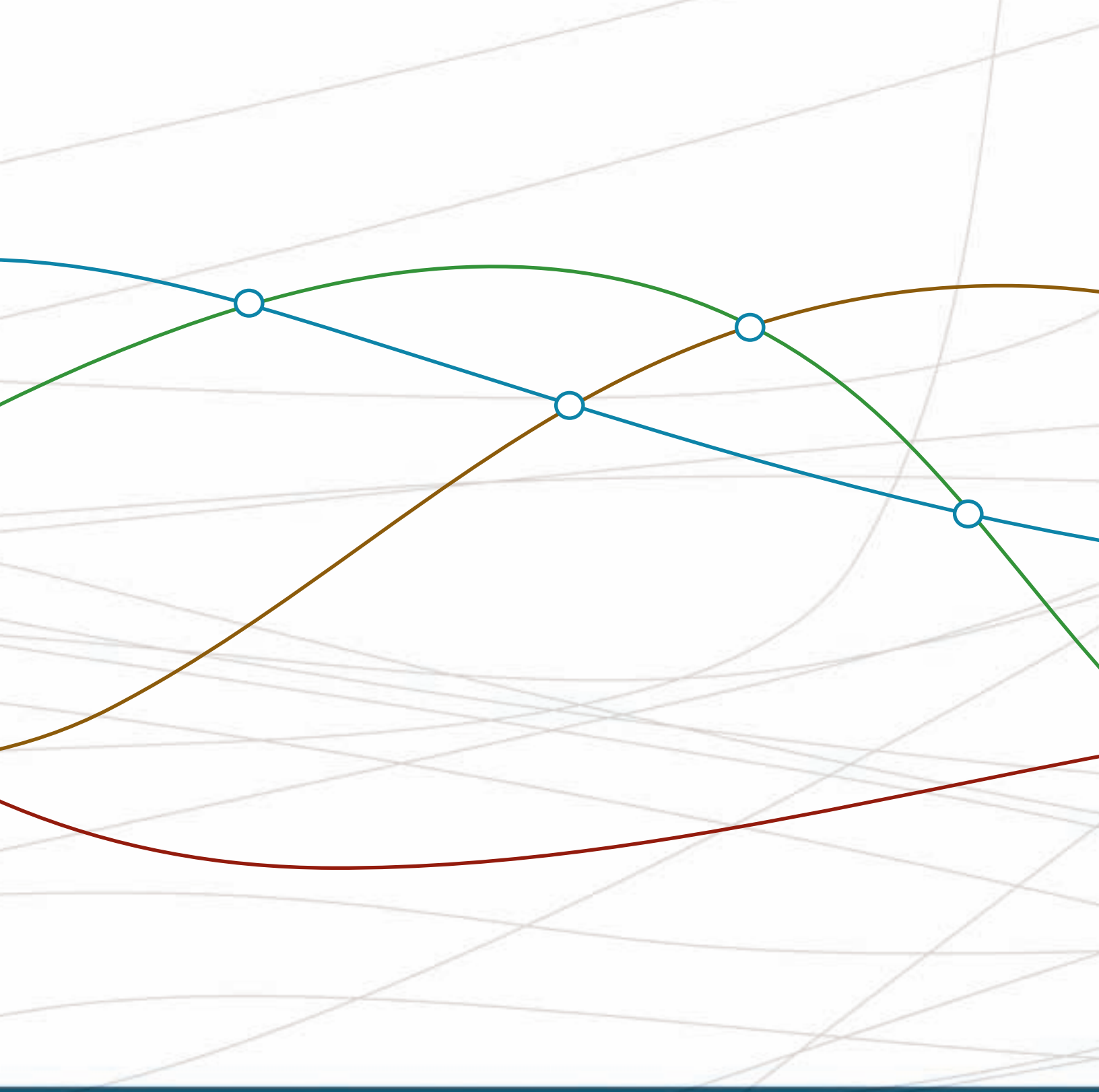


The Ingenuity Way ° ° °

BIBLIOMETRIC ANALYSIS OF INDIVIDUALS SUPPORTED
BY THE ALBERTA INGENUITY FUND

The Alberta Ingenuity Fund was established in 2000 by the Government of Alberta to establish and support a balanced long-term program of science and engineering research directed to the discovery of new knowledge and the application of that knowledge to improve the quality of Alberta's economy, communities and environment. The organization is guided by a Board of Trustees and advised by an international panel of experts, the Science and Engineering Advisory Council. Every six years, the organization is evaluated by an International Board of Review.

Throughout its history, Alberta Ingenuity has strived to become a performance-based organization delivering programs of real benefit to Alberta and its knowledge-based economy. Program design and the quality of the decisions taken at Alberta Ingenuity are at the heart of how we deliver on our strategic goals. All decisions involve peer review and expert panels, and all decisions are subject to regular quality assurance evaluations leading to program improvement. This independent bibliometric analysis of some of Alberta Ingenuity's programs that support highly qualified people in Alberta's universities carried out by Science-Metrix forms part of our approach to performance management and commitment to continuous improvement. It is a companion to an economic impact study of the Alberta Ingenuity Industry Associates program carried out by Deloitte.

Alberta Ingenuity's highly qualified people programs support graduate students, new faculty and senior researchers (Alberta Ingenuity Scholars) at Alberta's research intensive universities. Since 2001, 387 graduate student scholarships, 47 new faculty awards and nine Alberta Ingenuity Scholars awards have received $35 million in funding from Ingenuity. The programs are competitive and the success rates in the competitions are low, typically in the range of 20 to 30 per cent. Only the best-of-the-best are funded. This evaluation uses bibliometric evaluation to test the quality of the selection processes at Alberta Ingenuity and provides evidence that the organization selects very high performers and that these individuals maintain their high performance standards following their award. In addition, the results show that papers produced by the researchers applying from Alberta's research intensive universities had significantly higher average relative citations than other papers from Alberta and Canada over the period between 1996 and 2008. This reflects equally well upon the researchers and their institutions.

The papers produced by AIF-funded researchers had significantly higher ARC and ARIF scores than other papers from Alberta and Canada as whole over the 1996–2008 period.

Alberta Ingenuity will incorporate the lessons learned from this study as it seeks continuous improvement and greater effectiveness in the future. We will also repeat and refine the evaluation in the years to come.

Our thanks to our colleagues at Science-Metrix for their excellent work.

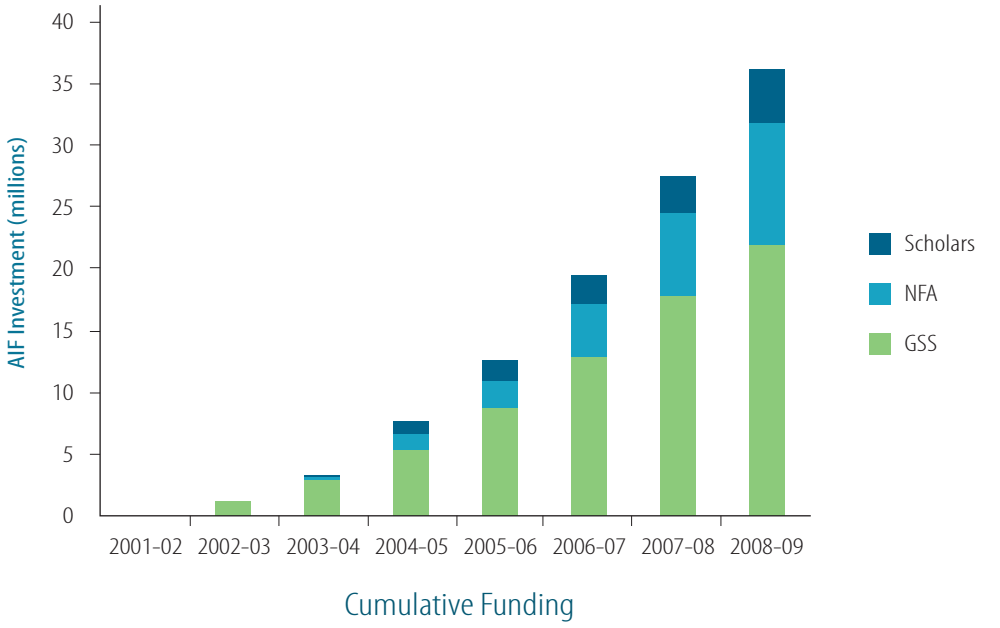
Sincerely,

Peter Hackett
President and CEO, Alberta Ingenuity

HQP Programs

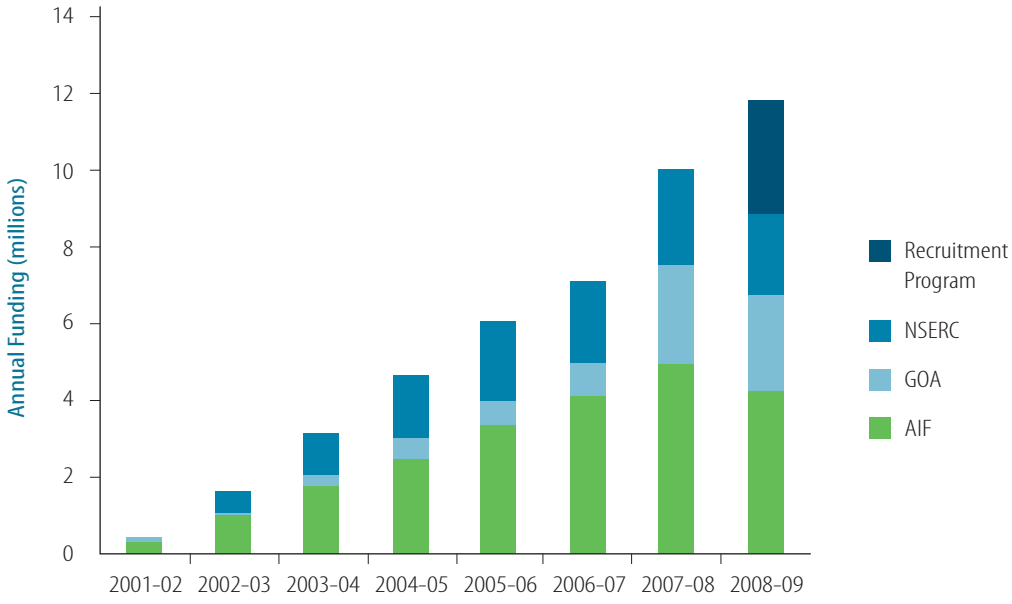
Alberta Ingenuity provides funding to help recruit and retain outstanding researchers in Alberta's universities, colleges and technical institutes. The Graduate Student Scholarships enable academically superior graduate students to undertake full-time research. The New Faculty Awards program provides start-up support to investigators in their first academic appointment at an Alberta university or college. The Alberta Ingenuity Scholar program attracts the world's top researchers to Alberta in areas of strategic importance for the Province.

To date, Ingenuity has invested $36 million to support 441 individuals.



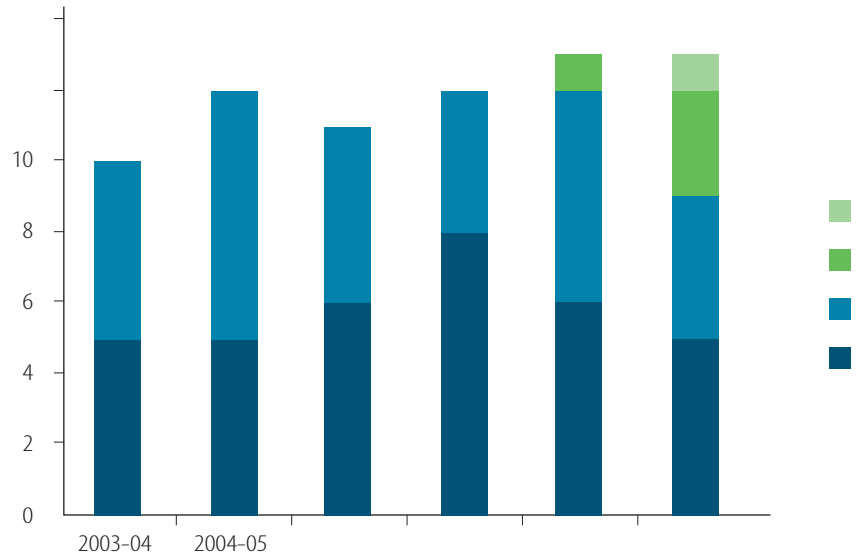
Cumulative Funding

- Ingenuity has invested $22 million in the GSS program; $9.8 million in the New Faculty Award program and $4.3 million in the Scholars program.
- 387 graduate student scholarships, 47 New Faculty Awards and 7 Scholars Awards been funded.
- The GSS program provides MSc and PhD students salary support and their first research funds to manage.



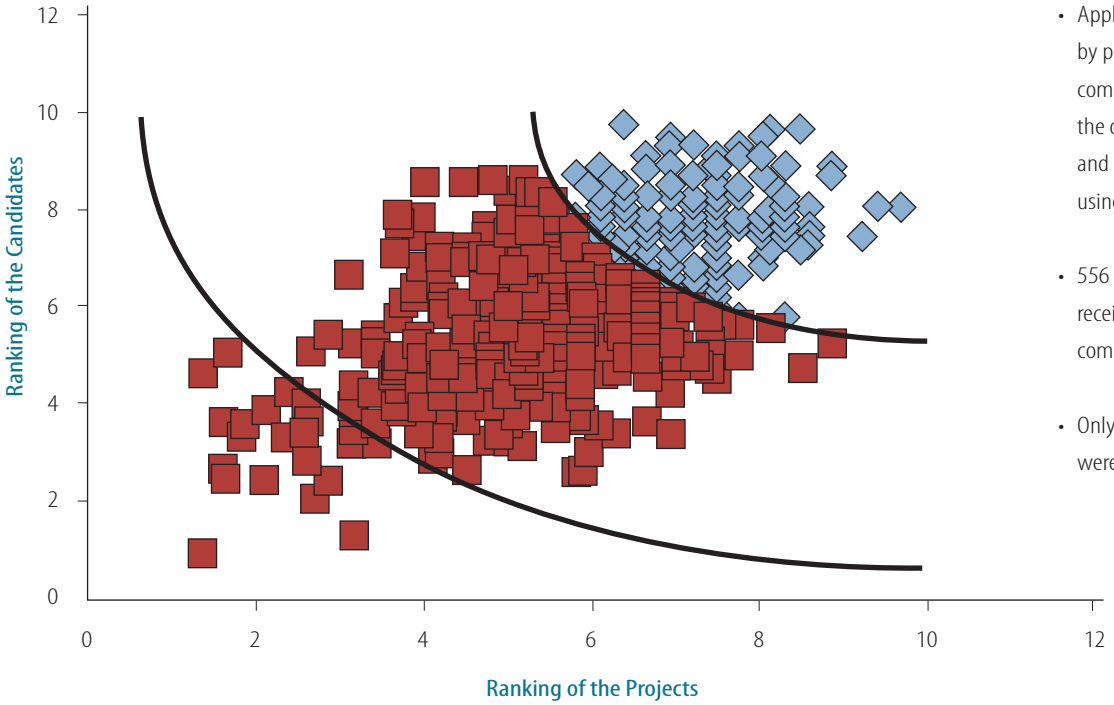
GSS Program: Leveraged Funding

- GSS funds students from across Alberta, Canada, and all over the world.
- GSS awardees have received $12.2 million in additional funding from NSERC.
- The Alberta Nano/ICT Recruitment Program is funded by Ingenuity, iCORE, and Alberta Advanced Education and Technology.



New Faculty

- Ingenuity has supported 71 New Faculty at the four provincial universities.
- Athabasca University received its first award in 2008.



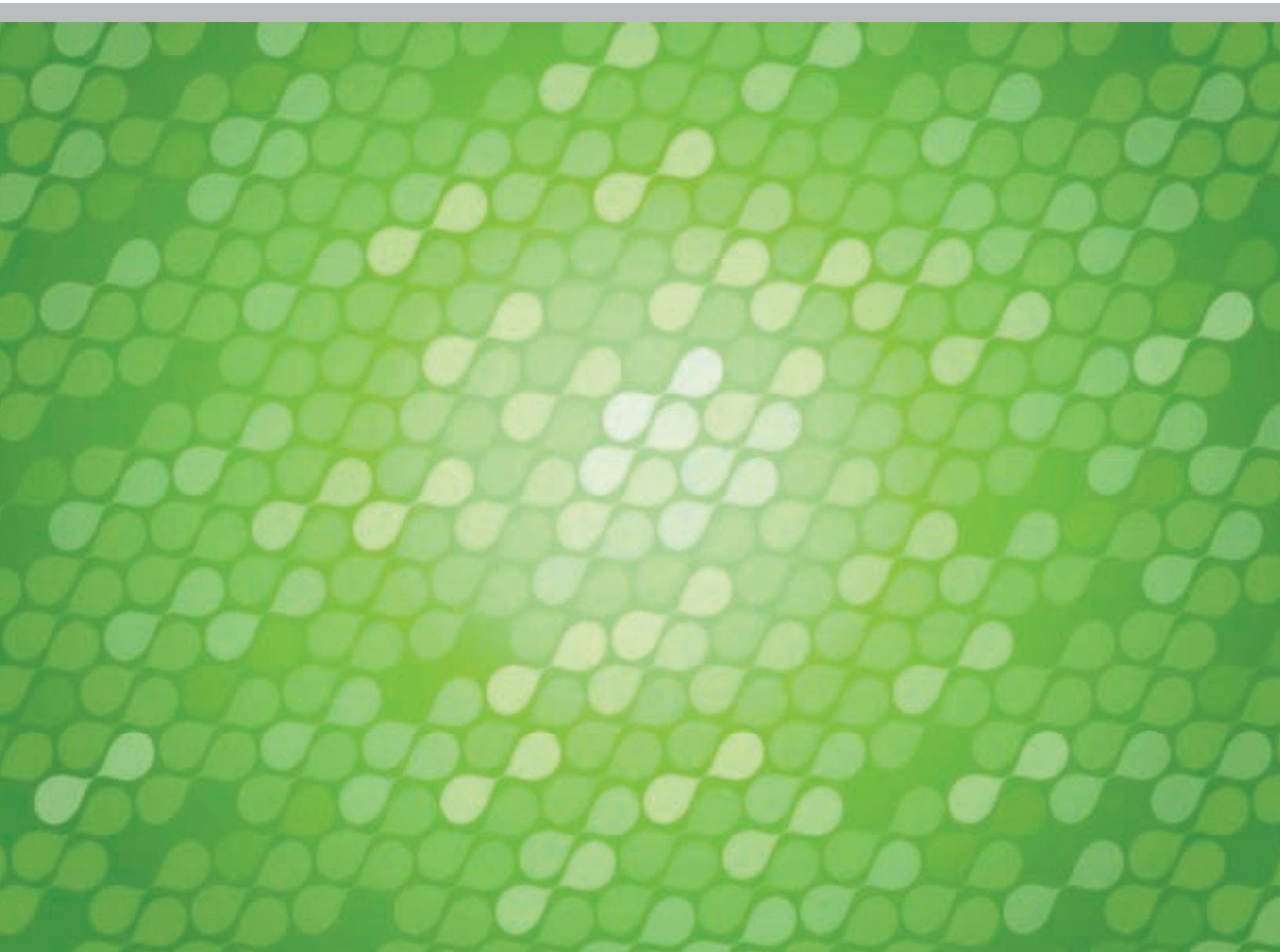
2008-09 Graduate Student Scholarship (GSS) Competition

- Applications are evaluated by peer review and expert committees who evaluate the quality of the applicant and the quality of the project using specific criteria.
- 556 applications were received in the 2008-09 competition.
- Only 169 applicants were approved.

Annual Awards

Science-Metrix

Bibliometric Analysis of Individuals Supported by Alberta Ingenuity Fund



Science-Metrix

Bibliometric Analysis of Individuals Supported by Alberta Ingenuity Fund

May 22, 2008

by

Michelle Picard-Aitken

David Campbell

Isabelle Labrosse

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submitted to

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Executive Summary

This study provides quantitative data on the scientific production of researchers and graduate students who received financial support from Alberta Ingenuity Fund (AIF). The scientific output of about 120 researchers who were awarded an AIF grant from 2002 to 2006 and 300 graduate students who were awarded an AIF scholarship from 2001 to 2008 was analyzed based on three bibliometric indicators of scientific performance:

- number of papers
- average of relative citations (ARC)
- average of relative impact factors (ARIF).

The selection of high-calibre researchers and academically superior graduate students is a crucial component of AIF funding programs. As such, by comparing the scientific output of successful researchers and students to their respective comparable groups (i.e., other Albertan, Canadian and world researchers, and unsuccessful applicants [researchers or graduate students]), the analysis provides insight as to whether AIF has effectively selected outstanding researchers and highly promising students. In addition, by comparing the applicants' output prior to receiving support (or before application, in the case of unsuccessful applicants) to their output while receiving support (or after application, in the case of unsuccessful applicants), the effect of AIF funding on the volume and impact of the scientific production of funded applicants was investigated. In the case of graduate students, the analysis also looked at the effect of AIF funding on mobility. Following are the key findings for AIF-funded scientists and AIF-supported graduate students.

Scientific output of AIF-funded researchers

- Papers produced by AIF-funded researchers (unsupported papers only) had significantly higher ARC and ARIF scores than other papers from Alberta and Canada as a whole over the 1996–2008 period. This suggests that AIF has effectively selected outstanding researchers through its funding programs.
- ARC scores of successful applicants to the New Faculty Awards and Alberta Prion Research Institute (APRI) program are higher than for unsuccessful applicants, both for unsupported papers (or papers published before application to AIF, in the case of unsuccessful applicants) and supported papers (or papers published after application to AIF, in the case of unsuccessful applicants), although these differences are not significant.
- These results provide preliminary evidence that AIF has effectively selected the best researchers among those who applied for funding in terms of impact on the scientific community.
- However, AIF does not appear to have selected researchers who stand out among those who applied for funding in terms of scientific production volume.
- No definitive conclusions could be made regarding the effect of AIF funding on the scientific impact and production (i.e., number) of papers authored by AIF-supported researchers.
- As additional data for the period under support becomes available in the years to come, sample sizes will increase, providing more robust results to interpret the effect of AIF funding.

Scientific output of AIF-supported graduate students

- AIF awarded scholarships to students whose prior research experience resulted in papers that had a significantly higher scientific impact than other papers by researchers in Alberta and Canada.
- These results suggest that AIF selection process has effectively assessed the prior research experience of students who applied to the GSS program.
- The difference between the scientific impact of papers (ARC) published before and after application *within each group* (successful and unsuccessful applicants) suggests an increase in the scientific impact of papers produced with AIF support.

- Indeed, the ARC of papers authored by successful applicants with support from AIF is higher than that of unsupported papers (i.e., papers authored by AIF-supported graduate students before they received GSS funds), although this difference is not statistically significant. This difference was not observed for unsuccessful applicants.
- Successful applicants published more papers per year than unsuccessful applicants in the period before application and overall (before and after application).
- Almost 60% of successful applicants published more papers per year after application (while receiving support from AIF) than before application, and the difference between the two periods is highly significant.
- A similar increase in average yearly output is observed for unsuccessful applicants, again with a highly significant difference. However, fewer unsuccessful applicants increased their production in the period after application (40% versus 60% for successful applicants).
- Nevertheless, the fact that a greater percentage of successful applicants increased their production after they applied for the scholarship than did unsuccessful applicants does not necessarily indicate that AIF funding had a positive effect on the number of papers produced by the students it supported.
- In fact, one would expect to obtain this finding if AIF effectively selected the most promising students among those who applied for a GSS, which appears to be the case, based on the analysis of scientific impact and scientific production of students prior to application.
- The analysis of graduate student mobility (both successful and unsuccessful applicants) did not provide any conclusive results.
- For all the above-presented analyses, sample sizes for comparison purposes were small. Therefore, the analysis should be repeated in a few years when larger numbers of funded graduate students can be examined over a longer period of time, which should yield more conclusive results.

Contents

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1 Introduction

Alberta Ingenuity Fund (AIF) was established in 2000 by the Government of Alberta to develop internationally competitive science and engineering expertise and to build greater capacity for innovation, particularly in areas with lasting social and economic impact for the province. Through an integrated suite of programs that are aligned with provincial priorities, Alberta Ingenuity makes connections between the research community and industry to commercialize technology and create new business opportunities.

Alberta Ingenuity aims to increase the quality of research in Alberta by offering generous, sustained and flexible funding to a variety of highly qualified personnel throughout the province. This funding is administered through a number of award programs, including Scholar Awards, New Faculty Awards, Ingenuity Centres and Ingenuity Institutes, such as the Alberta Prion Research Institute (APRI) and Graduate Student Scholarships (GSS).

The purpose of the present bibliometric study is to perform an analysis of the scientific output (i.e., scientific publications) of approximately 120 researchers in the suite of programs it funds and approximately 300 students funded through the GSS. The scientific output of these individuals was examined over the 1996–2008 period. In addition, the scientific output of researchers and graduate students who applied for AIF funding but did not obtain it (i.e., unsuccessful applicants) was analyzed in a comparable sample.

The data garnered from this bibliometric study will help determine how AIF support affects the scientific output of funded individuals in terms of volume and scientific impact. The scientific output of AIF-funded researchers is presented in Section 2, which includes a comparison of the output of AIF-funded researchers with that of unsuccessful applicants. Finally, this study will help determine how AIF support in the form of Graduate Student Scholarships affects the scientific output and mobility of funded graduate students compared with those of unsuccessful student applicants (Section 3).

Three bibliometric indicators of scientific performance were used in this study. First, the number of papers published by researchers was counted before and during the support period (or before and after they applied, in the case of unsuccessful applicants) and by graduate students (both successful and unsuccessful) before and after they applied for the GSS. Second, two indicators of scientific impact were examined: the average of relative citations (ARC) and the average of relative impact factors (ARIF). These indicators and the methods used in this study are presented in detail in Section 5.

2 Scientific output of AIF-funded researchers

A total of 117 AIF-funded researchers are examined in this section of the report. These researchers obtained funding from 2002 to 2006. Researchers funded after this period were not included because they would be unlikely to have had sufficient time (i.e., at least two years) to publish papers that benefited from the support of the AIF award. Note that the database coverage ends in 2008. In this study, "AIF-supported papers" are those published in the period starting two years after the first year of financial support and ending two years after the last year of financial support. Papers published in the period from 1996 to 2008 but which fall outside the period during which papers are considered supported constitute the "unsupported papers" subset (see Section 5.2 for more details on supported and unsupported papers).

Section 2.1 provides a brief description of the distribution of researchers and papers among AIF programs examined in this study. Next, AIF selection of successful applicants is discussed through comparisons of the scientific output of AIF researchers with that of other researchers in Alberta, Canada and the world, and with unsuccessful applicants to AIF awards (Section 2.2). Finally, the scientific output of AIF-funded researchers before the support period is compared to their scientific output authored during the support period (sections 2.3 and 2.4).

2.1 Overview of AIF programs

The 117 researchers received grants in the period from 2002 to 2006, and were funded through four AIF programs: Ingenuity Institutes—more specifically, the Alberta Prion Research Institute (APRI), Ingenuity Centres, New Faculty Awards (NFA) and Scholar Awards. The number of researchers per grant type is as follows: 54 are in the APRI program, 32 were funded as part of Ingenuity Centres, 33 received NFAs and 5 received Scholar Awards. Note that some researchers obtained two types of awards and are counted twice (i.e., once for each type of award), so that the total number of researchers ismore than 117.

As explained above, the papers authored by AIF-funded researchers are considered supported when they are published in the period starting two years after the first year of the grant (i.e., starting in 2004 at the earliest). Figure 1 presents the number of papers published per year and per grant type by AIF-funded researchers. As can be seen, the higher the number of researchers (shown in italics), the higher the number of papers. Interestingly, Scholar Award holders produced the highest number of papers per researcher per year. Considering only the output of the 117 AIF-funded researchers over the 2004–2008 period, a total of 202 papers were supported by APRI grants, 462 by Ingenuity Centre grants, 193 papers by New Faculty Awards and 73 by Scholar Awards.

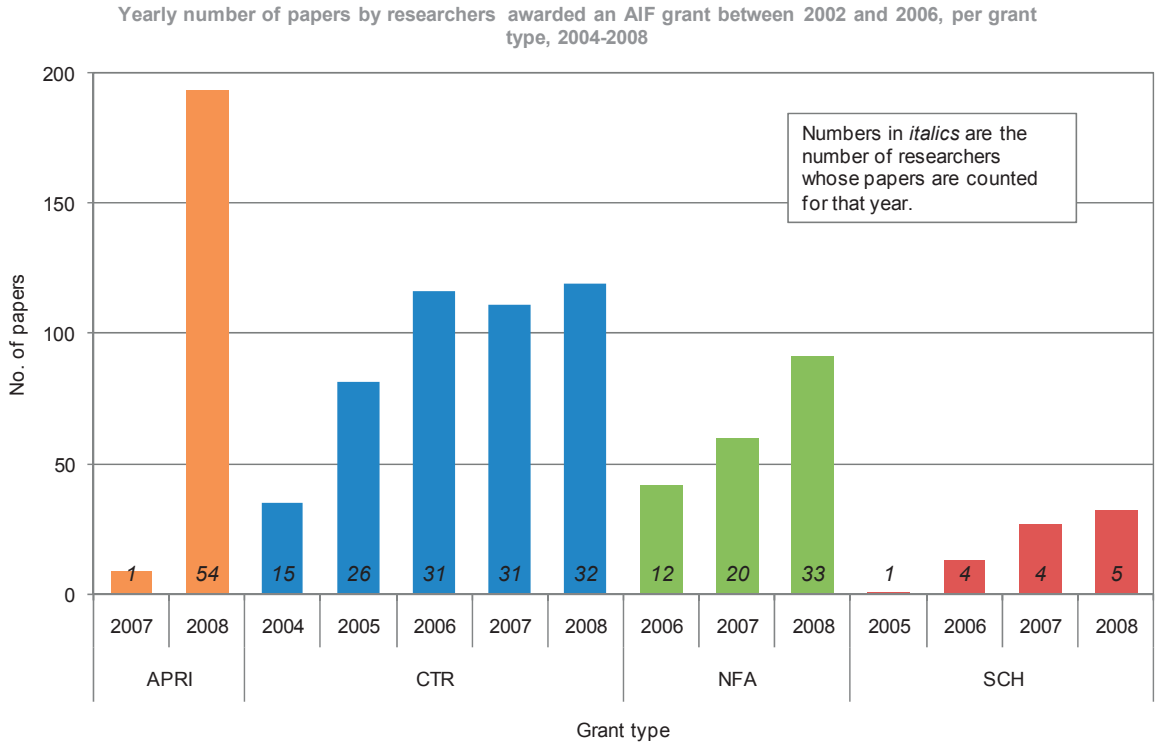

Figure 1 Yearly number of papers by researchers awarded an AIF grant from 2002 to 2006 per grant type, 2004–2008

Note: Abbreviations: APRI - Alberta Prion Research Institute, CTR - Ingenuity Centres, NFA - New Faculty Awards and SCH - Scholar Awards. The number of researchers considered for each year is indicated at the base of each column. Some researchers obtained two types of awards and are therefore counted twice (i.e., once for each grant). Because supported papers are considered those published in the period starting two years after the first year of financial support, only applicable years are shown.

Source: Calculated by Science-Metrix using the Scopus database.

2.2 Comparisons of the scientific output of AIF-supported researchers with non-AIF-funded researchers

As the selection of high-calibre researchers is a crucial component of the AIF programs, the scientific impact of 117 AIF-funded researchers was compared with that of average Albertan, Canadian and world researchers (excluding AIF researchers). This comparison offers evidence as to whether the AIF selection process has been effective (i.e., whether it has selected outstanding researchers). If so, supported researchers should have achieved higher scientific impact prior to receiving support (i.e., for unsupported papers) than did comparable groups.

Two indicators of scientific impact were computed: the average of relative citations (ARC), which is a *direct* measure of the impact of scientific research based on citation counts to papers, and the average of relative impact factors (ARIF), which is an *indirect* measure of its impact based on journal impact factors. As shown in Table I, the papers produced by AIF-funded researchers (unsupported papers only) had significantly higher ARC and ARIF scores than other papers from Alberta and Canada as a whole for the 1996–2008 period ($p < 0.001$).

AIF researchers also published unsupported papers that had higher scientific impact than world papers (Table I). For example, the ARC score of AIF researchers (1.5) indicates that their papers are cited 50% more on average than world papers, whereas papers by other Albertan and Canadian researchers are cited 20% more on average than world papers (ARC of 1.2). These results suggest that AIF has effectively selected outstanding researchers through its funding programs.

Table I Comparison of the scientific impact (based on ARC and ARIF) of papers produced by AIF-funded researchers (unsupported papers only) with that of papers by other researchers from Alberta, Canada and the world, 1996–2008

Group	ARC*	*p*-value	ARIF**	*p*-value
AIF researchers	1.5	–	1.3	–
Alberta without AIF researchers	1.2	< 0.001	1.1	< 0.001
Canada without AIF researchers	1.2	< 0.001	1.1	< 0.001
World without AIF researchers	1.0	–	1.0	–

Note: * Because relative citation counts are unreliable at this analytical level for the most recent years (2007 and 2008), papers published in those years were not included in the computation of the ARC indicator (see Section 5.3).
** Because the impact factors of journals prior to 1998 cannot be calculated in Scopus, papers published in 1996 and 1997 were not included in the computation of the ARIF indicator (see Section 5.3).
Source: Calculated by Science-Metrix using the Scopus database.

A similar comparison can be made between the scientific impact of researchers who obtained AIF funding and those who applied to AIF but failed to obtain a grant. Because data was provided on unsuccessful applicants to the APRI and NFA programs, the analyses presented below were limited to the output of applicants who obtained APRI and NFA grants. To ensure comparability of results, sample sizes for both programs (N = 16 for APRI and N = 24 for NFA) were made equal for both groups of researchers (N = 40 for each of two groups: successful and unsuccessful applicants) using random sampling to avoid having a program over- or underrepresented in one group relative to the other (see Section 5.2 for more details on the constitution of datasets).

The ARC scores of successful applicants to these two programs are higher than for unsuccessful applicants, both for unsupported papers (or papers published before application to AIF, in the case of unsuccessful applicants) and supported papers (or papers published after application to AIF, in the case of unsuccessful applicants), although these differences are not significant ($p > 0.05$; Table II). This non-significant difference is likely due to the small sample sizes for supported papers (or papers published after application to AIF). Repeating this test in a few years when larger numbers of funded researchers and supported papers can be examined should yield more conclusive results. As for the ARIF, there was no difference between successful and unsuccessful applicants (Table II). Nevertheless, these results provide preliminary evidence that AIF has effectively selected the best researchers among those who applied for funding in terms of impact on the scientific community.

Table II Comparison of the scientific impact (based on ARC and ARIF) of papers produced by AIF*-funded researchers with those of papers by unsuccessful applicants, 1996–2008

Group	Successful applicants	Unsuccessful applicants	*p*-value
ARC**			
Non-supported/Before application papers	1.7	1.4	> 0.05
Supported/After application papers	1.8	1.0	> 0.05
ARIF***			
Non-supported/Before application papers	1.2	1.3	> 0.05
Supported/After application papers	1.2	1.2	> 0.05

Note: *To ensure comparability of the two groups, only APRI and NFA grants are considered (no data was provided on unsuccessful applicants for other grant types).
* Because relative citation counts are unreliable at this analytical level for the most recent years (2007 and 2008), papers published in those years were not included in the computation of the ARC indicator (see Section 5.3).
** Because the impact factors of journals prior to 1998 cannot be calculated in Scopus, papers published in 1996 and 1997 were not included in the computation of the ARIF indicator (see Section 5.3).
Source: Calculated by Science-Metrix using the Scopus database.

In Figure 2, trends in the average number of papers produced per researcher are examined up to 12 years prior to receiving support (or prior to AIF application, in the case of unsuccessful applicants, P12–P1) and up to 3 years with support (or the period after application, in the case of unsuccessful applicants, S1–S3). Successful applicants to APRI and NFA grants published a similar number of papers per year on average, as did unsuccessful applicants. This is observed for unsupported papers (or papers published prior to AIF application) and supported papers (or those published after AIF application) (Figure 2). In fact, the average number of papers produced per researcher over the entire period (1996–2008) is not significantly different between successful and unsuccessful applicants ($p > 0.05$, Mann-Whitney U test; data not shown). While the data on the scientific impact provides preliminary evidence that AIF has effectively selected the best researchers in terms of scientific impact, it does not appear to have selected researchers who stand out among those who applied for funding in terms of scientific production volume.

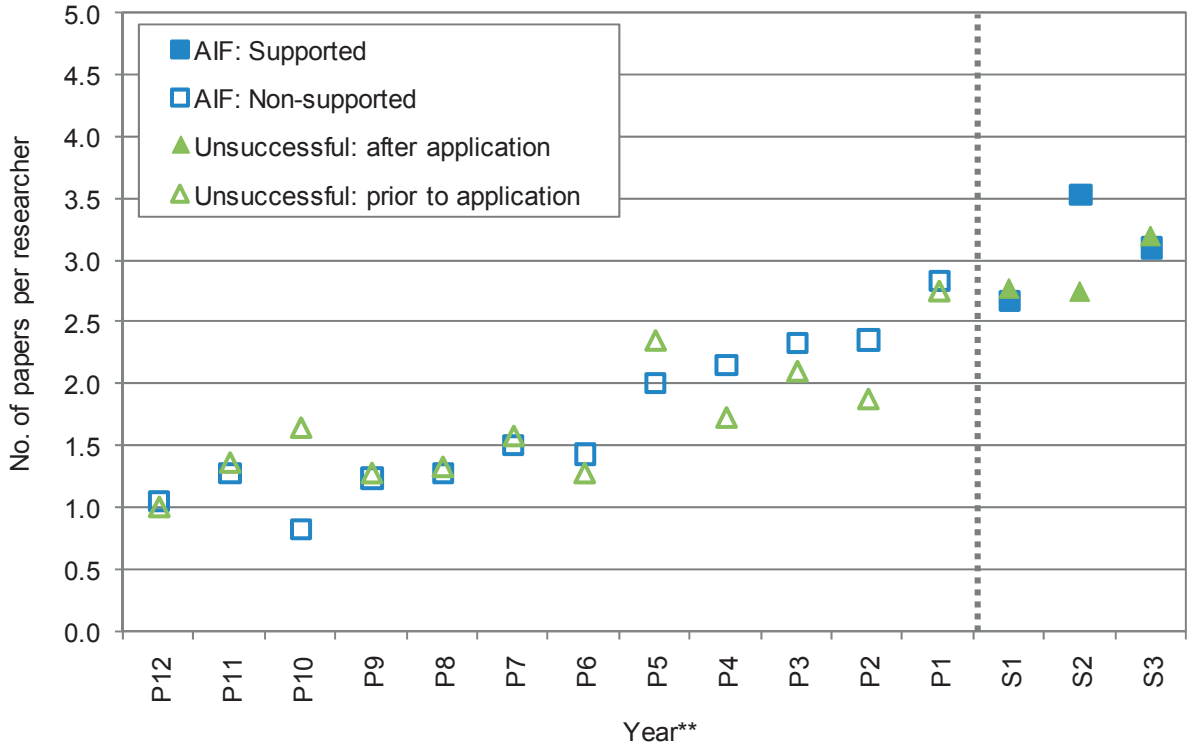

Figure 2 Trends in the number of published papers per AIF-funded researcher* and per unsuccessful applicant (up to 12 years prior to application; up to 3 years with support; and after unsuccessful application), 1996–2008

Note: * To ensure comparability of the two groups, only APRI and NFA grants are considered (no data was provided on unsuccessful applicants for other grant types).
** Letters refer to one of two periods: P = prior to receiving support or prior to unsuccessful application, and S = with support or after unsuccessful application. Sample size (i.e., no. of researchers) decreases across the period with support (or after unsuccessful application).

Source: Calculated by Science-Metrix using the Scopus database.

2.3 Scientific production of researchers funded by AIF

To assess the effect of AIF financial support on the scientific production of the researchers it supported (N = 117), the average number of papers produced per funded researcher was examined up to 12 years prior to receiving support (unsupported papers) and up to 5 years during which support was received (AIF-supported papers) (Figure 3).

As shown in Figure 3, AIF-funded researchers produced a gradually increasing number of papers on average over the period prior to support (P12–P1). This number continues to increase, albeit less steadily, in the period with support (S1–S5). In fact, the average number of papers produced per year increased for about 63% of the researchers when they received funds from AIF compared to the period prior to funding. Moreover, there is a significant difference between the production of supported researchers before and while they were funded by AIF ($p < 0.001$, two-sample paired [Wilcoxon] signed rank test; data not shown).

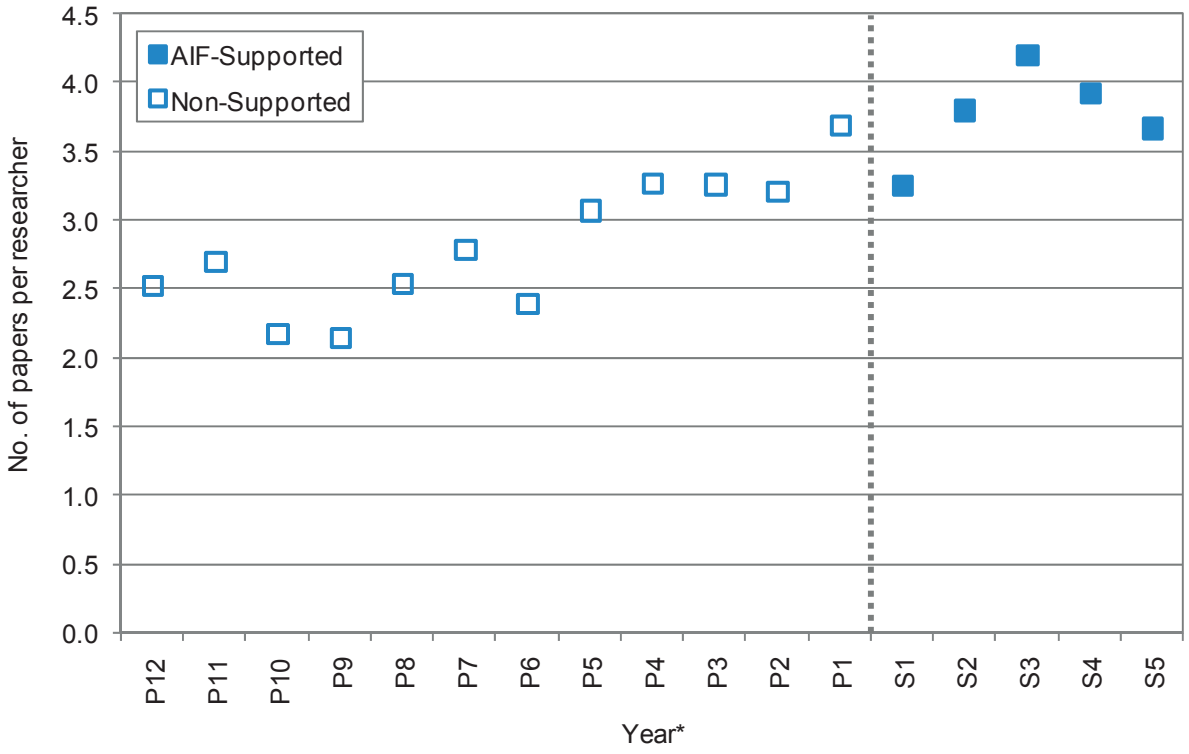

Figure 3 Trends in the number of published papers per AIF-funded researcher (N = 117) up to 12 years prior to receiving support and up to 5 years with support, 1996-2008

Note: * letters refer to one of two periods (P = prior to receiving support, S = with support). Sample size (i.e., no. of researchers) decreases across the period with support, since not all researchers received AIF funding for the full five years.

Source: Calculated by Science-Metrix using the Scopus database.

However, there is no clear trend shift between unsupported and supported papers (Figure 3), which means that it cannot be concluded that AIF funding induced an increase in production that would not have occurred without the funding. For example, if AIF supported a number of young and promising researchers (such as through the New Faculty Awards), whose scientific production often increases during the first 25 years of their career, this pattern might have been observed when analyzing the same group of researchers without AIF support.[1] In order to explore this possibility, it would be necessary to examine unsupported papers published before *and after* the support period. A decrease in the production of funded researchers following the support would provide strong evidence in support of AIF's positive impact on the production of the researchers it funded. Unfortunately, not enough time has elapsed since AIF established its funding programs in 2002 to analyze unsupported papers *after* the support period.

[1] Gingras, Y., Lariviere, V., Macaluso, B. Robitaille, J.P. (2008). The effects of aging on researchers' publication and citation patterns. PLoS ONE, 3(12): e4048.

2.4 Scientific impact of AIF-funded researchers

The scientific impact (based on ARC and ARIF) of papers authored with financial support from AIF is significantly lower than that of unsupported papers (i.e., papers authored by AIF-supported researchers before they received AIF funds) (Table III). This indicates that papers written by AIF-supported researchers after they received the award are less cited on average than those published before, although the underlying reason for this is unclear at this time. It is important to note that relatively little time has elapsed since the start date of many of the AIF awards, which means that the number of AIF-supported papers for which the impact can be reliably calculated is small. This renders the ARC and ARIF indicators of AIF-supported papers more prone to fluctuations. As additional data for the period under support becomes available in the years to come, sample sizes will increase and will provide more robust results to interpret the effect of AIF funding on the scientific impact of the researchers it supported.

Table III Comparison of the scientific impact (based on ARC and ARIF) of AIF researchers' supported and unsupported papers, 1996–2008

Group	ARC*	ARIF**
Non-supported	1.5	1.3
Supported	1.1	1.2
p-value	< 0.001	< 0.001

Note: * Because relative citation counts are unreliable at this analytical level for the most recent years (2007 and 2008), papers published in those years were not included in the computation of the ARC indicator (see Section 5.3).
** Because the impact factors of journals prior to 1998 cannot be calculated in Scopus, papers published in 1996 and 1997 were not included in the computation of the ARIF indicator (see Section 5.3).

Source: Calculated by Science-Metrix using the Scopus database.

3 Scientific output of AIF-supported graduate students

A total of 300 AIF-funded graduate students and a comparable sample of 300 unsuccessful graduate student applicants to the Graduate Student Scholarships (GSS) are examined in this section of the report. These 600 students, whether successful or unsuccessful, applied for a GSS award in the period from 2001 to 2008. To ensure comparability of the two groups, an equal number of graduate students were sampled randomly from the list of 579 successful and 1,706 unsuccessful applicants provided by AIF for each application year (the number of applicants sampled per year is proportional to the number of successful applicants for that year).

This section is thus slightly different from the section on AIF-supported researchers, as the main comparisons are between AIF-supported graduate students and unsuccessful GSS applicants. Unsuccessful applicants were chosen as the comparable group because other groups, such as Albertan, Canadian and world researchers, are not directly comparable to graduate students, as they contain researchers who are older on average, and who therefore have more established research activities than students.

Of the 600 graduate students, 194 students for each group (i.e., successful and unsuccessful applicants) had received funding (or applied for funding in the case of unsuccessful applicants) in or before 2006. As such, 194 successful applicants had the opportunity in the period covered in this study (1996–2008) to publish papers that benefited from the support of an AIF scholarship (a time lag of two years from the first year of funding is used to ensure that individuals had enough time to publish papers using this financing source; see Section 5.2 for more details on supported and unsupported papers). The scientific papers published by the 194 successful applicants were therefore tagged as published "after application" (i.e., starting two years after the start year of their scholarship) or "before application" (i.e., all other papers) to assess the effect of AIF funding early in their career (i.e., during graduate studies and soon after). Similarly, the scientific papers published by the 194 unsuccessful applicants who applied in or before 2006 were tagged as published "after application" (i.e., starting two years after the application year) or "before application" (i.e., all other papers) and serve as a control group for the analysis of the effect of AIF funding.

Section 3.1 provides a comparison of the scientific output of AIF-supported graduate students and unsuccessful applicants with that of researchers in Alberta, Canada and the world. Although these groups (graduate students versus researchers in Alberta, Canada and the world) are not directly comparable, this analysis enables a discussion of the selection of students for AIF funding, as does the comparison of the scientific impact of the two groups (i.e., successful and unsuccessful applicants) before and after application (Section 3.2). Next, the scientific production (number of papers) of successful and unsuccessful GSS applicants (Section 3.3) and their mobility before and after the support period (Section 3.4) are analyzed to better identify the effect of AIF funding on graduate students.

3.1 Comparison of the scientific output of AIF graduate student applicants with researchers from Alberta, Canada and the world

As the selection of academically superior graduate students is a crucial component of AIF's GSS program, the scientific impact of GSS applicants was compared to that of average Albertan, Canadian and world researchers. Although the scientific impact of students is not directly comparable to that of average researchers (i.e., because of differences in age and experience), this comparison offers evidence as to whether AIF has effectively selected outstanding students, as revealed by the scientific impact of applicants' papers prior to application for a GSS.

Two indicators of scientific impact were computed: the average of relative citations (ARC), which is a *direct* measure of the impact of scientific research based on citation counts to papers, and the average of relative impact factors (ARIF), which is an *indirect* measure of its impact based on journal impact factors. As shown in Table IV, the papers produced by 300 graduate students who were subsequently funded by AIF (papers published prior to application only) had significantly higher ARC and ARIF scores than other papers from Alberta and Canada as a whole for the 1996–2008 period (excluding AIF-supported students, $p < 0.001$). This finding is remarkable, considering that researchers in the database are on average older than graduate students, and therefore have more established research activities.

Table IV Comparison of the scientific impact (based on ARC and ARIF) of papers produced by AIF-supported students (prior to application only) with that of papers by researchers from Alberta, Canada and the world, 1996–2008

Group	ARC*	*p*-value	ARIF**	*p*-value
AIF-supported students	1.5	–	1.3	–
Alberta without AIF-supported students	1.2	< 0.001	1.1	< 0.001
Canada without AIF-supported students	1.2	< 0.001	1.1	< 0.001
World without AIF-supported students	1.0	–	1.0	–

Note: * Because relative citation counts are unreliable at this analytical level for the most recent years (2007 and 2008), papers published in those years were not included in the computation of the ARC indicator (see Section 5.3).
** Because the impact factors of journals prior to 1998 cannot be calculated in Scopus, papers published in 1996 and 1997 were not included in the computation of the ARIF indicator (see Section 5.3).
Source: Calculated by Science-Metrix using the Scopus database.

Papers published by AIF-supported students also had a higher scientific impact in terms of both ARC and ARIF than the world average (Table IV). For example, the ARC score of AIF-supported students (1.5) indicates that their papers are cited 50% more on average than other world papers, whereas papers by other Albertan and Canadian researchers are cited 20% more on average than world papers (ARC of 1.2).

The same analysis was conducted for a comparable group of 300 students who applied to the GSS program but who failed to obtain AIF scholarships (Table V). The scientific impact of the papers by unsuccessful applicants published prior to application was equivalent to the average score of other

world papers and lower than that of papers by other Albertan and Canadian researchers (excluding unsuccessful GSS applicants). These differences were not statistically significant for ARC (Alberta and Canada) or ARIF (Alberta). However, the ARIF of Canadian papers (without unsuccessful GSS applicants) was significantly higher than that of papers by unsuccessful GSS applicants ($p < 0.05$).

Table V Comparison of the scientific impact (based on ARC and ARIF) of papers produced by unsuccessful GSS applicants (prior to application only) with that of papers by researchers from Alberta, Canada and the world, 1996–2008

Group	ARC*	*p*-value	ARIF**	*p*-value
Unsuccessful GSS applicants	1.0	–	1.0	–
Alberta without unsuccessful GSS applicants	1.2	> 0.05	1.1	> 0.05
Canada without unsuccessful GSS applicants	1.2	> 0.05	1.1	< 0.05
World without unsuccessful GSS applicants	1.0	–	1.0	–

Note: * Because relative citation counts are unreliable at this analytical level for the most recent years (2007 and 2008), papers published in those years were not included in the computation of the ARC indicator (see Section 5.3).
** Because the impact factors of journals prior to 1998 cannot be calculated in Scopus, papers published in 1996 and 1997 were not included in the computation of the ARIF indicator (see Section 5.3).
Source: Calculated by Science-Metrix using the Scopus database.

Thus, AIF selection process appears to have effectively assessed the prior research experience of students who applied to the GSS program, as scholarships were awarded to 300 students whose prior research experience resulted in papers that had a significantly higher scientific impact than papers by other researchers in Alberta and Canada, whereas AIF scholarships were not awarded to 300 comparable students whose papers (published prior to application only) tended to have lower scientific impact on average than that of other Albertan and Canadian researchers.

3.2 Scientific impact of successful and unsuccessful AIF graduate student applicants

The scientific impact of successful and unsuccessful applicants to AIF GSS program was compared before and after they applied to determine whether AIF funding contributes to increased scientific excellence among AIF-supported graduate students early in their career (i.e., during graduate studies and soon after) relative to those who did not receive award funding. As only the funded students who received grants in or before 2006 had the opportunity to publish papers produced with AIF support (i.e., two years or more after the start year of the scholarship; see Section 5.2 for more details on supported and unsupported papers), only students (N = 194 for each group, successful and unsuccessful applicants) who applied in or before 2006 are considered in this analysis. This enabled comparisons between the two groups and over time for the period during which AIF potentially had an effect on the scientific output of the students it supported, i.e., the period "after application."

There is no difference in the ARC of papers published by successful and unsuccessful GSS applicants before application (ARC of 1.1; Table VI), and the difference in ARIF is small and non-significant

(ARIF of 1.2 and 1.1, respectively). Note that this result differs from that seen in Section 3.1, where successful GSS applicants had an ARC of 1.5 and an ARIF of 1.3 and unsuccessful applicants had a score of 1.0 for both ARC and ARIF indicators. In Section 3.1, 300 successful and 300 unsuccessful applicants, of which 35% were students who applied after 2006, were analyzed, whereas the groups of 194 students analyzed in this section include only students who applied in or before 2006. Thus, this seemingly contradictory result might indicate that AIF's selection of academically superior graduate students improved over time. This variability might also be partly explained by the difference in sample sizes (i.e., 300 students/group in Section 3.1 versus 194 students/group in this section). In either case, this finding suggests that the analysis should be repeated in a few years when larger numbers of funded graduate students can be examined over a longer period of time to yield more conclusive results.

Table VI Comparison of the scientific impact (based on ARC and ARIF) of papers produced by AIF-supported students with that of papers by unsuccessful GSS applicants, 1996–2008

Group	Successful applicants	Unsuccessful applicants	*p*-value
ARC*			
Before application papers	1.1	1.1	> 0.05
After application papers	1.3	1.0	> 0.05
All papers (before and after application)	1.4	1.0	< 0.001
ARIF**			
Before application papers	1.2	1.1	> 0.05
After application papers	1.2	1.2	> 0.05
All papers (before and after application)	1.3	1.1	< 0.001

Note: The sample size for both successful and unsuccessful applicants was reduced from 300 to 194 to enable comparisons between the periods before and after application.
* Because relative citation counts are unreliable at this analytical level for the most recent years (2007 and 2008), papers published in those years were not included in the computation of the ARC indicator (see Section 5.3).
** Because the impact factors of journals prior to 1998 cannot be calculated in Scopus, papers published in 1996 and 1997 were not included in the computation of the ARIF indicator (see Section 5.3).
Source: Calculated by Science-Metrix using the Scopus database.

In the period after application, when the effect of AIF funding would be seen, the ARC scores of successful applicants to the GSS program are higher than those of unsuccessful applicants, although this difference is not significant ($p > 0.05$; Table VI). This non-significant difference is likely due to the small sample size for papers published after application. Once again, repeating this test in a few years should yield more conclusive results. There is no difference between successful and unsuccessful applicants in terms of the ARIF indicator.

The difference between the scientific impact of papers published before and after application *within each group* suggests that the scientific impact of papers produced with AIF support increased, as revealed by the ARC indicator, which provides a *direct* measurement of the impact based on citations

received by papers produced by an entity (e.g., an individual, a country) (Table VI). More specifically, the ARC of papers authored by successful applicants with support from AIF (ARC of 1.3) is higher than those of unsupported papers (i.e., papers authored by AIF-supported graduate students before they received GSS funds, ARC of 1.1), although this difference is not statistically significant ($p > 0.05$; data not shown). This difference between the period before and with support is not observed when using the ARIF indicator, which provides an *indirect* measure of the research impact, as it is based on journal impact factors. Meanwhile, only small changes were observed in the scientific impact of papers by unsuccessful applicants, with ARC scores decreasing slightly from 1.1 before application to 1.0 after application and ARIF scores increasing slightly from 1.1 to 1.2.

Interestingly, when all papers (before and after application) are compared between the two groups of students, both the direct (ARC) and indirect (ARIF) scientific impact of papers published by successful applicants are significantly higher than those for unsuccessful applicants ($p < 0.001$; Table VI). While this finding does not inform on the contribution of AIF funding to increased scientific excellence between the period before and the period after application, it does confirm that graduate students holding GSS awards had a higher overall scientific impact than unsuccessful GSS applicants in their scientific career thus far.

3.3 Scientific production of successful and unsuccessful AIF graduate student applicants

The data shown in Table VII clearly illustrates the difference in scientific production between successful and unsuccessful GSS applicants: while the 300 AIF-funded graduate students produced a total of 900 papers over the 1996–2008 period (i.e., before and after application) for an average of 3 per student, the 300 comparable unsuccessful applicants published a total of 435 papers for an average of 1.45 per student. The difference between the two groups is highly significant ($p < 0.001$).

Table VII Comparison of the scientific production in terms of number of papers of AIF-supported students with that of unsuccessful GSS applicants, 1996–2008

Indicator	Successful applicants	Unsuccessful applicants	*p*-value
Papers	900	435	
Number of students	300	300	
Papers per student	3	1.45	< 0.001

Source: Calculated by Science-Metrix using the Scopus database.

This data was broken down according to the period before application and the period after application, which limited the analysis to 194 students per group (i.e., those who received the GSS award in or before 2006 and those who had the opportunity to publish papers with AIF support). Several significant findings emerged when examining changes in production between the two periods for each group of students:

- Successful GSS applicants published more papers per year than unsuccessful applicants in the period *before* application ($p < 0.001$) and overall (before and after application, $p < 0.001$).

- Almost 60% of successful applicants published more papers per year after application (while receiving AIF support) than before application, and the difference between the two periods is highly significant ($p < 0.001$).
- 40% of unsuccessful applicants also published more papers per year, and the difference is again highly significant ($p < 0.001$). However, fewer unsuccessful than successful applicants published more papers per year in the period after application (40% versus 60% for successful applicants).

It therefore appears that AIF Graduate Student Scholarships were given to students whose annual scientific production is higher prior to application, and that a higher percentage of successful applicants increased their average yearly output after application compared to the preceding period than did unsuccessful applicants. It is also worth noting that during the period after application (i.e., with AIF support in the case of successful applicants), 61% of successful GSS applicants published at least one paper (119 out of 194 students, for a total of 367 supported papers), versus only 40% of unsuccessful GSS applicants (77 out of 194, for a total of 186 papers). However, the fact that a greater percentage of successful than unsuccessful applicants increased their production after they applied for the scholarship does not necessarily indicate that AIF funding had a positive effect on the number of papers produced by the students it supported. In fact, because researchers, *especially high-calibre researchers*, often increase their production during the first 25 years of their career, one would expect to obtain this finding if AIF effectively selected the most promising students among those who applied for a GSS, which appears to be the case, based on the analysis of the scientific impact and scientific production of students prior to application.

The findings on scientific production are clearly seen in Figure 4, which illustrates trends in the average number of papers produced per student up to 12 years prior to AIF application (P12–P1) and up to 4 years after application (A1–A4) (see Section 5.2 for details on the tagging of papers as published before or after application and for the analysis of these trends). For the first six years prior to application, both groups of applicants published almost no papers. It can be assumed that they were not sufficiently advanced in their research career at that point to have a measurable scientific output. In the six years prior to application, the average number of papers per student was higher for successful than unsuccessful applicants, and this number increased progressively for both groups. In the period after application, successful and unsuccessful applicants produced more papers per student per year on average than in the preceding period, and their output continued to increase to some extent. Note that sample sizes for the most recent year (A4) are small, and data for this year should be interpreted with care.

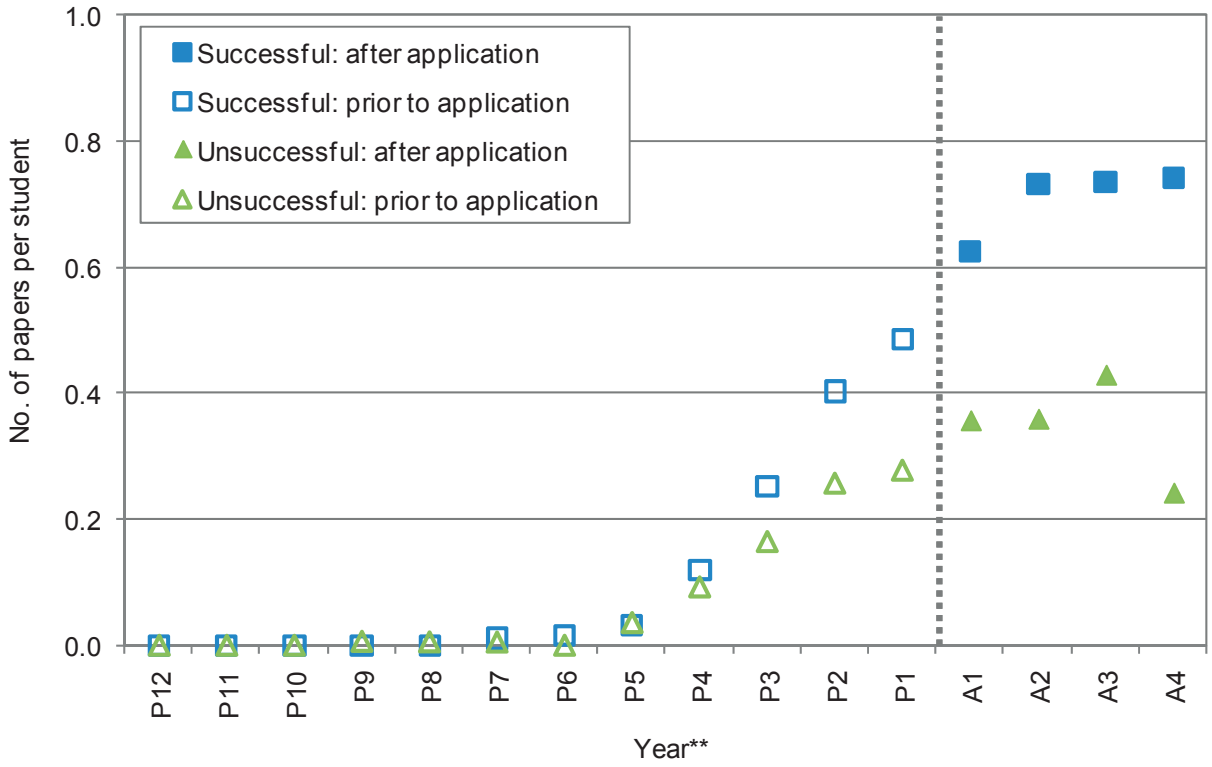

Figure 4 Trends in the number of published papers per AIF-supported student (N = 194) and per unsuccessful GSS applicant (N = 194)* up to 12 years prior to application and up to 4 years after application, 1996–2008

Note: * The sample size for successful applicants was reduced from 300 to 194 in order to compare the periods before and after application.
** Letters refer to one of two periods: P = prior to receiving support or prior to application, A = after application. Sample size (i.e., no. of students) decreases across the period after application.

Source: Calculated by Science-Metrix using the Scopus database.

3.4 Effect of AIF funding on graduate student mobility

Graduate student mobility was first analyzed by considering all papers irrespective of the period in which they were published (i.e., before or after application to AIF's GSS program; N = 300 for each group: successful and unsuccessful applicants). Second, student mobility in two distinct periods was analyzed (i.e., before and after application to AIF's GSS) in order to determine the potential impact of AIF funding on mobility (N = 194 for each groups: successful and unsuccessful applicants). Student mobility was measured at two levels:

- proportion of graduate students who published papers with addresses in more than one country
- proportion of graduate students who published papers with at least one address in Alberta and at least one address outside Alberta.

Since the analysis is based on student addresses as they appear on published papers, students who did not publish any papers are necessarily considered immobile. Since immobile students are more frequent among unsuccessful than successful applicants (Table VIII), mobility is likely to be lower for the unsuccessful group.

Table VIII Proportion of successful and unsuccessful applicants to AIF's GSS who did not publish papers, before and/or after application, 1996–2008

Dataset	Number of students who did not publish	Sample size	Proportion of students who did not publish
Successful applicants			
Before application	81	194	42%
After application	75	194	39%
Both periods	81	300	27%
Unsuccessful applicants			
Before application	125	194	64%
After application	117	194	60%
Both periods	158	300	53%

Source: Calculated by Science-Metrix from Scopus

Source: Calculated by Science-Metrix using the Scopus database.

Overall, a greater proportion of successful applicants (26 out of 300; 8.7%) than unsuccessful applicants (17 out of 300; 5.7%) published papers with addresses in at least two different countries. However, the difference is not statistically significant ($p > 0.05$). Similarly, a greater proportion of successful applicants (62 out of 300; 20.7%) than unsuccessful applicants (30 out of 300; 10%) published papers with at least one address in Alberta and at least one address outside Alberta. In this case, the difference is statistically significant ($p < 0.01$).

When comparing students' addresses on papers published before and after GSS application, it was found that a greater proportion of successful applicants published in at least two different countries after application (14 out of 194; 7.2%) than prior to application (4 out of 194; 2.1%). Note that international addresses were most commonly in the United States. For unsuccessful applicants, no such difference in mobility is observed between the two periods (8 out of 194 after application and 7 out of 194 before application; 4.1% versus 3.6%).

In terms of mobility between Alberta and other regions (i.e., provinces or countries), the opposite was found. A smaller proportion of successful applicants published both within and outside Alberta after application (16 out of 194; 8.2%) compared to before application (27 out of 194; 13.9%). Meanwhile, no difference was observed between the periods for unsuccessful applicants (14 out of 194 after application and 13 out of 194 before application; 7.2% versus 6.7%).

It is tempting to draw conclusions regarding the potential role of AIF in student mobility between the two periods (before and after application). However, the numbers involved are very small and many of the successful applicants have not yet or have only recently completed their AIF-supported graduate programs (i.e., at an Alberta university, as specified in the GSS eligibility requirements). These students are therefore less likely to have moved and published at their new address since applying to the GSS, such that the two periods are not directly comparable. This analysis should be repeated in a few years when larger numbers of funded graduate students have completed their AIF-funded degree. In addition, because these results are based on the students' addresses as they appear on published papers rather than resumes, they may have underestimated the mobility of students who published very few papers. The analysis should therefore be used to complement other information sources (i.e., information on mobility provided by students themselves).

4 Conclusions

This study provides quantitative data on the scientific production of researchers and graduate students who received financial support from Alberta Ingenuity Fund (AIF). The scientific output of about 120 researchers who were awarded an AIF grant in the period from 2002 to 2006 and 300 graduate students who were awarded an AIF scholarship in the period from 2001 to 2008 was analyzed based on three bibliometric indicators of scientific performance:

- number of papers
- average of relative citations (ARC)
- average of relative impact factors (ARIF).

The selection of high-calibre researchers and academically superior graduate students is a crucial component of the AIF funding program. As such, by comparing the scientific output of successful researchers and students with their respective comparable groups (i.e., other Albertan, Canadian and world researchers, and unsuccessful applicants [researchers or graduate students]), the analysis provides insight as to whether AIF has effectively selected outstanding researchers and highly promising students. In addition, by comparing applicants' output prior to receiving support (or before they applied in the case of unsuccessful applicants) to their output while receiving support (or after they applied in the case of unsuccessful applicants), the effect of AIF funding on the volume and impact of the scientific production of funded applicants was investigated. In the case of graduate students, the analysis also considered the effect of AIF funding on mobility.

Researchers

Prior to being awarded an AIF grant, AIF-supported researchers published papers that had significantly higher scientific impact, as measured by ARC and ARIF indicators, than other papers by Albertan and Canadian researchers. ARC and ARIF scores for AIF-supported papers are also higher than world scores. These results show that AIF has effectively selected researchers who stand out nationally and internationally in terms of research impact. Similarly, the ARC scores of AIF-funded scientists are higher than those of unsuccessful applicants, although the difference is not significant. This non-significant difference is likely due to the small sample sizes involved (N = 40 instead of 117 for successful applicants and N = 40 for unsuccessful applicants). Thus, repeating this test in a few years when larger numbers of researchers and papers can be compared between the two groups should yield more conclusive results. Nevertheless, these results provide preliminary evidence that AIF has effectively selected the best researchers in terms of scientific impact among those who applied for funding. On the other hand, the average number of papers published each year per researcher does not differ between successful and unsuccessful applicants. Therefore, whereas there is preliminary evidence that AIF has effectively selected researchers with high scientific impact, it does not appear to have selected researchers who stand out among those who applied for funding in terms of scientific production volume.

The production of AIF-supported researchers increased over time both in the period before they received AIF funding and in the period while they were supported by AIF. Whereas the average production of these researchers is significantly greater in the later period, there is no clear trend shift

between unsupported and supported papers. Therefore, it cannot be concluded that AIF funding induced an increase in production that would not have occurred without the funding. For example, if AIF supported a number of young and promising researchers (such as through the New Faculty Awards), whose scientific production often increases during the first 25 years of their career, this pattern might have been observed when analyzing the same group of researchers without AIF support. In order to explore this possibility, it would be necessary to examine unsupported papers published before *and after* the support period. Unfortunately, not enough time has elapsed since AIF established its funding programs in 2002 to analyze unsupported papers *after* the support period.

The scientific impact (based on ARC and ARIF) of AIF-funded researchers' supported papers is significantly lower than that of their unsupported papers. This indicates that papers written by AIF-supported researchers after they received the award are less cited on average than those published prior to receiving AIF support, although the underlying reason for this is unclear at this time. It is important to note that relatively little time has elapsed since the start date of many AIF awards, which means that the number of AIF-supported papers for which the impact can be reliably calculated is small. This renders the ARC and ARIF indicators of AIF-supported papers more prone to fluctuations. As additional data for the support period becomes available in the years to come, sample sizes will increase and will provide more robust results to interpret the effect of AIF funding on the scientific impact of the researchers it supported.

Graduate students

Prior to being awarded a Graduate Student Scholarship (GSS), AIF-supported students published papers that had significantly higher ARC and ARIF scores than other papers from Alberta and Canada as a whole. The papers published by AIF-supported students also had a higher scientific impact than the world average. In comparison, the scientific impact of unsuccessful applicants prior to GSS application was similar to the world impact and lower than that of other Albertan and Canadian researchers. Thus, AIF selection process appears to have effectively assessed the prior research experience of students who applied to the GSS program, as scholarships were awarded to students whose prior research experience resulted in papers that had a significantly higher scientific impact, even when compared to researchers in Alberta and Canada, who are older and more established on average. Meanwhile, AIF scholarships were not awarded to comparable students whose papers (published prior to application only) tended to have a lower average scientific impact than those of Albertan and Canadian researchers.

When analyzing the output of successful and unsuccessful GSS applicants before and after application, the difference in the scientific impact of papers between the two periods *within each group* suggests an increased scientific impact of papers produced with AIF support. Indeed, whereas the ARC of papers authored by successful applicants with support from AIF is higher than that of their unsupported papers, this difference between the period before and after application is not observed for unsuccessful applicants. GSS awards were also given to students whose annual scientific production was higher prior to application, and a higher percentage of successful applicants (compared to unsuccessful applicants) produced a higher yearly average output after they applied for the scholarship than before. However, the fact that a greater percentage of successful than

unsuccessful applicants increased their production after they applied for the scholarship does not indicate that AIF funding had a positive effect on the volume of papers produced by the students it supported. In fact, because researchers, *especially high-calibre researchers*, often increase their production during the first 25 years of their career, one would expect to obtain this finding if AIF effectively selected the most promising students among those who applied for a GSS. Again, this appears to be the case, based on the analysis of scientific impact and production of AIF-funded students prior to application.

The analysis of graduate student mobility (both successful and unsuccessful applicants) did not provide any conclusive results. The numbers involved are very small, and many of the successful applicants have not yet completed the AIF-supported study program (i.e., a program at an Alberta university). These students are therefore less likely to have moved since applying. Consequently, the two periods are not directly comparable, which impedes the analysis of the effect of AIF funding on graduate student mobility. The analysis should be repeated in a few years when larger numbers of funded graduate students have completed their degrees. In addition, because student mobility was assessed using addresses as they appear on published papers rather than resumes, the analysis could have underestimated the mobility of students who did not publish any papers (or only very few papers). Therefore, the current analysis should be used to complement other information sources (i.e., information on mobility provided by students themselves).

In brief, the bibliometric data collected in this study provide preliminary evidence that AIF has effectively selected the best researchers and graduate students among those who applied to its funding programs in terms of scientific impact. In addition, successful applicants, both scientists and graduate students, stand out among other researchers in Alberta, Canada and the world for their impact on the scientific community. However, for researchers only, successful applicants do not stand out among those who applied for funding in terms of scientific production volume.

The results did not show a positive effect of AIF funding on the production volume or the scientific impact of the researchers it supported. However, the results did provide some evidence of a positive effect of AIF funding on the scientific impact of AIF-supported students (but not on production volume). Nevertheless, in most instances where an attempt was made to investigate the effect of AIF funding on the scientific output of the individuals it supported, sample sizes were too small to draw definitive conclusions. Therefore, as additional data for the period after application (i.e., the support period) becomes available in the years to come, sample sizes will increase, from which more robust results can be derived to interpret the effect of AIF funding on the scientific output of the individuals it supported.

5 Bibliometric Methods

The results of scientific research, especially in the natural sciences and engineering (NSE), are mainly disseminated through articles published in scientific journals. Bibliometrics can be broadly defined as a set of methods and procedures used to measure bibliographic records. Bibliometric methods can be used to measure scientific outputs (scientometrics; basic units of measurement are articles in scientific journals) and technological outputs (technometrics; basic units of measurement are patents). Bibliometric methods comprise a set of indicators that can be used to draw a picture of the evolving performance of various entities (i.e., institutions, countries) in diverse scientific areas.[2]

The selection of the bibliographic database for the constitution of the datasets used in this study is discussed in Section 5.1. These datasets were used to produce reliable indicators of scientific production for AIF-funded individuals. Section 5.2 addresses the construction of these datasets. Section 5.3 presents the bibliometric indicators used to quantify scientific outputs and Section 5.4 describes the statistical analysis performed on bibliometric indicators.

5.1 Databases

The scientometric analysis was based on Elsevier's Scopus abstract and citation database of peer-reviewed literature. Scopus was chosen over other databases for its broad coverage of scientific literature in NSE and the social sciences, including more than 15,000 peer-reviewed journals from over 4,000 international publishers. Among comparable databases, Scopus is the only citation database that links the authors of papers to their institutional addresses. Scopus also includes cited references for each document it contains (e.g., articles, conference papers, letters, reviews, notes and press releases), allowing for the analysis of scientific impact based on citation counts and journal impact factors.

In producing bibliometric data, only documents that were peer-reviewed prior to being accepted for publication were retained. The peer-review process ensures that the research is of good quality and constitutes an original contribution to scientific knowledge. Moreover, the study is based on a selection of document types that include references to and are cited by other academic documents. These document types are mainly articles, conference papers and reviews, collectively referred to in this report as "papers." Note that the fields and subfields used in this report are based on the scientific journal classification used by the National Science Foundation (NSF) in the production of its Science and Engineering Indicators.[3]

5.2 Constitution of datasets

A bibliometric dataset for an institution (or a country) is usually built by retrieving papers in which the name of the institution is found in the authors' addresses. Because AIF is an organization that supports research as opposed to a research institute per se, its name is not expected to be found in

[2] King, J. 1987. A review of bibliometric and other science indicators and their role in research evaluation. *Journal of Information Science*, 13: 261-276.
[3] See: http://www.nsf.gov/statistics/seind06/.

the address field of papers published by the researchers and graduate students it funds. This makes it virtually impossible to know precisely which papers were produced with financial support from AIF. Accordingly, to build a dataset of AIF-supported papers, a publication portfolio had to be reconstituted for each researcher and graduate student who received funding from AIF.

Given the objectives of this study, four datasets needed to be constructed. Two datasets were built for the first part of the study (on researchers): one for AIF-funded researchers and one for a paired sample of unsuccessful applicants (i.e., researchers who did not receive funding). Similarly, two datasets were constructed for the second part of the study (on graduate students): one for AIF-supported graduate students and one for a paired sample of unsuccessful applicants (graduate students who did not receive scholarships). AIF provided a list containing the name and affiliation of 163 AIF-funded researchers. Because papers were considered "supported" if they were published in the period starting two years after the first year of financial support and ending two years after the last year of financial support, and because the study covers papers published in the period from 1996 to 2008, papers with a financial contribution from AIF could not be recorded for those researchers who received funding in or after 2007 (46 researchers in all). As such, publication portfolios were reconstituted for 117 of the 163 AIF-funded researchers.

AIF also provided a list of 93 unsuccessful applicants who applied before 2007; 77 of these researchers had applied for an NFA (New Faculty Award) grant and 16 had applied for an APRI (Alberta Prion Research Institute) grant. In all, publication portfolios were reconstituted for 24 unsuccessful applicants who applied for an NFA grant and 16 unsuccessful applicants who applied for an APRI grant. To perform a comparative analysis of successful and unsuccessful applicants, 24 AIF-funded researchers who received an NFA grant were sampled randomly from the 33 successful applicants and paired with the 24 unsuccessful applicants, and 16 AIF-funded researchers who received an APRI grant were sampled randomly from the 54 successful applicants and paired with the 16 unsuccessful applicants. This procedure ensured that both types of grants were in the same proportion on both sides of the comparison.

For the second part of the study, AIF provided a list containing the name and affiliation of 2,285 graduate students (579 successful and 1,706 unsuccessful applicants). A publication portfolio was reconstituted for 600 of these graduate students, of which half were successful applicants. To ensure comparability of the two groups (successful versus unsuccessful), an equal number of graduate students (N = 300) were sampled randomly from successful and unsuccessful applicants for each application year (the number of applicants sampled per year is proportional to the number of successful applicants for that year).

Building Publication Portfolios

The names of selected researchers and graduate students were then used in an automatic query that retrieved their scientific output covered in Scopus. Before executing the automatic retrieval of papers by AIF-funded researchers and graduate students, the names as they appear in AIF's list were transformed to match the format of author names in Scopus, which does not systematically include authors' first names, and usually provides only their initials. As such, "John W. Smith" is transformed into "Smith-JW" and also "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 and graduate student, all of the papers bearing his/her name as an author between 1996 and 2008.

Due to homograph problems, the automatic query overestimates the number of publications in many paper portfolios, especially for researchers with a common surname (e.g., Smith or Chen). However, compared to other bibliographic databases, Scopus has two characteristics that reduce the occurrence of these problems:

- It is the only bibliographic database of scientific literature that links all authors on a paper to their corresponding institutional address. This feature accelerates the process of building an author's publication portfolio while minimizing the risk of linking too few papers to an author whose name has been written in several ways over a time period (e.g., Smith JF, Smith J, Smith-McDonald JF), or linking too many papers to an author as a result of homographs.
- It includes, although not systematically, the first name of authors, allowing to more easily differentiate papers by authors with the same family name and initials, such as John Smith, James Smith and Joan Smith.

Since there is no *a priori* mechanism to determine which researchers will be overestimated and which will not, the papers retrieved by automatic query must be validated manually for each researcher, a process known as portfolio cleaning.

Portfolio Cleaning

Cleaning the publication portfolios consists of manually removing the papers that were erroneously assigned to a researcher or graduate student by 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 analyzing whether or not a set of papers belongs to a given researcher (e.g., Are these papers consistent with respect to the researcher's discipline, 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 a historian would be seriously questioned. However, given the commonness of multidisciplinarity in science, it is not sufficient to mechanically rely on researchers' departmental affiliations to validate the publications in their portfolio. For example, a philosopher may publish articles on medical ethics in clinical medicine journals, and an engineer may collaborate on papers dealing with environmental problems published in biology or earth sciences journals. Institutional addresses may provide additional clues, since they often include the authors' departments and because authors' names are linked to their institutional address in Scopus.

Besides false positives, another issue relates to false negatives, or papers authored by a researcher or graduate student that were not retrieved by the automatic query. These "missing papers" reflect the fact that the Scopus database only covers a fraction of all the work published by researchers worldwide. 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 systematically indexed by Elsevier. Therefore, the

publications in Scopus may not encompass the entire CV of researchers or graduate students who applied for AIF funding. Nevertheless, the database indexes the portion of their publications that is the most visible and the most frequently cited by the scientific community.

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.

Supported and unsupported papers

AIF researchers' papers were considered "AIF-supported" if they were published in the period starting two years after the first year of financial support and ending two years after the last year of financial support. For example, if a researcher was supported by AIF from 2001 to 2005, the papers published between 2003 and 2007 were counted as "AIF-supported papers." Papers published by AIF researchers in the period from 1996 to 2008 but which fall outside the period during which papers are considered as supported constitute the "unsupported papers" subset. It should be underscored that researchers receiving AIF funding could also be receiving grants from other funders; papers considered AIF-supported may therefore have been also partly supported by other funding sources. Therefore, the authors of this report do not assume that the performance of these papers in terms of scientific impact can be entirely attributed to AIF. However, because AIF-funded researchers also receive funding from other sources when they do not receive support from AIF, everything being equal, the protocol suggested here takes into account the variation in financing that should accrue to AIF.

To maximize the sensitivity of the analysis, it would have been necessary to tag unsupported papers as published before or after the support period. Unfortunately, not enough time has elapsed since AIF was established to allow for an analysis of unsupported papers published after the support period. Consequently, the analyses presented in this report compare only papers published before the support period (unsupported papers) to papers published during the support period (AIF-supported papers).

In the case of unsuccessful applicants (both researchers and graduate students) and successful graduate students, papers were tagged as "after application papers" if they were published in the period starting two years after the application year. Papers published in the period from 1996 to 2008 but which fall outside the "after application" period constitute the "before application papers."

To measure trends in the average production (i.e., average number of papers per individual per year) of researchers and graduate students (both successful and unsuccessful applicants) before and during the support period (or before and after application), papers were reclassified based on the number of years before and during support (or before and after application); year S1 corresponds to the first year for which papers are considered supported (similarly, A1 corresponds the first year after application). This allowed data from individuals supported in different periods (i.e., covering different years) to be pooled. For example, a 2007 paper was tagged as supported for a researcher funded in the period from 2005 to 2008, but was tagged as unsupported for a researcher funded in the period from 2006 to 2009. In the first case, the paper is reclassified as year S1 (first year with

support), whereas in the second case it is reclassified as year P1 (one year prior to support). For each individual, the range of reclassified years (i.e., between P12 and S5/A3) during which they could have published papers, based on the years covered by the AIF award(s), was determined. This was used to calculate the average number of papers per individual per reclassified year.

5.3 Scientometric indicators

Using researcher and graduate student portfolios built using the aforementioned methods, as well as papers computed at the province (i.e., Alberta), country (i.e., Canada) or world level, the following indicators were calculated:

Number of papers: Whole counting of the number of scientific papers written by authors associated with a funding organization (i.e., AIF) based on author names, or by authors associated with a region (i.e., Alberta, Canada) based on author addresses.

Graduate student mobility: This indicator was computed at two levels: 1) the proportion of graduate students who published papers with addresses in more than one country; and 2) the proportion of graduate students who published papers with at least one address in Alberta and at least one address outside Alberta.

Average of relative citations (ARC): This is an indicator of the *scientific impact* of the papers produced by an entity (e.g., country, institution) on the scientific community. It is based on the number of citations received by the papers (i.e., citation counts) produced by the entity. In general, papers reach a citation peak year (i.e., when they receive the highest number of citations) two to three years after publication.[4] Thus, the number of citations to each paper was counted for the year in which it was published and the two subsequent years. This ensures a uniform citation window of three years from the year of publication, for all papers. For papers published in 1998, for example, citations received in 1998, 1999 and 2000 were counted. The only exceptions are 2006, which has a citation window of two years (2006 and 2007), and 2007, which has a citation window of one year, because citation data is not yet available for the subsequent years.

Because citation practices vary across scientific fields and over time, citation counts for individual papers were divided by the average citation count for all papers in their subfield for the year in which they were published to obtain a relative citation count (RC). For example, papers published in the field of biochemistry include around 30 references, while mathematics papers generally have fewer than 10. Thus, a mathematics paper with only 5 citations would have as much impact as a biochemistry paper with 15. The ARC of a given entity (e.g., a country, an institution) is the average of the RC of papers belonging to it (i.e., if an institution has 20 papers, the ARC is the average of 20 RC, or one per paper). When the ARC is above 1, the entity (e.g., country, institution) scores better than the world on average; when it is below 1, this means that the papers it publishes are cited less often than the world average.

Average relative impact factor (ARIF): This indicator is a proxy for the impact of the journals in which an entity publishes. Each journal has an impact factor (IF), which is calculated annually by

[4] *Essential Science Indicators*, http://www.in-cites.com/ESI_Product_Info/1-HotPapers.htm, accessed May 2009.

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), computed using Elsevier's Scopus database.

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. 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 subsequently divided by the average IF of the papers published the same year in its 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, or 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.

5.4 Statistical Analyses

To establish whether there were significant differences between the scientific impact of various entities, a series of statistical tests was 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 output (i.e., number of papers, ARC, ARIF) is not normally distributed, non-parametric tests were used. The Mann-Whitney U test was used to compare pairs of independent samples and the Wilcoxon signed rank test was used to compare two related samples. The Z-test was used to compare two proportions.

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