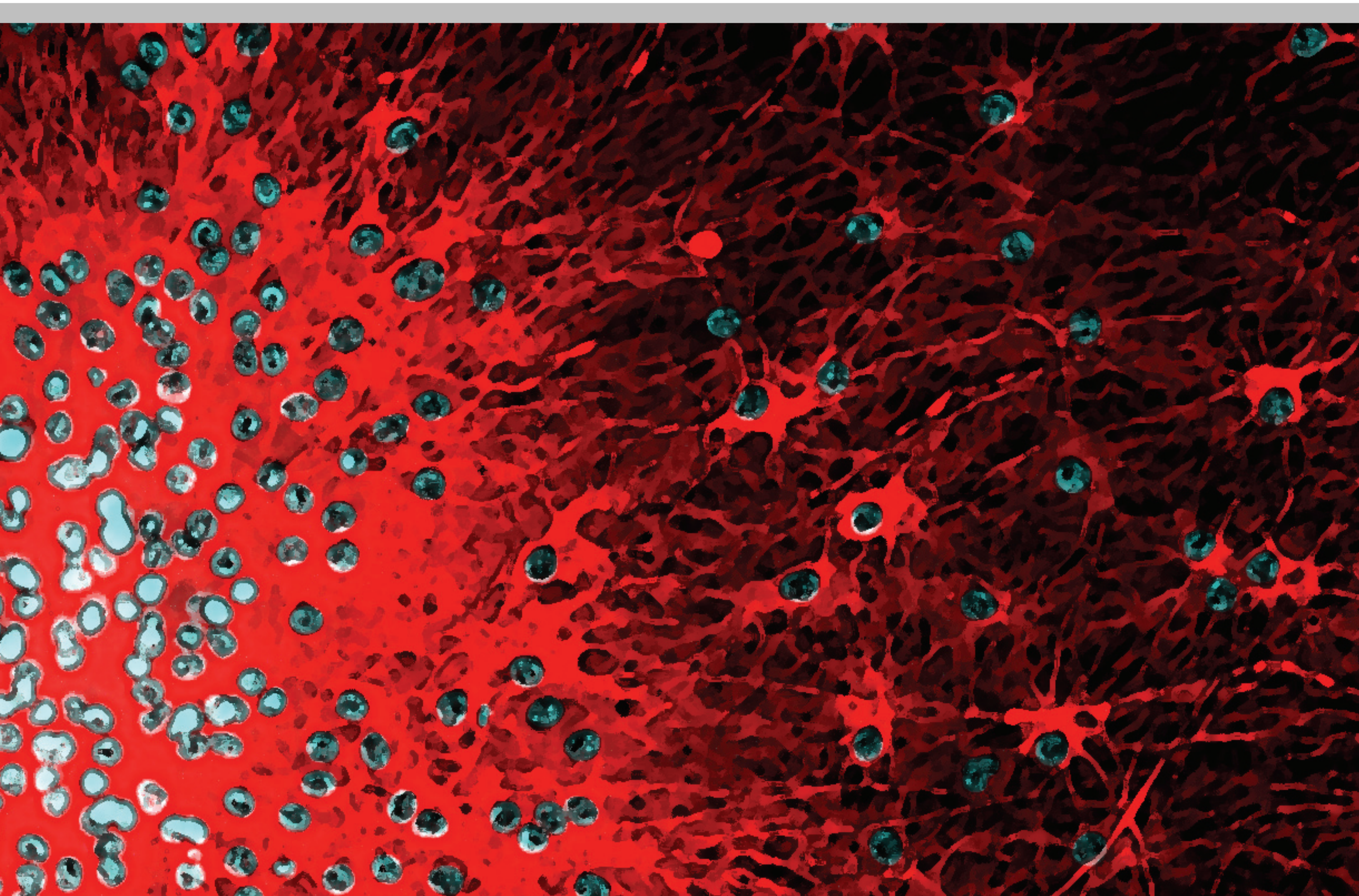
# Bibliometric Analysis of National Cancer Institute of Canada–Supported Research



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# Bibliometric Analysis of National Cancer Institute of Canada–Supported Research

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# Executive Summary

The National Cancer Institute of Canada (NCIC) supports cancer research across the country through funds from two charitable organizations: the Canadian Cancer Society and the Terry Fox Foundation. By doing so, the NCIC aims to foster the creation of knowledge that will help to reduce the incidence, morbidity, and mortality rates in connection with cancer. As it is accountable to the public for the value it creates through research, the institute undertook an evaluation of its Operating and Program Project Grants in 2005 as part of its 2015 Strategic Plan. As part of this evaluation, the NCIC is seeking data on the calibre of the research it has supported.

Accordingly, Science-Metrix and the Observatoire des Sciences et des Technologies (OST) quantified the scientific output of the NCIC's successful applicants between 1994 and 2006, while they were being supported ("NCIC-supported papers") and also while they were not receiving support ("non-supported papers"). The output of NCIC-supported researchers was also benchmarked against those of Canadian researchers as a whole and of researchers funded by the US National Cancer Institute (NCI), using five bibliometric indicators of scientific performance: number of papers, average of relative citations (ARC), number of papers in the 5% most cited papers, average of relative impact factors (ARIF), and specialization index (SI). Following are the key findings, presented by comparator group.

## NCIC-Supported Papers versus Non-Supported Papers by NCIC Researchers

- Just over half of the scientific papers produced by NCIC-supported researchers were published while they were financially supported by the NCIC (12,244 out of 22,793 papers).
- The scientific impact of NCIC-supported papers, as indicated by the average of relative citations and the proportion of published papers that are in the 5% most cited papers, is significantly higher than that of non-supported papers.
- When considering only the papers by NCIC awardees that were published in scientific journals dealing specifically with cancer research, the impact of their papers when they were supported by the NCIC was generally (for 10 out of 13 years) higher than when they were not supported, and the difference was significant.

## Output of NCIC-Supported Researchers versus that of Canada

- Researchers who were supported by the NCIC at any one time have a substantially higher scientific impact—as measured by the average of relative citations and the proportion of published papers that are in the 5% most cited papers—than Canadian researchers who themselves score above the world average (the difference is always highly significant, whether the comparison involved NCIC-supported papers, non-supported papers, or all papers by NCIC researchers).
- Researchers who received funding from the NCIC during the period analysed (1994–2006) made an important contribution to Canada's scientific production in the subfield of cancer research. These researchers authored nearly half of Canadian papers published in cancer-related journals, and about one quarter of Canadian papers in these journals with support from the NCIC (i.e., one year after the start of the grant until one year after the end of the grant).
- In cancer-specific journals, the scientific impact of papers by NCIC researchers was slightly higher than that of Canadian papers from 1994 to 2006, and the difference was highly significant whether the comparison involved NCIC-supported papers, non-supported papers, or all papers by NCIC researchers.

- Considering that the scientific impact of NCIC researchers is significantly higher than that of Canada, which itself ranks in 2nd place among the G7 countries for scientific impact in cancer research, it is obvious that researchers funded by the NCIC are of a high calibre.

## NCIC-Supported Researchers versus NCI-Supported Researchers

- Compared to researchers funded by the NCI, NCIC-supported researchers produced, on average, nearly as many papers annually from 2000 to 2006 despite receiving about five times less funding per researcher (considering only financial support from the NCI and the NCIC).
- On the other hand, NCI researchers published papers that, on average, have had greater impact on the scientific community than those published by NCIC researchers, as measured by citations.
- The difference in volume of the scientific output of NCIC- and NCI-supported researchers is more pronounced when considering only papers published in cancer-related journals because NCI researchers published 22% of their papers in these journals, compared to 17% in the case of NCIC researchers.
- When looking only at papers published in cancer-related journals, NCI-supported papers had even higher scientific impact than NCIC papers than when all papers by both groups are considered
- The main subfields in which NCIC- and NCI-funded researchers pursue investigations include cancer and biochemistry research. While NCI researchers are more active and have a higher impact in cancer research than in biochemistry, the opposite is true for NCIC researchers.
- For both the NCI and the NCIC, a small fraction of funded researchers are responsible for most of the papers published with their support. For example, the most active third of NCIC-supported researchers produced 65% of the NCIC-funded output, compared to 73% in the case of the most active third of researchers with NCI grants.

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# Table and Figures

# 1 Introduction

The National Cancer Institute of Canada (NCIC) was established in 1947, owing to a joint initiative of the Department of National Health and Welfare (now named Health Canada) and the Canadian Cancer Society (see: http://www.ncic.cancer.ca). Since 1988, the main goal set forth by the NCIC's Board of Directors has been:

> To undertake and support cancer research and related programs in Canada that will lead to the reduction of the incidence, morbidity and mortality from cancer.

Among the various actions undertaken by the NCIC to achieve this mission, the support of cancer research through grants plays a pivotal role. By funding research that addresses the entire range of cancer-related issues—from investigations into the causes of cancer and potential treatments, to studies that may help reduce the burden on the health system and the quality of life of people living with cancer—the NCIC directly fuels its other endeavours, which consist of but are not limited to:

- supporting the training of highly qualified personnel; and
- disseminating information related to cancer research and cancer control.

As the funds awarded by the NCIC are raised exclusively through donations, the institute recognizes that it is accountable to the public for the value it creates through research. Thus, the NCIC launched an evaluation of its Operating and Program Project Grants in 2005 as part of its 2015 Strategic Plan (see: http://www.ncic.cancer.ca/vgn/images/portal/cit_86751114/1/34/530236530ncic_strategic_plan_en.pdf). So far, the NCIC has conceptualized and implemented an assessment of its awarding process scrutinizing both the application and review of proposals. This has involved surveying both applicants (successful and unsuccessful) and members of the peer review panels. To supplement this evaluation, Science-Metrix and the Observatoire des Sciences et des Technologies (OST) have been mandated to provide performance measurements of the scientific research supported by the NCIC.

The results of scientific research in the natural sciences and engineering (NSE, including the health sciences) are mainly disseminated through the publication of peer-reviewed papers in scientific journals (Larivière *et al.*, 2006; Leydesdorff, 2003). Consequently, the scientific performance of NCIC-supported research is best assessed through the use of bibliometrics, a set of methods and procedures used in the quantification of bibliographic records (basic units of measurement are bibliographic records of peer-reviewed publications).

Initially developed by information scientists, bibliometrics is now being applied more frequently to the field of research evaluation as accountability for public spending in research is increasingly recognised as a crucial issue by governing bodies (King, 1987). In addition, bibliometric indicators, because they rest on a set of internationally recognized standards, are by far the most reliable measures of academic research outputs. Within an evaluative context, bibliometric analysis must include comparables of the assessed entity to allow for conclusions to be drawn about its relative strengths and weaknesses. In this study, the US National Institute of Health's National Cancer Institute (NIH-NCI) was chosen as the comparator group for the NCIC.

Bibliometric evaluation usually makes use of a variety of indicators to draw the most complete picture possible of the complex aspects that account for the performance of research organizations. The bibliometric indicators presented in this study provide information on the size, growth, impact, and relative effort in specific scientific areas of NCIC-supported researchers compared to Canadian and NCI-supported researchers.

The next section presents greater detail on the methods used in this report. Section 3 compares the output of NCIC-funded researchers with that of Canada as a whole (i.e., papers with at least one author with a Canadian address, excluding papers by NCIC researchers) and, subsequently, compares their output during the periods when they *are* and when they *are not* supported by the NCIC. Note that in the following text, papers written with NCIC support are called “NCIC-supported papers” whereas all other papers written by NCIC researchers are called “non-supported papers” (see Section 2.2.1 for details). This analysis extends over 13 years worth of NCIC Operating and Program Project Grants (1994–2006). Section 4 presents a comparative analysis of the population of NCIC-funded researchers with a paired sample of researchers (random selection) funded by the NCI. As only data on researchers receiving NCI grants after 2000 are available, the analysis is limited to the 2000–2006 period.

# 2 Methods

The selection of the bibliographic databases for the constitution of the datasets used in producing reliable indicators of scientific production for NCIC-funded applicants (core dataset) and NCI-funded applicants (benchmark dataset) is discussed in Section 2.1. Section 2.2 addresses the construction of these datasets in detail, while Section 2.3 presents the taxonomy used in determining the domains of activity of NCIC and NCI researchers. The bibliometric indicators used to quantify scientific outputs are detailed in Section 2.4, while the statistical analysis performed on bibliometric indicators is presented in Section 2.5. Finally, Section 2.6 discusses the limitations of bibliometric methods.

## 2.1 Databases

Access to a database containing the most complete bibliographic information on scientific serials published worldwide is essential for the gathering of bibliometric data. In this study, Thomson Reuters' Web of Science (WoS), which includes three databases (the *Science Citation Index Expanded™* [SCI Expanded], the *Social Sciences Citation Index™*, and the *Arts & Humanities Citation Index™*) covering various fields of science (e.g., NSE, social sciences and humanities [SSH]) was used to produce statistics on the scientific production of NCIC researchers and their comparables. Although the vast majority of papers relevant to their area of practice (i.e., cancer research) are indexed in SCI Expanded, using all of WoS allowed for the retrieval of additional papers in other areas of interest, such as the socioeconomics of cancer.

The WoS was chosen because it indexes some 9,000 of the world's most cited refereed journals (i.e., about 1,500,000 peer reviewed scientific documents each year), which are generally regarded by the scientific community as the most renowned and reliable journals available in their respective fields. Furthermore, unlike Medline, the WoS lists the cited references of each document it includes (e.g., articles, chapters published in journals or book series). This permits the analysis of the scientific impact of publications based on citation counts and the impact factor (see: http://scientific.thomsonreuters.com/free/essays/journalcitationreports/impactfactor). Also, compared to databases that only provide the address of the first author of a publication (e.g., Medline), the WoS includes all authors and their institutional affiliations, which allows collaboration rates between various entities (e.g., countries, institutions, and researchers) to be analysed. Scopus®, which is a database produced by Elsevier, could also have been used. However, as neither organization involved in this project (i.e., Science-Metrix and OST) possessed a license from Elsevier to produce bibliometric data using Scopus at the time this project was initiated, this option was not available.

Although the WoS lists several types of documents, only articles, research notes, and review articles were retained in producing the bibliometric indicators, as these are considered to be the main types of documents through which new knowledge is disseminated in the NSE. In addition, all of these documents have been subject to peer review prior to being accepted for publication, ensuring that the research is of good quality and constitutes an original and robust contribution to scientific knowledge. In this report, articles, notes and reviews are collectively referred to as papers.

## 2.2 Constitution of Datasets

This section details how the core (NCIC, Section 2.2.1) and benchmark (NCI, Section 2.2.2) datasets were produced.

### 2.2.1 Constitution of the Core Dataset: NCIC-Funded Applicants

A bibliometric dataset for an institution is usually built by retrieving papers in which the name of the institution is found in the authors' addresses. Because the NCIC is an organisation that supports research as opposed to a research institute per se, its name is not expected to be found in the address field of papers published by the researchers it funds. This makes it virtually impossible to know precisely which papers were produced with financial support from the NCIC. As a result, to build a dataset of NCIC-supported papers, a publication portfolio had to be reconstituted for each researcher who received funding from the NCIC.

The construction of the dataset followed a two-part process. First, the NCIC provided a list of principal investigators (PI) who were awarded operating and program project grants over the last decade (685 PIs). The names of these researchers where then used in an automatic query to retrieve their scientific output that is indexed in the WoS. Second, to avoid overestimates created by homograph problems, each researcher's paper portfolio was manually cleaned to remove false positives (i.e., papers belonging to another researcher with the same surname and initials). A similar procedure was used to reconstitute the publication portfolio of NCI-funded researchers (Section 2.2.2).

#### Automatic Querying

Before executing the automatic retrieval of papers by NCIC researchers, the names as they appear in the NCIC's list were transformed to match the format of author names in the WoS. Author names in the WoS do not include the first name of the authors, only their initials. For example, "John W. Smith" is transformed into "Smith-JW" and also into "Smith-J". The latter form ensures that publications wherein the middle name (or its initial) is omitted are retrieved. Subsequently, the formatted names are queried against the database to retrieve, for each researcher, all of the papers bearing his/her name as an author between 1994 and 2006. The search is limited to papers bearing a Canadian address to minimize the occurrence of false positives resulting from homographs in researchers' names.

Due to the prevalence of homograph problems, the automatic query overestimates the number of publications in many paper portfolios, especially for researchers with a common surname (e.g., Smith). Moreover, the occurrence of these problems is increased by two limitations of the WoS database:

- it includes only the initials of the first name—John Smith, James Smith and Joan Smith are all identified as "Smith-J"; and
- it does not contain any information on the relation between the names of the authors and their institutional addresses. For example, in retrieving papers by "Smith-J", who is affiliated with McGill University, a paper co-authored by "Smith-J" of McMaster University and

"Anderson-WC" of McGill University would be selected. This is due to the fact that, in the absence of links between author names and their addresses, "Smith-J" could be from either McGill or McMaster University. Hence, the presence of homographs is not limited to researchers located in the same institution (Figure 1).

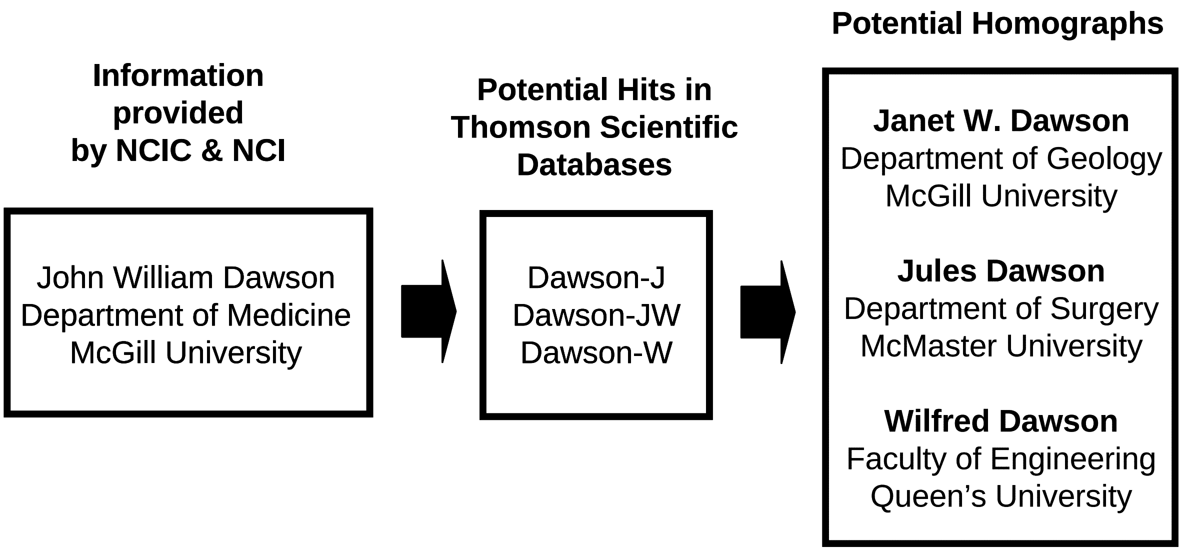


Figure 1 Example of potential homographs in the Web of Science
Source: OST and Science-Metrix

Using a sample of researchers from Quebec universities for which cleaned publication portfolios were available, the prevalence of homographs and false positives was recently estimated using researchers from the sample for which the automatic query returned at least one article (n = 9,273):

- 44.8% of researchers (4,156) had no homographs (no overestimation of their portfolios);
- 5.6% of researchers (518) had homographs generating between 1% and 24.9% of false positives;
- 5.6% of researchers (517) had homographs generating between 25% and 49.9% of false positives;
- 7.6% of researchers (702) had homographs generating between 50% and 74.9% of false positives;
- 9.3% of researchers (863) had homographs generating between 75% and 99.9% of false positives;
- 27.1% of researchers (2,517) had only false positives which, in turn, meant that they had no papers in the database used (all papers were written by homographs).

The automatic query was therefore accurate for about 45% of the researchers. For the remaining 55%, a significant overestimation of scientific production occurs, emphasizing the need to clean paper portfolios built automatically. Since there is no a priori regarding which researchers will be overestimated and which will not, the papers retrieved automatically must be validated manually for each researcher.

### Portfolio Cleaning

Cleaning the publication portfolios consists of manually removing the papers that were erroneously assigned to a researcher by the automatic query (described above). In other words, the process aims to remove the overestimation resulting from this procedure.

In so doing, careful attention was paid to the disciplines and specific topics of papers belonging to a publication portfolio. Several questions arise when analysing whether or not a set of papers belong to a given researchers (e.g. Are those papers consistent with respect to the discipline of the researcher as revealed by his/her departmental affiliation? Is the scope of those papers broader than the products of only one individual researcher?). For example, the attribution of an engineering paper to a biologist, or a physics paper to an historian would be seriously questioned. However, given the commonness of multidisciplinarity in science, it is not sufficient to rely mechanically on departmental affiliations of researchers to validate the publications of their portfolio. For example, a philosopher may publish articles dealing with medical ethics in clinical medicine journals, and an engineer may collaborate on papers dealing with environmental problems published in biology or earth sciences journals. The institutional addresses may provide additional clues, since they often include the authors' departments (although these are not harmonized in the WoS).

In cases where the previous actions failed to discriminate whether a paper should or should not be considered a part of a researcher's portfolio, the publication was downloaded when it was electronically available through libraries or open access. The article's signatures on the paper itself often provide a link between each author's name and her/his institutional address (including departmental affiliation), which normally allows one to unambiguously identify false positives (Figure 2).

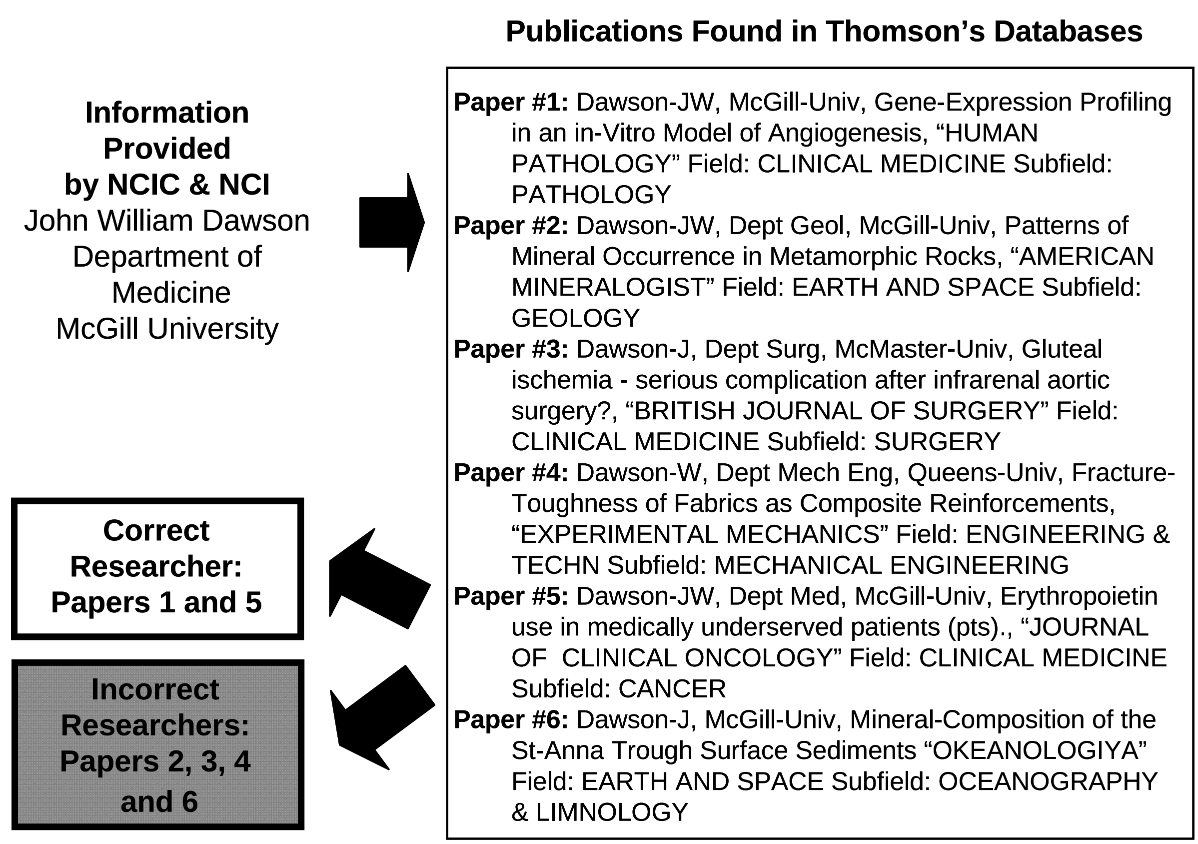


Figure 2 Example of portfolio cleaning

Source: Developed by OST and Science-Metrix

Besides false positives, another issue relates to false negatives; papers authored by a researcher that were not retrieved by the automatic query. These "absent papers" reflect the fact that the WoS only covers a fraction of all the work published worldwide by researchers. For example, journals of national interest, books, and various official publications that are generally referred to as "grey literature" (including minutes from conferences and symposiums, research reports, in-house journals, etc.) are not indexed in Thomson Reuters' scientific databases. Therefore, the publications in the WoS do not encompass the entire CV of researchers funded by the NCIC. More specifically, 22% of the scientific output (mostly papers) compiled in the NCIC's annual reports were not published in journals indexed in the WoS. Nevertheless, the three databases index the portion of their publications that is the most visible and the most frequently cited by the scientific community.

In building the dataset for NCIC-funded applicants, the cleaning process removed half of the initial number of papers automatically assigned to researchers, leaving 24,208 papers authored by NCIC-supported researchers at any given time between 1994 and 2006. Papers were considered to be "NCIC-supported" if they were published between the year after the start of the grant and the year after the end of the grant. For example, if a researcher was supported by the NCIC from 1997 to 2000, the papers she published between 1998 and 2001 were counted as "NCIC-supported papers". As the study period begins in 1994, papers are considered as of 1995 to allow for the one-year lag for 1994 funding. Between 1995 and 2006, a total of 22,793 papers were authored by NCIC-supported researchers, of which 54% (12,244) were "NCIC-supported papers". The balance (22,793 – 12,244 = 10,549) are referred to as "non-supported papers" (i.e., these are all other papers by NCIC researchers). Note that researchers receiving NCIC funding could also be receiving grants from other funders; papers considered as "NCIC-supported" may thus have been also partly supported by other sources of funding and, therefore, this report does not assume that these papers can be entirely attributed to NCIC.

As the cleaning of publication portfolios involves judgement on the part of individuals performing the task, errors inevitably occur. In this respect, OST previously performed a validation of this procedure, which demonstrated that when working with aggregated portfolios (i.e. a number of researchers associated with a given organization), the error rate is negligible (<1%) enabling the production of reliable indicators of scientific production. Altogether, manual cleaning of publication portfolios is a time- and resource-consuming process requiring careful attention. Yet it is the only way to guarantee that results are sufficiently robust to evaluate important questions such as the impact of funding on specific groups of researchers.

### 2.2.2 Constitution of the Benchmark Dataset: NCI-Funded Applicants

The benchmark dataset consists of a set of papers from an organization comparable to the NCIC, namely the US NCI. As was the case for the NCIC, inclusion of the NCI in the address field of papers published by the researchers it funds is not expected. Therefore, a publication portfolio had to be reconstituted for each researcher in a sample of PIs with support from the NCI using the method described above for NCIC-supported researchers (Section 2.2.1). The list of funded researchers was made available to the NCIC by the NCI.

To compare the scientific output of NCIC- and NCI-supported researchers, a random sample of NCI-supported researchers was paired to the population of NCIC-supported researchers to obtain an equal number of researchers on both sides of the comparison. Data on researchers who received NCI grants were only made available from 2000 onward and because the list of NCI-funded researchers did not provide information on the type and amount of grants awarded to them, researchers having received funding from 2000 to 2006 from different types of NCI grants will be selected by randomly sampling NCI-supported researchers. As such, to obtain the population of NCIC-supported researchers, Canadian researchers were selected so long as they obtained NCIC funding from 2000 to 2006 regardless the type of grants they received (NCIC Program Project grant or NCIC Operating grant). A population of 523 NCIC-supported researchers was thus obtained. Consequently, 523 NCI-supported researchers were chosen at random from those funded between 2000 and 2006 to match the population size of NCIC-supported researchers over this seven-year period. All papers published by both groups of researchers from 2000 to 2006 were counted regardless of whether these researchers were funded over the whole period or not.

## 2.3 Disciplinary Classification

The categories and methods used to delineate the various domains of activity of NCIC and NCI researchers are, by and large, those used by the US National Science Foundation (NSF) in the Science and Engineering Indicators series (see: http://www.nsf.gov/statistics/seind06/); the taxonomy is a journal-based classification and has been in use since the 1970s. Because the NSF classification does not entirely satisfy the needs in the SSH, OST modified this taxonomy with its own classification of journals for the social sciences.

The resulting taxonomy has one important advantage over other classifications (such as that used by Thomson Reuters); it is mutually exclusive, which means that each paper is attributed to a single field or subfield based on the journal in which it is published. One limitation of this classification is that papers published on a subject, such as, for example, the environment, but in a journal specialized in chemical engineering, would be classified as belonging to the field of chemistry and the subfield of chemical engineering, even though its subject is the environment. The anomalies have little effect when large numbers are considered; however, their impact is greater when the number of papers considered is small (e.g., below 30). Some of the subfields are categorized as general (e.g., general biomedical research), and this reflects the fact that in many fields there are some journals that address a broader readership.

## 2.4 Bibliometric Indicators

Using researcher portfolios built using the aforementioned methods as well as papers computed at the country level (for Canada, and for the US and G7 countries in specific cases) the following indicators were calculated:

**Number of publications:** Count of the number of scientific papers written by authors associated with a funding organization (i.e., NCIC or NCI) based on author names (see Section 2.2) or with a country based on author addresses.

**Average of Relative Citations (ARC):** This is an indicator of the *scientific impact* of papers produced by a given entity (e.g., a country, an institution) that considers citations in papers published in peer reviewed journals. In general, health research papers reach their citation peak (year in which they have received the most citations) about two to three years after publication (see: http://www.in-cites.com/ESI_Product_Info/1-HotPapers.htm). Thus, the number of citations received for each paper was counted for the year in which they were published and for the two subsequent years. For instance, for papers published in 1994, citations received in 1994, 1995, and 1996 were counted. The exceptions are 2005, which has a citation window of two years (2005 and 2006), and 2006, which has a citation window of one year, since there were no citation data for subsequent years. To account for different citation patterns across fields and subfields of science (e.g., there are more citations in biomedical research than mathematics), the citation count of a paper in a given subfield (see Section 2.3 for information on the classification of papers by subfield) is divided by the average count of all papers in its subfield within the WoS, to obtain a relative citation count (RC). The ARC of a given entity (e.g., a country, an institution) is the average of the RC of papers belonging to it. When the ARC is above 1, an entity (e.g., country, institution, researcher) scores better than the world; when it is below 1, an entity publishes papers that are cited less often than the world average. Self-citations are excluded.

**Number of most cited papers:** The number of papers published by an entity that are in the 5% of papers with the highest RC (see above definition in the ARC's description). Self-citations are excluded. The use of a fixed citation window is preferred to total citation counts to avoid favouring old papers over recent papers.

**Average relative impact factor (ARIF)**: This indicator is a proxy for the quality of the journals in which an entity publishes. Each journal has an impact factor (IF), which is calculated annually by Thomson Reuters based on the number of citations it received relative to the number of papers it published (see: http://scientific.thomson.com/free/essays/journalcitationreports/impactfactor/). Thus, each journal's IF will vary from year to year. The IF of papers is calculated by ascribing to them the IF of the journals in which they are published, for the year in which they are published. Subsequently, to account for different citation patterns across fields and subfields of science (e.g., there are more citations in biomedical research than mathematics), each paper's IF was divided by the average IF of the papers in its subfield (see Section 2.3 for information on the classification of papers by subfield) to obtain the Relative Impact Factor (RIF). The ARIF of a given entity is the average of its RIFs (i.e., if an institution has 20 papers, the ARIF is the average of 20 RIFs, one per paper). When the ARIF is above 1, it means that an entity scores better than the world average; when it is below 1, it means that on average, an entity publishes in journals that are not cited as often as the world level.

**Specialization index (SI):** This is an indicator of the *intensity of research* of an entity in a given research area (e.g., field, subfield) relative to the intensity of the reference entity (usually the world) in the same research area. The SI can be formulated as follows:

$$\mathbf{SI} = \frac{(X_S/X_T)}{(N_S/N_T)}$$

where,

$X_S$ = Papers from entity X in a given subfield (e.g., NCIC-supported papers in cancer research);
$X_T$ = Papers from entity X in a reference set of papers (e.g., NCIC-supported papers in the WoS);
$N_S$ = Papers from the reference entity N in a given subfield (e.g., the world in cancer research);
$N_T$ = Papers from the reference entity N in a reference set of papers (e.g., the world in the WoS);

An SI value above 1 means that a given entity is specialized relative to the reference entity, while an index value below 1 means the opposite.

**Positional analysis:** To more easily interpret the strengths and weaknesses of an entity through the use of several separate indicators, a graphical representation called positional analysis was used (Figure 3). This graphical representation combines three of the previously mentioned indicators (number of papers, SI, and ARC). The horizontal axis of this positional graph corresponds to the SI and the vertical axis to the ARC. These data are transformed to obtain a symmetrical distribution of possible values between -100 and +100, with zero representing the world level. The size of the bubbles is proportional to the number of papers produced by the country or institution. The position of a country or institution in one of four quadrants can therefore be interpreted as follows.

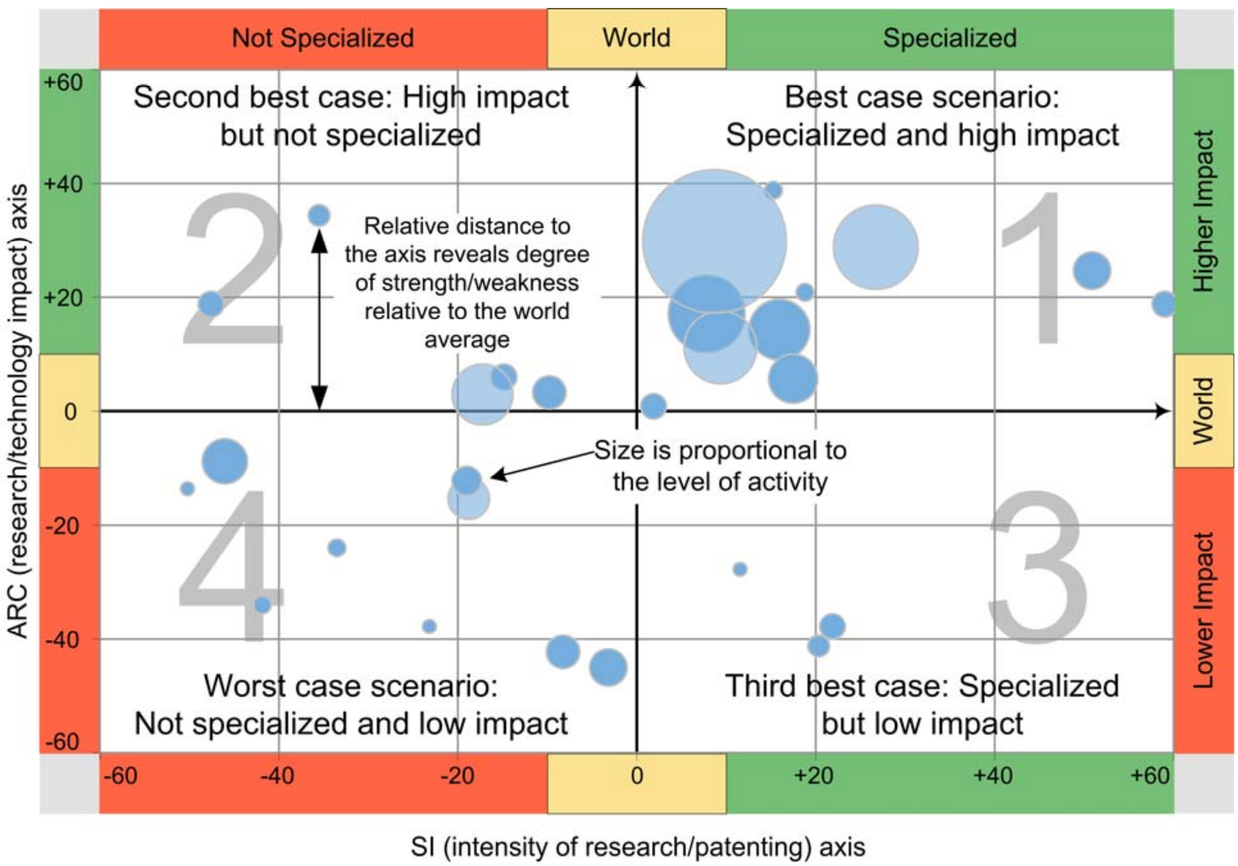


Figure 3 The positional analysis graph
Source: Developed by Science-Metrix

- **Quadrant 1:** Located at the top right of the graph, this quadrant is synonymous with excellence. Entities in this quadrant specialize in the given subfield, and their papers are more frequently cited than the world average in this domain.
- **Quadrant 2:** Located at the top left of the graph, this quadrant is synonymous with high impact scientific production (citedness), but the entities are not specialized in the subfield.
- **Quadrant 3:** Located at the bottom right of the graph, this quadrant signals specialization in the subfield, whereas impact is below the world average.
- **Quadrant 4:** Located at the bottom left of the graph, this quadrant represents the worst case scenario, as both the intensity of activity and its impact are below the world average in the subfield.

## 2.5 Statistical Analyses

To establish whether there were significant differences between the scientific impact of various entities, a series of statistical tests were performed in SPSS (version 16.0). For each statistical test, the difference in scientific impact was considered to be:

- significant at $p < 0.05$;
- very significant at $p < 0.01$; and
- highly significant at $p < 0.001$.

Because data on scientific impact are not normally distributed, non-parametric tests were used. Here is a list of null hypotheses that were tested for significance. Except when specified otherwise (in brackets), the Mann-Whitney U test was used:

- $H_o$ = The ARC of the papers authored by researchers who were supported by the NCIC at any one time (including NCIC-supported papers and non-supported papers) is not significantly different from the ARC of Canadian papers as a whole (excluding papers by NCIC researchers);
- $H_o$ = The ARC of NCIC-supported papers is not significantly different from the ARC of Canadian papers as a whole (excluding papers by NCIC researchers);
- $H_o$ = The ARC of non-supported papers by NCIC researchers is not significantly different from the ARC of Canadian papers as a whole (excluding papers by NCIC researchers);
- $H_o$ = The ARC of NCIC-supported papers is not significantly different from the ARC of non-supported papers by NCIC researchers;
- $H_o$ = The ARC of papers authored by researchers who were supported by the NCIC at any one time (including NCIC-supported papers and non-supported papers) is not significantly different from the ARC of Canadian papers as a whole (excluding papers by NCIC researchers) in cancer research;
- $H_o$ = The ARC of NCIC-supported papers is not significantly different from the ARC of Canadian papers as a whole (excluding papers by NCIC researchers) in cancer research;
- $H_o$ = The ARC of non-supported papers by NCIC researchers is not significantly different from the ARC of Canadian papers as a whole (excluding papers by NCIC researchers) in cancer research;

- $H_o$ = The ARC of NCIC-supported papers is not significantly different from the ARC of non-supported papers by NCIC researchers in cancer research;
- $H_o$ = The proportion of papers by researchers who were supported by NCIC at any one time (including NCIC-supported papers and non-supported papers) that are in the 5% most cited papers is not significantly different from the proportion of papers by Canadian researchers (excluding NCIC researchers) that are in the 5% most cited papers [Z-test for two proportions];
- $H_o$ = The proportion of NCIC-supported papers that are in the 5% most cited papers is not significantly different from the proportion of papers by Canadian researchers (excluding NCIC researchers) that are in the 5% most cited papers [Z-test for two proportions];
- $H_o$ = The proportion of non-supported papers by NCIC researchers that are in the 5% most cited papers is not significantly different from the proportion of papers by Canadian researchers (excluding NCIC researchers) that are in the 5% most cited papers [Z-test for two proportions];
- $H_o$ = The proportion of NCIC-supported papers that are in the 5% most cited papers is not significantly different from the proportion of non-supported papers by NCIC researchers that are in the 5% most cited papers [Z-test for two proportions];
- $H_o$ = The ARC of NCIC papers is not significantly different from the ARC of NCI papers;
- $H_o$ = The ARC of NCI papers is not significantly different from the ARC of US papers;
- $H_o$ = The ARIF of NCIC papers is not significantly different from the ARIF of NCI papers;
- $H_o$ = The ARC of NCIC papers is not significantly different from the ARC of NCI papers in cancer research;
- $H_o$ = The ARC of NCI papers is not significantly different from the ARC of US papers in cancer research;
- $H_o$ = The ARIF of NCIC papers is not significantly different from the ARIF of NCI papers in cancer research.

## 2.6 Limitations of Bibliometrics

Internationally, bibliometrics is the most widely accepted method for measuring the outputs of scientific activity. As bibliometrics is often used in the context of performance assessment and management, it is not uncommon to find that comparative approaches using different time periods, organizations, and countries are favoured. The key to comparability is to use a bibliographic database with extensive coverage of the scientific literature over time, countries and scientific domains. In this respect, it is worth mentioning that the WoS, which is used in this study, has some well documented weaknesses:

- It has a slight bias for countries that publish in English-language journals. Thus, for countries whose researchers would tend to publish more in other languages, their scientific production is underestimated in the context of international comparisons. In the NCIC-versus-NCI comparison, the impact is limited, given that researchers of both groups are from Anglo-Saxon countries, namely Canada and the US.
- Another factor affecting publication counts is the difference in publication and citation practices between disciplinary fields. For instance, it is well known that mathematicians publish and cite less

than biomedical researchers. Hence, one should not directly compare publications and citation counts between fields.

- Due to differential coverage of sources in Thomson Reuters' scientific databases, bibliometrics indicators are quite reliable for natural sciences, engineering, and health fields but are much less so in social sciences and humanities fields (Archambault *et al.*, 2006; Glänzel and Schoepflin, 1999; Hicks, 2004; Moed, Luwel and Nederhof, 2002; van Raan, 2005). For example, documents (e.g., articles, reviews) published in refereed journals are covered extensively, while books are not. Therefore, it is not surprising to see that publication counts of professors from social sciences and humanities are smaller than those from the natural sciences. In the current study, this limitation has little effect because the main subfields of activity of NCIC- and NCI-supported researchers fall within the fields of clinical medicine and biomedical research, in which refereed journals constitute the core medium for knowledge dissemination.
- Errors in counting the number of papers or citations of an entity (e.g., institution, country) could occur in the WoS (as it could in any other database) due to indexing errors arising from different ways of citing the name of an institution (e.g., Can For Serv, CFS, Canadian Forest Service, Can Forest Service) or to historical changes in an institution's name (e.g., Forestry Canada became the Canadian Forest Service). To limit these types of errors, OST and Science-Metrix analysts spent an appreciable amount of time harmonizing the name of researchers, institutions, and countries in the database.

The simplest bibliometric indicator is the number of papers published by an entity (i.e., a researcher, an institution, a country). However, because entities can differ substantially with respect to their levels of resources (e.g., funding, number of researchers, equipment) available to them as they conduct their research, this approach cannot be used to compare the efficiency with which these entities have produced their papers. King (1987) reviewed a number of objections to the use of publication counts for performance assessment in scientific research:

- Social and political pressures, such as those favouring researchers with the highest number of publications in grant or tenure competitions, might affect the emphasis that different entities (i.e., researchers, institutions, countries) will put on publishing results and, therefore, could affect data comparability. These pressures could also lead to undesirable publication practices, such as fragmentation of results in many papers to obtain "least publishable units".
- Along with the increasing number of multi-authored papers as a result of increased collaboration, it seems that the "gratuitous conferring" of co-authorship is becoming more common. This could lead to what appears to be a better performance by those institutions whose researchers adopt this strategy.

Because all bibliometric indicators have some weaknesses when considered individually, they are better used as a set of indicators for the assessment of scientific performance. When all of the indicators point in the same direction, the results are regarded as being more reliable than those based on a single indicator (King, 1987). It is also important to recognize that bibliometric indicators do not reveal which, among comparables, is the most efficient entity at performing research (or the best at converting research inputs into research outputs), as none of these indicators relates research inputs to research outputs. Compared to data on research outputs, it is very difficult to find comparable data of research inputs.

# 3 NCIC-Supported Researchers Compared to Canadian Researchers

This section examines the research output of researchers supported by the NCIC over the 1994–2006 period (N=685, of which 679 published at least one paper during the period). It compares their output when they are supported and when they are not, and compares their output with that of Canada as a whole (i.e., papers with at least one author with a Canadian address, excluding papers by NCIC-funded researchers). Note that because NCIC-supported papers are counted starting one year after the first year of the grant, all subsequent data are presented over the 1995–2006 period.

## 3.1 Total Scientific Production

Overall, just over half of scientific papers by researchers supported by the NCIC at any time over the 1994–2006 period were published with financial support from the NCIC: 12,244 out of 22,793 papers by NCIC-funded researchers were published after their first year of NCIC funding up until the year after the end of the grant. As shown in Figure 4, the proportion of NCIC-supported papers by NCIC-researchers has been shrinking since 1995, as the number of non-supported papers (i.e., all other papers by NCIC researchers) has increased steadily, while the number of NCIC-supported papers published per year has been more stable. It should be highlighted that researchers receiving NCIC funding could also be receiving grants from other funders; papers considered as "NCIC-supported" may thus have been also partly supported by other sources of funding.

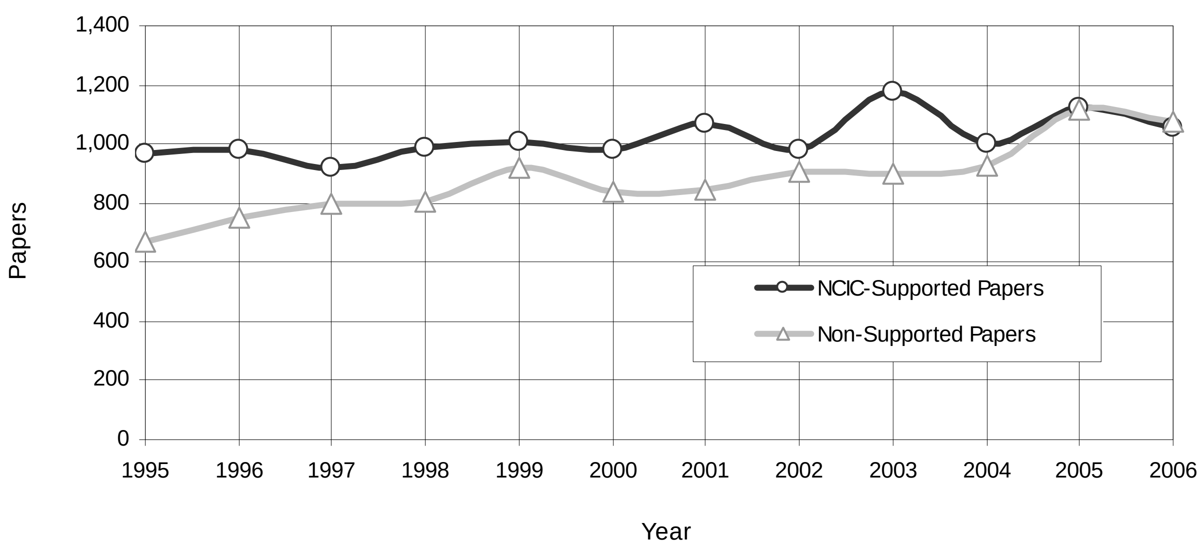


Figure 4 Yearly number of papers written by NCIC-supported researchers, 1995–2006

Source: Calculated by OST and Science-Metrix from Thomson Reuters' WoS

Besides the number of published papers, another important indicator of scientific performance is the impact that the published papers had on the scientific community. The average of relative citations (ARC) is an indicator of the number of times an entity's papers (e.g., a group of researchers, a country) are cited relative to the world average and can therefore be used as a proxy of scientific impact. All entities considered in this section score above the world average (i.e., above 1).

Researchers who were supported by the NCIC at any one time between 1994 and 2006 have a substantially higher scientific impact than Canadian researchers as a whole (highly significant for the three sets of papers [all papers by NCIC researchers, NCIC-supported papers, and non-supported papers], $p < 0.001$; Figure 5). The impact of their papers when they were supported by the NCIC (i.e., those published one year after the start of the grant period until one year after the end of the grant period) was even higher than the impact of their papers authored without the support of the NCIC (highly significant, $p < 0.001$). However, the difference between the scientific impact of NCIC-supported papers and those without NCIC support was slightly smaller in the five most recent years; the latter set of papers even had greater impact than the former in 2006 (Figure 5).

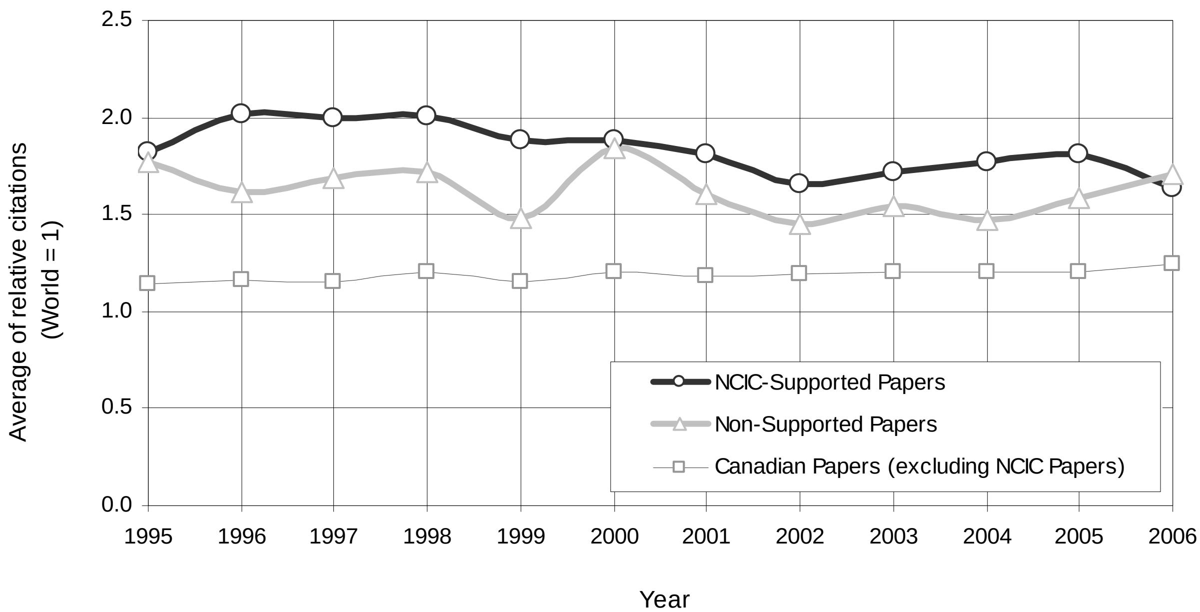


Figure 5 Average of relative citations of papers by NCIC and Canadian researchers, 1995–2006

Source: Calculated by OST and Science-Metrix from Thomson Reuters' WoS

Another indicator of scientific impact (or scientific excellence) is the proportion of published papers that are in the 5% of papers with the highest citation counts. This indicator was calculated for both NCIC researchers (including NCIC-supported papers and non-supported papers) and for Canadian researchers as a whole (Figure 6). NCIC researchers have a higher proportion of papers than Canadian researchers in the 5% most cited papers, and the difference is highly significant ($p < 0.001$) for the three following sets of papers: all papers by NCIC researchers, NCIC-supported papers, and non-supported papers. In addition, papers by researchers who were supported by the NCIC at any one time are more frequently found in highly cited papers when they are authored with the financial support of the NCIC (highly significant, $p < 0.001$, Figure 6).

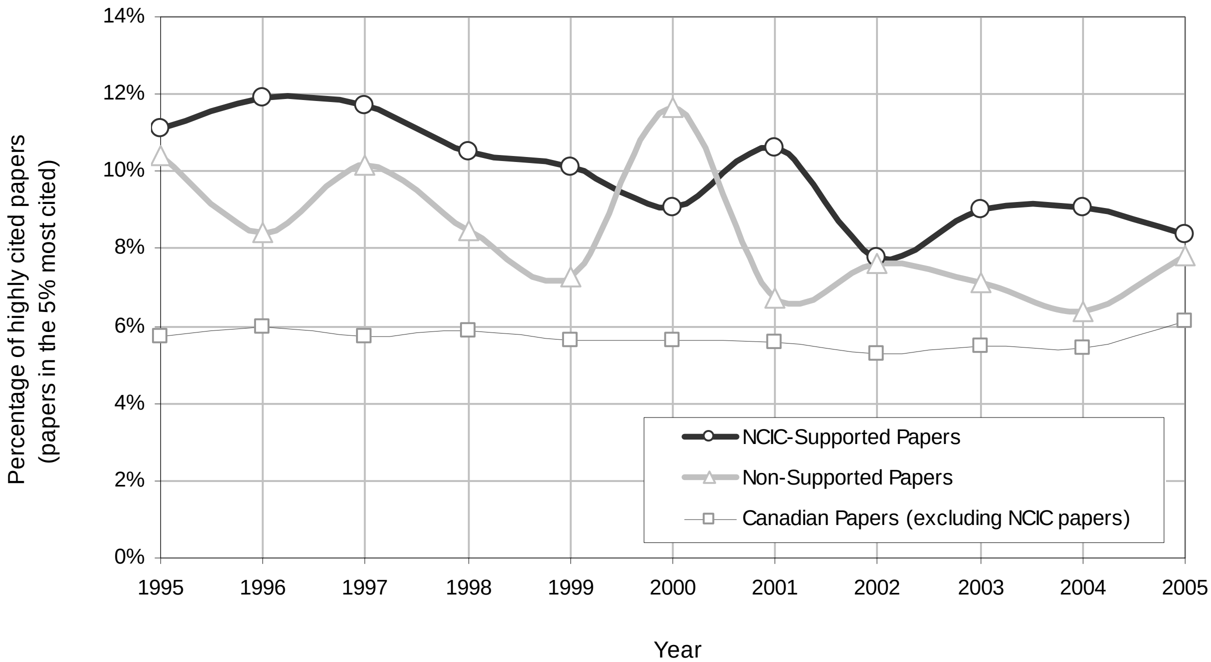


Figure 6 Proportion of papers by NCIC and Canadian researchers in the 5% most cited papers, 1995–2005

Source: Calculated by OST and Science-Metrix from Thomson Reuters' WoS

## 3.2 Scientific Production in Cancer-Related Journals

The positional analysis of the G7 countries based on scientific impact, specialization, and number of papers in cancer research, based on their scientific output for the 2000–2006 period, is presented in Figure 7. The methods describing these bibliometric indicators can be found in Section 2.4.

Within the G7 countries, the US dominates, ranking 1st for both the number of papers it published in cancer-related journals and the scientific impact of these papers (Figure 7); this latter measure indicates that US papers in cancer-related journals are more often cited than those from other countries. The US is specialized in cancer research, meaning that the proportion of scientific papers they published in cancer-related journals is higher than the proportion of papers published in these journals at the world level—the intensity of cancer research in the US is greater than the intensity of cancer research at the world level. Japan, Germany, and Italy, which respectively ranked 2nd, 3rd and 4th based on their numbers of published papers, are the only other countries specializing in cancer research among the selected countries.

Canada actually published the least in cancer-related journals compared to G7 countries (Figure 7). On the other hand, it ranked 2nd behind the US for the scientific impact of its published papers. Although Canada, the UK and France are not specialized in cancer research, the intensity of their research activities in this area is only slightly below the world level. In addition, Canada, along with the US, and the UK, has a much higher scientific impact than the world level, especially compared to the other G7 countries. More specifically, France and Germany score slightly above the world level, while Italy and Japan published papers that received, on average, fewer citations than the average world paper in cancer-related journals. An examination of citations patterns over time shows that within the last two years (2005 and 2006), Canada was overtaken by the UK in terms of scientific impact, and the gap that separated it from France and Germany got smaller (data not shown).

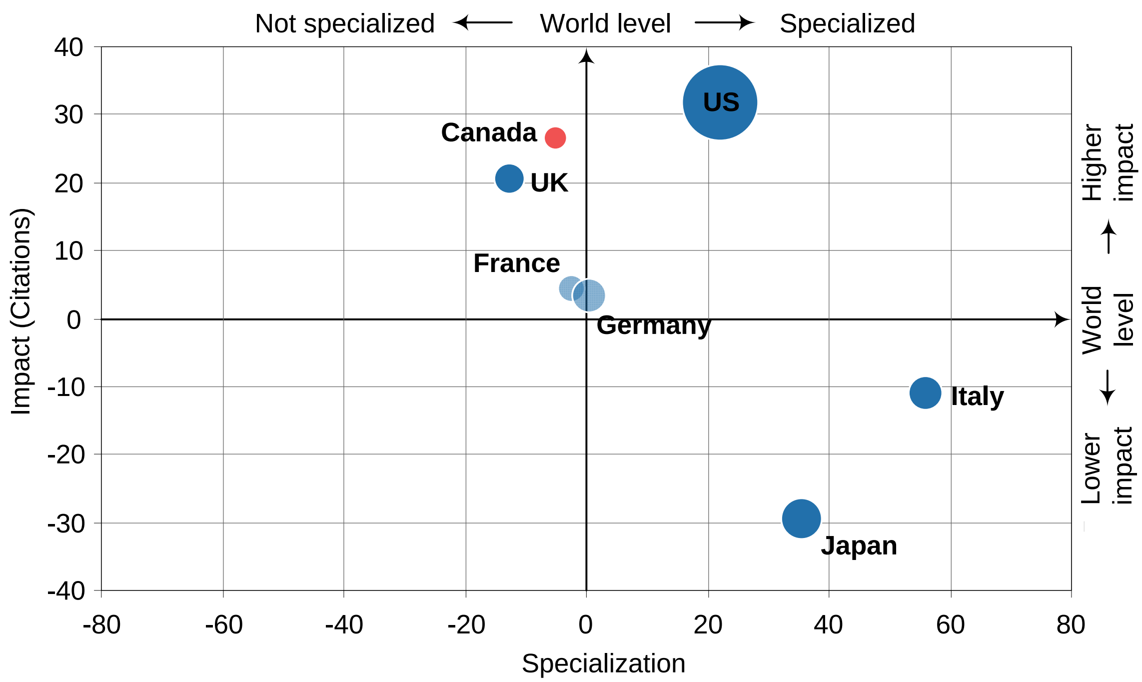


Figure 7 Positional analysis of the G7 countries based on impact, specialization, and number of papers in cancer research, 2000–2006

Source: Calculated by OST and Science-Metrix from Thomson Reuters' WoS

Researchers who received support from the NCIC at any given time contributed to nearly half of the Canadian papers published in the subfield of cancer research (Table I). About one quarter of Canadian papers in cancer-related journals were supported by the NCIC, having been published by researchers one year after up the start of their NCIC grant until one year after the end of their grant period. The NCIC also provided support for a substantial proportion of Canadian papers in embryology, cell biology, hematology, genetics, and biochemistry.

In cancer research, the scientific impact of papers by researchers who were supported by the NCIC at any one time (NCIC-supported papers together with non-supported papers) was slightly higher than the scientific impact of Canadian papers from 1995 to 2006 (Figure 8), and the difference was highly significant ($p < 0.001$) for the three following sets of papers: all papers by NCIC researchers, NCIC-supported papers, and non-supported papers. As was the case for the total output of NCIC researchers (all subfields included), the impact of their papers in cancer research when they were supported by the NCIC was generally (for 10 out of 13 years) higher than when they were not supported, and the difference was significant ($p < 0.05$; Figure 8).

Table I NCIC researchers' share of Canadian output by subfield, 1994–2006

| Subfield | % of Canadian Output by NCIC-researchers | | |
|---|---|---|---|
| | NCIC-Supported Papers | Non-Supported Papers | Total |
| Cancer | 26% | 22% | 48% |
| Embryology | 20% | 9% | 29% |
| Cellular Biology Cytology & Histology | 17% | 11% | 28% |
| Hematology | 14% | 9% | 23% |
| Genetics & Heredity | 14% | 9% | 23% |
| Biochemistry & Molecular Biology | 14% | 8% | 22% |
| Pathology | 8% | 11% | 19% |
| Immunology | 12% | 7% | 19% |
| Urology | 9% | 9% | 19% |
| Virology | 12% | 6% | 19% |
| General Biomedical Research | 11% | 6% | 16% |
| *Other subfields (N=132)* | *0.9%* | *1.2%* | *2.0%* |
| *All Subfields* | *2.8%* | *2.4%* | *5.2%* |

Source: Calculated by OST and Science-Metrix from Thomson Reuters' WoS

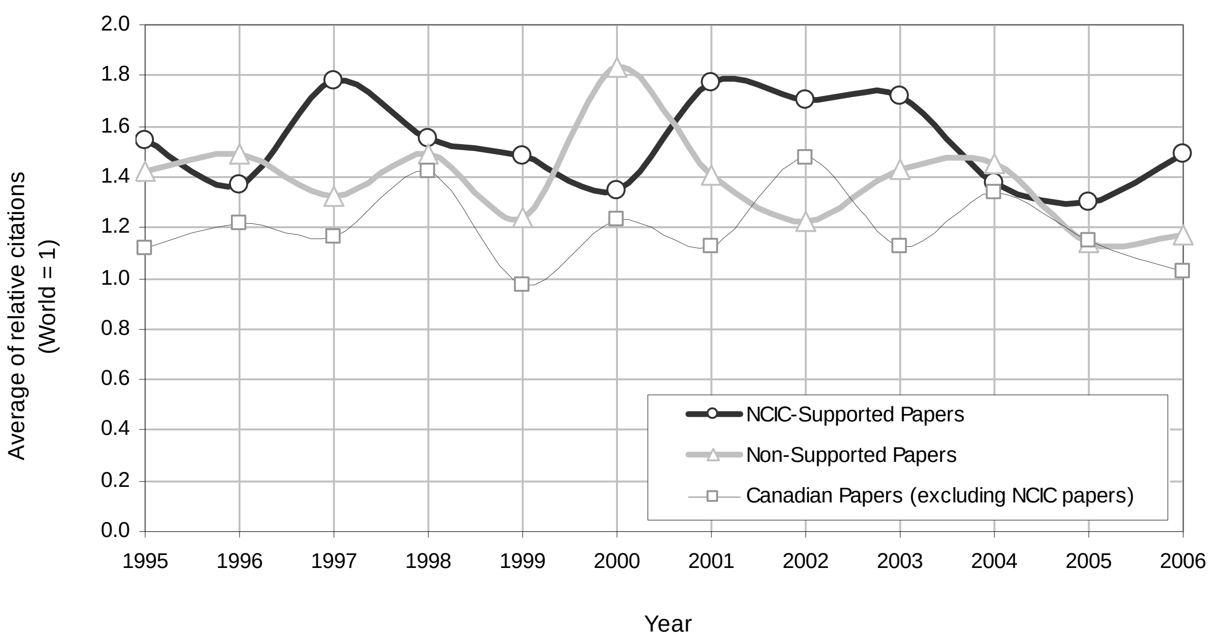


Figure 8 Average of relative citations of papers by NCIC and Canadian researchers in cancer research, 1995–2006

Source: Calculated by OST and Science-Metrix from Thomson Reuters' WoS

# 4 NCIC-Supported Researchers Compared to NCI-Supported Researchers

This section presents a comparative analysis of the output of researchers funded by the NCIC with that of researchers supported by the NCI. First, funding trends from both institutes are examined. Then, the output of NCIC-supported researchers is compared to a paired sample of NCI-supported researchers (random selection).

## 4.1 Funding Level of NCIC- and NCI-Supported Researchers

For the 2001–2007 period, the average level of funding awarded per researcher by the NCI was 4.5 times that awarded by the NCIC (Figure 9). On average, NCI-supported researchers received about US$600,000 at Purchasing Power Parity (PPP) in 2006 compared to about US$150,000 PPP for NCIC-supported researchers. It should be noted, however, that NCI grants also include PI salaries whereas NCIC grants do not provide for personal salary support of the PIs and/or co-applicants. Furthermore, based on financial data provided by both institutes, grants awarded to American researchers by the NCI covered, on average, 3.85 years of research out of 7, compared to 3.64 years out of 7 for Canadian researchers who received NCIC grants. Thus, although the amount of funding is disproportionately different, the length of the funding is highly comparable.

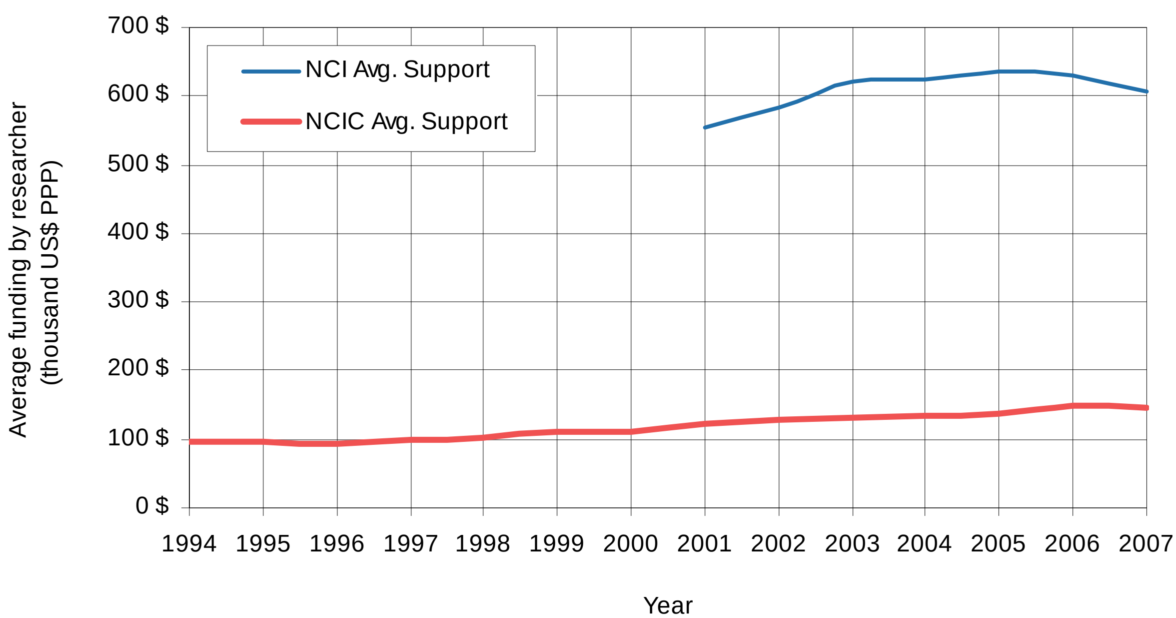


Figure 9 Average funding per researcher, NCI and NCIC, 1994–2007

Source: Calculated by OST and Science-Metrix from financial data provided by NCI and NCIC

## 4.2 Scientific Output of NCIC- and NCI-Supported Researchers

To compare the scientific output of NCIC- and NCI-supported researchers, a random sample of NCI-supported researchers was paired to the population of NCIC-supported researchers in order to obtain an equal number of researchers on both sides of the comparison (see Section 2.2 for details on the construction of the datasets for the NCIC and the NCI).

The number of papers produced by NCIC- and NCI-supported researchers follows a Pareto distribution. Although the difference is not vast between the two groups, there is a small difference in concentration of output. Indeed, one can see in Figure 10 that the scientific output supported by the NCI is slightly more concentrated (i.e., most of the papers are produced by a small proportion of supported researchers) than that of NCIC-supported output. For instance, the 5% most active NCIC-supported researchers produced 19% of the output, compared to 23% of the output for NCI-supported scientists. Similarly, the most active third of NCIC-supported researchers produced about two-thirds of the NCIC-funded output (65%), compared to 73% in the case of researchers with NCI grants. At the other end of the spectrum, the least active third of the NCIC researchers produced only 9% of the output, versus 5% in the case of scientists that received NCI grants.

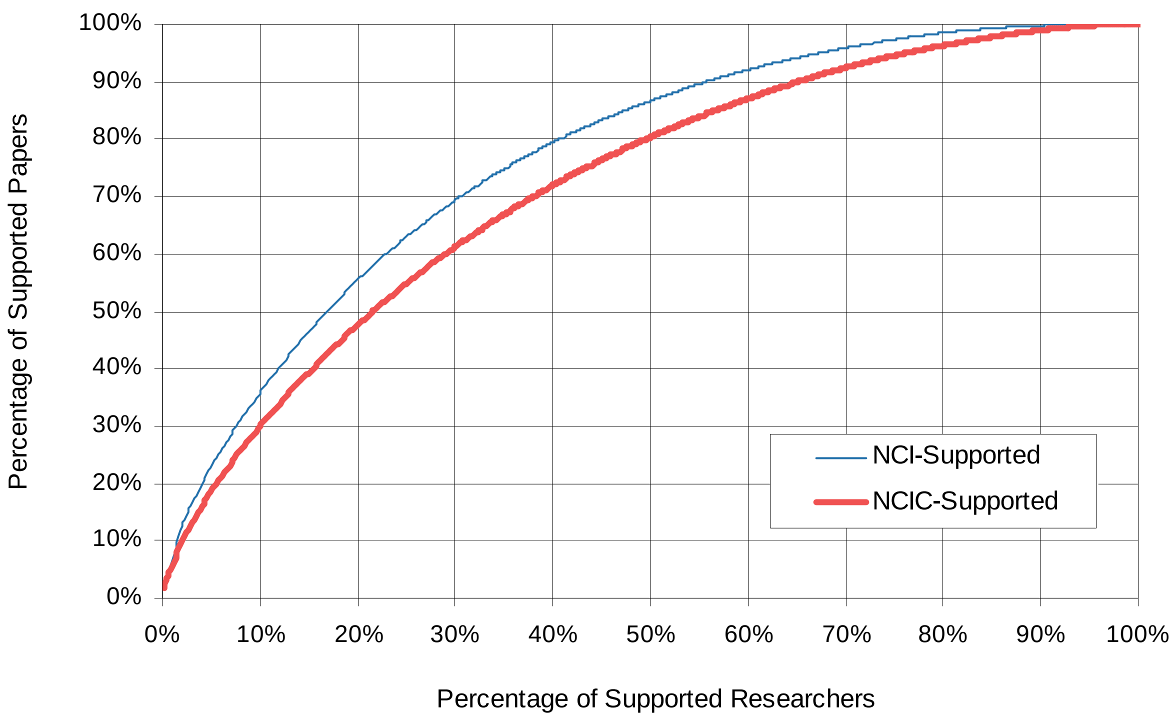


Figure 10 Cumulative distribution of scientific output per researcher
Source: Calculated by OST and Science-Metrix from Thomson Reuters' WoS

The scientific production of the two groups was similar throughout the 2000–2006 period, although the output of NCI-supported researchers experienced a slightly stronger increase (net increase of 25%) than the output of NCIC-supported researchers (net increase of 21%) (Figure 11). In total, NCIC-supported researchers published nearly as many papers as did NCI-supported researchers (11,019 versus 11,794), despite a level of funding that is nearly five times smaller (considering only financial support from the NCI and the NCIC).

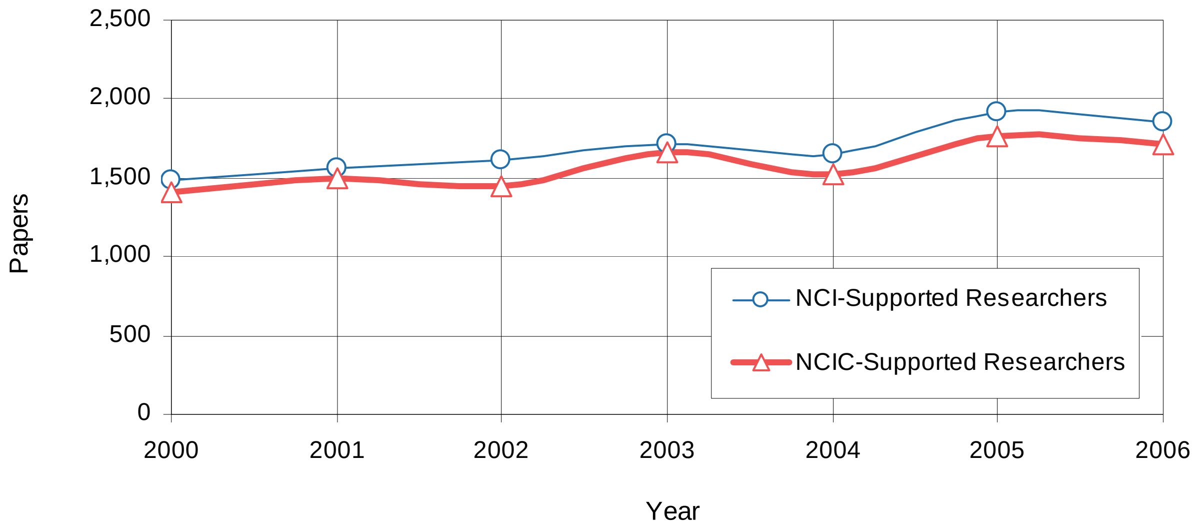


Figure 11 Yearly scientific output, NCIC population versus NCI-paired sample, 2000–2006

Source: Calculated by OST and Science-Metrix from Thomson Reuters' WoS

On the other hand, the papers produced by NCI-supported researchers have had stronger scientific impact than the papers published by NCIC-supported scientists (highly significant, $p < 0.001$), with the exception of the year 2000, during which both groups had similar ARC values (Figure 12). For the 2000–2006 period, papers by NCI-supported researchers received, on average, about 120% more citations than the average world paper, while those of NCIC researchers received about 70% more citations. Both groups produced papers that achieved greater scientific impact than their respective nation's average paper (highly significant, $p < 0.001$, Figure 12).

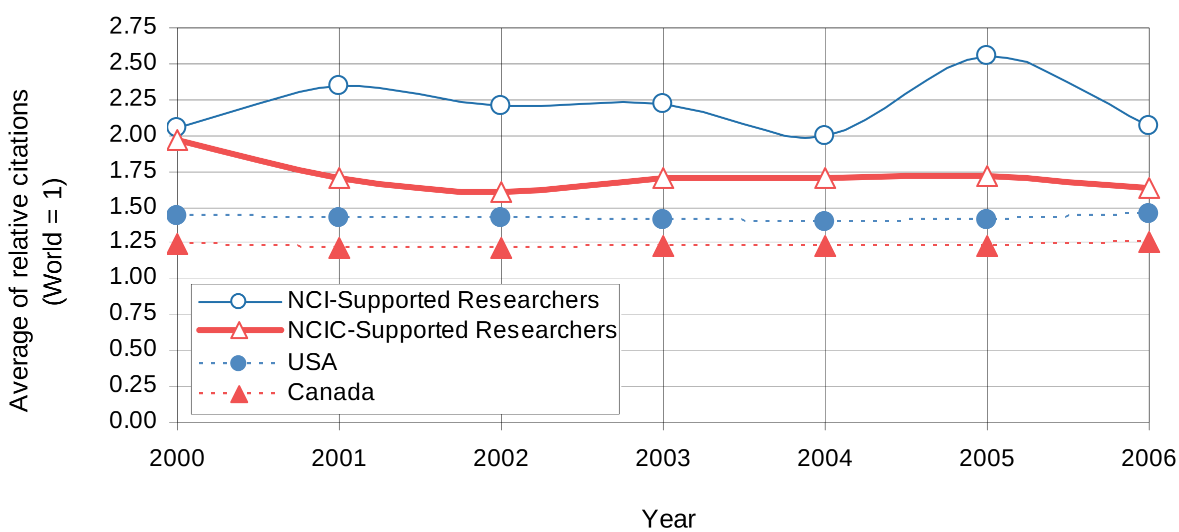


Figure 12 Average of relative citations of papers, NCIC population versus NCI-paired sample, 2000–2006

Source: Calculated by OST and Science-Metrix from Thomson Reuters' WoS

The difference in volume of the scientific output of NCIC- and NCI-supported researchers is more pronounced when considering only papers published in cancer-related journals (Figure 13). From 2000 to 2006, NCI researchers published 35% more papers than NCIC researchers in cancer-related journals, while they published only 7% more papers when considering their overall output. For instance, NCI researchers published 22% of their papers in this specialty compared to 17% in the case of NCIC researchers. Nevertheless, the trend in the output of both groups is similar, such that the gap in the size of their production in cancer journals remained fairly stable throughout the period analyzed (Figure 13). Only in 2004 did the output of NCI-supported researchers drop to a number comparable to that of papers produced by NCIC-supported researchers.

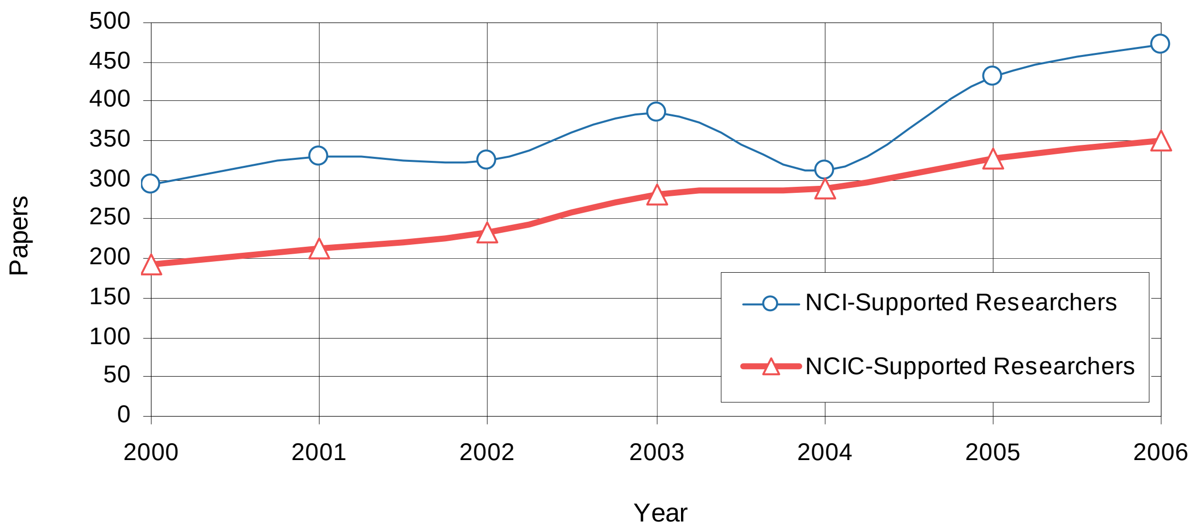


Figure 13 Yearly scientific output in cancer journals, NCIC population versus NCI-paired sample, 2000–2006

Source: Calculated by OST and Science-Metrix from Thomson Reuters' WoS

When focusing on the subset of NCI- and NCIC-supported papers that are published in journals dealing specifically with cancer research, the difference observed previously in terms of scientific impact is even more appreciable (highly significant, $p < 0.001$, Figure 14). Indeed, the ARC of NCI papers (2.37) surpasses that of NCIC papers (1.48) by 90 percentage points in cancer-related journals, compared to 50 percentage points when all papers are considered (2.21 versus 1.72), for the 2000–2006 period. Both groups still perform better than the world average in impact for papers published in cancer-related journals. However, the scientific impact of NCI-supported researchers well surpasses the US average (highly significant, $p < 0.001$), while that of NCIC researchers is only slightly above the Canadian average for papers in cancer journals (Figure 14).

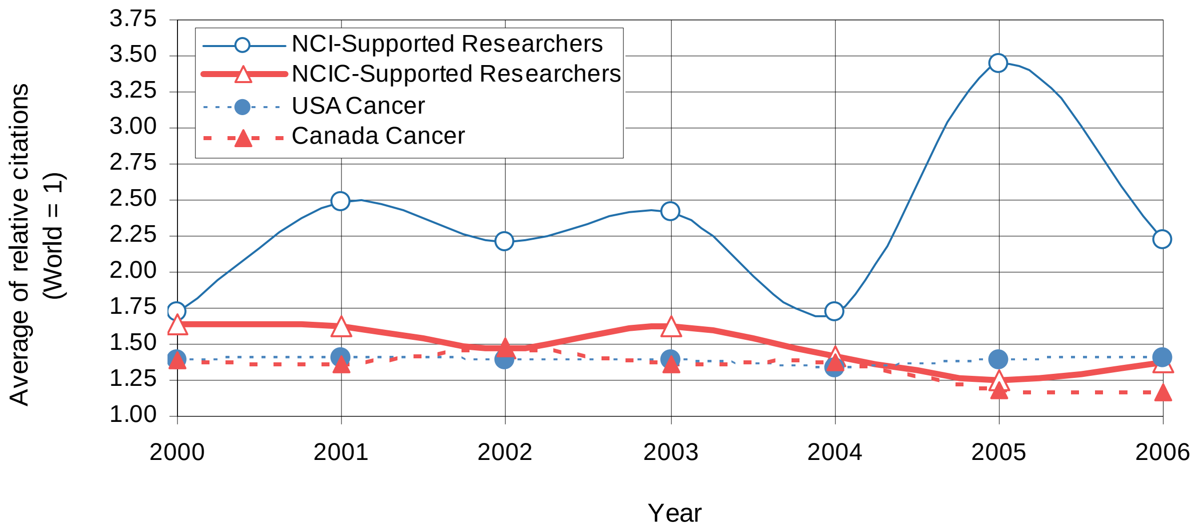


Figure 14 Average of relative citations of papers in cancer journals, NCIC population versus NCI-paired sample, 2000–2006

Source: Calculated by OST and Science-Metrix from Thomson Reuters' WoS

Using an alternative measure of scientific impact, namely the ARIF (a measure of expected impact), similar observations can be made. There is an appreciable difference in the scientific impact of NCIC- and NCI-supported research overall, and this difference is more pronounced in cancer-related journals (highly significant in both cases, $p < 0.001$, Figure 15). In addition, NCIC researchers publish in the most cited journals more frequently overall than they do within the cancer specialty.

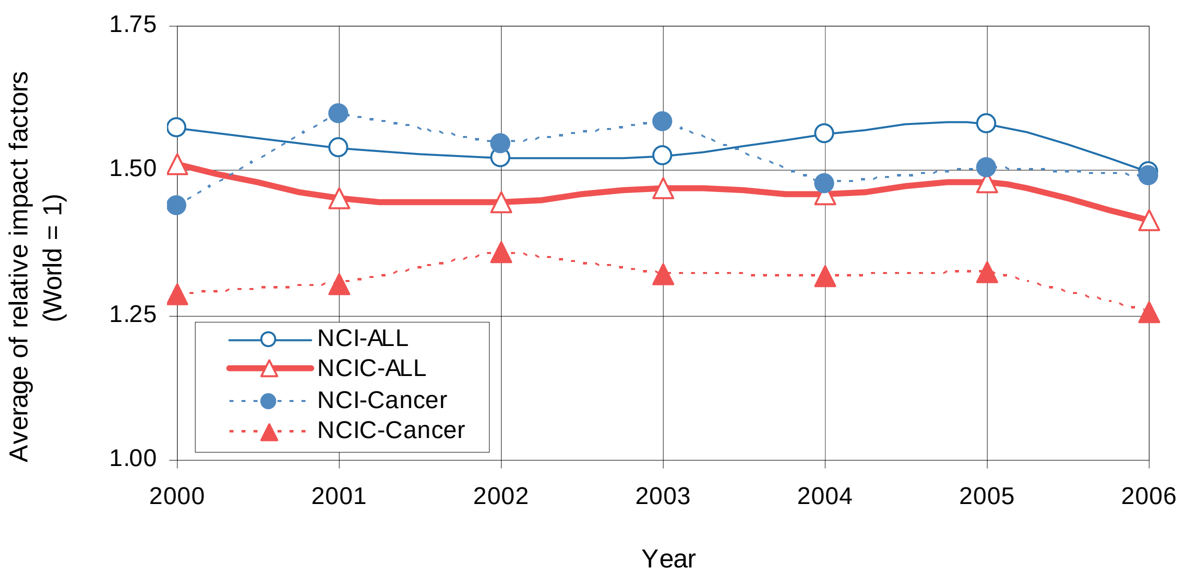


Figure 15 Average of relative impact factors of papers overall and in cancer journals, NCIC population versus NCI-paired sample, 2000–2006

Source: Calculated by OST and Science-Metrix from Thomson Reuters' WoS

# 5 Discussion and Conclusion

During the 1994–2006 period, about two-thirds of the scientific production of researchers who received funding from the NCIC during this time was produced with financial support from the institute (i.e., papers published by these researchers between the year after the start of the grant and the year after the end of the grant) (15,766 out of 24,208 papers). These researchers were authors on nearly half of the Canadian papers published in cancer-related journals from 1994 to 2006; meanwhile about one-third of Canadian papers in these journals were published with NCIC support. There is therefore no doubt that the NCIC makes a chief financial contribution to these researchers' activities, while these researchers make a sizeable contribution to Canadian output in cancer research. The NCIC awarded over $60M in 2005—almost 25% of all funds for cancer research in Canada distributed by members of the Canadian Cancer Research Alliance (CCRA), which includes federal and provincial governments, and voluntary funding organizations like NCIC (CCRA, 2007).

In funding research, the NCIC strives to advance cancer research by supporting outstanding researchers selected through peer review. A number of studies found a positive correlation between peer ratings and citation scores of researchers in grant competitions (Anderson, Narin and McAllister, 1978; Lawani and Bayer, 1983; McAllister, Anderson and Narin, 1980). When these measures of scientific excellence point in the same direction, the selection of awardees is generally regarded as being more reliable than when only peer ratings are considered (King, 1987). Because peers are making increased use of bibliometric indicators in rating researchers, as appears to be the case among members of NCIC's review panel (information provided by NCIC's representatives), positive correlations between peer ratings and citation scores will appear even more frequently in the future, especially if reviewers make formal use of bibliometric indicators (using measures provided by statistical offices, companies, or specialized university departments) rather than using their tacit knowledge about how well a researcher performs with respect to these indicators. If NCIC's peer-review process has been efficient at selecting leading researchers, papers authored by successful applicants while they were not financially supported by the NCIC are expected to have, on average, greater scientific impact than other Canadian papers. In the present case, the expectation is realized as shown by the ARC (an indicator of scientific impact) and the proportion of papers in the 5% most cited papers (an indicator of scientific impact/excellence) (see Sections 3.1 and 3.2).

Considering that the scientific impact of NCIC researchers is significantly higher than that of Canada (i.e., excluding papers by NCIC-funded researchers), which itself scores above the world average and is in 2$^{nd}$ place among the G7 countries for scientific impact in cancer research, it is quite clear that researchers funded by the NCIC are of a high calibre.

Armed with additional financing from the NCIC, successful applicants are better equipped to conduct leading-edge research, such that their supported papers should achieve greater scientific impact than the papers they authored without the NCIC's support. This is again the case, as demonstrated using the ARC and the proportion of papers in the 5% most cited papers (see Sections 3.1 and 3.2). Thus, the NCIC appears to have had a positive effect on the scientific impact of papers produced by the researchers it funds, and by extension, on the recognition of the work by other researchers. This result also indicates that the knowledge produced by NCIC awardees was effectively disseminated within the scientific community.

However, the data presented in this report do not allow conclusions as to whether the financial support provided by the NCIC has had a measurable impact on the production volume of the researchers it funds. Are researchers producing more papers per year on average during those years when they are supported than during those years when they are not supported? Answering this question would require a deeper analysis of the research outputs and of funding at the level of individual NCIC researchers throughout their entire career.

Compared to researchers funded by the NCI, NCIC-supported researchers produced, on average, nearly as many papers per year from 2000 to 2006, despite receiving about five times less funding per researcher (taking into account only financial support from the NCI and the NCIC). Considering that the NCI provides approximately 70% of the total public funding for cancer research in the US, compared to the NCIC's contribution of about 25% in Canada (CCRA, 2007), NCIC researchers probably only have access to about one sixth of the total public funds available to NCI researchers. Since, on average, NCIC researchers likely have less financial resources, the present result could indicate that they are more productive (more papers produced per dollar investment) than NCI researchers.

However, as investigations into the causes of cancer and potential cures are becoming high-tech, the cost of cancer research has also increased significantly, requiring ever greater investment on the part of funding bodies. As such, access to greater financial resources may not directly translate into more scientific publications, but might instead result in projects (e.g., large-scale, long-term or innovative projects, such as the Human Genome Project) that could not have been accomplished otherwise. The higher scientific impact of the papers produced by NCI researchers (compared to those published by NCIC researchers) might then be explained, at least in part, by NCI performing more research projects of this type; these are likely to attract more attention from the scientific community. Nevertheless, the scientific impact of NCIC researchers is above the US and Canadian averages, which are themselves above the world level.

The difference in volume of the scientific output of NCIC- and NCI-supported researchers is more pronounced when considering only papers published in cancer-related journals. This is explained by the fact that NCI researchers publish a slightly greater proportion of their papers in these journals compared to NCIC researchers. Similarly, when focusing on papers that are published in journals dealing specifically with cancer research, the difference in the scientific impact of NCIC and NCI weighs even more heavily in favour of NCI-supported researchers. In fact, the scientific impact of NCIC researchers is, in this case, only slightly above that of Canada and the US. Thus, Canadian scientists who are active in cancer research and who are funded by the NCIC publish their most influential work in journals not classified in the subfield of cancer research. A combination of factors likely underlies this finding. For example, their most influential papers might be of interest to a broader readership than just the cancer research community; a paper detailing the structure of a protein involved in cancer might be of interest to biochemists in general such that it gets published in a biochemistry journal not exclusively dedicated to cancer research. It could also be that their most significant discoveries are published in multidisciplinary and high impact journals such as *Nature* or *Science*.

When considering the various subfields in which researchers from both groups are active, it was found that they always had more impact than the world average, with the exception of the NCIC in the subfield of public health. From this analysis, it is clear that the main areas of activity for both groups include cancer and biochemistry research. However, while NCI researchers are more active and have a greater impact in cancer research than in biochemistry, the opposite is true for NCIC researchers (it should be noted that papers, for example those classified in biochemistry, could and probably are related to cancer research).

A small fraction of the researchers funded by the NCIC and the NCI are responsible for most of the published papers supported by these organizations. For example, the most active third of NCIC-supported researchers produced 65% of the NCIC-funded output, compared to 73% in the case of the most active third of researchers with NCI grants. A variety of factors could underlie the observed Pareto distribution in both groups such as a higher productivity of the most active researchers (i.e., greater number of published papers per dollar of funding) and/or a non-uniform distribution of funding (including all sources of funding), with the most active researchers having raised substantially greater financial resources. It is not impossible that output is related to age and thus to the capacity to operate a large research laboratory. If the least active researchers indeed have access to a smaller level of funding, this might be due to lower recognition of their work by their peers. Before any conclusion can be drawn from the observed distributions, more data is required on the resources (e.g., infrastructure, financial and human resources) available to these researchers. It would also be interesting to examine the scientific impact of papers produced by the most active third relative to that of papers published by the least active third in both groups to establish whether or not there is a positive or negative correlation between the size and impact of these researchers' scientific production.

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