Bibliometric Analysis of Funded Research.

A Feasibility Study

Report to the Program Evaluation Committee of NSERC

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1. Introduction and Terms of the Study

Over the last fifteen years, there has been an increased interest in the evaluation of scientific research, be it at the level of programmes or institutions. Whereas in period of economic growth it was easy to jusfify new programs of research, budgetary cuts, or at best steady state funding despite a growing number of applicants, have forced administrators of research, as well as researchers, more than ever before, not only to justify their projects, but also to find ways to phase out existing ones. There has also been a growing awareness of the importance of having a global evaluation of the effects of funded research on the development of knowledge. In these circumstances, performance indicators and evaluation methods have been looked at as a way of assisting the taking of informed decisions. This conjuncture led to the development of a variety of tools designed to circumscribe the multidimentional nature of scientific research[1]. Among them, bibliometric methods, that is statistical analysis of published papers, have become an important tool for measuring the dynamic of scientific research. Despite the considerable literature devoted to the subject, R. N. Kostoff, recently noted in a survey of the American practices of Federal research impact assesment that though the generalization of systematic evaluation practices is inevitable, "the implementation of these methods by the research sponsoring community remains minimal[2]".

The objective of this study is to present the kind of results that can be obtained with bibliometric indicators to assess the impact of scientific research. Using as case studies two Grant Selection Committees (Mechanical Engineering and Evolution and Ecology), its aim is thus to present concrete examples of the kind of data and indicators that can be obtained from bibliometry and show how they can shed light on the global effect of funding on research output and help to raise questions about allocation policies.

Using the case of the Mechanical Engineering and Evolution and Ecology Grant Selection Committees of NSERC, this report tries to answer two specific questions concerning GSC-NSERC-funded research:

1) What are the relationships between grants, productivity and impact, as measured by the number of published papers and place of publication?

2) What is the global impact of the Canadian production in each field, as compared to its respective world average?

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[1] For recent surveys, see M. Callon, P. Laredo, P. Mustard, *La gestion stratégique de la recherche et de la technologie*, Paris, Economica, 1995; A.F.J. Van Raan (Ed), *Handbook of Quantitative Studies of Science and Technology*, Amsterdam, North Holland, 1988, and the special issues of *Research Evaluation*.

[2] R. N. Kostoff, "Federal Research Impact Assessment: Axioms, Approaches, Applications", *Scientometrics*, vol. 34, 1995, pp. 163-206.

These two questions are based on the premise that GSC funds relatively fundamental research — as opposed say to industrial development — and that scientific publications are the usual output of such activities. As we will see, the results do corroborate this view since most grantees did have publications in scientific journals covered by the ISI data base.

Since not every discipline is centered on the production of scientific publications, it is important to note that this methodology cannot be used as a panacea, across the board of all disciplines or research centers, but must be applied only to domains for which the production of scientific publications is a primary and acknowledged product of research[3]. As Derek de Solla Price wrote 30 years ago, scientists tend to be "papyrocentric" whereas technologists tend to be "papyrophobic"; that is, whereas the first like to write and read scientific publications, the second don't.[4] As we will see, however, this does not mean that engineers do not produce scientific publications, but that, on average, we should expect a lower productivity as measured by bibliometric indicators.

After having described the method of data acquisition, sections 3 to 5 will present the analysis of NSERC funded research and section 6 will be devoted to comparing Canadian research with world research in the two chosen fields. The general objective being to investigate the feasibility of a long term permanent evaluation system using bibliometric methods, the conclusion will be followed by recommendations concerning possible mechanisms to implement in order to proceed on a regular basis to such evaluations and provide NSERC with survey of Canadian research trends[5].

2. Description of the populations and methods of data acquisition

NSERC provided the investigator with a data base containing, essentially, the name, first name and sometimes the initials of the principal investigators, their institutional affiliation and the amounts (if any) of the grants obtained for the the 10-year period 1984-1993. It also indicated the date of the first application for a grant (New applicants). Table 1 shows the distribution of applicants for the period 1984-1993, as given in the data base.

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[3] R. Miller, "The Influence of Primary Tasks on R&D Laboratory Evaluation: A Comparative Bibliometric Analysis", *R&D Management*, vol. 22, 1992.

[4] D. K. De Solla Price, "Is Technology Historically Independent of Science? A Study in Statistical Historiography", *Technology and Culture*, Vol. 6, 1965, pp. 553-568.

[5] The analysis presented in this report does not exhaust the possibilitites of bibliometric indicators. One could deepen the analysis by grouping grants by 3 year periods; grouping grantees by equal and continuous time-period of grants; looking at relations between age and grants and productivity. We could not make all these analysis here, but the ones chosen are sufficient to exemplify the general bibliometric approach to the analysis of funded research.

For each name in the NSERC data base, the number of publications[6] in journals covered by the Science Citation Index CD-ROMS of the Institute of Scientific Information were searched for the period 1984-1993 (See Appendix 1 for the details of the procedure and discussion of its limitations). For each journal in which a paper was published, we also associated the Impact Factors (I.F.), for the years 1984, 1988 and 1992 (when available), as given by I.S.I. in his *Journal Citation Reports* . Except otherwise noted, all tables and Figures refer to publications and grants for the 1984-1993 period.

Table 1
Distribution of applicants over the period 1984-1993.

Year of first application	Number of new applicants	
	Mechanical Engineering	Evolution and Ecology
before 1984	384	561
1984	30	23
1985	20	23
1986	31	25
1987	39	27
1988	32	33
1989	38	33
1990	23	24
1991	28	33
1992	30	26
1993	41	30
Total	696	838

3. Relations between grants and publications

The analysis thus consists essentially of searching for statistical relationships between the existence and amount of grants obtained from NSERC and the production of publications during the period 1984-1993. It is important to note that the analysis is conducted *at the level of the whole group* and that we do not look at individual applicants. In other words, *we evaluate the domain and the global effect of NSERC grants and not the productivity of individual researchers*.

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6 For simplicity, we use the terms "publications" or "papers", to include all kinds of publications: usual papers, reviews, notes, etc.

Table 2, gives the annual number of publications and the total amount of grants for each discipline[7]. One can see that for similar amount of investments one gets an important difference in production of papers. As we mentioned above, this is related to the different attitude of the researchers of these two disciplines towards publications in scientifc journals. This is a first reason not to use a simple "papers/dollar" ratio to evaluate scientific research.

Table 2
Annual distribution of publications and amount of grants

Year	Evolution and Ecology		Mechanical Engineering	
	Number of publications	Amount of grants (Millions $)	Number of publications	Amount of grants (Millions $)
1984	952	8.04	365	6.9
1985	999	8.7	353	7.40
1986	1185	8.64	475	7.43
1987	1223	9.10	431	8.07
1988	1088	9.66	427	8.65
1989	924	10.15	337	9.18
1990	988	10.65	323	9.77
1991	953	11.95	341	10.49
1992	970	12.46	433	10.90
1993	1101	12.75	464	10.98
Total	10383	102.10	3949	89.77

Table 3 shows that in Mechanical Engineering, 12% of the applicants did not receive a grant, while this percentage is 20,4% for Evolution and Ecology. 25,7% of the applicants in Mechanical Engineering had no publications during the period 1981-1993, whereas in Evolution and Ecology only 12,7% of them did not publish in journals covered by the ISI data base[8]. As could be expected, the percentage of grantees with no publications is lower: 20% in Mechanical Engineering (compared to 62% among the non-grantees) and 11,2% in Evolution and Ecology (compared with 18,7% among the non-grantees).

For new applicants — those who applied for a first grant in 1984 or later (a category which accounts for 45% of the total number of applicants in Mechanical Engineering and 33% in Evolution and Ecology) —, the percentage of those who have published but did not receive a grant are 36,3% in Mechanical Engineering and 73,6% in Evolution and Ecology (Table 4).

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[7] For reasons of brevity we will refer to both populations as "disciplines" even though the Mechanical Engineering and Evolution and Ecology committees do in fact cover more than one discipline each.

[8] We have covered the years 1981-1983 in order to take into account applicants who published in the three years before 1984, the first year covered by NSERC data bank.

Globally, the average number of publications per year for all applicants is 0.64 in Mechanical Engineering and 1.34 in Evolution and Ecology. If we take into account only the grantees, the figures are a bit higher: 0.68 and 1.47 respectively[9].

Table 3
Relation between the award of grants and the publication of papers

	All applicants					
Grants	Mechanical Engineering			Evolution and Ecology		
	Total	Applicants with Papers*	Applicants with No Papers*	Total	Applicants with Papers*	Applicants with No Papers*
Yes	612	485	127	667	592	75
No	84	32	52	171	139	32
Total	696	517	179	838	731	107

* For the period 1981-1993

Table 4
Relation between the award of grants and the publication of papers

	New applicants					
Grants	Mechanical Engineering			Evolution and Ecology		
	Total	Applicants with Papers*	Applicants with No Papers*	Total	Applicants with Papers*	Applicants with No Papers*
Yes	246	165	81	182	128	54
No	66	24	42	95	70	25
Total	312	189	123	277	198	79

* For the period 1981-1993

The different propensity to publish in these two disciplines can be related to the more fundamental and academic aspect of research in Evolution and Ecology as compared to Mechanical Engineering. However, the

[9] The time average is taken for the period starting with the first year of application for those who applied after 1984.

fact remains that most grantees do in fact publish at least once in the main journals covered by the SCI, for the ten year period covered.

In fact, the real difference between a fundamental discipline like Evolution and Ecology and a more applied engineering one like Mechanical Engineering can be seen in the average number of publications which, as can be expected, is twice higher in the former than in the latter as shown in Table 5. Tables 3 and 4 also show that among those who applied for a grant but failed to get one, there is also twice as much (in percentage) who had publications in Evolution and Ecolgy than in Mechanical Engineering.

Table 5 also shows that there is an important difference of productivity between those who obtained a grant from NSERC and those who failed to obtain it.

Table 5
Relation between average number of publications/year and the award of grants

	Mechanical Engineering			Evolution and Ecology		
Grantee	Applicants	Number of Publications	Average papers/year	Applicants	Number of Publications	Average papers/year
No	84	198	.29	171	1092	.81
Yes	612	3751	.68	667	92911	1.47
TOTAL	696	3949	.64	838	10383	1.34

It is well known in bibliometry that the distribution of the productivity of researchers active in a given discipline is very skewed and tends to follow what is known as Lotka's law (Figure 1)[10]. Figure 2 shows the corresponding distribution of the average grants per applicant per year[11].

[10] Lotka, A. "The Frequency Distribution of Scientific Productivity", *Journal of the Washington Academy of Science* , vol. 16, 1926, pp. 317-323. This "law" states that the number of scientists publishing N papers is roughly inversely proportinal to N squared.

[11] Given that we search for a relation between grants and publications, the average grants per applicant per year is calculated as the total amount obtained divided by the number of years starting from the first year of application to the end of the period, that is 1993. The time-period is thus not the same for all applicants: it measures the time "in the system".

Figure 1
Frequency Distribution of Scientific Productivity (1981-1993)

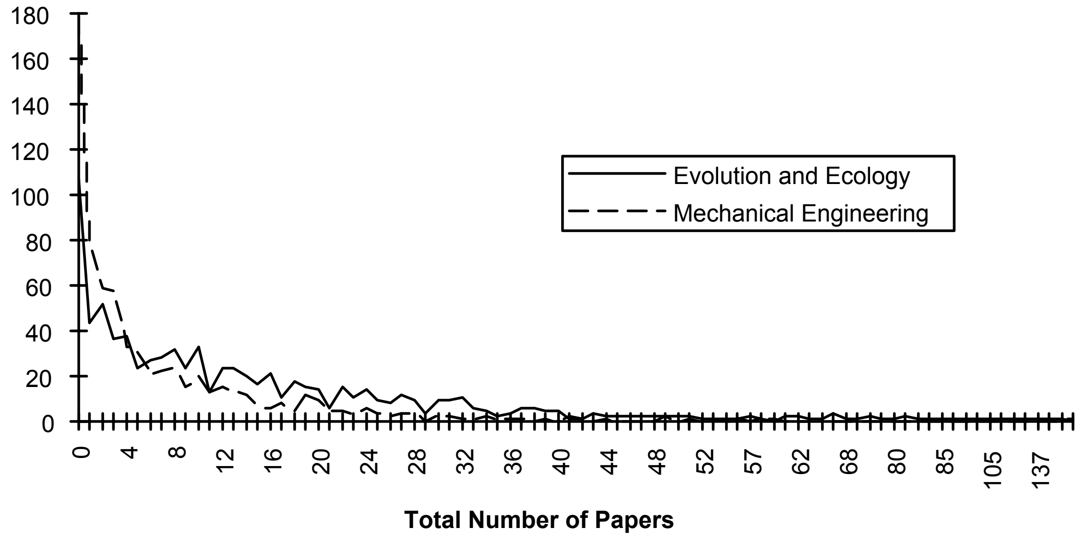
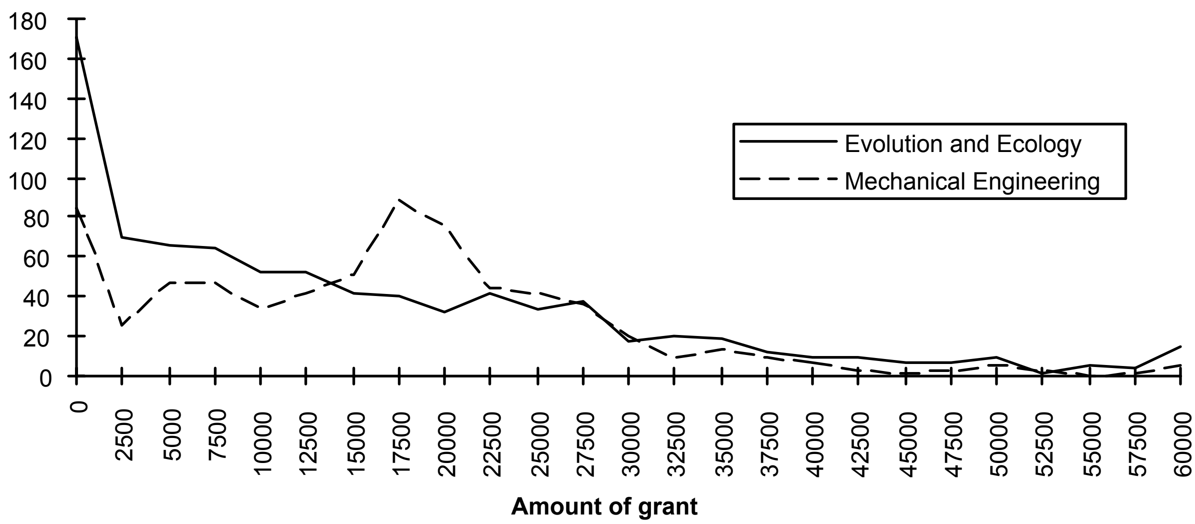


Figure 2
Distribution of Average Grants/year (1984-1993)



Given these skewed distributions, it is more significant to use the quartile distribution (Table 7) for searching correlations betweeen grants and productivity than subdividing the population using standard deviations above or below the mean. In the case of Evolution and ecology, for example, the class of researchers receiving a grant less than two standard deviations below the mean is empty, while for Mechanical Engineering it contains 130 researchers (Table 6).

Table 6
Relation between average grants per year and average number of publications per year (all applicants)

	Mechanical Engineering			Evolution and Ecology		
Class of grants	Applicants	Papers	Average papers/year	Applicants	Papers	Average papers/year
From min. to 1 S.D. below AV.	130	384	0.34	0	-	-
From 1 S.D. below to 1 S.D. above AV	481	2386	0.58	715	7003	1.08
From 1 S.D. above AV. to max.	85	1179	1.42	123	3380	2.83
TOTAL	696	3949	0.64	838	10383	1.34

Table 7
Relation between amount of grants per year (in quartiles) and average number of publications per year (all applicants)

Quartile of average grants per year	Mechanical Engineering			Evolution and Ecology		
	Applicants	Papers	Average papers/year	Applicants	Papers	Average papers/year
0-25	174	571	0.36	207	1349	0.80
25-50	174	666	0.44	212	2443	1.18
50-75	174	710	0.53	209	2132	1.12
75-100	174	2002	1.22	210	4459	2.24
TOTAL	696	3949	0.64	838	10383	1.34

In any case, both views show the existence of a positive and significant (at the .0001 level) difference between groups of quartile in terms of average number of publications published during the period from first application to 1993: the group of researchers having the highest average grants produces twice as much as the group just below them (which comprises half the total population), while the group in the 0-25 quartile produces three times less than them (Table 7). These observations are valid for both disciplines, though the difference between the 0-25% and 50-75% groups is less significant in Evolution and Ecology (.11) than in Mechanical Engineering (.03). Globally, there is also a significant, though weak, correlation (.53 in Evolution and Ecology and .48 in Mechanical Engineering) between the total amount of funding received by applicants and the total number of publications. Table 8 shows the results when we exclude the applicants who did not receive grants.

Table 8
Relation between amount of grants/year (in quartiles) and average number of publications/year
(All Grantees)

Quartile of average grants per year	Mechanical Engineering			Evolution and Ecology		
	Grantees	Papers	Average papers/year	Grantees	Papers	Average papers/year
1-25	154	586	0.40	168	1742	1.05
25-50	152	641	0.52	166	1760	1.13
50-75	153	703	0.58	167	1773	1.20
75-100	153	1821	1.24	166	4010	2.51
TOTAL	612	3751	0.68	667	9285	1.47

The existence of a positive relation between grants and publications had been noted in the literature devoted to research evaluation. Already in 1964, Orr and his collaborators related the amount of money invested in Research by NIH and the output of publications[12]. In 1977, the group of F. Narin at Computer Horizon, (CHI), showed a strong relationship betweeen amount of funding and publications for research conducted in universities and hospitals[13].

One could object to these data in that they do not take into account the fact that more money gives access to more research assistants and thus to more publications. The only way to take that into account would be to normalize the data using the number of research assistants participating in the project but such a procedure require data not always easily available. An alternative would be to take into account the number of authors per publication. Using data on psychology, Gillet has shown that once corrected for the number of research assistants, the correlation between grant and productivity disappears[14]. The present report being only a feasibility study, lack of time (and limited resources), have not permitted us to take that variable into consideraton here. In any case, it should be noted that whatever the path through which money affects

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[12] R.H. Orr, G. Abdian, A.A. Leeds, "Generation of Information: Published Output of U.S. Biomedical Research", *Federation Proceedings*, vol. 23, 1964, pp. 1297-1309; R.H. Orr, A.A. Leeds, "Biomedical Literature: Volume, Growth and Other Characteristics", *Federation Proceedings*, vol. 23, 1964, pp. 1319-1331.
[13] F. Narin, R.T. Shapiro, "The Extramural Role of the NIH as a Research Support Agency", *Federation Proceedings*, vol. 36, 1977, pp. 2470-2476; see also F. Narin, S.B. Keith, "The Intramural Role of the NIH as a Research Support Agency", *Federation Proceedings*, vol. 37, 1978, pp. 2120-2123.
[14] R. Gillet, "Serious Anomalies in the UGC Comparative Evaluation of the Research Performance of Psychology Departments" *Bulletin of the British Psychological Society*, vol. 40, 1987, pp. 42-49; R. Gillet, "Pitfalls in Assessing Research Performance by Grant Income", *Scientometrics*, vol. 22, 1991, pp. 253-263.

production, it is important to take the result into account for it is in some sense reassuring to observe that more "input" results in more "ouput".

Tables 8 shows that if we look only at the population who received grants, the results are essentially the same: we observe a correlation between level of grants and average productivity.

4. Relations between grants and bibliometric impact

In view of the frequent comment that the sheer "quantity" of published papers does not necessarily imply "quality", an important question is whether more money results in better quality. Though the idea that it is possible to measure the "quality" of any given publication, or of individuals, is hotly debated[15] , it is generally accepted in bibliometrics that it is meaningful to use as an index of the mean "impact" at the aggregate level, the real or expected number of citations received by publications. McAllister and Narin have used citation measures to correlate impact and funding and found a positive relation[16]. Other studies have also showed that funded research is more cited than unfunded research[17]. For evaluation purposes, bibliometric analysis mainly use the Impact factor (I.F.) defined and published by the Institute for Scientific Information (ISI)[18]. This index is in fact a measure of the expected number of citations one is likely to recieve in publishing in a given journal (see Appendix 2 for details). It correlates strongly with the perceived importance of the scientific journals as judged by researchers[19]. And since it is well known that informally scientists judge their colleagues in large part through the journals in which they publish their paper — who does not envy a collleague publishing in *Nature* or *Science* ? — one could even argue that the use of the Impact factor largely reflects scientists' own evaluations. Of course, Impact factors are not perfect but neither are "peer" evaluations[20]. Since Impact factors are defined for journals and can be grouped for discipline and specialty,

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[15] P. Vinkler, "Some Aspects of the Evaluation of Scientific and Related Performancess of Individuals, Scientometrics, vol. 32, 1995, pp. 109-116, and references therein.

[16] P. R. McAllister, F. Narin, "Characterization of the Research Papers of U.S. Medical Schools", *Journal of the American Society for Information Science*, vol. 34, 1983, pp. 123-131.

[17] B. C. Peritz, "The Citation Impact of Funded and Unfunded Research in Economics", *Scientometrics*, vol. 19, 1990, pp. 199-206; H.A. Abt, "Citations

[18] For a discussion of this choice see Appendix 2.

[19] P. R. McAllister, R. Anderson, F. Narin, "Comparison of Peer and Citation Assessment of the Influence of Scientific Journals", *Journal of the American Society for Information Science*, vol. 31, 1980, pp. 147-152. Wallimack, J. T., Sedig, K. G., "Quality of Research Measured by Citation Method and by Peer Review — A Comparison", *IEEE Transactions on Engineering Management*, VOl. Em-33, november 1986.

[20] E. Garfield, "Is Citation Analysis a Legitimate Analysis Tool?", *Scientometrics*, vol. 4, 1979, pp. 359-375. H.F. Moed, Th. N. Van Leeuwen, "Improving the Accuracy of Insitute for Scientific Information's Journal Impact Factors", *Journal of the American Society for Information Science*, vol. 46, 1995, pp. 461-465; A.J. Nederhof, "The Validity and Reliability of Evaluation of Scholarly Performance", in, A. F. J. Van Raan (Ed.), *Hanbook of Quantitative Studies of Science and Technology*, Amsterdam, North-Holland, 1988, pp. 193-228.

one should use them only for comparisons within the same discipline or specialty. Cross-disciplinary comparisons can only be made after having properly normalized the data[21].

We found a strong correlation (R=0.83 in Mechanical Engineering and 0.84 in Evolution and Ecology) between the average number of publications per year and the average impact of publications. This result suggests that contrary to widespread belief, there is in fact a strong link between quantity and quality; in other words, the probabilty of having an applicant publishing a large number of publications in low impact journals is low, and those who have a large impact are usually among the most productive. And since we have seen that there was a relation between grants and publications, one should thus expect a significant link between funding and impact.

Table 9 shows that the average impact for those who did receive a grant is significantly higher (at the .0001 level) than for the applicants who did not receive one. Table 10 shows that in Mechanical Engineering, only the group with the largest grants (75-100 quartile) differs significantly from the three other groups in terms of impact, whereas in Evolution and Ecology there is a regular raise in impact from the 25th to the 75th centile. As was the case for productivity, there is also a significant difference between the group who received its first grant in or after 1984 and those who were active before 1984.
Table 11, shows the results obtained for all applicants when we exclude those who did not receive grants.

Table 9
Relation between average Impact Factor per year
and the award of grants (All Applicants)

	Mechanical Engineering		Evolution and Ecology	
Grants	Applicants	Average Impact Factor per year	Applicants	Average Impact Factor per year
No	82	0.29	168	1.45
Yes	595	0.54	662	2.21
TOTAL	677	0.51	830	2.05

Table 10
Relation between amount of grants/year (in quartiles) and average Impact Factor/year
(All Applicants)

Quartile of average grants per year	Mechanical Engineering			Evolution and Ecology		
	Applicants	Papers	Average Impact Factor per year	Applicants	Papers	Average Impact Factor per year
0-25	171	440	0.41	204	1065	1.37

[21] For a recent discussion of impact factors, see P. O. Seglen, "How Representative is the Journal Impact Factor?", *Research Evaluation*, vol. 2, december 1992, pp. 143-149. On problems of normalization, see Y. Gingras, "Performance Indicators: Keeping the Black Box Open", Proceedings of the Second International Conference on the Impact of R&D, Ottawa, 1995.

25-50	167	539	0.34	208	2177	1.54
50-75	167	617	0.33	209	1982	1.57
75-100	172	1767	0.96	209	4115	3.72
TOTAL	677	3363	0.51	830	9339	2.05

Table 11
Relation between amount of grants/year (in quartiles) and average Impact Factor/year (All Grantees)

Quartile of average grants per year	Mechanical Engineering			Evolution and Ecology		
	Grantees	Papers	Average Impact Factor per year	Grantees	Papers	Average Impact Factor per year
1-25	151	460	0.44	164	1561	1.33
25-50	145	548	0.36	165	1594	1.58
50-75	148	606	0.35	166	1628	1.75
75-100	151	1611	1.01	166	3719	4.16
TOTAL	595	3225	0.54	661	8502	2.21

5. Variation in time of the relationships between grants and productivity

Since the data covers a ten year period, we applied a MANOVA (Multiple analysis of variance) procedure to look at the evolution in time of the productivity of applicants. Dividing the population of applicants into groups ("New" for the group who received its first grant in or after 1984 and "Old" for those who received it before 1984), and the grants according to quartile, we find that there is a significant time effect for the productivity as well as a significant difference between groups. As Figure 3 shows, the productivity of "New" grantees and "Old" grantees with grants lower than the median do not move appreciably upward during the period, whereas "New" grantees with grants above the median rapidly move forward in productivity to join the group of grantees active before 1984 ("Old") and receiving grants above the median. This effect is observed in the two disciplines, and Figures 3 to 6 show the effects for various groupings of quartiles.

Figure 3
Variation of Productivity in Evolution and Ecology

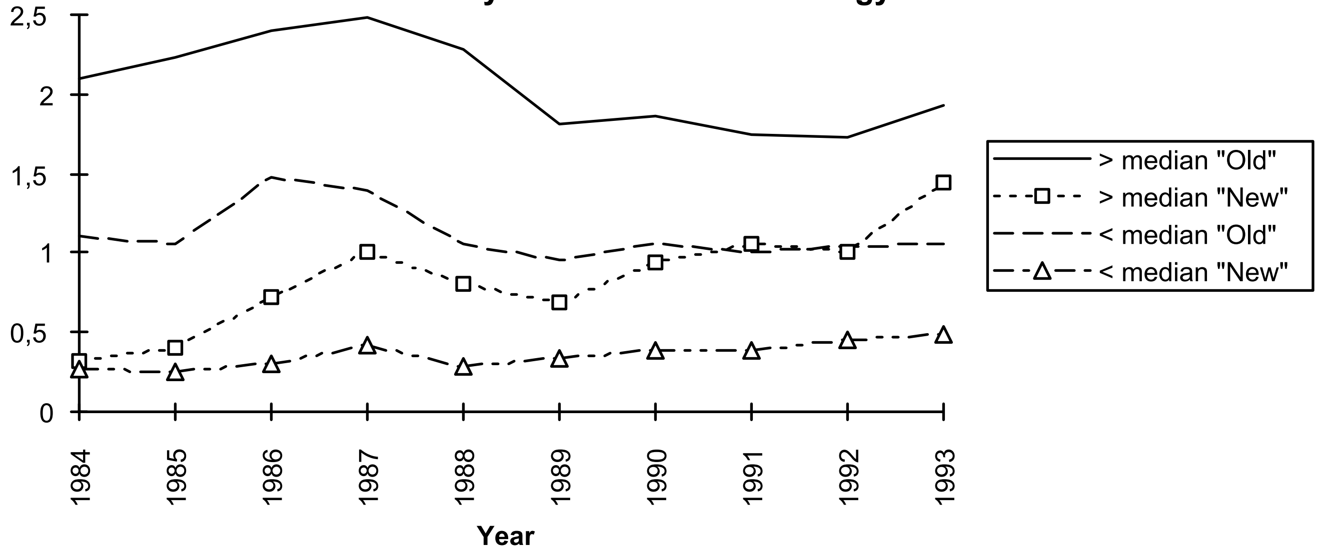


Figure 4
Variation of Productivity in Mechanical Engineering

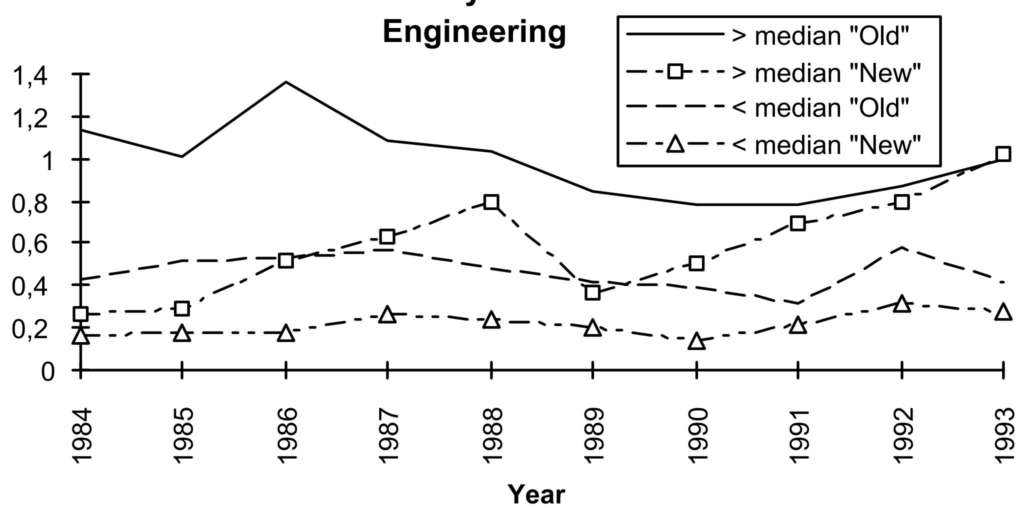


Figure 5
Variation of Productivity in Evolution and Ecology

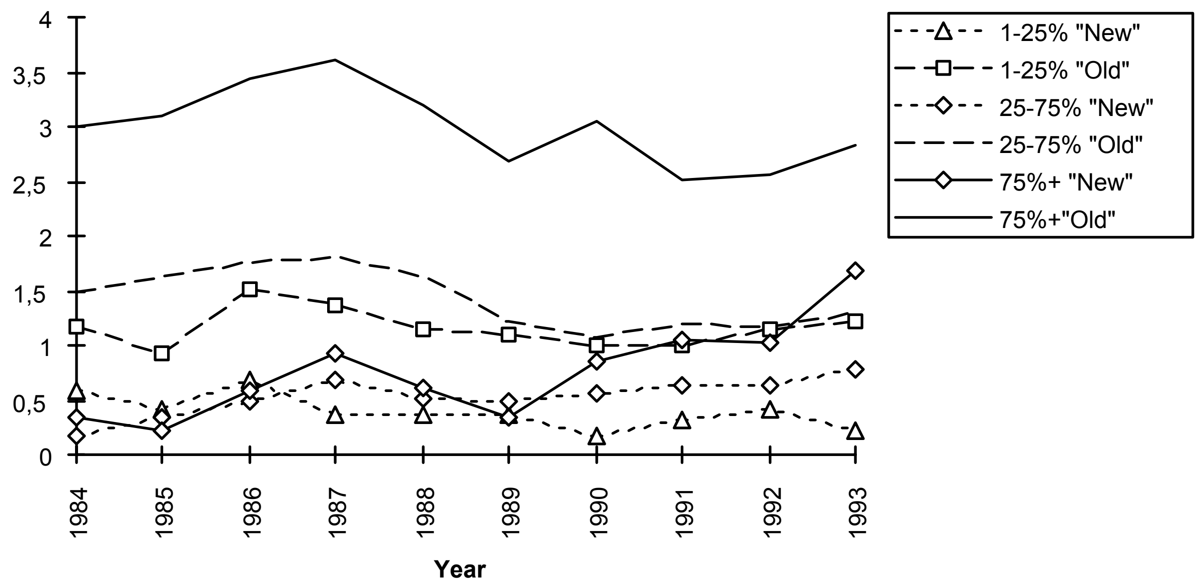
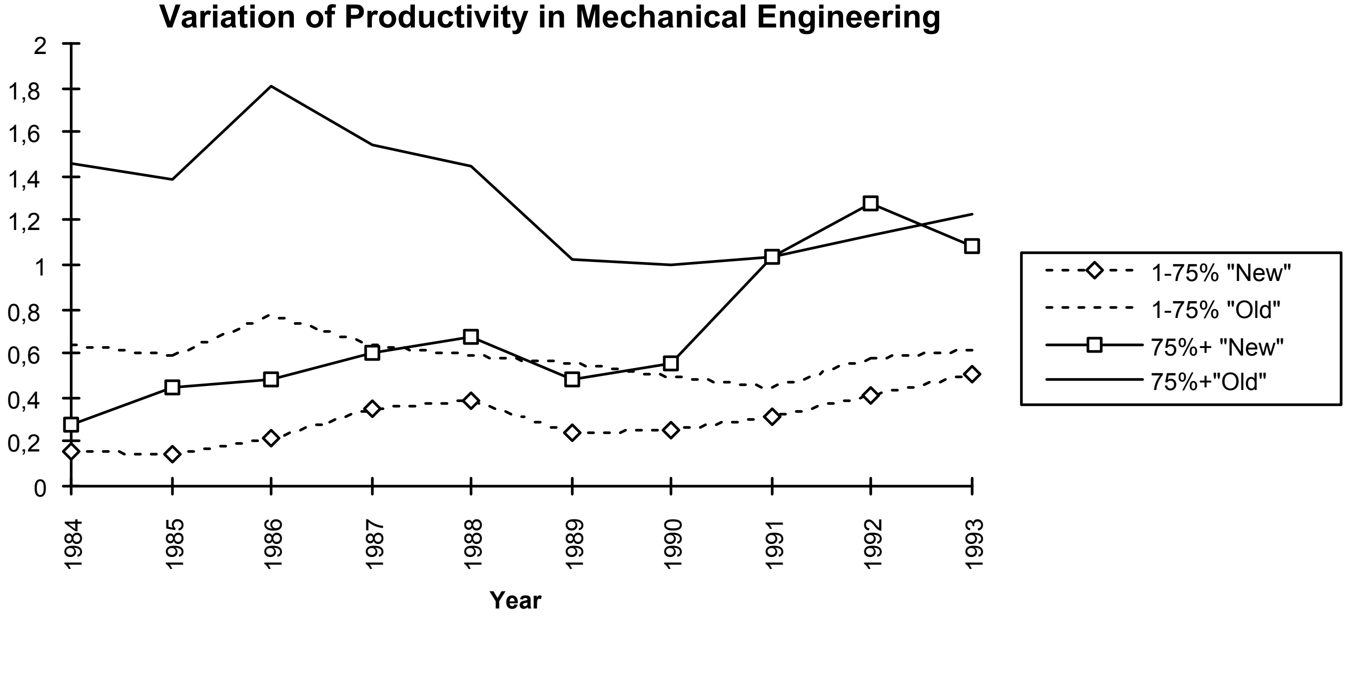


Figure 6
Variation of Productivity in Mechanical Engineering



The importance of these figures lies in the trend they show, which suggests that a certain "critical" amount of funding seems necessary to bring new grantees to the level of the most productive in the group already active. On the other hand, small grants do not seem to help the new grantees to move upward; they seem to stagnate as do older grantees with funds less than the median. Though no firm conclusions can be reached from these data alone, they certainly raise questions of funding policy: should a granting agency concentrate its funding on fewer applicants or spread it over a larger number of applicants to give them the possibility of doing research, though at a rate much lower than those with large grants?

6. The Comparative Impact of Canadian Research in Mechanical Engineering and Evolution and Ecology

After having showed how bibliometric methods can shed light on the internal structure of a given population of applicants to NSERC grants, we will show how it can be used to assess the global impact of Canadian research in a given field as compared to world averages in the same fields.

In order to make a comparative analysis of the impact of Canadian research in a given field, the key point is to find an appropriate group for comparison. This can be done by defining a set of journals which is agreed upon by researchers to represent the core journals in their discipline or specialty. This step is usually done in collaboration with active researchers in the field[22].

Though scientists publish in a large number of different journals, it is well known that only a small number account for the majority of the publications. This "law" of concentration is known as Bradford's law[23]. Figure 7 shows the distribution for Evolution and Ecology and for Mechanical Engineering. In both cases, we see that only 50 journals are needed to account for more than 50% of the total number of published papers, while the other half is spread among more than 300 different journals.

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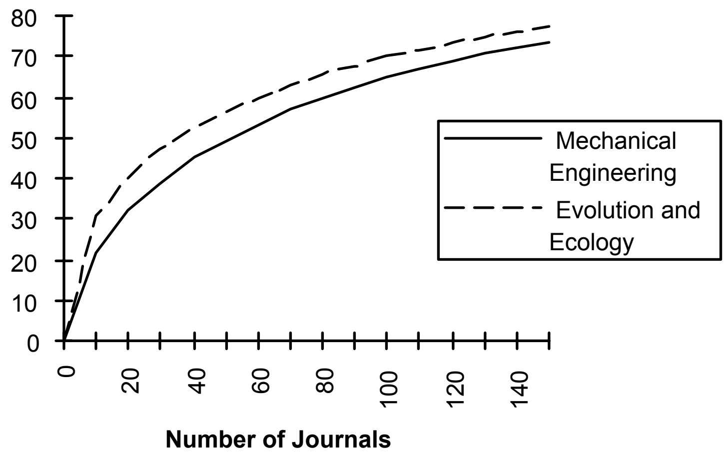
[22] For an example of this procedure see the report of the Molecular Biology Committee of the Royal Society of Canada, *Molecular Biology and Canada's Future. Study Report. Basic Molecular Biology Resarch in Canada: Performance Relative to World Standards*, Ottawa, RSC, 1994.

[23] S. C. Bradford, "Sources of Information on Specific Subject", *Engineering*, vol. 137, 1934, pp. 85.

Figure 7
Distribution of Publications in Scientific Journals (1981-1993)



For the two cases under study, Appendix 3 describes the selection procedure for the set of journals and the indicator adopted to compare the performances of Canadian researchers with world standards. Tables A 1 and A 2 of Appendix 3 list the journal-set selected for each discipline with the number of Canadian papers published in each of them for the years 1988 and 1993 and the Impact factors for the years 1988 and 1992. Using these sets of journals to define the fields, we can compare the average impact of Canadian research with the world average defined by publications in the same journals[24].

A normalized value of 1 means than the mean Canadian impact is the same as the World average. A value lower than 1 means that research in the domain is less visible than the world average. One could do the same kind of calculations for making comparisons with different countries. Figures 8 and 9 show the results for Evolution and Ecology and Mechanical Engineering respectively.

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[24] To obtain a complete view of the period, one would only have to reiterate the method for the the intervening years.

Figure 8
Normalized Mean Impact of Canadian Papers in Evolution and Ecology

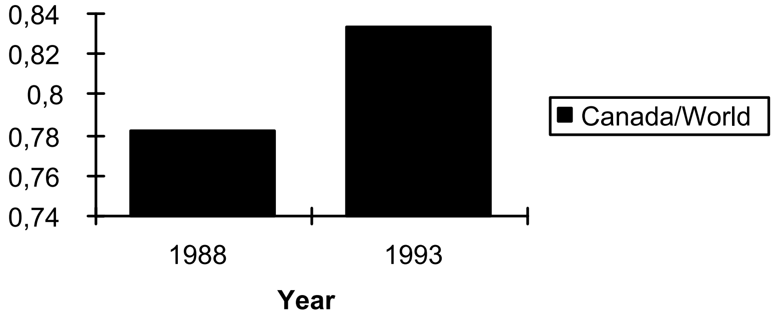
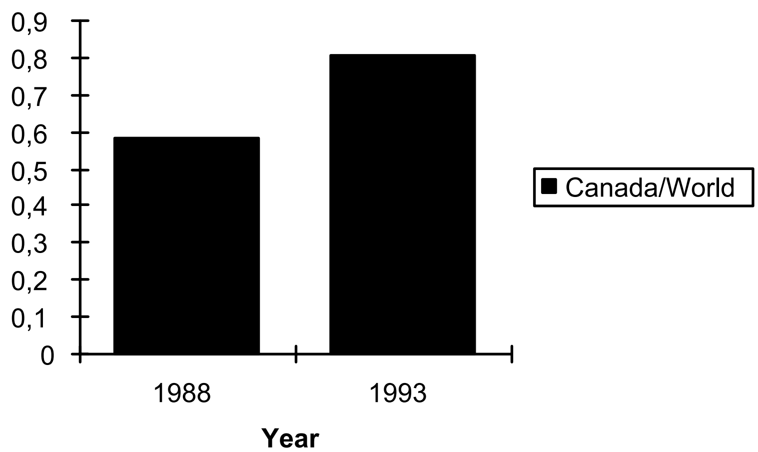


Figure 9
Normalized Mean Impact of Canadian Papers in Mechanical Engineering



In both domains, the results suggest a raise in impact between 1988 and 1993, though Canadian research in those fields stays a little below world average. This tendency of Canadian research to be just below world average is also visible through other indicators. In engineering, (as defined by ISI subject category), Braun et al, finds that for the period 1985-89, Canada gets .94 of the world average observed citations[25]. Though their definition of Engineering encompass much more than Mechanical Engineering as here conceived, the order of magnitude of their results seems consistent with ours. Their data do not contain "Evolution and Ecology" but their result for "Life Sciences" is 0.90.

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[25] T. Braun, et al., World Science in the Eighties. National Performances in Publication Output and Citation Impact, 1984-1989 versus 1980-1984. Part II. Life Sciences, Engineering and Mathematics", *Scientometrics*, vol. 31, 1994, pp. 3-30.

The same kind of calculations could be done for the sub-set of NSERC funded researchers to compare their impact with the Canadian average. One could also evaluate the percentage of Canadian research in a given field conducted by NSERC grantees.

Though the field was defined globally by adding the number of publications published in each journal of the set, one could also make fine-grained analysis by dividing the list into sub-specialties and calculating the mean impact for each such specialty and comparing it with the total as well as with world average. But such a fine classification is best done with the collaboration of experts in the field, in order to select the appropriate core journals of each specialty[26].

7. Conclusion and Recommendations

The above analysis has shown that **it is feasible to undertake systematic evaluations of funded research and Canadian research in general at the level of disciplines or specialties**. It has given a sample of the kind of results that can be obtained using bibliometric indicators of the productiviy and impact of scientific research. Such evaluative bibliometric can be performed at many levels of aggregations: Countries, Provinces, Research Institutions, Research groups, but are not recommended for application to individuals. They can be used for strategic and policy evaluations or for tracking information on the existing level of activity in any given field of scientific research.

In this report, we have shown that bibliometric indicators give significant information about the relationships between grants, productivity and impact, and that these results do not confirm the prejudices many scientists have concerning the links between these variables. We also suggested that these analyses help raise questions concerning funding policy. By providing a global view of the activities of applicants and grantees, and of general trends in scientific research as seen through publications, bibliometric indicators can provide decision-makers with information not easily accessible otherwise and too often replaced by the not always accurate portrait of the few members of a committee. They certainly have, through their network, a fair view of local tendencies but often lack the necessary distance from the lab-bench necessary to gain a global vision. Though the use of objective bibliometric indicators should never replace quality peer reviews, they could certainly complement the existing tools used to define priorities and funding policies.

As we have shown, one can use existing bibliographic data bases for searching papers published by applicants to NSERC funding programs. However, given the problems and limitations associated with these data bases

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[26] One could also do it automatically by using ISI or CHI predefined set of journals by specialty. This procedure is usually sufficient for evaluating countries or Provinces, but hardly useful for pre-defined research groups, institutions or Grant Committees like NSERC GSCs.

(discussed in Appendix 1), it would be less expensive in the medium and long term for NSERC to constitute its own data base of publications of applicants to its funding programs. **We thus recommend that if NSERC decide to use bibliometric evaluations on a systematic basis in the future, the organization should create its own data base of the publications of applicants along the lines explained in Appendix 1**. Since in most bibliometric evaluations the largest amount of time is devoted to cleaning the data obtained from existing data bases, and that this step would have to be repeated for every evaluation, this strategy would diminish considerably the cost of future evaluations.

IF NSERC decide to take steps toward implementing Recommendation 1, two avenues are then open for the undertaking of systematic evaluations: **1)** the organization could train some of its personnel to master the methodologies of evaluative bibliometrics and undertake the evaluations in-house or, **2)** it could contract out the evaluations and provide the chosen experts in evaluative bibliometrics with the data base of publications, specifying the dimensions to be evaluated. In addition to evaluating on a regular basis its granting programs, NSERC should also take steps to obtain regular overviews of the trends of Canadian and world research in the disciplines under its purview. These global data would be helpful for planning purposes.

Acknowledgments

The author thanks Benoît Godin for his collaboration to the design of this study and for his comments on the first draft of the report. I am also indebted to Eric Desrochers for his contribution to the creation of the publication data base, to Martine Foisy for the section on the comparison of Canadian research with world standards, and to Johanne Lemay for the statistical analysis.

Appendix 1

Choice of Data Base and Methodology for the Identification of the Publications

A.1 Selection of the bibliographic data base.

Among the many different data base accessible to locate scientific publications in any given discipline, only SCI contain the address of all authors of a given publication, most other bases listing only the address of the first author. Though many studies use only the first address to locate papers, we think this procedure miss too many papers for the kind of analysis suggested here. Given that the only procedure to obtain the total number of Canadian publications is to use the presence of a Canadian address, SCI is then the only data base which makes possible to locate Canadian authors who happens not to appear as first author in a publication.

A.2 Procedure for locating papers published by Applicants.

Given that the SCI data base — like all others for that matters — do not survey all existing scientific journals, but only about 3500 considered as the most important and influencial, papers published in journals not covered are not counted in our evaluation. Though this aspect is certainly a drawback when considering the bibliography of a given scientist, it is not crucial for the evaluation of a large population, if one acccepts that the probability of having a really influencial journal not covered by SCI is low, and that we are less interested in knowing the exact number of total articles than in having a representative sample in order to make comparative evaluations.

Given the large number od applicants for which we had to search the publications (1534), we had to find an automatic procedure of interrogation. For large numbers, all bibliometric studies use automatic procedures though there is no single one generally accepted. We have used the last name, the name of the university, and the presence of the first letter of the first name in one of the initials present in the publication. The proceudre would have been made easier had the NSERC data base of applicants included all their initials in addition to their first, middle and last name. fter having made tests using other search procedures, we evalaute the percentage of errors in identification to be between 5 and 10%.

The problems associated with the automatic identification of names are well known: the existence of homonyms, variations in the way authors present themselves (using different initials and first names), and errors made during the constitution of the SCI data base. There is also the possibility that an author indicate on his/her papers a different institutional affiliation from the one indicated in the grant application, either because he/she was visiting another institution or moved in the interval between the time of application and the date of publication. This problem becomes more important when one looks at a long period of time. In our data, the number of applicants with no papers is probably over-estimated.Another problem associated with most bibliographic data bases is the fact that coverage change with time so that variations in the the number of papers do not necessarily indicate a real change in production.

For these reasons, whatever the procedure used, a large amount of time is necessary to check the resulting data base to eliminate spurious authors and publications. For the present purposes, **which were not to evaluate the chosen domains but to use them to show the kind of results that can be obtained from bibliometry**, time have not permitted us to make the manual final check of all the 13,000 entries obtained. **It is thus important to note that the actual numbers presented in the tables should not be used as an evaluation**.

Recommendation 1:

Given the importance of constituting a high quality data base of publications, we recommend that **if NSERC decide to use bibliometric evaluations on a systematic basis in the future, the organization should create its own data base of the publications of applicants**. Since Application Forms are now accessible in Computerized format, and that one should expect their general use in the near future, NSERC should design the format of the section devoted to publications in such a way that each applicant would have to fill it in a prescribed way: a field would be reserved for authors, titles and journals, with the specification that *the names should be written as they are on the publications of the author*. This procedure, not very complicated for the applicants, would permit NSERC to create its own data base of papers, from which bibliometric evaluations could be done. Since the whole process depends crucially on the completeness of the publication data base, this procedure would have the great advantage of eliminating the problems associated with interrogating existing data bases for searching publications of the applicants.

Appendix 2
Methodology for the Calculation of the Mean Impact of Publications

The Journal Citation reports, defines the Impact Factor (I. F.) of a journal for a given year, as the total number of citations obtained that year by the papers published in the preceeding two years, divided by the total numbers of papers published during these two years. This index is in fact a measure of the expected average number of citations one is likely to recieve in publishing in a given journal.

In order to be useful in the on going process of decision-making, evaluations cannot always be done too many years after the end of a given project. For this reason, one cannot always use real citations obtained by papers because one would have to wait 3 or 4 years after the date of publication to observe the real rate of citations and this precludes short terms evaluations. To solve this problem, bibliometrics use the expected citations as defined by the Journal Impact factor. This procedure has the advantage that: 1) it is much less than costly than to collect the citations really obtained by each paper, 2) the sources of errors in collecting citations are many and Journals citations do not have these problems, and 3) we do not have to wait 3 or 4 years after the date of publication before attempting an evaluation. Finally, since scientists themselves tends to evaluate their colleagues using the journals into which they publish the results of their research, Journal impact factors reflects the scientist's point of view. As we mentioned in the report, this index is strongly correlated with peer evaluations of the quality of journals.

The indicator of the Mean Impact per paper for the period 1984-1993, is obtained by using the average impact factor of each journal for the years 1984, 1988 and 1992. Impact facors being relatively stable over time[27], this procedure is simpler than using a different Impact factor for each year and matching it with the corresponding papers. For the papers for which we have not found the impact factor, we have chosen to attribute them the mean value of the impact of the articles for which we did have the data. We could also have excluded them from the calculation, but the results do not differ significantly, since we have the Impact factor of more than 85% of the publications. The Mean Impact per year for each researcher is thus the product of the average Impact factor with the total number of papers divided by the number of years starting from the first application to 1993.

For the comparison of Canadian research with World average for the years 1988 and 1993, (Figures 8 and 9), we have used the value of the Impact factors for the years 1988 and 1992, respectively. See Appendix 3 for a discussion of the choice of journal sets.

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[27] P. O. Seglen, "How Representative is the Journal Impact Factor?", *Research Evaluation*, vol. 2, december 1992, pp. 143-149.

Appendix 3

Methodology for the Selection of the Journal Sets in Evolution and Ecology and Mechanical Engineering

In order to choose the journal set for the fields of Mechanical Engineering and Evolution and Ecology, we asked the members of each Selection Committee to select what they considered the best journals in their field, starting from an alphabetical list obtained from the most frequently used journals by the applicants in each Committee. They could also add titles of journals not represented in the list but that they considered important.

From the input obtained from the Members of the Committees, and from discussions with Richard Snell and Danielle Ménard, we constructed a final list containing the most frequently mentioned titles to wich we added, for consistency, some journals heavily used by the applicants but not mentioned by the Committee members (Ex: *Canadian Journal of Zoology*). We also selected only journals for which data existed for both of the years used for comparisons (1988 and 1993). Though *Nature* and *Science* were mentioned by most members, we excluded them from the list because they are very general journals containing publications on very different topics besides Evolution and Ecology. For technical reasons the very large number of "World" publications in these two journals would introduce a large bias in the normalized indicator, diminishing its value by about 50%.

For the case of Evolution and Ecology, the journal set obtained from the consultation (and containing 43 titles), corresponds very well, for the ecology part, with the core set of ecology journals obtained by Nordstrom using an automatic procedure based on Bradford's law[28]. From the 38 titles generated in this way 18 are in our list. His list contains *Canadian Journal of Zoology* as well as *Canadian Journal of Botany*. While the first of these was not included in the list generated by the members of the Evolution and Ecology Committee, we added it on the basis of its frequency of use, and before having found Norstrom's paper.

By fixing the journal set, one fixes the comparison set. It is thus important that the set chosen be accepted by the scientists concerned before the analysis begin: once it is accepted, one must then accept the corresponding results. Of course using a different journal sets will generate different results. But this should come as no surprise, for it is normal that the result of a comparative evaluation depends on whom one chooses to be compared with.

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[28] l. O. Nordstrom, "Bradford's Law and the Relationship Between Ecology and Biogeography", *Scientometrics*, vol. 18, 1990, pp. 193-203.

The list used in the report (Tables A1 and A2) are based on the premise that we want to evaluate research corresponding to the domains covered by the Grant Selection Committees, which are not homogeneous and in fact cover many specialties. Instead of using these lists, we could have used the predefined subject categories of CHI, as is most often done in global analysis at the level of countries. But this approach would not have permitted to evaluate the impact of research pursued in the domains covered by the Committees, because choosing these fixed lists means looking only at the subset of Canadian publications in narrow specialties.

To give a concrete example, we have calculated the mean expected impact of Canadian publications in the field of "Mechanical Engineering" and "Ecology" (not "Evolution and Ecology") as defined by CHI (Tables A3 and A4 respectively give the list of these journals containing Canadian papers). For Ecology, Figure A1 shows that the results are much better, for they are slightly above 1, and show the same upward trend in time as Figure 8. For Mechanical Engineering (Figure A2), the results are also higher though, contrary to the results of Figure 9, they show a decline from 1988 to 1993. In this case, this suggests that there has been a raise in the number of Canadian papers in higher impact journals but a decline in the sub-set used by CHI to define Mechanical Engineering. Given that the GSC Committee covers much more than "Mechanical Engineering" stricly defined, this list is not a good indicator of the trends of the impact of the grantees, and we have not used that list for the results incuded in the report.

In bibliometry, as in statistics in general, it is thus important that one begins by clearly defining the objective of the evaluation as well as the unit to be evaluated in order to tailor the methodology accordingly and not using bibliometry as a "black box" giving universal tools to be applied blindly[29].

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[29] For more details on this question see Y. Gingras, "Performance Indicators: Keeping the Black Box Open" *op. cit.*, note 20.

Figure A 1
Normalized Mean Impact of Canadian Papers in Ecology
(CHI List)

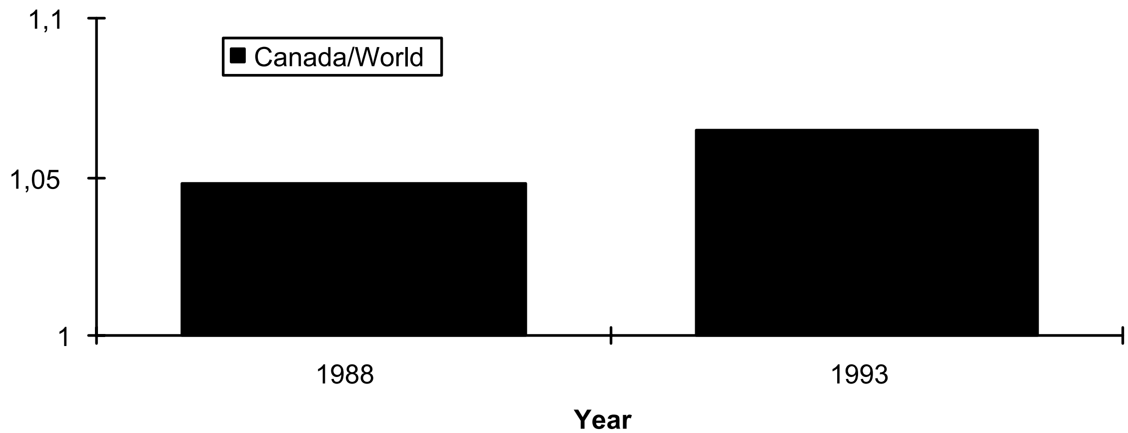

Figure A 2
Normalized Mean Impact of Canadian
Papers in Mechanical Engineering
(CHI List)