. FRANKFORT and A.F.G. van RAAN, *On the measurement of research performance: The use of bibliometric indicators,* Leiden, Leiden University Research Policy Unit, 1983.

NARIN, F., "Subjective vs. bibliometric assessment of biomedical research publications", *NIH program evaluation report,* US Department of Health and Human Services, Public Health Service, National Institutes of Health, April 1983.

VINKLER, P., "Some aspects of the evaluation of scientific performances and related performances of individuals", *Scientometrics*, Vol. 32, No. 2, 1995, pp. 109-116.

4.2 Program evaluation

This section continues to deal with research evaluation, though in the context of program evaluation. Again, particular attention is brought to bear on the experience of various countries. The documents selected include papers on the European Community, Japan, the United Kingdom and Germany. A number of contributions, e.g. by Leydesdorff, Moed, Mullins and Narin, and specifically van Raan, deal with the methodology used in bibliometric program evaluation. The special issue published by *Research Evaluation* on evaluation practices in Europe provides some interesting approaches to national experiences.

BOBE, B., "Trends in the use of research-and-development output indicators in EC program evaluation", *Scientometrics*, Vol. 21, No. 3, 1991, pp. 263-282.

CLARKE, Thomas E., *The evaluation of R&D programs and personnel: A literature review,* 1986, Stragate Consultants.

CUNION, K.M., "U.K. Government departments experience of RT&D programme evaluation and methodology", *Scientometrics*, Vol. 34, No. 3, 1995, pp. 375-389.

CUNNINGHAM, P., "The evaluation of European programmes and the future of scientometrics", *Scientometrics*, Vol. 38, No. 1, 1997, pp. 71-86.

DALPÉ, R. and F. ANDERSON, *L'Évaluation des politiques scientifiques et technologiques*, Montréal, Centre interuniversitaire de recherche sur la science et la technologie (CIRST), Notes de recherche 92-04, 1992.

GEORGHIOU, L., A. DALE and H. CAMERON (Eds.), Special issue on national systems for evaluation of R&D in the European Union", *Research Evaluation*, Vol. 5, No. 1, April 1995, pp. 1-108.

GONDA, K. and F. KAKIZAKI, "Research, technology and development evaluation: Developments in Japan", *Scientometrics*, Vol. 34, No. 3, 1995, pp. 375-389.

HILLS, P., "PREST's experience of evaluation (University of Manchester, Programme of policy research in engineering, science and technology)", *Scientometrics*, Vol. 34, No. 3, 1995, pp. 401-414.

IRVINE, John and Ben R. MARTIN, "Evaluating big science: CERN's past performance and future prospects", *Scientometrics*, 7, 1985, pp. 281-308.

KYRIAKOU, D., "Macroeconomic aspects of S/T programme evaluation", *Scientometrics*, Vol. 34, No. 3, 1995, pp. 451-459.

KUHLMANN, S., "German government departments experience of RT&D programme evaluation and methodology", *Scientometrics*, Vol. 34, No. 3, 1995, pp. 461-471.

LARADO, P., "Structural effects of EC RT&D programmes", *Scientometrics*, Vol. 34, No. 3, 1995, pp. 473-487.

LEYDESDORFF, L. and P. van der SCHAAR, "The use of scientometric methods for evaluating national research programs, *Science and Technology Studies*, Vol. 5, No. 1, 1987, pp. 22-31.

MOED, H.F., *The use of bibliometric indicators for the assessment of research performance in the natural and life sciences*, Leiden, DSWO Press, (Science Studies Series, No. 2), 1989.

MULLINS, N. C., "Evaluating research programs: Measurement and data sources", *Science and Public Policy*, Vol. 14, No. 2, April 1987, pp. 91-98.

NARIN, F., "Bibliometric techniques in the evaluation of research programs", *Science and Public Policy*, Vol. 14, No. 2, April 1987, pp. 99-106.

NEDERHOF, A.J., "A bibliometric assessment of research council grants in linguistics", *Research Evaluation*, Vol. 6, No. 1, April 1996.

Van RAAN, A.F.J., "Advanced bibliometric methods to assess research performance and scientific development: Basic principles and recent practical applications", *Research Evaluation*, Vol. 3, No. 3, December 1993.

WALSCHE, G., "Research and development trends: Criteria for assessment", *Science and Public Policy*, Vol. 19, No. 2, 1992, pp. 75-88.

4.3 Evaluating national performance

This section lists sources on the utilisation of bibliometric tools to evaluate national performance. Some of them discuss the method, while others, e.g. Callon and Leydesdorff, provide an illustration of bibliometric evaluation. The papers by Leydesdorff and Gauthier and by Sylvain describe the evaluation of a specific field of scientific activity: materials research and biotechnology on the one hand, and aquaculture on the other. The paper by Leydesdorff and Gauthier is based on a comparative study of strategic research programs in Canada and the

Netherlands. The contribution by Glänzel contains a bibliometric evaluation of research in the social sciences. Few bibliometric studies have dealt with this field of scientific research.

BRAUN, T., W. GLÄNZEL and A. SCHUBERT, "An alternative quantitative approach to the assessment of national performance in basic research", in D. EVERED and S. HARNETT (eds.), *The evaluation of scientific research*, Chichester (UK), John Wiley & Sons, 1989.

CALLON, M. and L. LEYDESDORFF, "La recherche française est-elle en bonne santé?", *La recherche*, Vol. 18, No. 186, 1987, pp. 412-419.

GLÄNZEL, W., "A bibliometric approach to social sciences: National research performances in 6 selected social science areas 1990-1992", *Scientometrics*, Vol. 35, No. 3, March 1996, pp. 291-307.

KYVIK, S. and I. MARHEIM LARSEN, "International contact and research performance", *Scientometrics*, Vol. 29, No. 1, 1994, pp. 137-159.

LEYDESDORFF, L., "The Science Citation Index and the measurement of national performance in terms of numbers of scientific publications, *Scientometrics*, Vol. 17, Nos. 1-2, 1989, pp. 111-120.

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LEYDESDORFF, L. and É. GAUTHIER, "The evaluation of national performance in selected priority areas using scientometric methods", *Research Policy*, Vol. 25, 1996, pp. 431-450.

MOED, H.F., R.E. de BRUIN and TH.N. van LEEWEN, "New bibliometric tools for the assessment of national research performance. Database description, overview of indicators and first applications", *Scientometrics*, Vol. 33, No. 3, 1995, pp. 367-380.

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SYLVAIN, C., "Canadian research activity in aquaculture: A bibliometric analysis", *Scientometrics*, Vol. 27, No. 3, 1993, pp. 295-316.

TIJSSEN, R.J.W., T.N. van LEEUWEN and J.C. KOREVAAR, "Scientific publication activity of industry in the Netherlands", *Research Evaluation*, Vol. 6, No. 2, August 1996.

4.4 Evaluating public institutions

The evaluation of public institutions covers several issues. The institutions in question may be public laboratories, universities, or research groups. In each case, the challenge is different. The terms of reference of public laboratories may be based on pure research or on applied research, for example. Likewise, evaluation procedures in a university setting may concern the institution as a whole, one faculty, one department, or even one research group. Bibliometric evaluations must keep in mind the particular characteristics of the institution. The contributions included here cover a wide selection of institutions and national experiences: public laboratories in Canada, of course, but also in Germany, as well as universities in the United Kingdom, Australia, Greece, Chile and Holland. Some very specific cases are dealt with: the Max Planck Institute in Germany, technical universities in the United Kingdom, and also the Joint Research Centre of the European Commission. Readers who wish to know more about the evaluation of university research will read with interest the contributions by Martin and Skea and by Nederhof and Noyons. The former provides a critical review of the potential of bibliometrics; the latter compares various methods. Note the originality of the paper by Nederhof and Noyons, who propose a means of comparing university departments at the international level.

ANDERSON, F. and R. DALPÉ, "S&T indicators for strategic planning and assessment of public research institutions", *Knowledge and Policy: The international journal of knowledge transfer and utilization*, Vol. 9, No. 1, Spring 1996, pp. 49-69.

ANDERSON, F. and R. DALPÉ, "The evaluation of public applied research laboratories", *Canadian Journal of Program Evaluation*, Vol. 6, No. 2, 1991, pp. 107-125.

BECK, M.T. and V. GÁSPÁR, "Scientometric evaluation of the scientific performance at the faculty of natural sciences, Kossuth Lajos University, Debrecen, Hungary", *Scientometrics*, Vol. 20, No. 1, 1991, pp. 37-54.

COLMAN, A.M., D. DHILLON and B. COULTHARD, "A bibliometric evaluation of the research performance of British university politics departments: Publications in leading journals", *Scientometrics,* Vol. 32, No. 1, 1995, pp. 37-48.

COLLINS, P., "*Quantitative assessment of departmental research: A survey of academics views*, London, SEPSU, (Policy Studies, No. 5), 1991.

DALPÉ, R. and É. GAUTHIER, "Evaluation of the industrial relevance of public research institutions", *Research Evaluation*, Vol. 3, No. 1, pp. 43-54.

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HERBSTEIN, F.H., "Measuring 'publications output' and 'publications impact' of faculty members of a university chemistry department", *Scientometrics*, Vol. 28, No. 3, 1993, pp. 349-373.

IRVINE, J., "Evaluation of scientific institutions: Lessons from a bibliometric study of UK technical universities", in D. Evered and S. Harnett (Eds.), *The evaluation of scientific research*, Chichester (UK), John Wiley and Sons, 1989.

KRAUSKOPF, M., M. INÉS VERA and R. ALBERTINI, "Assessment of a university's scientific capabilities and profile: The case of the faculty of biological sciences of the Pontificia Universidad Catolica de Chile", *Scientometrics*, Vol. 34, No. 1, 1995, pp. 87-100.

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MOED, H.F. and A.F.J. van Raan, "Indicators of research performance: Applications in university research policy", in A.F.J. van Raan, *et al.*, (Eds.), *The handbook of quantitative studies of science and technology*, Amsterdam, Elsevier Science Publishers B.V., 1988, pp. 177-192.

NARIN, F., *Measuring the research productivity of higher education institutions using bibliometric techniques*, OECD, DSTI/SPR/85, June 1985.

NEDERHOF, A.J., "The validity and reliability of evaluation of scholarly performance", in A.F.J. van Raan, *et al.*, (Eds.), *The handbook of quantitative studies of science and technology*, Amsterdam, Elsevier Science Publishers B.V., 1988, pp. 193-228.

NEDERHOF, A.J. and A.F.J. van Raan, "A bibliometric analysis of six economics research groups: A comparison with peer review", *Research Policy*, 22, 1993, pp. 353-368.

NEDERHOF, A.J., R.F. MEIJER, H.F. MOED and A.F.J. van RAAN, "Research performance indicators for university departments: A study of an agricultural university", *Scientometrics*, Vol. 27, No. 2, 1993, pp. 157-178.

NEDERHOF, A.J. and E.C.M. NOYONS, "Assessment of the international standing of university departments' research: A comparison of bibliometric methods", *Scientometrics*, Vol. 24, No. 3, 1992, pp. 393-404.

PEREIRA, J.C.R., M.L. PIRES, P.S. DUARTE, A.T. PAES and V. OKANO, "Introducing a method of research evaluation into a university: Medical research at the University of São Paulo, Brazil", *Research Evaluation*, Vol. 6, No. 1, April 1996.

Van RAAN, A.F.J., "Evaluation of research groups", in D. EVERED and S. HARNETT (Eds.), *The evaluation of scientific research*, Chichester (UK), John Wiley and Sons, 1989.

RINALDINI, C., "Experience on research evaluation at the Joint Research Centre of the European Commission", *Scientometrics*, Vol. 34, No. 3, 1995, pp. 519-525.

SKEA, J.E.F., B.R. MARTIN and E.N. LING, "Assessing university departments: Some problems and partial solutions", in A.F.J. van RAAN, *et al.*, (Eds.), *Science and technology in a policy context*, (Select Proceedings of the Joint EC - Leiden Conference on Science and Technology Indicators, Leiden, The Netherlands, 23-25 October 1991), Leiden, DSWO Press, (Science Studies Series, No. 8), 1992, pp. 106-121.

ZACHOS, G., "Research output evaluation of 2 university departments in Greece with the use of bibliometric indicators", *Scientometrics*, Vol. 21, No. 2, 1991, pp. 195-221.

5. Scientific and technological monitoring

The various contributions brought together in this section are an illustration of the broad potential of bibliometrics. Relevant bibliometric data can be used to provide the information needed by decision-makers dealing with a specific subject. Such information may be used by public policy-makers as well as by business leaders. Thus bibliometrics might provide information about the technological dynamics of a city (Dou *et al.*) or of an industry (Koening). Bibliometrics can also be used to guide research in accordance with managerial considerations. These are issues of strategic positioning as is shown by Miller and Manseau with respect to research and development laboratories, Moed and colleagues on the subject of university research, or Hicks, Martin and Irvine on the topic of applied research. Moreover, the results of bibliometric studies help provide information for the peer evaluation process as well as for reflections on policies.

BAYEN, M., "La veille technologique: un enjeu national", *Revue française de bibliométrie*, 1990.

COURTIAL, J.-P. and J.-C. REMY, "Toward the cognitive management of a research institute", *Research Policy*, Vol. 17, 1988, pp. 225-233.

COURTIAL, J.-P., M. CALLON and A. SIGOGNEAU, "The use of patent titles for identifying the topics of invention and forecasting trends", *Scientometrics*, Vol. 26, No. 2, 1993, pp. 231-242.

DESVALS, H. and DOU H., *La veille technologique*, Paris, Dunod, 1992.

DOU, H., L. QUONIAM, and P. HASSANALY, "The scientific dynamics of a city: A study of chemistry in Marseille from 1981 to the present", *Scientometrics*, Vol. 22, No. 1, 1991, pp. 83-93.

HICKS, D., B. MARTIN and J. IRVINE, "Bibliometric techniques for monitoring performance in technologically oriented research: The case of integrated optics", *R&D Management*, Vol. 16, No. 3, 1986.

JAGODZINSKI, S., J.P. COURTIAL and B. LATOUR, "How to measure the degree of independence of a research system", *Scientometric*s, 4, 1982, pp. 119-133.

KOENING, Michael E.D., "A bibliometric analysis of pharmaceutical research", *Research Policy*, 12, 1983, pp. 16-36.

MEADOWS, A.J. and J.G. O'CONNOR, "Bibliographic statistics as a guide to growth points in science", *Science Studies*, 1, 1971, pp. 95-99.

MILLER, R. and A. MANSEAU, "Bibliometric indicators and the competitive environment of R&D laboratories", *Scientometrics*, Vol. 36, No. 3, 1996, pp. 421-434.

MOED, H.F., W.J.M. BURGER, J.G. FRANKFORT and A.F.J. van RAAN, "La bibliométrie et son utilité pour l'orientation générale des recherches universitaires", *Revue internationale de gestion des établissements d'enseignement supérieur,* Vol. 9, 1985, pp. 210-220.

MOED, H.F., R.E. de BRUIN, A.J. NEDERHOF and R.J.W. TIJSSEN, “International scientific cooperation and awareness within the European Community: problems and perspectives", *Scientometrics*, Vol. 21, 1991, pp. 291-311.

MOED, H.F. and F.T. HESSELINK, "The publication output and impact of academic chemistry research in the Netherlands during the 1980s: Bibliometric analyses and policy implications", *Research Policy*, Vol. 25, 1997, p. 819.

NAGPAUL, P.S. and L. SHARMA, "Science in the eighties: A typology of countries based on inter-field priorities", *Scientometrics*, Vol. 34, No. 2, 1995, pp. 263-283.

Van RAAN, A.F.J., "Advanced bibliometric methods as quantitative core of peer review based evaluation and foresight exercises", *Scientometrics*, Vol. 36, No. 3, 1996, pp. 397-420.

6. Bibliometric studies of Canada

There are several published bibliometric studies dealing with specific aspects of scientific activity in Canada. These studies cover a broad range of subjects, reflecting the existence of a group of active bibliometric specialists. In addition to scientific publications, there are many research reports. The following selection is by no means exhaustive.

ANDERSON, F. and R. DALPÉ, *A comparison of alternative data sources to profile national research communities: The case of Canadian polymer research*, Montréal, Centre interuniversitaire de recherche sur la science et la technologie (CIRST), Notes de recherche 92-05, 1992.

ANDERSON, F. and R. DALPÉ, "A profile of Canadian coal and petroleum research communities", *Scientometrics*, Vol. 25, No. 3, 1992, pp. 447-463.

DALPÉ, R., "International activities of public laboratories in Canada", *Technology in Society*, Vol. 19, No. 2, 1997, pp. 127-143.

DALPÉ, R. and ANDERSON, F., "National priorities in academic research: Strategic research and contracts in renewable energies", *Research Policy*, Vol. 24, 1995, pp. 563-581.

DALPÉ, R., É. GAUTHIER, M. PARENT, and M. PRUD'HOMME, *Les activités internationales des laboratoires publics au Québec*, Québec, Conseil de la science et de la technologie, November 1993.

DALPÉ, R. and Y. GINGRAS, "Recherche universitaire et priorités nationales: l'effet du financement public sur la recherche en énergie solaire au Canada", *Canadian Journal of Higher Education*, Vol. 20, 1990, pp. 27-44.

DALPÉ, R. and B. LONGPRÉ, *The state of Canadian research in physics and electrical engineering*, Report to the NRCC, Montréal, Centre interuniversitaire de recherche sur la science et la technologie (CIRST), August 1995.

DAWSON, P., R. DALPÉ, B. LONGPRÉ and C. CARON, "A bibliometric view of the state of Canadian research in semiconductors and photonics", *La Physique au Canada*, July/August, 1996, pp. 151-158.

GAGNÉ, J. and M. LECLEC, "Quebec's science indicators: A survey", *Science and Public Policy*, Vol. 19, No. 5, October 1992.

GEORGHIOU, L., *Evaluation of research: Evaluation of research in Canada*, Ad-hoc Group on Scientific and University Research, Directorate for Science, Technology and Industry, Paris, OECD, January 1986.

GINGRAS, Y., *Bibliometric analysis of funded research: A feasibility study*, Report to the Program Evaluation Committee of NSERC, Montréal, Centre interuniversitaire de recherche sur la science et la technologie (CIRST), January 1996.

GINGRAS, Y., C. MÉDAILLE, *La langue de publication des chercheurs québécois en sciences naturelles, génie et sciences biomédicales (1980-1988)*, Québec, Ministère de l'Enseignement supérieur et de la Science, Direction du développement scientifique, 1991.

GINGRAS, Y., M. LECLERC, C. MÉDAILLE, La recherche scientifique au Québec: production et productivité de 1980 à 1988, *Interface*, Vol. 12, No. 3, May-June 1991, pp. 25-32.

GODIN, B., *"Endangered Species?" Une nouvelle estimation de la part du français dans les communications scientifiques*, Rapport de recherche présenté au Conseil de la langue française, Montréal, INRS/Centre interuniversitaire de recherche sur la science et la technologie (CIRST), November 1995.

GODIN, B., *Profil des thématiques de la recherche québécoise: application au génie*, Rapport de recherche présenté au Fonds FCAR, Montréal, INRS/Centre interuniversitaire de recherche sur la science et la technologie (CIRST), June 1995.

GODIN, B., "Research and the practice of publication in industries", *Research Policy*, Vol. 25, 1997, pp. 587-606.

GODIN, B., *Profil bibliométrique de la recherche financée en sciences naturelles, génie et sciences biomédicales*, Rapport de recherche présenté au Fonds FCAR, Montréal, INRS/Centre interuniversitaire de recherche sur la science et la technologie (CIRST), April 1997.

GODIN, B., R.S. BARKER and M. LANDRY, "Besides academic publications: Which sectors compete, or are there competitors?", *Scientometrics*, 33, 1, 1995, pp. 3-12.

GODIN, B. and M.P. IPPERSIEL, "Scientific collaboration at the regional level: The case of a small country", *Scientometrics*, 36, 1, 1996, pp. 59-68.

GODIN, B. and R. LANDRY, *L'avenir de la collaboration scientifique au Québec: une analyse basée sur la convergence d'indicateurs*, Rapport de recherche présenté au fonds FCAR, Montréal, INRS/Centre interuniversitaire de recherche sur la science et la technologie (CIRST), January 1995.

GODIN, B. and C. LIMOGES, *Les revues scientifiques québécoises: une évaluation du programme de soutien aux revues du fonds FCAR*, Rapport de recherche présenté au fonds FCAR, Montréal, INRS/Centre interuniversitaire de recherche sur la science et la technologie (CIRST), May 1995.

GODIN, B. and M. TRÉPANIER, *Les matériaux composites à matrice polymérique*, Rapport de recherche présenté à l'Ordre des ingénieurs du Québec et au ministère de l'Industrie, du Commerce, de la Science et de la Technologie, Montréal, INRS/Centre interuniversitaire de recherche sur la science et la technologie (CIRST), May 1994.

INHABER, H., "The leading edge of science in Canada", *Research Policy*, Vol. 7, 1978, pp. 88-98.

LECLERC, M., *La coopération scientifique du Canada avec les autres pays membres de l'ALENA et certains pays d'Amérique latine 1980-1990*, Rapport préparé pour Industrie Canada, Bureau du conseiller scientifique principal, Québec, April 1994.

LECLERC, M., "La coopération scientifique internationale: l'exemple du Canada", *La recherche*, Vol. 24, n° 252, March 1993, pp. 350-357.

LECLERC, M., and J. GAGNÉ, "La coopération scientifique internationale du Québec", *Nouvelles de la science et des technologies*, Vol. 9, n° 2, 1991, pp. 133-136.

LECLERC, M., J.-F. MIQUEL, N. NARVAEZ, L. FRIGOLETTO, and Y. OKUBO, "La coopération scientifique France-Québec: analyse des cosignatures", *Interface*, vol. 12, n° 5, septembre-octobre 1991, pp. 19-23.

LECLERC, Michel, Y. OKUBO, L. FRIGOLETTO and J.-F. MIQUEL, "Scientific co-operation between Canada and the European Community", *Science and Public Policy*, Vol. 19, No. 1, February 1992, pp. 15-24.

LEYDESDORFF, L. and É. GAUTHIER, "The evaluation of national performance in selected priority areas using scientometric method", *Research Policy*, Vol. 25, 1996, pp. 431-450.

MACAULEY, James B., *An indicator of excellence in Canadian science*, Ottawa, Statistics Canada, Catalogue 88-501E , 1985.

MARCHESSAULT, R., R. DALPÉ and É. GAUTHIER, *Evaluation of Canadian research in metals and alloys*, Report to the Royal Society of Canada, 1992.

REES-POTTER, Lorna K., "Identification of areas of social science research in Canada: A bibliometric analysis", *Proceedings of the American Society for Information Science*, 17, 1980, pp. 282-284.

TRÉPANIER, M., and B. GODIN, *Les matériaux composites à matrice polymérique; les bioréacteurs; les technologies de reconnaissance de la voix et de l'image*, trois rapports de recherche présentés à l'Ordre des ingénieurs du Québec et le ministère de l'Industrie, du Commerce, de la Science et de la Technologie du Québec, 1994.

SMITH, W.A.,"Evaluating research, technology and development in Canadian industry: Meeting the challenges of industrial innovation", *Scientometrics*, Vol. 34, No. 3, 1995, pp. 527-539.

SYLVAIN, C., "Canadian research activity in aquaculture: A bibliometric analysis", *Scientometrics*, Vol. 27, No. 3, 1993, pp. 295-316.

7. Supplementary reading

7.1 Classification and mapping techniques

This section contains contributions on various methods of graphic representation. Mapping is the preparation of maps showing the position of scientific output and of researchers. The goal is to provide a graphic representation of the structure of scientific output, at a given moment, in a two-dimensional or three-dimensional space. As tools used to define specialities, mapping and classification are based on co-word analysis and co-citation analysis. The book by Braam is a comparative study of current mapping methods. In the contribution by Engelsman and van Raan, the method of key-word mapping is applied to patents.

BRAAM, R.R., *Mapping of science: Foci of intellectual interest in scientific research*, Leiden, DSWO Press, (Science Studies Series, No. 4), 1991.

CALLON, M., J. LAW and A. RIP, *Mapping the dynamics of science and technology*, London, Macmillan Press Ltd., 1986.

COZZENS, S.E. and L. LEYDESDORFF, "Journal systems as macro-indicators of structural change in the sciences", in A.F.J. van RAAN, *et al.*, (Eds.), *Science and technology in a policy context*, (Select Proceedings of the Joint EC - Leiden Conference on Science and Technology Indicators, Leiden, The Netherlands, 23-25 October 1991), Leiden, DSWO Press, (Science Studies Series, No. 8), 1992.

ENGELSMAN, E.C. and A.F.J. van Raan, "A patent-based cartography of technology", *Research Policy*, Vol. 23, pp. 1-26.

LEYDESDORFF, L. "Various methods for the mapping of science", *Scientometrics*, Vol. 11, Nos. 5-6, 1987, pp. 295-324.

LEYDESDORFF, L. and S. COZZENS, "The delineation of specialties in terms of journals using the dynamic journal set of the SCI", *Scientometrics*, Vol. 26, 1993, pp. 133-154.

Van RAAN, A.F.J. and R.J.W. TIJSSEN, "Numerical methods for information on aspects of science scientometrics analysis and mapping", in Oppenheim C., J.-M. Griffiths and C. L. Citroen, (Eds), *Perspective in information management Vol. 2*, London, Butterworths, 1990.

REES-POTTER, Lorna K., "Identification of areas of social science research in Canada: A bibliometric analysis", *Proceedings of the American Society for Information Science*, 17, 1980, pp. 282-284.

ROTHMAN, Harry, "Science mapping for strategic planning", in Michael Gibbons, Philip Gummett and B.M. Udgaonkar (Eds.), *Science and technology policy in the 1980s and beyond*, London and New York, Longman's, 1984, pp. 99-116.

SMALL, H. and E. GARFIELD, "The geography of science: Disciplinary and national mapping", *Journal of Information Science*, Vol. 11, 1985, pp. 147-159.

SMALL, H. and B.C. GRIFFITH, "The structure of scientific literature: Part II Identifying and graphing specialties", *Science Studies*, Vol. 4, 1974, pp. 339-365.

TIJSSEN, R.J.W., *Cartography of science: Scientometric mapping with multidimensional scaling methods*, Leiden, DSWO Press, (Science Studies Series, No. 5), 1992.

TIJSSEN, R.J.W. and A.F.J. van Raan, "Mapping changes in science and technology", in R.N. Kostoff (Ed.), Special issue on research impact assessment, *Evaluation Review*, 18, 1, 1994.

TODOROV, R., "Representing a scientific field: A bibliometric approach", *Scientometrics*, Vol. 15, 1989, pp. 593-605.

7.2 Indicators of technological innovation

Narin and Carpenter and Coward and Franklin are the specialists of bibliometric analysis applied to patents. This method is used to study technological innovation as well as the links between science and technology. Computer Horizons have developed a method for evaluating the technological performance of a firm, a technological sector or even a national technological activity. Likewise, Carpenter and Narin have developed the analysis of citations in patents as a means of measuring the links between scientific literature and technological development. Coward and Franklin used co-citation analysis to explore the links between science and technology. Both methods are currently used to identify the areas of research having a strong technological potential, and inversely those technologies that rely on basic research. The paper by Pavitt looks at the problems and difficulties linked to the use of patents as an indicator of technological innovation.

ARCHIBUGI, D., "Patenting as an indicator of technology innovation: A review", *Science and Public Policy*, Vol. 16, No. 6, December 1992.

BASBERG, B., "Patents and the measurement of technological change: A survey of the literature", *Research Policy*, Vol. 16, 1987, pp. 131-141.

CARPENTER, M.P. and F. NARIN, "Validation study: Patent citations as indicators of science and foreign dependence", *World Patent Information*, Vol. 5, No. 3, 1983, pp. 180-185.

CARPENTER, M.P. and F. NARIN, *Assessment of the linkages between patents and fundamental research*, Paris, OECD Patents and Innovation Statistics Seminar, June 28-30, 1982.

COWARD, H.R. and J.J. FRANKLIN, *The interaction of science and technology: Exploring the relationship of a bibliometric model to patents*, Center for Research Planning, 1985.

NARIN, F., "Patents bibliometrics", *Scientometrics*, Vol. 30, No. 1, 1994, pp. 147-155.

NARIN, F., "Patents indicators for the evaluation of industrial research output", *Scientometrics*, Vol. 34, No. 3, 1995, pp. 489-496.

NARIN, F., M.P. CARPENTER and P. WOOLF, "Technological performance assessments based on patents and patent citations", *IEEE Transactions on Engineering Management*, EM-31, No. 4, 1984, pp. 172-183.

NARIN, F., E. NOMA and R. PERRY, "Patents as indicators of corporate technological strength", *Research Policy*, Vol. 16, 1987, pp. 143-155.

NAUWELAERS, C. and A. REIDS, "Methodologies for the evaluation of regional innovation potential", *Scientometrics*, Vol. 34, No. 3, 1995, pp. 497-511.

OECD, *Using patent data as science and technology indicators: Patent Manual 1994,* Paris, OECD, 1994.

PAVITT, K., "Patent statistics as indicators of innovative activities: Possibilities and problems", *Scientometrics*, Vol. 7, No. 1-2, 1985, pp. 77-99.

RABEHARISOA, V., A. SIGOGNEAU, and F. LAVILLLE, *Guide pratique pour l'utilisation des données sur les brevets comme indicateurs scientométriques*, Paris, OCDE, 1992.

SIMONETTI, R., *et al.*, "Product and process innovations: How are they defined? How are they quantified", *Scientometrics*, Vol. 32, No. 1, 1995, pp. 77-89.

SMITH, K., "Technological innovation indicators: Experience and prospects", *Science and Public Policy*, Vol. 19, No. 6, 1992, pp. 383-392.

TEITEL, S., "Patents, R&D expenditures, country size, and per-capita income: An international comparison", *Scientometrics*, Vol. 29, No. 1, 1994, pp. 137-159.

7.3 Citation and co-citation analysis

This subsection contains a list of documents dealing with citation and co-citation methods. Small and Garfield are pioneers of citation analysis. The papers by Small and Sweeney and by Small, Sweeney and Greenlee provide a good description of co-citation analysis. A few empirical studies using one or the other of these methods have been added to illustrate the many possible applications. The paper by Milman and Gavrilova deals with the study of one discipline. Nederhof *et al.* describe the use of citations for academic evaluation purposes. Wallmark and Sedig establish a comparison between citation analysis and peer judgment as evaluation tools. Much has been written about citation and co-citation analysis, because of the many possible applications and as a result of the many debates aroused by citation analysis. This short bibliography will provide interested readers with an overview.

GARFIELD, E., *Citation indexing: Its theory and application in science, technology, and humanities*, New York, Wiley, 1979.

GARFIELD, E. and A. WELLJAMS-DOROF, "Citations data: Their use as quantitative indicators for S&T evaluation and policy-making, *Science and Public Policy*, Vol. 19, No. 5, October 1992.

NARIN, F., *Evaluative bibliometrics: The use of publication and citation analysis in the evaluation of scientific activity*, Contract NSF C-627, National Science Foundation, March 31, 1976, Monograph: 456, NTIS Accession #PB252339/AS.

MILMAN, B.L. and Y.A. GAVRILOVA, "Analysis of citation and co-citation in chemical engineering", *Scientometrics*, Vol. 27, No. 1, 1993, pp. 53-74.

SMALL, H. and SWEENEY, E., "Clustering the Science Citation Index using co-citations: Part I. A comparison of methods", *Scientometrics*, Vol. 7, 1985, pp. 391-409.

SMALL, H., E. SWEENEY and GREENLEE, E., "Clustering the Science Citation Index using co-citations: Part II. Mapping science", *Scientometrics*, Vol. 8, 1985, pp. 331-340.

WADE, N., "Citation analysis: A new tool for science administrators", *Science*, Vol. 188, 1975, pp. 429-432.

WALLMARK, J.T. and K.G. SEDIG, "Quality of research measured by citation method and by peer review: A comparison", *IEEE Transactions on Engineering Management*, Vol. 33, No. 4, 1986.

7.4 Co-word analysis

Co-word analysis and co-citation analysis are both used to identify the dynamics of research areas. In both cases, results are most often presented in the form of maps. The first three papers in this list use both co-word analysis and co-citation analysis. The last four papers use only co-word analysis.

De BRUIN, R.E. and H.F. MOED, "Delimitation of scientific subfields using cognitive words from corporate addresses in scientific publications", *Scientometrics*, Vol. 26, No. 1, 1993, pp. 65-80.

CAMBROSIO, A., C. LIMOGES, J.P. COURTIAL and F. LAVILLE, "Historical scientometrics? Mapping over 70 years of biological safety research with co-word analysis", *Scientometrics*, Vol. 27, No. 2, 1993, pp. 119-143.

COURTIAL, J.P., "A co-word analysis of scientometrics", *Scientometrics*, Vol. 31, No. 3, 1994, pp. 251-260.

COURTIAL, J.P. and J. LAW, "A co-word study of artificial intelligence", (Notes & Letters), *Social Studies of Science*, Vol. 19, No. 2, pp. 301-311.

HINZE, S., "Bibliographical cartography of an emerging interdisciplinary discipline: The case of bioelectronics", *Scientometrics*, Vol. 29, No. 3, 1994, pp. 353-376.

Van RAAN, A.F.J. and R.J.W. TIJSSEN, "The neural net of neural network research: An exercise in bibliometric mapping", *Scientometrics*, Vol. 26, No. 1, 1993, pp. 169-192.

TIJSSEN, R.J.W. and A.F.J. van Raan, "Mapping co-word structures: A comparison of multidimensional scaling and Leximappe", *Scientometrics*, Vol. 15, No. 3-4, 1989, pp. 283-295.

ZITT, M. and BASSECOULARD, E., "Development of a method for detection and trend analysis of research fronts built by lexical or co-citation analysis", *Scientometrics*, Vol. 30, No. 1, 1994, pp. 333-351.

APPENDIX I -- Glossary

Citation: When a document A mentions a document B, document B is said to be cited as a source of information by document A. In this sense, all citations are derived from references. Whereas the term reference is applied to the source of information, the term citation emphasises the fact that a reference is cited or quoted. The concept of citation is therefore purely analytical.

Field of research:

A field of research is the set of research subjects brought together under one topic. Thus, a field of research can be interpreted as an aggregate of scientific journals that deal with related research topics, or that cite or quote each other. In the latter case, journal-to-journal citations are interpreted as an indicator of some affinity between the research subjects. A field of research is therefore a series of research projects dealing with interrelated subjects. A field of research is more or less consistent depending on the density of links between the research subjects.

Reference:

References are displayed in the footnotes and in the bibliography of a given document. The term reference is therefore applied exclusively to documents that another document uses as a source of information giving rise to a bibliographic description. The reference is part of the information contained in a document.

Institutional sector:

Generally speaking, science and technology policies recognise three main locations where research is carried out: universities, industry, and public laboratories. However, given the characteristics of the database of the *Observatoire des Sciences et des Technologies*, which includes the natural sciences, engineering, biology and medicine, the humanities as well as the arts, new sectors of activity had to be added in order to better reflect all the people involved in research in Canada. Such sectors correspond to types of institutions that can be grouped together in terms of analytical requirements. There are 16 types of institutions in the database. The definition of a sector of activity therefore includes one or several types of institution depending on the specific needs of analysis. Various groupings are used whenever the database is consulted.

APPENDIX II -- Specification of the database of the *Observatoire des Sciences et des Technologies*

A — Information sources

The database of *Observatoire des Sciences et des Technologies* was established using data from *Science Citation Index* (SCI), *Social Science Citation Index* (SSCI) and *Art & Humanities Citation Index* (AHCI).[38] It was established in four major steps: information gathering, information processing, data standardisation, and codification. The last two operations are what distinguish the database from other bibliographic databases available on the market.

The initial step was used to retrieve all documents having the word "Canada" in the address of publications covered by SCI, SSCI and AHCI for the years 1995 and 1996. These databases, produced by the *Institute for Scientific Information* (ISI), are available in hard copy, on compact disc (CD-ROM) and on line. They are all annual databases that are updated regularly, i.e. monthly for the on line version, and quarterly for the compact discs. The CD-ROM version was used to establish the database of Canadian authors.

Each of these databases covers several fields of scientific output. Thus, SCI covers all the areas of natural science, engineering, biology and medicine. SCI, available on CD-ROM since 1973,[39] includes each year between 3,500 and 4,000 scientific journals considered among the most representative of the literature.[40] The SSCI database is also available as of 1973; it regularly covers over 1,400 journals. To this must be added 3,100 journals in the natural sciences which are reviewed on a selective basis.[41] The AHCI database, started in 1978, covers publications in the arts and humanities, and indexes approximately 7,100 important journals, including about 1,400 which are fully indexed and 5,700 (from SCI and SSCI) which are indexed selectively.[42] All types of documents covered by ISI are included in the database. Overall, the database of Canadian authors contains 24 types of documents from the three sources of information. Table A indicates the types of documents covered by each database.

After the ISI data were gathered, the names of Canadian institutions contained in the addresses were standardised. This was done because the information contained on the ISI discs included errors and significant variations.[43] Thus, McGill University was recorded in three different ways: McGILL-

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[38] The data were selected on the basis of the year of publication and not on that of the year of the databases used.

[39] A retrospective version is available in hard copy going back to 1945.

[40] E. Garfield, "How ISI selects journals for coverage: Quantitative and qualitative considerations", *Current Contents*, No. 22, May 28, 1990.

[41] E. Garfield, "How to use the Social Sciences Citation Index", *Current Contents*, Vol. 27, No. 12-13, July 2, 1984.

[42] *Arts & Humanities Citation Index Journal Citation Report*, Philadelphia, Institute for Scientific Information Inc., 1995.

[43] A discussion of errors in the addresses will be found in R.E. de Bruin and H.F. Moed, "The unification of addresses in scientific publications", in L. Egghe and R. Rousseau (Eds), *Informatrics 89/90*, Amsterdam, Elsevier Science Publishers B.V., 1990, 65-78. J. Anderson, *et al.*, "On-Line approaches to measuring national scientific output: A cautionary tale", *Science and public policy*, Vol. 15, No. 3, 1988, 53-161. L. Leydesdorff, "Problems

UNIV, UNIV-McGILL and McGILLL-UNIV, the latter probably as a result of erroneous data entry. Consequently, standardisation brought about a reduction of the 4,524 Canadian institutions in the

Table A — Types of documents, Canadian authors in 1995

Types / sources	*SCI*	*SSCI*	*AHCI*	Total	%
article	22,997	3,891	1,129	28,017	66.4
meeting-abstract	3,851	812	4	4,667	11.1
book-review	3	1,397	2,183	3,583	8.5
note	2,015	198	34	2,247	5.3
letter	1,148	105	23	1,276	3.0
review	870	160	55	1,085	2.6
editorial-material	646	39	23	708	1.7
editorial	0	145	31	176	0.4
discussion	127	11	5	143	0.3
correction	82	3	1	86	0.2
poetry	0	0	56	56	0.1
biographical-item	27	10	15	52	0.1
bibliography	3	1	12	16	0.0
software-review	4	8	1	13	0.0
reprint	8	0	1	9	0.0
music-score-review	0	0	6	6	0.0
record-review	0	0	5	5	0.0
fiction	0	0	5	5	0.0
news-item	3	0	1	4	0.0
art-exhibit-review	0	0	4	4	0.0
excerpt	0	0	3	3	0.0
film-review	0	0	3	3	0.0
hardware-review	0	1	1	2	0.0
database-review	0	0	1	1	0.0
TV/radio-review	0	0	0	0	0.0
theatre-review	0	0	0	0	0.0
Total	31,784	6,781	3,602	42,167	100.0

Source: *Observatoire des sciences et des technologies* (CIRST).

addresses to 2,839 institutions in the database, i.e. a decrease of 37%. This procedure ensured that each institution was identified correctly under a single title. Errors caused by incorrect addresses can affect the results, and therefore the evaluation of national performance. The quality of an evaluation depends in part on the quality of the bibliometric data.

with the 'measurement' of national research performance", *Science and public policy*, Vol. 15, No. 3, June 1988, 149-152.

The database of the *Observatoire des Sciences et des Technologies* can also be used to identify the sector of activity (university, hospital, province, industry, other) to which the authors of a publication belong. These sectors were identified on the basis of the standardised addresses of the publications themselves. Thus, 99.3% of the publications were linked to a type of institution. Table B lists the 16 categories of institutions.

Three sources were used to identify disciplines and areas of specialisation. For articles from SCI, the classification of disciplines established by Computer Horizon Incorporated (CHI) was used. This classification includes 9 fields and 106 subfields. As for the arts, humanities and social sciences, the classification used was that proposed by ISI. A list of CHI and ISI classifications will be found in Appendix III.

Once the types of institutions have been identified, it is possible to provide detailed analyses of their scientific activities and of their interrelationships. This type of analysis can also be applied to specific industrial sectors, since industries can be linked to a standard industrial classification codes (SIC).

Table B — Categories of institutions in the database of Canadian authors

Sector	Type of institution
1. University:	university
2. Hospital:	hospital veterinary hospital
3. Government:	federal government municipal or regional government provincial government
4. Industry:	private enterprise, industry
5. Other:	library college school church art gallery museum orchestra and music theatre other

Likewise, the data on cities, provinces and countries found in the addresses can be used to analyse scientific activity in a given administrative region.

B — Database structure

The documentation on a database is not complete unless the structure of the information it contains has been described in detail. This section provides a general overview of the database of the *Observatoire des Sciences et des Technologies*. It includes all three files and their contents.

The database was given a relational structure. The operating principle is fairly simple. The information is classified by segments, in several specialised files. Data reconstruction requires that a link be established between the different files. This link is provided by a common key for all files. Thus, the database includes three files. The article file contains complete bibliographic data for all the documents. This central file is complemented by two other files: the author file and the address file. A document number common to all files is the key to data reconstruction for a given document. Each file operates individually, but together they form a whole. The diagram in Figure A shows how the information contained in the database is structured, as well as the relationships between the different files.

Figure A — How a relational database operates

ARTICLE FILE

Document number
Title of article
Name of journal **Discipline** **Impact factor**
Volume
Issue
Starting page
Final page
Language
Type of document
Total number addresses
Total number authors
Total number citations

AUTHOR FILE

document number
author #1
author #2
author #n

ADDRESS FILE

document number
address
name of institution **institution** **SIC code**
city **regional code**
province
country

The article file comprises 12 searchable fields. This file contains complete information on the bibliographic reference of each document. The entry number for the database is the document number. This is also the key that identifies the document in all three files. The article file also provides the title of the document. In the case of a journal article, for example, the entry contains the title of the article, the title of the journal in which the article was published, the volume and issue of the journal, as well as the starting page and the final page of the article. The article file also shows the total number of authors, the total number of addresses, as well as the total number of references linked to the document. This type of information is included as a guide. Detailed information is provided in the address file and the author file.

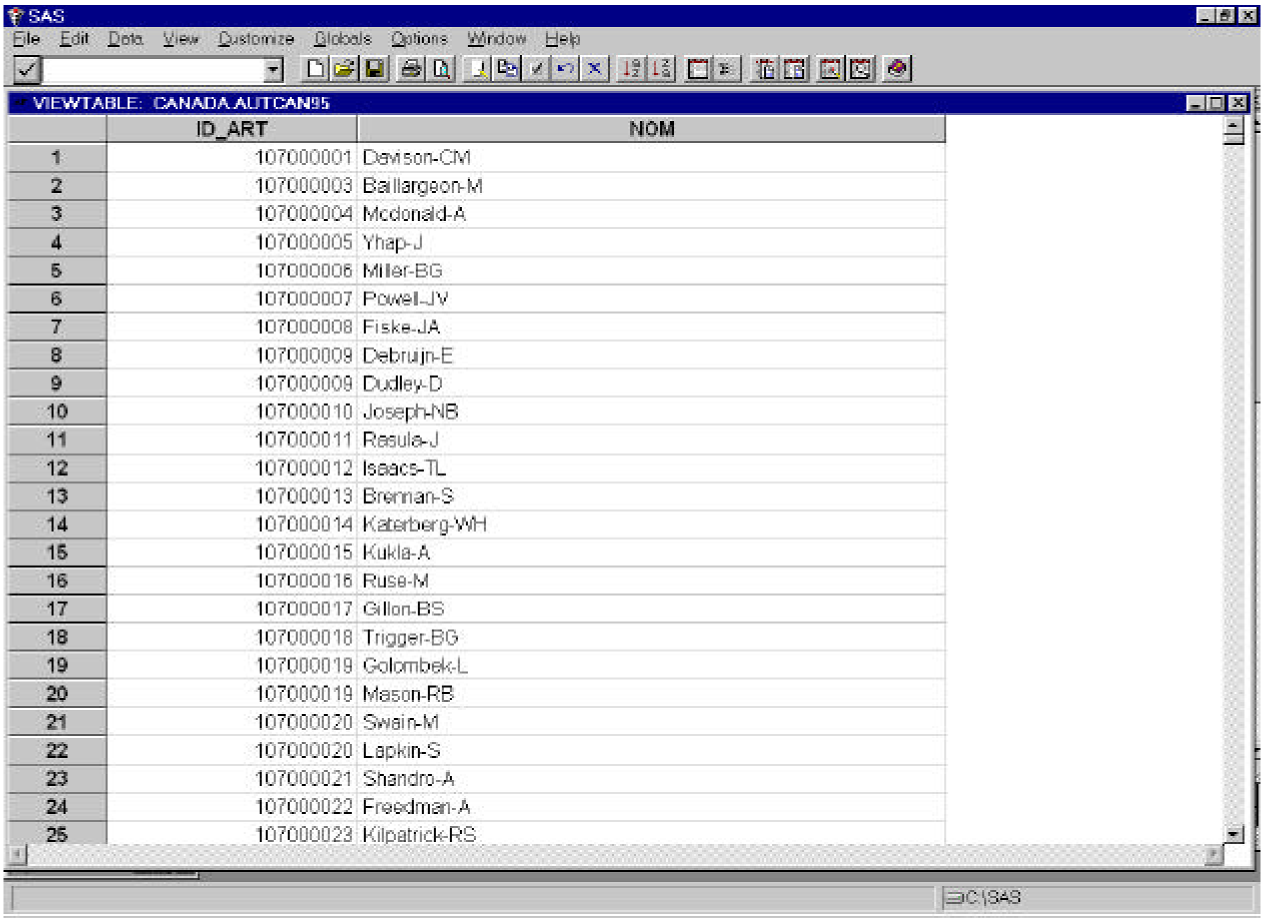
Figure B — Sample entry of the article file

SAS — VIEWTABLE: CANADA.ARTCAN95

	REVUE	ANNEE	VOLUME	NUMERO	DEB_PAGE	FIN_PAGE	LANGUE	TYPE_DOC	TITRE1	NBADRES	NBAUTEUR
18612	NATURE	1995	376	6541	596	599	English	Article	An Irf-1-Dependent Pathway of	5	10
18613	NATURE	1995	376	6540	486	490	English	Article	The Variable Effect of Clouds on	3	3
18614	NATURE	1995	376	6539	415	417	English	Article	Size and Structure of the	3	5
18615	NATURE	1995	376	6539	424	427	English	Article	Distinguishable Functions for	2	4
18616	NATURE	1995	376	6539	444	447	English	Article	Sequestration of the	3	5
18617	NATURE	1995	376	6537	240	243	English	Article	Latitudinal Gradient of	3	3
18618	NATURE	1995	376	6535	37	43	English	Article	Identification and Inhibition of the	6	16
18619	NATURE	1995	376	6535	62	66	English	Article	Failure of Blood-Island Formation	6	7
18620	NATURE	1995	376	6535	66	70	English	Article	Role of the Flt-1 Receptor	2	4
18621	NATURE	1995	375	6534	754	760	English	Article	Cloning of a Gene Bearing	21	33
18622	NATURE	1995	375	6533	670	674	English	Article	Archean Subduction Inferred from	4	4
18623	NATURE	1995	375	6530	411	415	English	Article	Herpes-Simplex Virus Turns Off	3	8
18624	NATURE	1995	375	6530	427	431	English	Article	Ice-Binding Structure and	2	2
18625	NATURE	1995	375	6528	241	244	English	Article	Spontaneous Resistance to Acute	5	10
18626	NATURE	1995	375	6527	131	134	English	Article	Observational Evidence for	12	15
18627	NATURE	1995	375	6527	134	137	English	Article	Archean Cratonic Roots, Mantle	6	6
18628	NATURE	1995	375	6526	61	64	English	Article	Defective Axonal-Transport in a	1	3
18629	NATURE	1995	375	6526	84	87	English	Article	Allosteric Transition Intermediates	3	5
18630	NATURE	1995	374	6523	617	622	English	Article	Glycogen-Synthase Kinase-3 and	3	5
18631	NATURE	1995	374	6522	566	569	English	Article	RPA Involvement in the	3	4
18632	NATURE	1995	374	6521	474	477	English	Article	Defective T-Cell Receptor	5	6
18633	NATURE	1995	374	6521	477	479	English	Article	Direct Demonstration of an	5	6
18634	NATURE	1995	374	6517	68	69	English	Article	Immunological Function of a	2	2
18635	NATURE	1995	373	6514	512	515	English	Article	Mating Cost of Large Floral	2	2
18636	NATURE	1995	373	6512	347	349	English	Article	W/Kit Gene Required for	4	6
18637	NATURE	1995	373	6511	223	225	English	Article	Large-Size of Lyman-Alpha Gas	4	5
18638	NATURE	1995	373	6511	239	241	English	Article	Unexpected Patterns of Parentage	2	3
18639	NATURE	1995	373	6510	130	132	English	Article	Friction Melt Distribution in a	1	2
18640	NATURE	1995	373	6510	138	139	English	Article	Effect of Bed Morphology on Flow	1	2

The author file includes three fields, and the key field. This file shows the names of all authors for each document, as well as each of the addresses.

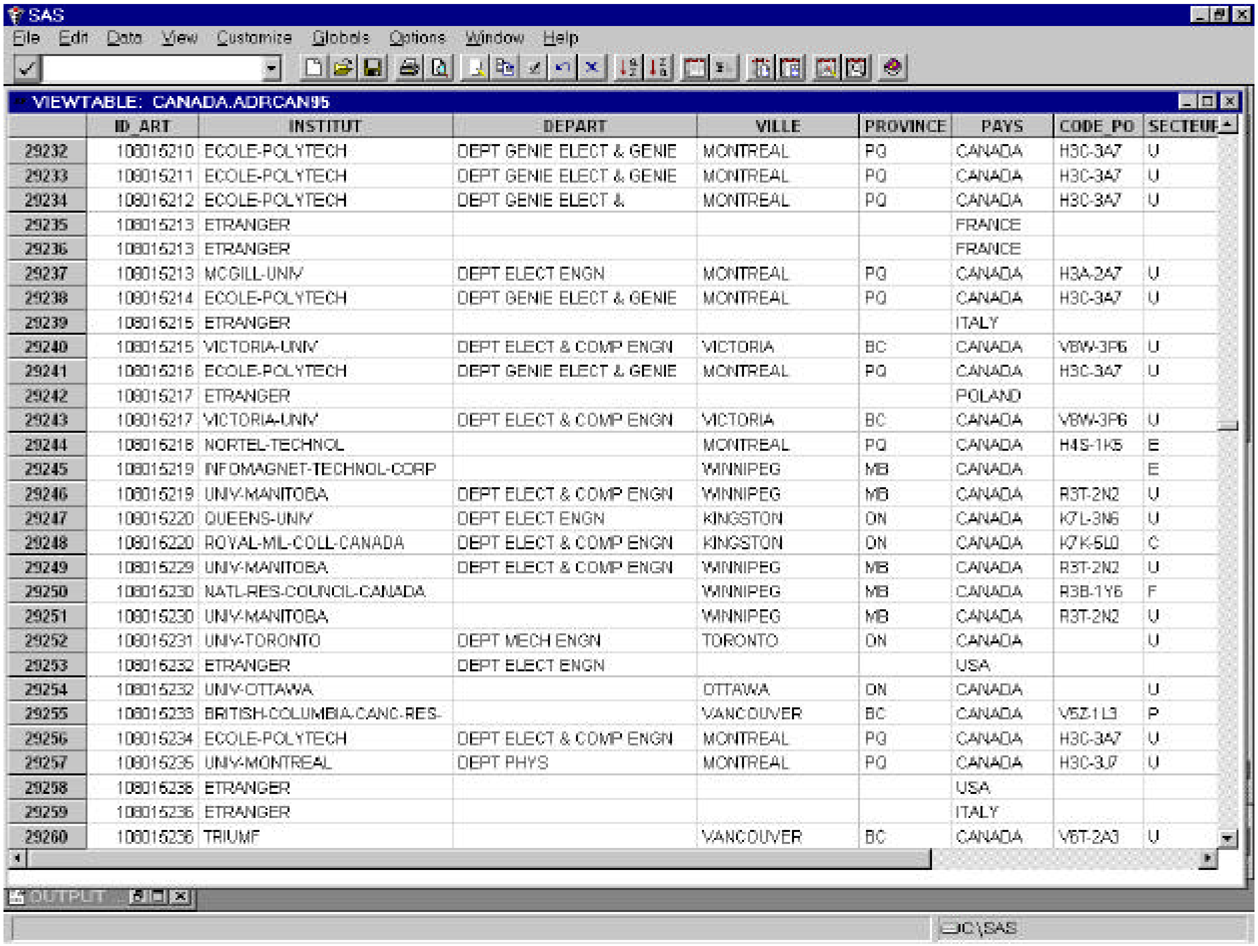
Figure C — Sample entry of the author file



	ID_ART	NOM
1	107000001	Davison-CM
2	107000003	Baillargeon-M
3	107000004	Mcdonald-A
4	107000005	Yhap-J
5	107000006	Miller-BG
6	107000007	Powell-JV
7	107000008	Fiske-JA
8	107000009	Debruijn-E
9	107000009	Dudley-D
10	107000010	Joseph-NB
11	107000011	Rasula-J
12	107000012	Isaacs-TL
13	107000013	Brennan-S
14	107000014	Katerberg-WH
15	107000015	Kukla-A
16	107000016	Ruse-M
17	107000017	Gillon-BS
18	107000018	Trigger-BG
19	107000019	Golombek-L
20	107000019	Mason-RB
21	107000020	Swain-M
22	107000020	Lapkin-S
23	107000021	Shandro-A
24	107000022	Freedman-A
25	107000023	Kilpatrick-RS

The address file contains a list of all the addresses linked to each document. The information has been standardised for all Canadian institutions. The address is used to encode the type of institution, the city, the administrative region, the province, as well as the country of origin of the authors who worked on the document.

Figure D — Sample entry of the address file



	ID_ART	INSTITUT	DEPART	VILLE	PROVINCE	PAYS	CODE_PO	SECTEUR
29232	108015210	ECOLE-POLYTECH	DEPT GENIE ELECT & GENIE	MONTREAL	PQ	CANADA	H3C-3A7	U
29233	108015211	ECOLE-POLYTECH	DEPT GENIE ELECT & GENIE	MONTREAL	PQ	CANADA	H3C-3A7	U
29234	108015212	ECOLE-POLYTECH	DEPT GENIE ELECT &	MONTREAL	PQ	CANADA	H3C-3A7	U
29235	108015213	ETRANGER				FRANCE		
29236	108015213	ETRANGER				FRANCE		
29237	108015213	MCGILL-UNIV	DEPT ELECT ENGN	MONTREAL	PQ	CANADA	H3A-2A7	U
29238	108015214	ECOLE-POLYTECH	DEPT GENIE ELECT & GENIE	MONTREAL	PQ	CANADA	H3C-3A7	U
29239	108015215	ETRANGER				ITALY		
29240	108015215	VICTORIA-UNIV	DEPT ELECT & COMP ENGN	VICTORIA	BC	CANADA	V8W-3P6	U
29241	108015216	ECOLE-POLYTECH	DEPT GENIE ELECT & GENIE	MONTREAL	PQ	CANADA	H3C-3A7	U
29242	108015217	ETRANGER				POLAND		
29243	108015217	VICTORIA-UNIV	DEPT ELECT & COMP ENGN	VICTORIA	BC	CANADA	V8W-3P6	U
29244	108015218	NORTEL-TECHNOL		MONTREAL	PQ	CANADA	H4S-1K5	E
29245	108015219	INFOMAGNET-TECHNOL-CORP		WINNIPEG	MB	CANADA		E
29246	108015219	UNIV-MANITOBA	DEPT ELECT & COMP ENGN	WINNIPEG	MB	CANADA	R3T-2N2	U
29247	108015220	QUEENS-UNIV	DEPT ELECT ENGN	KINGSTON	ON	CANADA	K7L-3N6	U
29248	108015220	ROYAL-MIL-COLL-CANADA	DEPT ELECT & COMP ENGN	KINGSTON	ON	CANADA	K7K-5L0	C
29249	108015229	UNIV-MANITOBA	DEPT ELECT & COMP ENGN	WINNIPEG	MB	CANADA	R3T-2N2	U
29250	108015230	NATL-RES-COUNCIL-CANADA		WINNIPEG	MB	CANADA	R3B-1Y6	F
29251	108015230	UNIV-MANITOBA		WINNIPEG	MB	CANADA	R3T-2N2	U
29252	108015231	UNIV-TORONTO	DEPT MECH ENGN	TORONTO	ON	CANADA		U
29253	108015232	ETRANGER	DEPT ELECT ENGN			USA		
29254	108015232	UNIV-OTTAWA		OTTAWA	ON	CANADA		U
29255	108015233	BRITISH-COLUMBIA-CANC-RES-		VANCOUVER	BC	CANADA	V5Z-1L3	P
29256	108015234	ECOLE-POLYTECH	DEPT ELECT & COMP ENGN	MONTREAL	PQ	CANADA	H3C-3A7	U
29257	108015235	UNIV-MONTREAL	DEPT PHYS	MONTREAL	PQ	CANADA	H3C-3J7	U
29258	108015236	ETRANGER				USA		
29259	108015236	ETRANGER				ITALY		
29260	108015236	TRIUMF		VANCOUVER	BC	CANADA	V6T-2A3	U

APPENDIX III – Classification of scientific disciplines

Discipline : Biology
- Agricult & food sci
- Botany
- dairy & animal sci
- Ecology
- Entomology
- General biology
- General zoology
- Marine bio & hydrobi
- Miscellaneous biol
- Miscellaneous zool

Discipline : Biomedical research
- Anatomy & morphology
- Biochem & molec biol
- Biomedical enginrng
- Biophysics
- cell biol cyt & hist
- Embryology
- Genetics & heredity
- genrl biomedical res
- Microbiology
- Microscopy
- misc biomedical res
- Nutrition & dietet
- Parasitology
- Physiology
- Virology

Discipline : Chemistry
- Analytical chemistry
- Applied chemistry
- General chemistry
- Inorganic & nucl chm
- Organic chemistry
- Physical chemistry
- Polymers

Discipline : Clinical medicine
- Personality & soc ps
- Addictive diseases
- Allergy
- Anesthesiology
- Arthritis & rheumat
- Behavioral science
- Cancer
- Cardiovascular systm
- Clinical psychology
- Dentistry
- Dermat & venerl dis
- Devel & child psycho
- Endocrinology
- Experimental psychol
- Fertility
- Gastroenterology
- General psychology
- Genrl & internal med
- Geriatrics
- Hematology
- Hygiene & publ hlth
- Immunology
- Misc clinical med
- Misc psychology
- Nephrology
- Neurol & neurosurg
- Obstetrics & gynecol
- Ophthalmology
- Orthopedics
- Otorhinolaryngology
- Pathology
- Pediatrics
- Pharmacology
- Pharmacy
- Psychiatry
- Radiology & nucl med
- Respiratory system
- Surgery
- Tropical medicine
- Urology
- Veterinary medicine

Discipline : Earth and space
- astronmy & astrophys
- earth & plantry sci
- environmental sci
- geography
- geology
- meteorol & atmos sci
- oceanography & limno

Discipline : Engineering & techn
- aerospace technology
- chemical engineering
- civil engineering
- computers
- electr eng & elctron
- general engineering
- industrial engineer
- library & info sci
- materials science
- mechanical engineer
- metals & metallurgy
- misc eng & technol
- nuclear technology
- op res & managmt sci

Discipline : mathematics
- applied mathematics
- general mathematics
- misc mathematics
- probablty & statist

Discipline : Physics
- acoustics
- applied physics
- chemical physics
- fluids & plasmas
- general physics
- miscellaneous phys
- nucl & particle phys
- optics
- solid state physics

APPENDIX IV – Classification of disciplines in humanities, social sciences, arts and literature

Discipline: Anthropology
- Anthropology
- Ethnology
- Folklore

Discipline: Archeology
- Archeology

Discipline: Arts & humanities
- Arts and humanities, in general

Discipline: Others
- Demography
- Environment
- Family studies
- Mathematical methods in the social sciences
- Interdisciplinary social sciences
- Substance abuse
- Transportation
- Environmental studies
- Asiatic studies
- Women's studies

Discipline: Fine Arts
- Architecture
- Art
- Dance
- Music
- Theatre

Discipline: Library science
- Information science & library science

Discipline: Communications
- Communications

Discipline: Law
- Criminology and penology
- Law

Discipline: Geography, development and urban studies
- Geography
- Planning and development
- Regional studies
- Urban studies

Discipline: History
- History
- History of the social sciences
- History and philosophy of science

Discipline: Linguistics
- Linguistics
- Language and linguistics

Discipline: Literature
- Classics
- Literary Review
- Literature, British Isles
- Literature, Romance
- Literature
- African, Canadian, Australian literature
- American literature
- German, Scandinavian, Dutch literature
- Slavic literature
- Poetry

Discipline: Philosophy
- Philosophy

Discipline: Psychiatry
- Psychiatry

Discipline: Psychology
- Psychology
- Applied psychology
- Clinical psychology
- Developmental psychology
- Experimental psychology
- Mathematical psychology
- Social psychology
- Psychology, biology
- Psychology, psychoanalysis
- Psychology, education

Discipline: Health
- Ergonomics
- Geriatrics and gerontology
- Health policy & services
- Nursing
- Forensic medicine
- Clinical neurology
- Rehabilitation
- Public health
- Biomedical social sciences

Discipline: Political sciences
- International relations
- Political science

Discipline: Administrative sciences
- Public administration
- Business
- Business Finance
- Management
- Industrial and labour relations

Discipline: Religious sciences
- Religion

Discipline: Sociology
- Social issues
- Sociology

Discipline: Social work
- Social work

Discipline: Economics
- Economics

Discipline: Education
- Education
- Special education
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