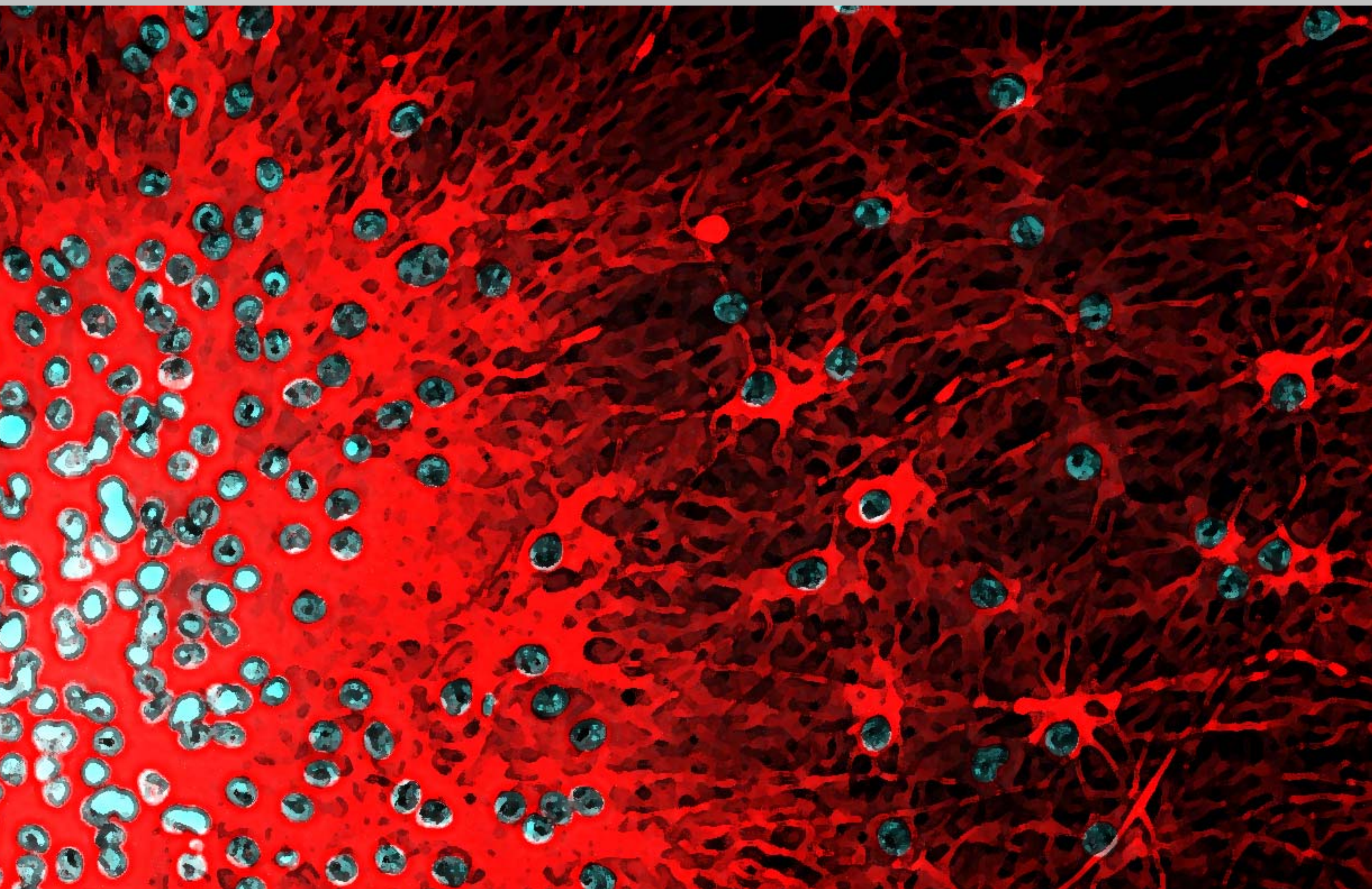
Bibliometric Analysis of Research Supported by the National Cancer Institute of Canada–Phase II



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Bibliometric Analysis of Research Supported by the National Cancer Institute of Canada–Phase II

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by

Science-Metrix[1]

David Campbell and Michelle Picard-Aitken

OST[2]

Guillaume Girard, Vincent Larivière, Benoît Macaluso, Jean-Pierre Robitaille

submitted to

National Cancer Institute of Canada (NCIC)

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Executive Summary

On February 1 2009, the Canadian Cancer Society integrated the operations of the National Cancer Institute of Canada (NCIC), creating the Canadian Cancer Society Research Institute. Note that because the period of time being examined in this study precedes the integration, the text will reference the NCIC. As the NCIC was accountable to the public for the value it created through research, the Institute launched an evaluation of its Operating and Program Project Grants in 2005. As part of this evaluation, Science-Metrix and the Observatoire des Sciences et des Technologies (OST) provided, in September 2008, a bibliometric report analyzing the scientific output of the NCIC's successful applicants over 13 years (1994–2006) worth of NCIC Operating and Program Project Grants. The 2008 report compared the scientific production of NCIC researchers while they were being supported ("NCIC-supported papers") to that while they were not receiving support ("non-supported papers"). It also compared their scientific production to that of Canada, of the world, and of a sample of researchers funded by the US National Cancer Institute (NCI). The current report follows from this study and adds a new dimension by investigating the effect of the different funding programs of the NCIC on the scientific performance of the researchers it supported.

The NCIC provided two types of grants (Operating Grants [OG] and Program Project Grant [PPG]) from two possible sources of financing (the Canadian Cancer Society [CCS] and the Terry Fox Foundation [TFF]). As a first step, this study repeats the analysis comparing the scientific production of NCIC researchers while they were being supported to that while they were not receiving support but this time focusing on NCIC researchers who received only grants financed by the CCS, i.e., excluding researchers who have also been supported by funds from the TFF. As a second step, this study provides a comparative analysis of NCIC-supported papers (i.e., papers supported by the CCS and the TFF) and non-supported papers between a group of researchers who only received OGs and another group that only received PPGs. Four bibliometric indicators of scientific performance were used: the number of papers, the average of relative citations (ARC), the number of papers in the 5% most cited papers, and the average of relative impact factors (ARIF). Following are the key findings of this bibliometric study.

Analysis of research supported by the NCIC through CCS grants

- CCS-supported papers represented about half of the production of CCS-funded scientists (1995–2007).
- In terms of scientific impact, findings similar to those of the previous study were obtained when focusing on researchers who received only CCS grants.
    - Researchers who were supported by the CCS had significantly higher ARC scores and a significantly higher proportion of papers in the 5% most cited papers than non-supported Canadian researchers in all fields.
    - The ARC scores and the proportion of papers in the 5% most cited papers of CCS-funded scientists were higher when they were supported by the CCS than when they were not supported. The difference is only significant in the case of the ARC.

Comparison of research supported through NCIC Operating Grants and Program Project Grants (financing was from the CCS and the TFF)

- Just over half of the scientific papers by NCIC-funded scientists, through either OGs or PPGs, were published while they were financially supported by the NCIC from 1995 to 2007.

- The analysis of trends in the number of papers per NCIC-funded scientist over four distinct periods (i.e., prior to receiving support, with support, after support, and with renewed support) revealed, for both types of grants, an increase during the period of support from the NCIC.
- This increasing trend in the period with support could be explained by three non-mutually exclusive factors:
    - The number of papers by highly promising researchers often exhibits substantial growth over the course of their careers, in which case the trend could be unrelated to NCIC funding—this is not unlikely as similar growth trends were observed in the period prior to support;
    - This increase could also be the result of a positive effect of NCIC funding, in which case the longer the period of support, the better it was for the production volume of researchers;
    - As we move through time in the period of support, it may be that only the most productive researchers remained, thereby increasing the average number of papers per NCIC-funded scientist. The length of support provided by the NCIC to researchers would therefore be correlated with the number of papers they produced annually.
- The latter two scenarios are reinforced by the fact that a decreasing trend in the scientific output of researchers was observed in the period after support (for both types of grants), followed by an increasing trend in the period with renewed support (in the case of OGs only).
- This decreasing trend during the period without support could be explained by two factors:
    - The decrease could be the result of the loss of the positive effect of NCIC funding on the number of papers produced by researchers, in which case the longer the period without support, the worse it was for the production volume of researchers.
    - As we move through time in the period without support, it may be that only the least productive researchers remained, thereby decreasing the average number of papers by scientist that were no-longer funded by the NCIC. The length of support provided by the NCIC to researchers—and consequently the length of time without support—would therefore be correlated with the number of papers they produced annually.
- Whereas the annual production of researchers with PPGs was similar to that of researchers with OGs prior to receiving support, the annual production of this group while receiving support was greater than for the OG group. This suggests that NCIC funding, at least in the case of PPGs, contributed to increasing the scientific production of the researchers it supported. It should be noted that PPGs were generally awarded to more senior and elite researchers than OGs, and that these researchers might be better equipped (e.g., resources and experience) to ramp up their scientific production upon receiving an additional source of financing.
- The scientific impact, as measured using the ARC and ARIF, of NCIC-supported papers was greater than that of non-supported papers, irrespective of the type of grant. The difference is highly significant in the case of OGs for the ARC and for both types of grants for the ARIF.
- Highly cited papers were more frequent within NCIC-supported papers than within non-supported papers for both types of grants, but the difference is only significant in the case of PPGs.
- When supported by the NCIC, researchers who received PPGs performed better than those who received OGs, with higher ARC scores and a significantly higher proportion of highly cited papers. This might again be explained by the fact that PPGs generally funded more senior and elite researchers.
- As was found in the previous study and in the analysis of CCS grants, NCIC-funded researchers, irrespective of the type of grant they received, had a higher level of scientific impact and a higher proportion of highly cited papers than non-supported Canadian researchers in all fields.

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Figures

1 Introduction

The National Cancer Institute of Canada (NCIC) was established in 1947 as a joint initiative of the Department of National Health and Welfare (now Health Canada) and the Canadian Cancer Society. On February 1 2009, the Canadian Cancer Society integrated the operations of the National Cancer Institute of Canada (NCIC), creating the Canadian Cancer Society Research Institute (see: http://www.cancer.ca/research/). Note that because the period of time being examined in this study precedes the integration, the text will reference the NCIC. 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.

As the funds awarded by the NCIC came from two charitable organizations (the Canadian Cancer Society and the Terry Fox Foundation), the Institute recognized that it was accountable to the public for the value it created through research. Thus, the NCIC launched an evaluation of its Operating and Program Project Grants in 2005 as part of its 2015 Strategic Plan. The NCIC conceptualized and implemented an assessment of its awarding process, scrutinizing both the application and review of proposals. This 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) provided, in September 2008, a bibliometric report analyzing the scientific output of the NCIC's successful applicants over 13 years (1994–2006) worth of NCIC Operating and Program Project Grants (Campbell *et al*, 2008).

The 2008 report compared the scientific production of NCIC researchers while they were being supported ("NCIC-supported papers") to that while they were not receiving support ("non-supported papers"). It also compared their scientific production to that of Canada, of the world, and of a sample of researchers funded by the US National Cancer Institute (NCI). One aspect that was not covered in that study, representing the first phase of bibliometric analysis, was the effect of the different funding programs of the NCIC.

The NCIC provided two types of grants (Operating Grants [OG] and Program Project Grant [PPG]) from two possible sources of financing (the Canadian Cancer Society [CCS] and the Terry Fox Foundation [TFF]). The current study, representing the second phase of bibliometric analysis, repeats the comparison of the scientific production of NCIC researchers while they were supported to that while they were not supported, but this time focusing on NCIC researchers who received only grants financed by the CCS; thus, NCIC researchers who received grants financed by the TFF are excluded (Section 2). This study subsequently aims to provide a comparative analysis of NCIC-supported papers (i.e., papers supported by the CCS and the TFF) and non-supported papers between a group of researchers who received only OGs (includes both sources of financing, i.e., CCS and TFF) and another group which received only PPGs (includes both sources of financing, i.e., CCS and TFF) (Section 3).

OGs were designed to stimulate Canadian investigators in a very broad spectrum of research having relevance to cancer. These areas include, but are not limited to:

- biological (studies in the genetics, protein chemistry, epigenetics, proteomics, immunology and molecular biology of cancer);
- chemical (studies in carcinogenesis, gene therapy, drug development, chemical genomics and drug delivery);
- physical (studies in imaging, radiobiology and medical physics);
- clinical (investigations such as chemotherapy, pathology, prevention and detection); and
- Population health sciences (including behavioural, community health, supportive care, palliative care, health promotion, health services, epidemiology, knowledge translation and occupational/environmental health sciences).

PPGs were designed to stimulate group interaction based on the premise that high impact work in complex areas of cancer research requires complementary skills and can be best carried out through a group effort. PPGs were thus intended to assist groups of investigators to approach a common problem in such a way that the end result would have the potential to achieve more than the simple sum of the individual efforts and to provide a high quality training environment.

Compared to OGs, PPGs promote collaboration between research teams, which subsequently may allow a greater number of established researchers to contribute to joint publications and may also allow for the engagement of a greater number of research personnel (e.g. lab personnel, graduate students, and post-docs). Finally, PPGs are generally awarded to more senior and elite researchers than OGs. Altogether, researchers that have been awarded PPGs might therefore be better equipped (e.g., in terms of resources and experience) than those who were awarded OGs to ramp up their scientific production upon reception of their grants.

Four bibliometric indicators of scientific performance were used in this study: the number of papers, the average of relative citations (ARC), the number of papers in the 5% most cited papers, and the average of relative impact factors (ARIF). Following are the key findings of this bibliometric study. The last section of this report presents the methods used in greater details (Section 5).

2 Analysis of research supported by the NCIC through CCS grants

This section examines the research output of researchers supported by the NCIC through CCS grants only (i.e., they have not received TFF grants) over the 1994–2006 period (N=440). It compares their output, in terms of number of papers (Section 2.1) and scientific impact (Section 2.2), when they were supported and when they were 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 the 440 researchers retained for analysis). Note that because CCS-supported papers are counted starting one year after the first year of the grant, all subsequent data are presented over the 1995–2007 period.

2.1 Scientific Production

Overall, just over half of scientific papers by researchers supported by the CCS at any time over the 1994–2006 period were published with financial support from the CCS: 8,839 out of 17,008 papers by CCS-funded researchers were published after their first year of CCS funding up until the year after the end of the grant. As shown in Figure 1, the number of CCS-supported papers has been stable since 1995, while the number of non-supported papers (i.e., all other papers by CCS researchers) has increased more or less steadily over the period. It should be highlighted that researchers who received CCS funding could also be receiving grants from other funders; papers considered as "CCS-supported" may thus have been also partly supported by other sources of funding. The same is also true for those papers without CCS support.

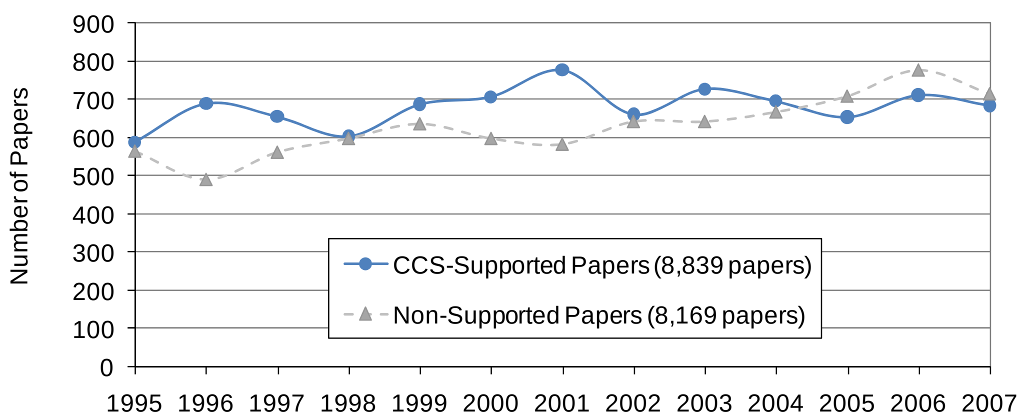

Figure 1 Yearly number of papers written by CCS-supported researchers (N=440), 1995–2007

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

Within the subfield of cancer research as defined using the NSF classification of scientific journals, researchers who received support from the CCS at any given time contributed to 33% of Canadian papers (2,755 out of 8,277 papers). About 20% of Canadian papers (1,555) in cancer-related journals were actually supported by the CCS, having been published by researchers after their first year of CCS funding up until the year after the end of the grant.

2.2 Scientific Impact

Besides the number of published papers, another important indicator of scientific performance is the impact that the published papers have 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; the ARC can therefore be used as an indicator of scientific impact. All entities considered in this section (CCS-supported, non-CCS supported, and other Canadian papers) scored above the world average (i.e., above 1).

Papers that were supported by the CCS at any time between 1995 and 2007 had a substantially higher scientific impact than other Canadian papers (ARC = 1.20) (highly significant for the three sets of papers [all papers by CCS-funded researchers, CCS-supported papers, and non-supported papers], $p < 0.001$; Figure 2). For the whole period (1995–2007), the impact of CCS-supported papers (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 (ARC = 1.67) than that of papers authored without the support of the CCS (ARC = 1.55; highly significant, $p < 0.01$). However, the scientific impact of CCS-supported papers and those without CCS support fluctuated slightly over time such that the latter set of papers had greater impact than the former in three out of thirteen years (Figure 2). Also the ARC of both groups of papers decreased slightly over time.

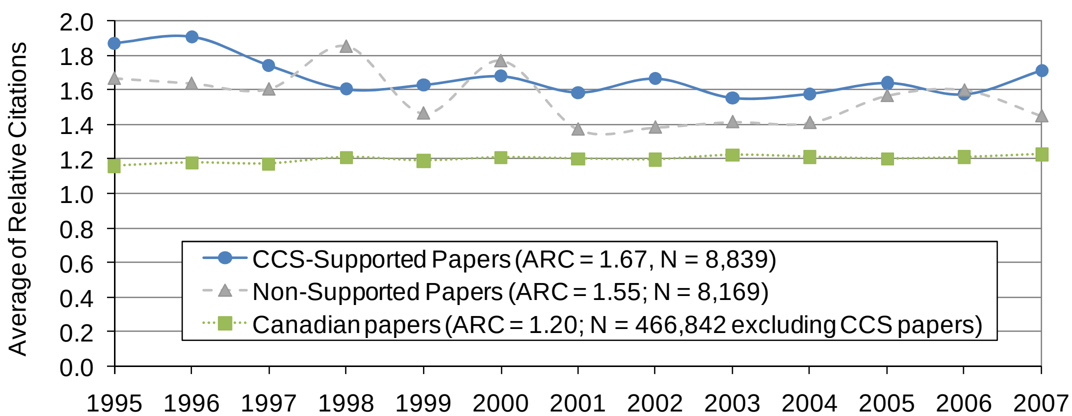

Figure 2 Average of relative citations of papers by CCS (N=440) and Canadian researchers, 1995–2007

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

Another indicator of scientific impact is the proportion of published papers that are in the 5% of papers with the highest citation counts. This indicator was calculated for both CCS-funded researchers and for Canadian researchers as a whole (Figure 3). CCS-supported researchers had 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 CCS-funded researchers, CCS-supported papers, and non-supported papers. In addition, papers by researchers who were supported by the CCS at any time between 1994 and 2006 were more frequently found in highly cited papers when they were supported by the CCS (8.4% for

CCS-supported papers compared to 7.7% for non-supported papers for the whole period, Figure 3). However, the difference is not statistically significant (*p* > 0.05).

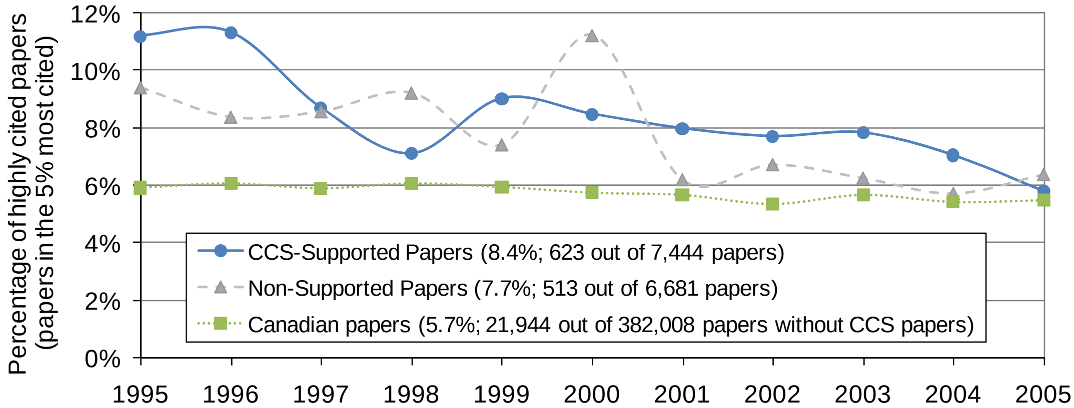

Figure 3 Proportion of papers by CCS (N=440) and Canadian researchers in the 5% most cited papers, 1995–2005

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

3 Comparison of research supported through NCIC Operating Grants and Program Project Grants (financing was from the CCS and the TFF)

This section presents a comparative analysis of a group of NCIC-funded researchers who received only Operating Grants (OG: N=568) and another group which received only Program Project Grants (PPG: N=100) over the 1994–2006 period. This analysis includes OGs and PPGs irrespective of the source of financing (i.e., financing came from both the CCS and the TFF). In this section, the term "NCIC" is thus meant to encompass grants financed through the CCS and the TFF. It compares the output of NCIC researchers who received OGs and PPGs, in terms of number of papers (Section 3.1) and scientific impact (Section 3.2), when they were supported and when they were 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 the 668 researchers retained for analysis). 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 1995–2007 period.

3.1 Scientific Production

From 1995 to 2007, the 568 researchers who received only OGs published 56% of their papers (11,538 out of 20,605 papers) while supported by the NCIC. Researchers who received only PPGs (N=100) published a similar percentage of their papers (57%; 2,117 out of 3,739 papers) while supported by the NCIC.

Figure 4 presents trends in the number of published papers per NCIC-funded scientist (OGs and PPGs) for four distinct periods (i.e., up to 11 years prior to receiving first ever support from the NCIC, P11 to P1; up to 13 years with support, S1 to S13; up to 10 years after support, A1 to A10; up to 4 years with renewed support, R1 to R4). As no single researcher's output can be tracked across the entire time frame from P11 to R4 (see Section 5.2 for details), the four periods, when put side by side, do not reflect the general production pattern of individual researchers. As such, care should be taken when linking the four periods to interpret trends in the production of researchers.

In the period preceding support, the average number of papers produced per funded researcher increased gradually and the yearly output of researchers with OGs was very similar to that of researchers with PPGs (from P11 to P1, Figure 4). As the NCIC was previously shown to have selected outstanding Canadian researchers (Campbell *et al*, 2008), this trend might reflect the fact that the scientific production of highly promising researchers often exhibits steady growth over the course of their careers.

The increase in the average number of papers produced per funded researcher observed for both types of grants during the period of support could be explained in at least three ways (from S1 to S13, Figure 4). First, this gradual increase in the average production of researchers could reflect the fact that researchers, especially high-calibre researchers, often increase their production during the first 25 years of their careers (Gingras *et al*, 2008). As such, the observed increase might be unrelated to NCIC funding since a similar trend was observed in the period preceding support for both types of grants. However, a second possible explanation is that the increasing trend could also be the result of a positive effect of NCIC funding, in which case the longer the period of support, the better it was for the production volume of researchers. A third hypothesis is that those researchers who produced the highest number of papers per year in our samples are the same as those who obtained NCIC funding repeatedly over the longest period of time without interruption; in order to have papers in year S13, a researcher must have received funding continuously from 1994 to 2006. For OGs and PPGs, there were 568 and 100 researchers, respectively, whose papers could be counted in year S1 whereas there were only 38 and 11, respectively, whose papers could be counted in year S13. If the third hypothesis is correct, the length of support provided by the NCIC to researchers would be correlated with the number of papers they produced annually. Importantly, these three scenarios are not mutually exclusive.

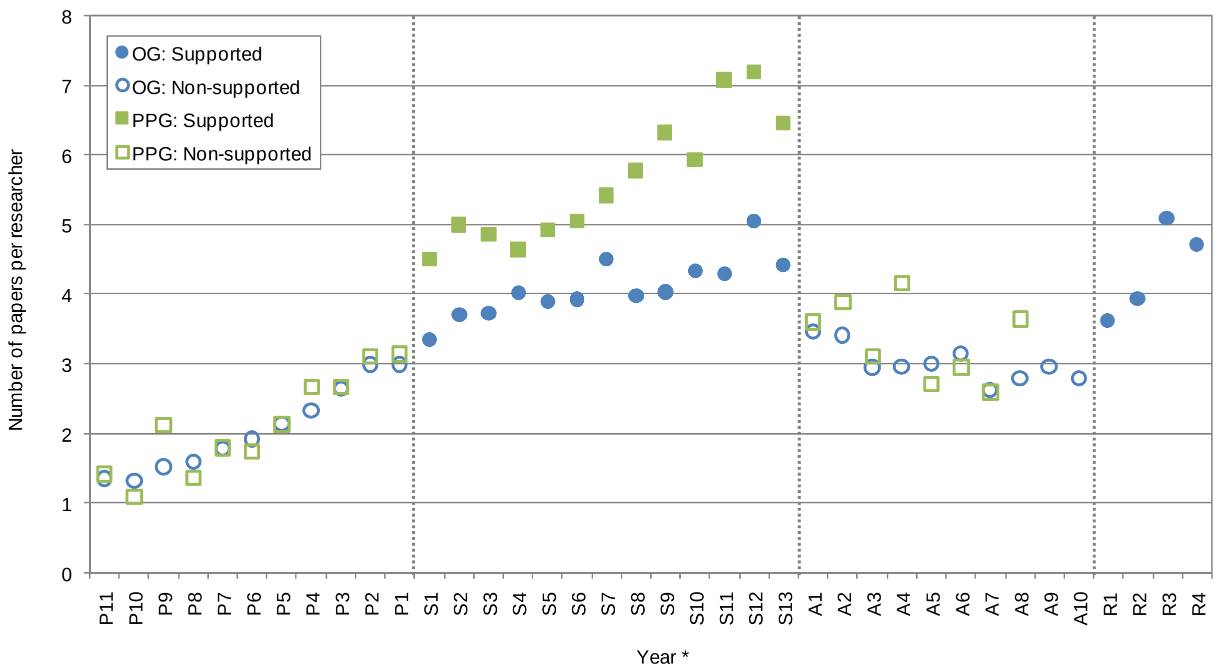

Figure 4 Trends in the number of published papers by NCIC researchers (OGs: N=568; PPGs: N=100), 1995–2007

Note: * Letters refer to one of four periods (P = prior to receiving support, S = with support, A = after support, R = renewed support). The trends extend up to 11 years prior to receiving first ever support from the NCIC, up to 13 years with support, up to 10 years after support, and up to 4 years with renewed support. Sample sizes per year are low in the case of PPGs; data points are not shown when the number of researchers is below 10. In the case of OGs, sample sizes are always above 30.

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

In the period after support (from A1 to A10), there was an apparent decline in the average number of papers produced per funded researcher, irrespective of the type of grant (Figure 4). This trend could be explained in at least two ways. It is possible that the loss of support from NCIC led to a reduction in the production volume of researchers and that this decline gets more pronounced as the length of the period without support increases. Alternatively, it could be that those researchers who produced the lowest number of papers per year were the same as those who obtained NCIC funding for the shortest periods of time; in order to have papers in year A10, a researcher must have received funding for a maximum of three years from 1994 to 1996. This explanation is consistent with the third hypothesis put forth for the period of support (from S1 to S13, see above); as such, it would also suggest that the length of support provided by the NCIC to researchers may be correlated with the number of papers they produced annually. Interestingly, the average number of papers produced per funded researcher increased again with renewed support from the NCIC (OGs only) (from R1 to R4, Figure 4).

Finally, it is worth mentioning that whereas the annual production of researchers with PPGs was similar to that of researchers with OGs prior to receiving support (P11 to P1), the annual production of this group while receiving support (S1 to S13) was greater than for the OG group. This suggests that NCIC funding, at least in the case of PPGs, may have contributed to increasing the scientific production of the researchers it supported (Figure 4).

3.2 Scientific Impact

The scientific impact, as measured with the average of relative citations (ARC), of NCIC-supported papers was greater than that of non-supported papers irrespective of the type of grant (Figure 5). The difference for the entire period (1995–2007) is not statistically significant in the case of PPGs (ARC of supported papers = 1.92 versus 1.62 for non-supported papers; $p > 0.05$) while it is significant in the case of OGs (ARC of supported papers = 1.68 versus 1.58 for non-supported papers, $p < 0.001$). Supported papers, when authored by researchers with PPGs, had higher ARC scores than researchers with OGs but the difference is not significant ($p > 0.05$). There is no difference between the two types of grants when considering non-supported papers. For the 1995–2007 period, NCIC-funded researchers, irrespective of the type of grant they received, had a higher level of scientific impact than those of non-supported Canadian researchers in all fields.

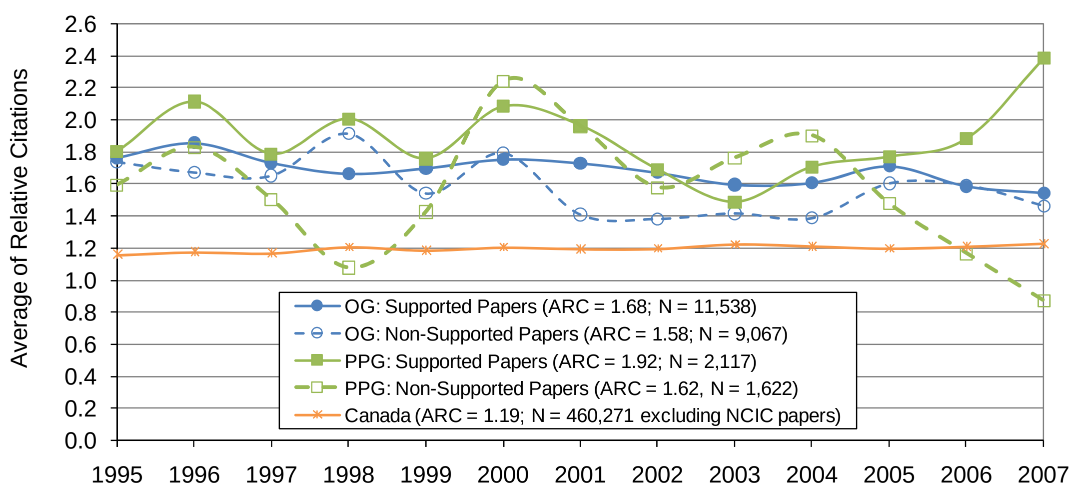

Figure 5 Average of relative citations of papers by NCIC (OGs: N=568; PPGs: N=100) and Canadian researchers, 1995–2007

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

The proportion of published papers by an entity (i.e., a research group, a country) that are in the 5% of papers with the highest citation counts allows for a comparison of different entities in terms of the frequency with which they publish ground-breaking discoveries. This indicator was calculated for both NCIC researchers (OGs and PPGs) and for Canadian researchers as a whole (Figure 6). For the 13 years considered (1995–2007), highly cited papers were more frequent within papers by NCIC-supported researchers than within papers by non-supported Canadian researchers in all fields irrespective of the type of NCIC grant; the difference is significant for the three sets of papers for each type of grant: all papers by NCIC researchers, NCIC-supported papers, and non-supported papers ($p < 0.05$). Highly cited papers were more frequent within NCIC-supported papers than within non-supported papers in the case of PPGs (statistically significant, $p < 0.05$), but they were not in the case of OGs ($p > 0.05$). Within NCIC-supported papers, highly cited papers were more frequent in the case of PPGs than in the case of OGs (statistically significant, $p < 0.05$). There was no such difference between PPGs and OGs when considering non-supported papers ($p > 0.05$).

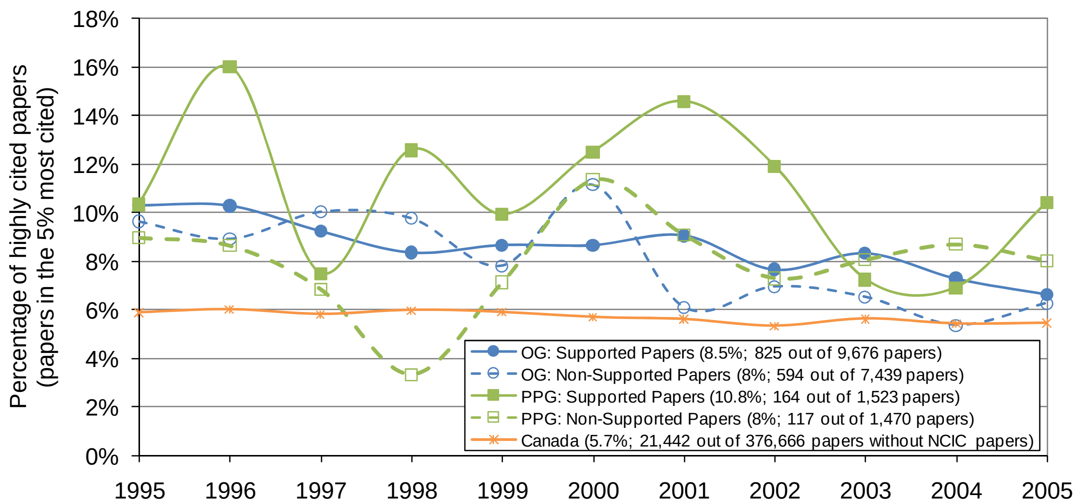

Figure 6 Proportion of papers by NCIC (OGs: N=568; PPGs: N=100) and Canadian researchers in the 5% most cited papers, 1995–2005

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

The scientific impact, as measured with the average of relative impact factors (ARIF), of NCIC-supported papers was greater than that of non-supported papers irrespective of the type of grant (Figure 7). The difference for the entire period (1995–2007) is statistically significant ($p < 0.01$) with both types of grants (OGs: ARIF of supported papers = 1.44 versus 1.33 for non-supported papers; PPGs: ARIF of supported papers = 1.45 versus 1.31 for non-supported papers). The ARIF of papers authored by researchers with OGs was not different from the ARIF of papers authored by researchers with PPGs. Over the entire period, papers by NCIC-funded researchers, irrespective of the type of grant they received, had a higher ARIF than those of non-supported Canadian researchers in all fields.

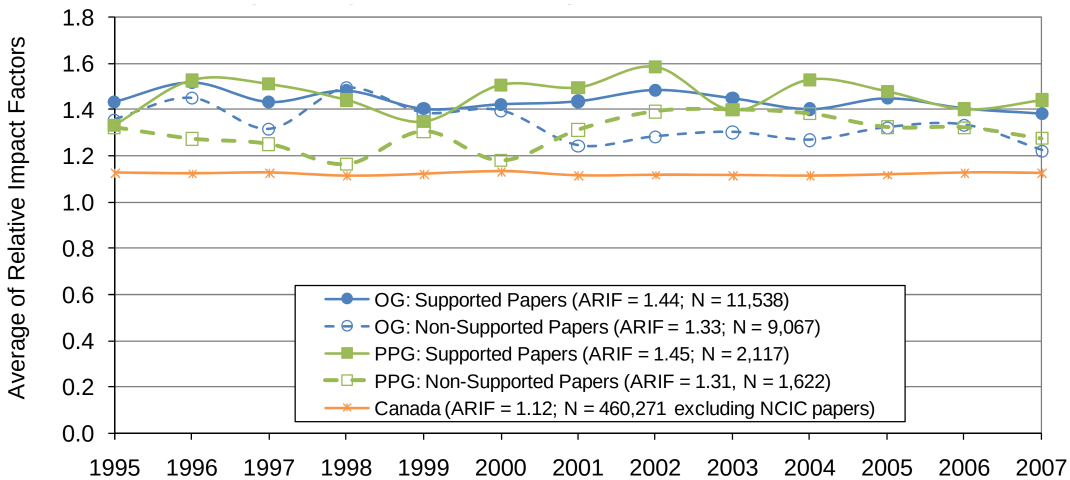

Figure 7 Average of relative impact factors of papers by NCIC (OGs: N=568; PPGs: N=100) and Canadian researchers, 1995–2007

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

4 Conclusion

This report follows from a study (Campbell *et al.*, 2008) that compared the scientific production of researchers who received financial support from the National Cancer Institute of Canada (NCIC) while they were being supported ("NCIC-supported papers") to that while they were not receiving support ("non-supported papers"). The 2008 study also compared the scientific production of NCIC researchers to that of Canada, of the world, and of a sample of researchers funded by the US National Cancer Institute (NCI). The current report adds a new dimension to the previous study by investigating the effect of the different funding programs of the NCIC on the scientific performance of the researchers it supported.

Analysis of research supported by the NCIC through CCS grants

As a first step, this study repeats the analysis comparing the scientific production of NCIC-funded researchers while they were being supported to that while they were not receiving support, but this time focusing on NCIC researchers who received only grants financed by the Canadian Cancer Society (CCS), i.e., excluding researchers who have also been supported by funds from the Terry Fox Foundation (TFF).

During the 1995–2007 period, about half of the scientific production of researchers who received funding from the CCS was produced with financial support from the CCS (i.e., 8,839 out of 17,008 papers were published between the year after the start of the grant and the year after the end of the grant). These researchers were authors on 33% of the Canadian papers published in cancer-related journals from 1995 to 2006; meanwhile about 20% of Canadian papers in these journals were published with CCS support. There is therefore no doubt that the CCS makes a chief financial contribution to these researchers' activities, while these researchers make a sizeable contribution to Canadian output in cancer research. The CCS awarded nearly $45M in 2006—about 11% 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 the CCS (CCRA, 2008).

When analyzing the scientific impact of papers using researchers who received only CCS grants, findings similar to those of the previous study, which considered NCIC grants irrespective of funding source, were obtained. In particular, researchers who were supported by the CCS had a significantly higher level of scientific impact and a significantly higher proportion of papers in the 5% most cited papers than non-supported Canadian researchers in all fields. Also, the scientific impact and the proportion of papers in the 5% most cited papers of CCS-funded scientists are higher when they were supported by the CCS than when they were not supported. The difference is only significant in the case of the scientific impact.

Comparison of research supported through NCIC Operating Grants and Program Project Grants (financing was from the CCS and the TFF)

As a second step, a comparative analysis of NCIC-supported papers and non-supported papers between a group of researchers who received only Operating Grants (OG) and another group which received only Program Project Grants (PPG) was performed. This analysis includes OGs and PPGs irrespective of the source of financing (i.e., financing came from both the CCS and the TFF). In this section, the term "NCIC" is thus meant to encompass grants financed through the CCS and the TFF. For both types of grants (i.e., OGs and PPGs), the papers published by researchers while they were supported represent slightly more than half of their total output from 1995 to 2007. The analysis of trends in the number of papers per NCIC-funded scientist over four distinct periods (i.e., prior to receiving support, with support, after support, and with renewed support) revealed, for both types of grants, an increasing trend in the period of support from the NCIC which could be explained by three non-mutually exclusive factors:

- The number of papers by highly promising researchers often exhibits substantial growth over the course of their careers, in which case the trend could be unrelated to NCIC funding—this is not unlikely as similar growth trends were observed in the period prior to support.
- This increase could also be the result of a positive effect of NCIC funding, in which case the longer the period of support, the better it is for the production volume of researchers.
- As we move through time in the period of support, it may be that only the most productive researchers remained, thereby increasing the average number of papers per NCIC-funded scientist. The length of support provided by the NCIC to researchers would therefore be correlated with the number of papers they produced annually.

The later two scenarios are reinforced by the fact that a decreasing trend in the period after support (for both types of grants) and an increasing trend in the period with renewed support (in the case of OGs only) were observed. In the period without support, the decreasing trend could be explained by two factors:

- The decrease could be the result of the loss of a positive effect of NCIC funding on the number of papers produced by researchers, in which case the longer the period without support, the worse it is for the production volume of researchers.
- As we move through time in the period without support, it may be that only the least productive researchers remain, thereby decreasing the average number of papers by scientist that were no-longer funded by the NCIC. The length of support provided by the NCIC to researchers—and consequently the length of time without support—would therefore be correlated with the number of papers they produced annually.

Determining which of these factors were truly responsible for the observed trends would require a micro-level analysis of scientific output by NCIC-supported researcher using detailed information on career paths and on alternative sources of funding besides NCIC grants.

Nevertheless, whereas the annual production of researchers with PPGs was similar to that of researchers with OGs prior to receiving support, the annual production of this group while receiving support was greater than for the OG group. This suggests that NCIC funding, at least in the case of PPGs, contributed to increasing the scientific production of the researchers it supported. It should be noted that PPGs were generally awarded to more senior and elite researchers than OGs, and that these researchers might be better equipped (e.g., in terms of resources and experience) to ramp up their scientific production upon receiving an additional source of financing.

The scientific impact, as measured using the average of relative citations (ARC) and the average of relative impact factors (ARIF), of NCIC-supported papers was greater than that of non-supported papers, irrespective of the type of grant. The difference is highly significant in the case of OGs for the ARC and for both types of grants for the ARIF. In addition, highly cited papers (i.e., in the 5% most cited papers) were more frequent within NCIC-supported papers than within non-supported papers for both types of grants but the difference is only significant in the case of PPGs. Therefore, whereas a positive effect of NCIC funding has not been clearly demonstrated with regard to the size of the scientific production of researchers who received OGs, its effect on the scientific impact has been clearly shown for both OGs and PPGs. It is worth mentioning that when supported by the NCIC, researchers who received PPGs performed better than those who received OGs, obtaining higher ARC scores (i.e., 1.92 versus 1.68)—although this difference is not statistically significant—and a significantly higher proportion of highly cited papers (i.e., 10.8% versus 8.5%). This might again be explained by the fact that PPGs generally funded more senior and elite researchers.

Finally, as was found in the previous study and in the analysis of CCS grants, NCIC-funded researchers, irrespective of the type of grant they received, had a higher level of scientific impact and a higher proportion of highly cited papers than when non-supported and than non-supported Canadian researchers, in all fields.

5 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 is discussed in Section 5.1. Section 5.2 addresses the construction of these datasets in detail, while Section 5.3 presents the taxonomy used in determining the domains of activity of NCIC researchers. The bibliometric indicators used to quantify scientific outputs are detailed in Section 5.4, while the statistical analysis performed on bibliometric indicators is presented in Section 5.5. Finally, Section 5.6 discusses the limitations of bibliometric methods.

5.1 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., natural sciences and engineering [NSE], social sciences and humanities) was used to produce statistics on the scientific production of NCIC researchers. 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 (with about 1,500,000 peer-reviewed scientific documents added 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 the previous bibliometric study was performed with the WoS, this option was not chosen.

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.

5.2 Constitution of Datasets

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 researchers (N=800) who were awarded Operating and Program Project Grants from 1994 to 2006. 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). For the first part of the study on research supported by the NCIC through CCS grants (i.e., the source of financing is the Canadian Cancer Society), 440 researchers who received only CCS grants were retained for analysis; in other words, none of them had received grants financed by the Terry Fox Foundation. For the second part of the study, comparing research supported through Operating Grants (OGs) and Program Project Grants (PPGs), 668 researchers who received either one or the other of these two types of grants (N=568 for OGs; N=100 for PPGs), but not both, were retained for analysis. In this case, the source of financing was either from the CCS or the TFF.

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 2007. The search is limited to papers bearing a Canadian address to minimize the occurrence of false positives resulting from homographs in researchers' names. This can lower the recall rate (i.e., does not retrieve all papers by a researcher) in cases where the researcher is newly established in Canada or has been a visiting scientist outside Canada, although in this case the scientist normally signs is papers specifying both affiliations (i.e., the Canadian and visiting addresses). Although imperfect, this approach favours precision over exhaustivity, which is appropriate when working with large samples such as the ones used in this study.

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 8).

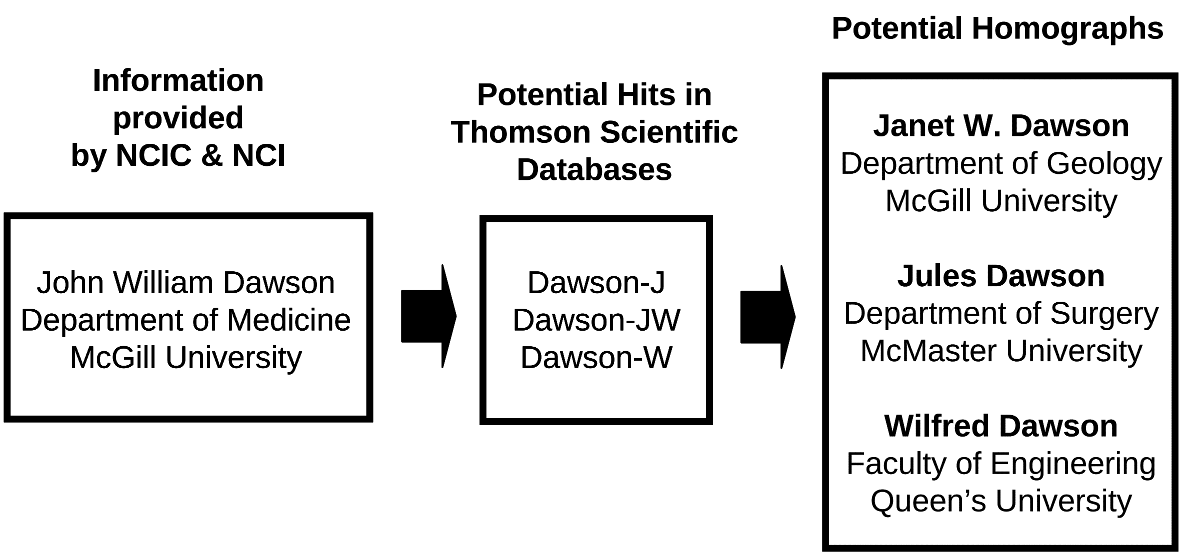

Figure 8 Example of potential homographs in the Web of Science
Source: OST and Science-Metrix

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 these papers consistent with respect to the discipline of the researcher as revealed by his/her departmental affiliation? Is the scope of these 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 9).

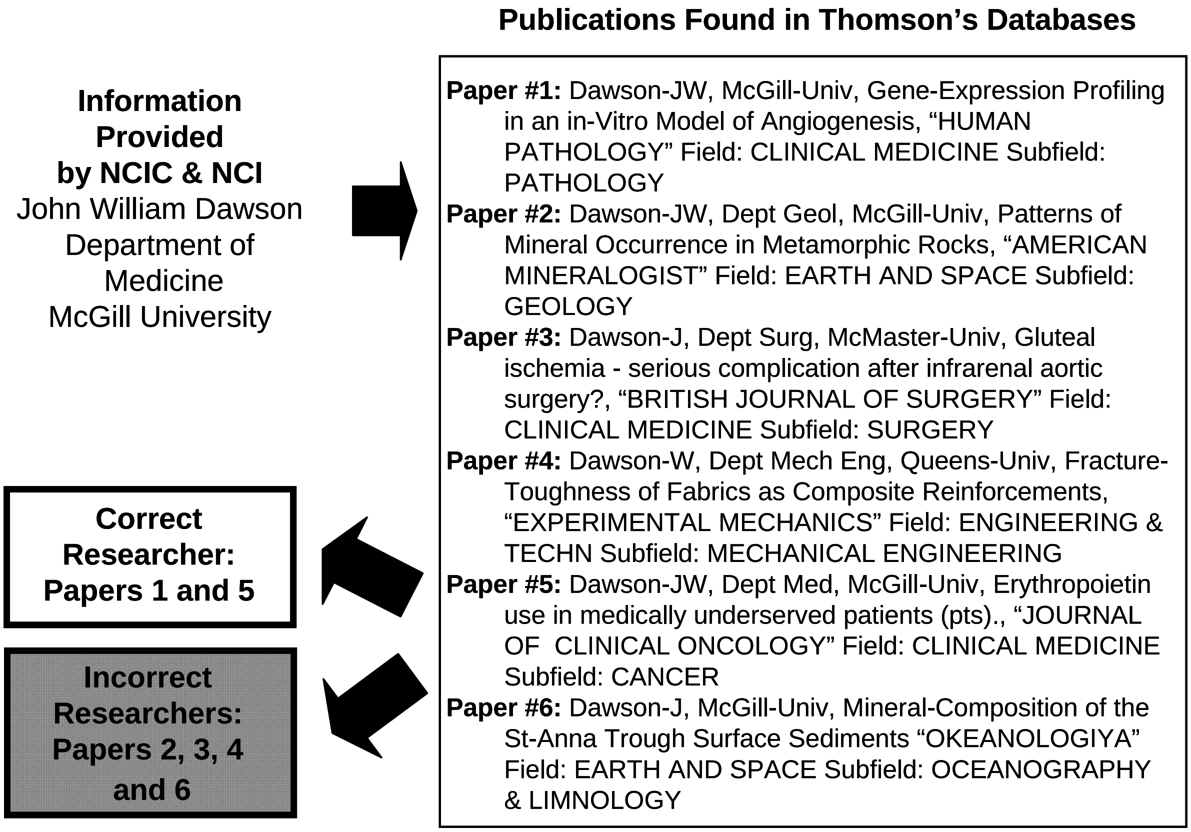

Figure 9 Example of portfolio cleaning
Source: Developed by OST and Science-Metrix

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.

As the cleaning of publication portfolios involves judgement on the part of individuals performing the task, errors inevitably occur. In this respect, the 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.

NCIC-supported and non-supported papers

Papers were considered to be "NCIC-supported" (or "CCS-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 2007, a total of 29,702 papers were authored by NCIC-supported researchers, of which 57% (16,845) were "NCIC-supported papers". The balance (29,702 – 16,845 = 12,857) are referred to as "non-supported papers" (i.e., these are all other papers by NCIC researchers). Note that researchers receiving NCIC (or CCS) funding could also be receiving grants from other funders; papers considered as "NCIC-supported" (or "CCS 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 (or the CCS).

To measure trends in the average production of NCIC-funded researchers (i.e., the average number of papers per researcher per year) before, during and after the period of support, and during renewed support (if applicable), the papers were reclassified based on the number of years prior to support (P), during support (S), after support (A) and with renewed support (R); year S1 corresponds to the first year for which papers are considered to be supported. This allowed data from researchers supported in different periods (i.e., covering different years) to be pooled. For example, a 2003 paper was tagged as supported for a researcher funded between 1999 and 2002 but was tagged as non-supported for a researcher funded between 2003 and 2005. In the first case, the paper is reclassified as year S4 (fourth year with support) whereas in the second case it is reclassified as year P1 (one year prior to support). Given the period covered by the study (1995–2007) and NCIC grant periods, the trends were examined for each researcher for up to 11 years prior to receiving first ever support from the NCIC (P11), up to 13 years with support (S13), up to 10 years after support (A10), and up to 4 years with renewed support (R4), based on the year(s) of their NCIC awards.

5.3 Disciplinary Classification

The categories and methods used to delineate the various domains of activity of NCIC 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.

5.4 Bibliometric Indicators

Using researcher portfolios built using the aforementioned methods as well as papers computed at the country level (for Canada) the following indicators were calculated:

Number of publications: Whole counting of the number of scientific papers written by authors associated with a funding organization (i.e., NCIC) based on author names (see Section 5.2), or by authors associated with a country (i.e., Canada) 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 5.3 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. The analysis of most cited papers is the most recent years (2006 and 2007) is risky and might lead to biased results since papers in those years have not yet reached their citation peak year. Therefore, the analysis of most cited papers is limited to the 1995–2005 period.

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 a journal in 2007 is equal to the number of citations to articles published in 2006 (8) and 2005 (15) divided by the number of articles published in 2006 (15) and 2005 (23) (i.e., IF = numerator [23] / denominator [38] = 0.605).

However, as pointed out by Moed and colleagues (1999), Thomson Reuters' IF is flawed in that its numerator and denominator are not symmetric:

> ISI classifies documents into types. In calculating the nominator of the IF, ISI counts citations to all types of documents, while as citable documents in the denominator ISI includes as a standard only normal articles, notes and reviews. However, editorials, letters, and several other types are cited rather frequently in a number of journals. When they are cited, these types do contribute to the citation counts in the IF's numerator, but are not included in the denominator. In a sense, the citations to these documents are "for free".

In this study, we therefore used a symmetric IF based on three documents types (i.e., articles, notes, and reviews) which is computed using Thomson Reuters' WoS.

The IF of papers is calculated by ascribing to them the IF of the journal 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 published the same year in its subfield (see Section 5.3 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.

5.5 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 $p < 0.01$; or
- highly significant at $p < 0.001$.

Because data on scientific impact are not normally distributed, non-parametric tests were used. When comparing the scientific impact, based on the ARC or ARIF, of a pair of independent samples, the Mann-Whitney U test was used. When comparing the proportion of papers that are in the 5% most cited papers of a pair of independent samples, a Z-test for two proportions was used.

5.6 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.

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