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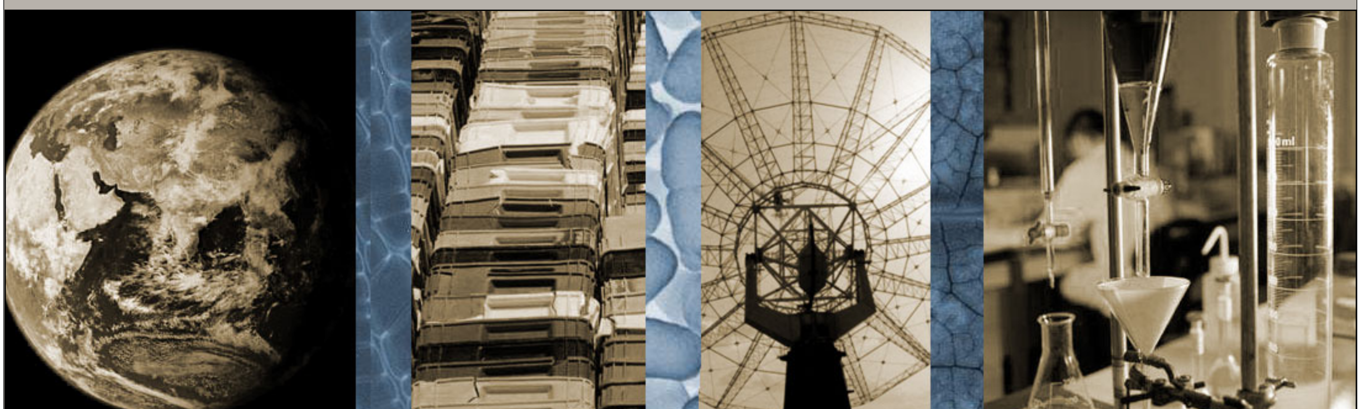
Scientometric Study



Scientometric Study on Collaboration between India and Canada, 1990-2001

Phase 1 of the 2004 Canada-India S&T Mapping Study

Prepared for:

Departments of Foreign Affairs Canada, International Trade Canada, and Industry Canada

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Alexandre Parent, Frédéric Bertrand,
Grégoire Côté and Éric Archambault

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Science-Metrix specializes in the measurement and evaluation of science, technology and innovation. Our data collection and assessment methods include bibliometrics, scientometrics, technometrics, surveys and interviews, environmental scans, monitoring and intelligence gathering. We perform program and policy evaluations, benchmarking and sector analyses, market studies and strategic planning. Science-Metrix has a robust knowledge of life and environmental sciences.

514.495.6505 • 4572 avenue de Lorimier • Montréal • Québec • Canada • H2H 2B5
info@science-metrix.com • www.science-metrix.com

Foreword

This scientometric and technometric analysis performed by Science-Metrix was made possible with the support of Industry Canada, Departments of Foreign Affairs Canada and International Trade Canada (FAC/ITCan).

The report was prepared as part of a broader Science & Technology mapping study sponsored by FAC/ITCan and as such should be read in conjunction with the main report entitled ***Canada-India S&T Mapping Study:*** *Institutional Linkages – Academic/Government/Private Partnerships in the Canadian and Indian Science & Technology Sector*. The final report contains a series of recommendations for enhancing Canada's S&T cooperation with India. In Cooperation with the Government of Canada, the Co-Chairs of this broader Canada-India S&T Mapping Study are Mr. Ravi Seethapathy, Past President of the Indo-Canada Chamber of Commerce and Prof. David Johnston, President, University of Waterloo.

Acknowledgments

We would like to thank the Observatoire des sciences et des technologies for its precious contribution in providing the raw bibliometric dataset presented in this report. More particularly, we would like to thank François Vallières, Vincent Larivière and Philippe Gendron for their contribution to the production of these data.

Executive Summary

There are important differences between Canada and India in terms of scientific and technological (S&T) production. Canada has a considerably larger output, but its production has reached a steady state, whereas India, although producing less, has experienced rapid growth in both science and technology outputs. Although these differences are substantial, some of the strengths are complementary, suggesting that areas for potentially fructuous collaboration exist.

PART I. INDIAN & CANADIAN SCIENTIFIC PUBLICATIONS

- The annual average number of scientific papers by India is higher than 10,000, while the Canadian average number of scientific papers per year is more than 24,000.
- India publishes most in the field of physics (more than 25,500 papers between 1990 and 2001), whereas Canada publishes most in clinical medicine (nearly 92,000 papers between 1990 and 2001).
- India specializes in chemistry with an index of specialization of 1.95 (where 1 is neutral and anything above this mark denotes specialization in one field), engineering & technology (1.47) and physics (1.35), whereas Canada specializes in biology (1.63) and earth & space sciences (1.61).
- India's scientific production is not yet mature and, in general, is not published in highly cited journals. This is indicated by its average relative impact factor (ARIF) being below 1 in the majority of scientific fields with an aggregate score of 0.7. Its strongest fields in terms of expected impact are physics (ARIF: 0.9), mathematics (0.9) and engineering and technology (0.9). On the other hand, Canadian scientific papers are generally published in highly cited journals which lead the country to have an aggregate ARIF of 1.1. Chemistry is the field where Canada has the greatest expected impact (ARIF: 1.2).
- The fields of chemistry and physics could provide fertile grounds for collaboration between India and Canada. Indeed, since Canada has a low specialization index but a very strong impact factor in these disciplines, it could be very advantageous for both parties if India, which is in a complimentary situation (high specialization, low impact) and Canada could work together. This complimentary pattern identifies the fields and subfields where Canada-India collaboration is most advantageous.

PART II. CANADA-INDIA SCIENTIFIC COLLABORATION

- Canada-India collaboration grew steadily throughout the period covered in this study (average annual growth: 8%). The largest number of collaborations occurred in the fields of physics (365) and engineering & technology (219).
- India and Canada have strong relations in the fields of physics and engineering & technology, which is predictable when the performance of both countries in these fields is taken into account.
- Universities are clearly the institutions responsible for most Canada-India collaborations. Indian universities participate in 73% of collaborations; Canadian universities participate in 89% of collaborations. The government sector comes far behind in second place for their importance in Canada-India collaborations.
- The Indian Institute of Science, which participated in 76 collaborations, is the most actively engaged institution in Canada-India collaboration. McMaster University is the most active Canadian institution with 114 collaborations with India. The most active institution-to-institution collaboration occurred between the Indian Center for Advanced Technology and the University of New-Brunswick in Canada with 24 collaborations.
- Dr. Mukhopadhyay is the Indian researcher having participated in the greatest number of collaborations (26). Dr. Mukhopadhyay of the Indian Center for Advanced Technology also participated in the most intense researcher-to-researcher collaboration (19 collaborations) with Dr. Lees of the University of New Brunswick. Dr. H.M. Srivastava is the Canadian researcher with the greatest number of collaborations with Indian scientists (34 collaborations).
- The large number of memoranda of understanding (MoU) and other bilateral agreements signed in the last two years clearly indicate a marked warming-up of the scientific and economic relations between Canada and India. Governmental agreements are concentrated in the field of earth and space science, while university and commercial agreements are principally in the field of environmental sciences and technologies.

PART III. INDIAN & CANADIAN TECHNOLOGICAL INVENTIONS

- India produces on average 3.5% of the Canadian patent output. More precisely, India was granted about 1,440 U.S. patents between 1990 and 2002 compared to the 41,393 U.S. patents granted to Canada during the same time period. However, it is noteworthy that Indian output is growing faster than Canadian output since Indian output grew from 1.6% of the Canadian output in 1990 to 7.8% in 2002.
- The net flow of intellectual property (IP) for India (the measure of the ability to keep the intellectual property of inventions) is -33.3%, meaning that a third of inventions involving individuals residing in India became the property of non-Indian interests. Although Canada also shows a negative flow of IP, it is considerably less important (-8.0%).

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Methods

Scientometric analysis

This scientometric analysis is based on the use of Thomson-ISI's Science Citation Index (SCI)[1] database for output indicators and the SCI Expanded database[2] for Canada-India collaboration indicators. These databases respectively contain papers from about 3,800 and 6,000 journals, which are considered to be the most important peer-reviewed journals in the world. They reflect significant scientific achievements and are the most widely cited journals (containing more than 80% of the world's citations). The statistics are drawn from four types of document that are considered to be original contributions to scientific knowledge: articles, notes, reviews and conference proceedings. The tables presented herein refer to these four types of document as "papers". The construction of the dataset is essentially based on the use of authors' addresses, that is, more specifically, selected authors with Canadian and/or Indian addresses.

The resulting dataset was used to produce detailed statistics based on the following indicators:

> **Number of papers** - Number of scientific papers written by authors located in a given geographical, geopolitical or organizational entity (e.g. countries, cities or institutions).
>
> **Percentage of papers relative to total output, index of specialization** - This is an indicator of the intensity of research in a given geographic or organizational entity relative to the overall output for a given reference. For example, if the percentage of Canadian papers (the geographic entity) in the field of biology is greater than the percentage of papers in this field at the world level (the reference), then Canada is said to be specializing in this field.
>
> **Average relative impact factor** - This indicator is a proxy for the quality of the journals in which papers are published. It is based on a calculation of citations received by journals. An average is calculated through the assignment of a journal impact factor to each paper belonging to a given geographic or organizational entity.

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[1] Compiled by Science-Metrix from data prepared by the Observatoire des sciences et des technologies. Copyright Institute for Scientific Information. All rights reserved. Data for 2001 are undervalued by about 10% for the SCI since a number of papers published in journals with a long lead-time (i.e. that are published very late) had not yet been added to the database at the time of production.

[2] Compiled by Science-Metrix from SCI Expanded. Copyright Institute for Scientific Information. All rights reserved.

Technometric analysis

Patents are often used as a measure of invention despite several well-known disadvantages associated with their use:

- **incompleteness** - many inventions are not patented since patenting is only one way of protecting an invention;
- **inconsistency in quality** - the importance and value of patented inventions vary considerably;
- **inconsistency across industries and fields** - industries and fields vary considerably in their propensity to patent inventions;
- **inconsistency across countries** - inventors from different countries have a different propensity to patent inventions, and countries have different patent laws.

Despite these limits, patents are widely used to compare the level of technological development of different geographic and organizational entities. This report uses the United States Patents and Trademark Office (USPTO) database. Its data are widely used to measure invention, since the USPTO is one of the largest repertories of patented inventions in the world. Because the USA is the largest market in the world, the most important inventions tend to be patented there. Although the USPTO database presents an obvious bias towards the USA, it is still a potent tool for comparing other countries. The database used by Science-Metrix contains information on all the patents granted by the United States Patent and Trademark Office (USPTO) since 1976. The statistics presented here are for patents granted (that is, not for patent applications) and cover utility patents only.

Unlike scientific publications, patents possess two fields that contain bibliographic information relevant to the calculation of where the patent originates: the inventor field and the assignee field. An inventor is necessarily a physical person, whereas an assignee can be a physical person and/or an institution. These fields are used to compute statistics on two different indicators, namely, invention and intellectual property (IP). The location of inventors provides a proxy for the creativity of regions, whereas the location of ownership of IP, particularly of institutional IP, provides an indicator of the potential economic impact of inventions.

Whole patent count is generally used, which explains why some totals (*n*) are lower than the arithmetic sum by region. This is due to collaboration between, for example, provinces (when an inventor in B.C. collaborates with an inventor in Newfoundland, then each province is given one patent; when this is calculated at the level of Canada, the patent is counted only once (*n*)). However, the net flow of IP was calculated on the basis of the proportion of inventions by region versus the proportion of IP owned by each region. In the calculation of provincial net flow of IP, the part of invention and IP whose origin is unknown was redistributed at the *pro rata* of known inventions and IP for each province.

Introduction

By sharing many important characteristics India and Canada have a natural affinity, making Canada-India bilateral relations a fertile ground for the economic, scientific and cultural development of the two nations. The fact that both countries are multi-ethnic, multicultural and multilingual societies, that they have a similar form of governance (both have secular, democratic governments with a federal structure, a parliamentary system, an independent judiciary system, a professional civil service etc.), that they are members of different multilateral bodies (the Commonwealth, the World Trade Organization, the United Nations, the ASEAN Regional Forum, to name but a few) and that about 800,000 Canadians are of Indian origin contributes greatly to facilitating bilateral relations[3].

However, Canada-India relations have nonetheless known successive phases of highs and lows. Economical and political interests have often brought India and Canada closer especially during the fifties and sixties, when Canada provided food aid, project financing and technical assistance to India for a total amount of $ 3.8 billion Canadian dollars over the last five decades, making India the largest recipient of Canadian bilateral aid in Canadian history.[4] The nineties were marked by a strong economic coming together that was sparked by the Indian government's reforms of the economy in the early to mid-1990s. These phases of closeness were divided by cooler periods caused by the Indian government's development of a nuclear strike capability. This happened for the first time in 1974, when Canada was accused of having supplied the nuclear reactor and the material that was allegedly used to produce fissionable material by India[5], and again during the late nineties (1998) when India tested several explosive nuclear devices. This last cold period ended in 2001 when a new Canadian economic delegation was sent to India. India's economic and political strengths were simply too important to be ignored. Its average yearly growth rate of six percent during the last ten years[6] and the fact that it is the second biggest national market in terms of population (after China) make India an inevitable partner in Southeast Asia.

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[3] Speech by High Commissioner Peter Sutherland to the India-Canada Dialogue on East Asia Regional Cooperation, http://www.dfait.gc.ca/new-delhi/canada-india_relations-en.asp

[4] Idem

[5] According to Andrew Koch of the Monterey Institute of International Studies, India's second research reactor, named Cirus, was supplied by Canada. This 40MWt heavy water reactor went critical in 1960 and can produce up to 10kg of weapons-grade plutonium in its spent fuel annually. Although the reactor is not under IAEA safeguards, a 1956 Canada-India agreement prohibits the use of plutonium produced in the reactor for non-peaceful purposes. However, the agreement includes a no enforcement mechanism, and India has interpreted the prohibition to exclude "peaceful nuclear explosions." India used plutonium produced in the Cirus reactor for its 1974 nuclear test, causing Canada to cease all nuclear cooperation with India, including nuclear fuel shipments (http://cns.miis.edu/research/india/nuclear.htm).

[6] Idem.

This report aims to identify India and Canada's different strengths and weaknesses in science and technology to provide a valuable tool for assessing the potential of Canada-India relations in these fields. The report is divided into three parts:

- Part One shows the strengths and weaknesses of Indian and Canadian scientific production and the position of each country relative to the other. It shows that India is specialized in engineering, physics and chemistry and that Canada specializes in biology and earth & space sciences.
- Part Two examines scientific collaboration between India and Canada on relevant scales (scientific fields, institutional sectors, institutions and researchers). India and Canada have strong relations in the fields of physics and engineering & technology, which is predictable when the performance of both countries in these fields is taken into account. Also predictably, the universities clearly dominate the collaboration between the two countries. This section also demonstrates that individual researchers have a great impact on the importance of institutional collaboration. The different bilateral agreements between the two countries are also discussed in this section.
- Part Three examines Indian and Canadian technological production. It presents patenting trends in the two countries and links the Indian growth in patenting to the change of Indian patenting policies in the 1990s. It also reveals a potential weakness of the Indian technological system, since an important part of the intellectual property of Indian patents is owned by foreign interests, making it evident that India has a strong "technological outflows".

PART I
INDIAN & CANADIAN
SCIENTIFIC PUBLICATIONS

1 Indian and Canadian Scientific Output

India plays an important role as a leader of the developing countries. This position is reflected on many levels (that is, economic, military, political etc.). It is also reflected on the scientific level. India has a space program and a strong indigenous nuclear program. India played an important part in the green revolution in the 1950s; it has successfully increased its food grains production from about 50 million tons in 1950 to about 190 million tons in 1997[7]. This strong scientific and technological background is clearly shown by the fact that India ranks fourteen worldwide in production of scientific papers, making it the only developing countries in the top fifteen (Table I).

Table I Ranking of leading countries according to the number of papers in the SCI database, 1990-2001

Rank	Country	1990-1992	1993-1995	1996-1998	1999-2001	Total
1	United States	533,359	564,907	565,504	563,172	**2,226,942**
2	Japan	127,345	147,834	167,828	179,228	**622,235**
3	United Kingdom	123,641	141,488	150,773	154,169	**570,071**
4	Germany	111,120	127,176	148,577	156,294	**543,167**
5	France	82,604	99,688	111,701	114,872	**408,865**
6	**Canada**	**70,678**	**76,407**	**75,648**	**73,734**	**296,467**
7	Italy	48,406	60,269	71,095	76,787	**256,557**
8	Russia	32,659	64,935	63,528	58,675	**219,797**
9	Australia	33,038	39,546	44,680	46,353	**163,617**
10	Spain	26,642	37,008	46,871	52,961	**163,482**
11	Netherlands	33,941	40,535	44,223	44,298	**162,997**
12	China	19,256	24,709	35,466	59,008	**138,439**
13	Sweden	28,040	32,248	35,758	36,937	**132,983**
14	**India**	**29,436**	**30,967**	**31,702**	**33,546**	**125,651**
15	Switzerland	23,710	28,811	32,495	34,187	**119,203**

Source: Compiled by Science-Metrix from data prepared by the OST from SCI.

As for Canada, its position in the G-7 is clearly reflected in its scientific output. Canada ranks sixth worldwide in terms of its production of scientific papers, demonstrating strong scientific production in all fields, but with a noticeable degree of specialization in the fields of biology and earth & space sciences.

[7] Rama Rao, P. (1997). India: Science and Technology from Ancient Time to Today. Technology in Society, Vol. 19, Nos 3-4, pp. 415-447.

1.1 Global trends in scientific publications

Figure 1 shows the number of papers produced per year by Canada and India between 1990 and 2001.

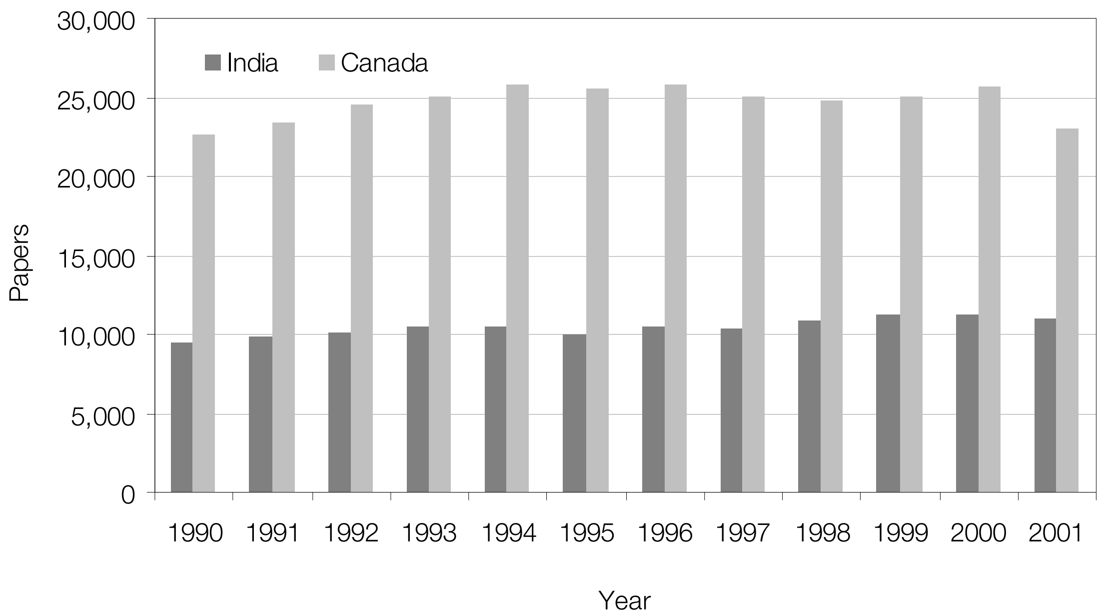


Figure 1 Number of papers by India and Canada per year, 1990-2001
Source: Compiled by Science-Metrix from data prepared by OST from SCI.

India's annual number of publications grew from between 9,450 in 1990 to more than 11,300 in 2000, a growth of 20%. The output of scientific papers by Canada grew from over 22,700 to 25,700, a growth of 13%. On average, the yearly production of Indian scientific papers is 42% that of Canada. Not surprisingly, considering these data and the important difference in population between both countries, there is a huge difference in terms of scientific output per capita. Whereas Canada produces 831 papers per million inhabitants per year on average, India averages 11 papers per million inhabitants per year. Thus, India's strong position in scientific production in absolute number can mainly be attributed to the fact that it's the second most populated country in the world.

1.2 Scientific publications by field

When the scientific production of India and Canada is broken down by fields (Table II), one can see that, while Canada usually has a bigger scientific production than India, the Canadian lead in scientific production is not equally important in all fields. In fact, in some fields, India has an important lead over Canada in terms of scientific production. The detailed data on scientific production per subfield is presented in Annex 1.

With 32,386 papers, which is more than Canada's production in the field (27,029 papers), chemistry clearly is India's forte. As shown in Annex 1, India has an important output in inorganic and nuclear chemistry with about one tenth of the world production in this subfield. Canada and India have a very similar scientific production in the field of physics since Indian production is more than 85% of that of Canada. In fact, India has a larger production in the subfields of general physics (8,639 papers for India and 8,263 papers for Canada) and solid state physics (3,464 papers for India and 3,072 papers for Canada). As for Canada, it has a slightly larger production in the subfields of applied physics (4,801 papers for India and 4,840 papers for Canada), nuclear and particle physics (3,906 papers for India and 4,584 papers for Canada) and fluids and plasma (642 papers for India and 723 papers for Canada). Clinical medicine is Canada's most productive field with 91,952 productions. India clearly lags behind in this field (17,280 papers), with the exception of the subfields of dermatology & venereal disease, where India produces nearly as many papers as Canada does, pharmacy, where India produces nearly twice as many papers as Canada does and tropical medicine, where India produces nearly four times as many papers as Canada does.

Table II Scientific production of India and Canada per field, 1990-2001

Field	Canada	India	World
Biology	37,244	9,830	487,166
Biomedical research	51,196	16,512	1,035,421
Chemistry	27,029	32,386	831,244
Clinical medicine	91,952	17,280	2,004,086
Earth & space	25,599	6,949	338,695
Engineering & technology	26,537	15,346	523,593
Mathematics	6,679	1,650	123,216
Physics	29,553	25,583	949,665
Unknown	678	115	13,661
Total	**296,467**	**125,651**	**6,306,747**

Source: Compiled by Science-Metrix from data prepared by the OST from SCI.

1.3 Index of specialization by field

Although the raw number of papers provides a potent indicator of scientific "strengths", it is often insightful to analyze a country's degree of specialization in different fields and subfields. Here, we use the specialization index which indicates when a country has a more important share of the world scientific production in one field relative to its overall share of World scientific production. Table III presents the specialization index for India and Canada by field. More detailed data per subfield is presented in Annex 2.

If one looks at both countries' specialization, it is possible to immediately see that there is a potential for collaboration in biology, earth and space and engineering and technology – all fields where both countries are specialized. Chemistry is India's prime field in terms of specialization with a specialization index of nearly 2.0, which means that India's share of papers in chemistry is twice as important as its share of world papers in science overall. In comparison, it is Canada's second least specialized scientific field (0.7). The most specialized field in Canadian science is biology (1.6). India, with a specialization index of 1.01, is neutral in the field of biology. Canada is neutral in engineering (1.08), while this is one of the most specialized fields for India (1.47). This can easily be explained by the fact that India possesses a very large number of engineering schools and colleges. Surprisingly, India is not all that specialized in aerospace technology (1.10), a curious observation when one takes into account the fact that India is developing is own military aircraft, its own missile guidance system and its own space program. Canada is highly specialized in civil engineering (2.90), which is not surprising considering Canadian expertise in large-scale projects such as the James Bay hydro-electrical projects, the confederation bridge, the extensive road network and many more. Canada is also specialized in operation research (2.03) which dabbles in process optimization, industrial logistics, etc.

Table III India and Canada's specialization index, 1990-2001

Field	Canada	India
Biology	1.63	1.01
Biomedical research	1.05	0.80
Chemistry	0.69	1.95
Clinical medicine	0.98	0.43
Earth & space	1.61	1.03
Engineering & technology	1.08	1.47
Mathematics	1.15	0.67
Physics	0.66	1.35

Source: Compiled by Science-Metrix from data prepared by the OST from SCI.

1.4 Scientific impact by field

Table IV shows the average relative impact factor of the different fields. More detailed data by subfield are presented in Annex 3. Whereas the specialization index is an indicator of the relative intensity of research in a given field, the average relative impact factor (ARIF) is an indicator of the general quality or importance of the papers published in a given field or subfield. It is calculated using the number of citations received by journals in which papers are published and can be seen as a proxy for the *expected impact* of papers.

Canada's overall ARIF is 1.1, which shows that Canadian papers are published in highly cited journals. India, on the other hand, with its ARIF of 0.7, shows some weakness in terms of the potential impact of its research. This could be caused by a propensity to publish in local journals that are less visible at the international level than journals such as Nature and Science, by research being too oriented to local problem solving or by a lack of quality of the papers, which could be caused by multiple factors (such as a lack of proper research equipment, deficiency in the educational system, scientific and technological outflows toward other countries etc.).

Fields in which India's ARIF is near 1 are physics (0.9), mathematics (0.9) and engineering & technology (0.9). India clearly puts emphasis on those fields (as shown in the section on the index of specialization) and it seems that it successfully translated this intensity of research into research of quality. Canada's strongest field is chemistry (1.2) but it also produces high quality scientific output in physics and clinical medicine

Table IV Average relative impact factor of India and Canada, 1990-2001

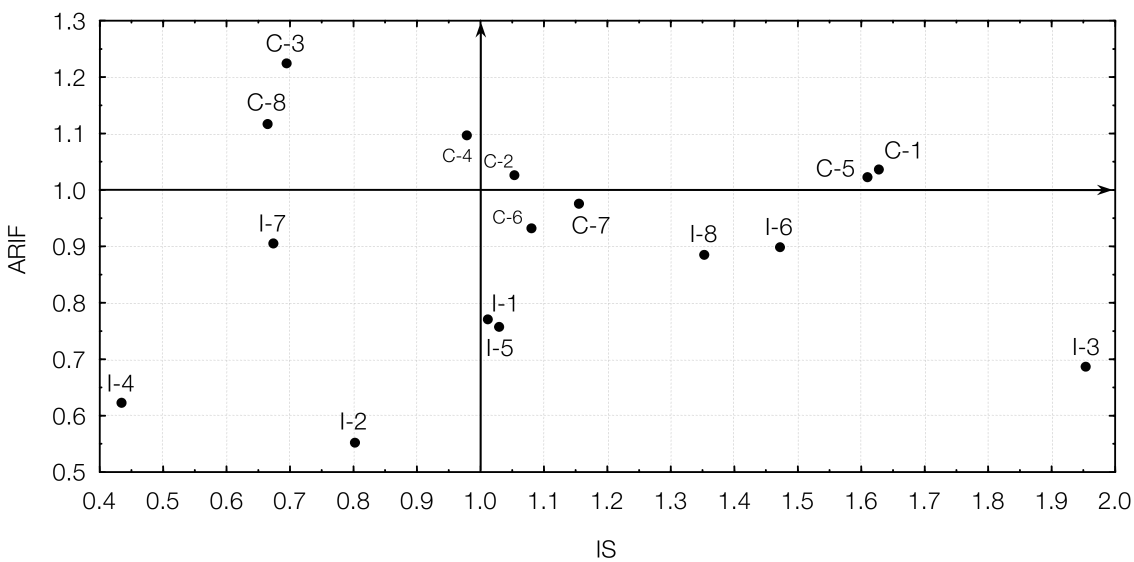
Field	Canada	India
Biology	1.0	0.8
Biomedical research	1.0	0.6
Chemistry	1.2	0.7
Clinical medicine	1.1	0.6
Earth & space	1.0	0.8
Engineering & technology	0.9	0.9
Mathematics	1.0	0.9
Physics	1.1	0.9
Unknown	0.9	0.7
Overall score	**1.1**	**0.7**

Source: Compiled by Science-Metrix from data prepared by the OST from SCI.

1.5 Indian and Canadian strengths and weaknesses

This section provides information about the relationship between the two composite indicators previously used – the index of specialization (IS) and average relative impact factor (ARIF). Scatter plots (figure 2 to 9) of the IS and the ARIF are presented at the field and subfield levels. The most important quadrant in terms of identifying a country's greatest strengths is located at the top right corner of the scatter-plot: this is where countries are specialized in one field and publish in highly cited journals. The weakest fields in which countries are neither specialized nor have a high impact are in the lower left-hand quadrant. The top left quadrant represents the fields or subfields with high impact and low specialization; the lower right quadrant represents the fields or subfields in which countries have a low level of impact but a high level of specialization.

Figure 2 shows the strengths and weaknesses of Canadian and Indian research by field. As mentioned earlier, there are no fields in which India has an ARIF above 1. However, one can see that India strongly specializes in chemistry, engineering and technology and physics. The latter two fields are those in which India has the best combined score of impact and specialization. Canada's greatest strength is clearly in the fields of biology and earth & space.



LEGEND			
Fields	**Symbol**	**Fields**	**Symbol**
Biology	1	Earth & space	5
Biomedical research	2	Engineering & technology	6
Chemistry	3	Mathematics	7
Clinical medicine	4	Physics	8
Countries	**Symbol**		
Canada	C		
India	I		

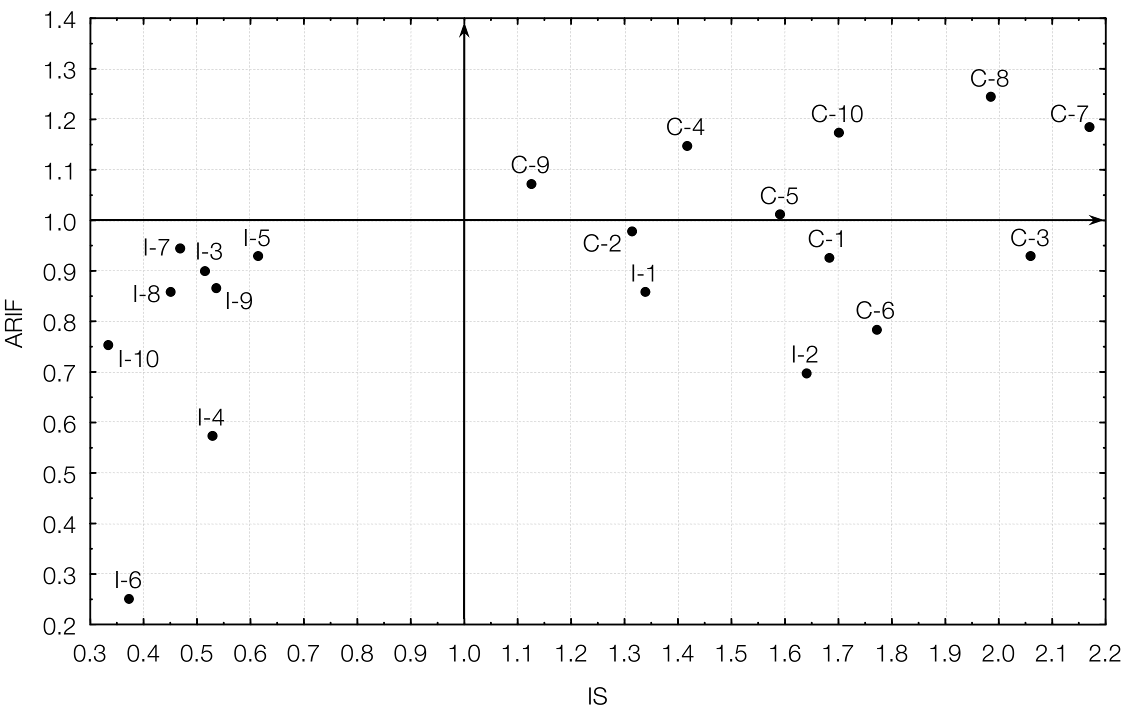
Figure 2 Map of India and Canada's strengths and weaknesses by field, 1990-2001

Source: Compiled by Science-Metrix from data prepared by the OST from SCI.

The fields of chemistry and physics could be fertile ground for collaboration between India and Canada. Indeed, since Canada has a low specialization index but a very strong impact factor for those disciplines, it could be very advantageous for both parties if India, which is in a complimentary situation (high specialization, low impact) and Canada could work together.

1.5.1 Strengths and weaknesses in biology

Figure 3 shows that India is under-specialized in 80% of the subfields of biology and that it has an ARIF below 1 in all of them. By contrast, as mentioned previously, Canada performs very well in biology since it has a high index of specialization in every subfield and a high impact factor above 1 in 60% of them. Nevertheless, there is a potential for mutually beneficial collaboration in botany and agriculture & food science since both countries are specialized in these subfields.



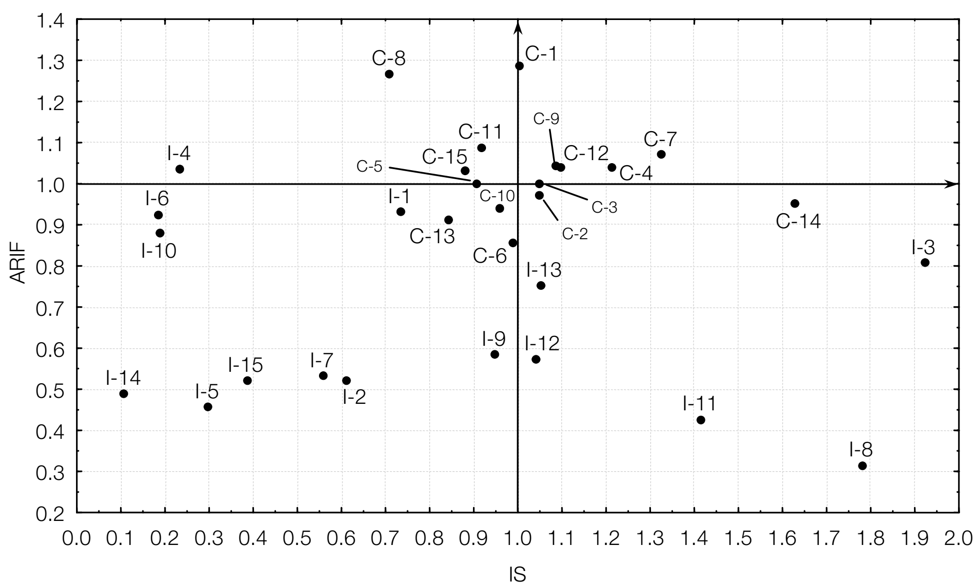
LEGEND			
Subfields	Symbol	Subfields	Symbol
Agriculture & food science	1	General biology	6
Botany	2	General zoology	7
Dairy & animal science	3	Marine biologie & hydrobiology	8
Ecology	4	Miscellaneous biology	9
Entomology	5	Miscellaneous zoology	10
Countries	Symbol		
Canada	C		
India	I		

Figure 3 Map of India and Canada's strengths and weaknesses in biology by subfield, 1990-2001

Source: Compiled by Science-Metrix from data prepared by the OST from SCI.

1.5.2 Strengths and weaknesses in biomedical research

Figure 4 shows Canada and India's strengths and weaknesses in the field of biomedical research. Canada's strength resides in the subfields of genetics & heredity, biophysics, nutrition and anatomy & morphology. General biomedical research also shows a strong impact factor but it is coupled with a weak index of specialization. Parasitology and embryology are the weakest subfields of Canadian biomedical research, they show an IS and an ARIF below 1. As for India, the only subfield with an ARIF above 1 is biophysics, hinting that there could be some good opportunity of collaboration between India and Canada in this subfield. Although having a low impact, India specializes in several subfields: miscellaneous biomedical research, biophysics and biomedical engineering. Canada-India cooperation in the subfields of biophysics and miscellaneous biomedical research could be advantageous for both countries since these fields are in complementary positions (Canada: high impact, low specialization; India: low impact, high specialization). The position of the rest of the subfields shows that, just like biology, there is a lot to do to develop this field of study in India.



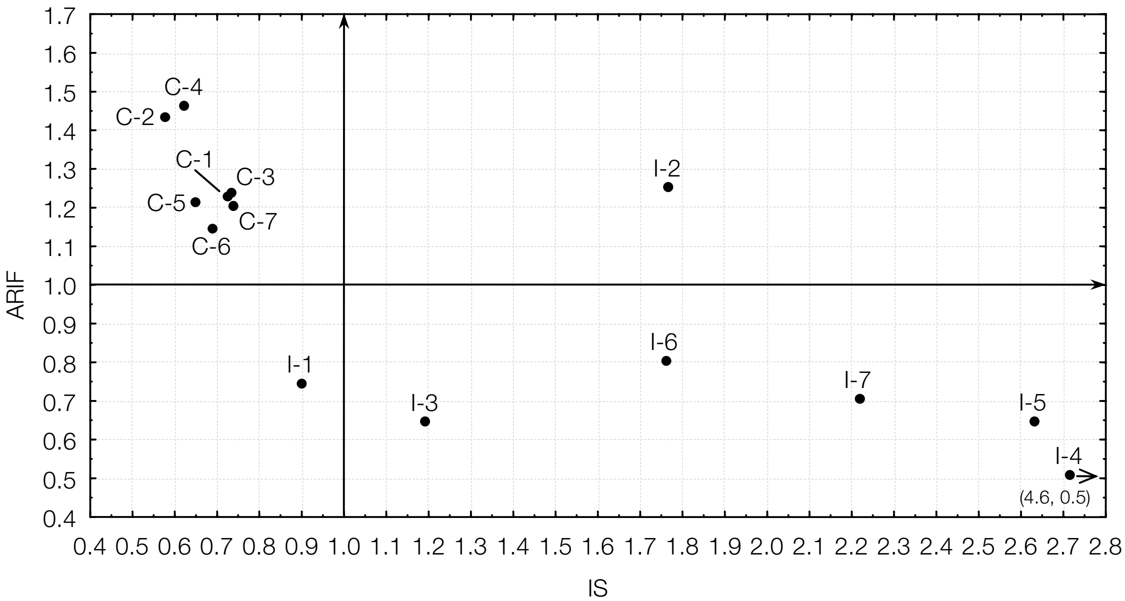
LEGEND			
Subfields	Symbol	Subfields	Symbol
Anatomy & morphology	1	Microbiology	9
Biochemistry & molecular biology	2	Microscopy	10
Biomedical engineering	3	Misc biomedical res	11
Biophysics	4	Nutrition & dietetics	12
Cell biology, cytology & histology	5	Parasitology	13
Embryology	6	Physiology	14
Genetics & heredity	7	Virology	15
General biomedical research	8		
Countries	**Symbol**		
Canada	C		
India	I		

Figure 4 Map of India and Canada's strengths and weaknesses in biomedical research by subfield, 1990-2001

Source: Compiled by Science-Metrix from data prepared by the OST from SCI.

1.5.3 Strengths and weaknesses in chemistry

Figure 5 shows Canada and India's strengths and weaknesses in the field of chemistry. As mentioned above chemistry is the strongest Indian field, as can easily be seen on the subfields map. All of the chemistry subfields except analytical chemistry show a high specialization index, the highest being in nuclear & inorganic chemistry. The subfield of applied chemistry also shows a high impact factor. As for Canada, all of the chemical subfields demonstrate a lack of specialization but a strong scientific impact. The two subfields with the highest ARIF are applied chemistry and inorganic & nuclear chemistry. Here again the complementarities of the two countries could represent a good opportunity for collaboration, especially in the subfields of applied chemistry and inorganic & nuclear chemistry.



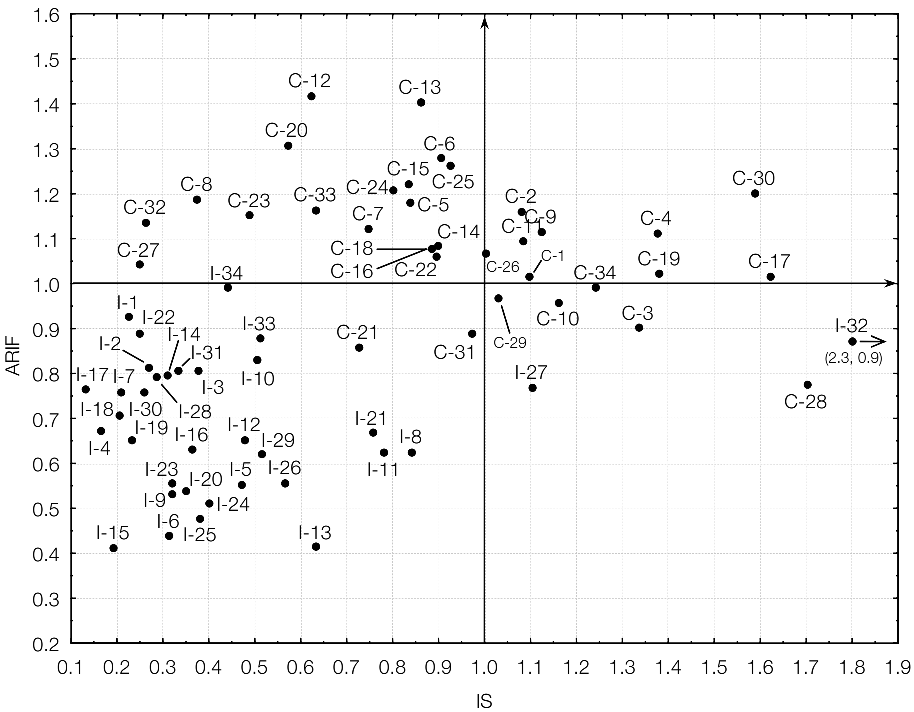
LEGEND			
Subfields	**Symbol**	**Subfields**	**Symbol**
Analytical chemistry	1	Organic chemistry	5
Applied chemistry	2	Physical chemistry	6
General chemistry	3	Polymers	7
Inorganic & nuclear chemistry	4		
Countries	**Symbol**		
Canada	C		
India	I		

Figure 5 Map of India and Canada's strengths and weaknesses in chemistry by subfield, 1990-2001

Source: Compiled by Science-Metrix from data prepared by the OST from SCI.

1.5.4 Strengths and weaknesses in clinical medicine

Figure 6 shows that in clinical medicine India and Canada occupy complementary positions in two specialties, that is, pharmacy and tropical medicine. In these subfields, Canada has a good impact factor but no specialization, whereas India specializes in them but has room to improve the quality of its publications. These are the most promising areas for mutually beneficial collaboration.



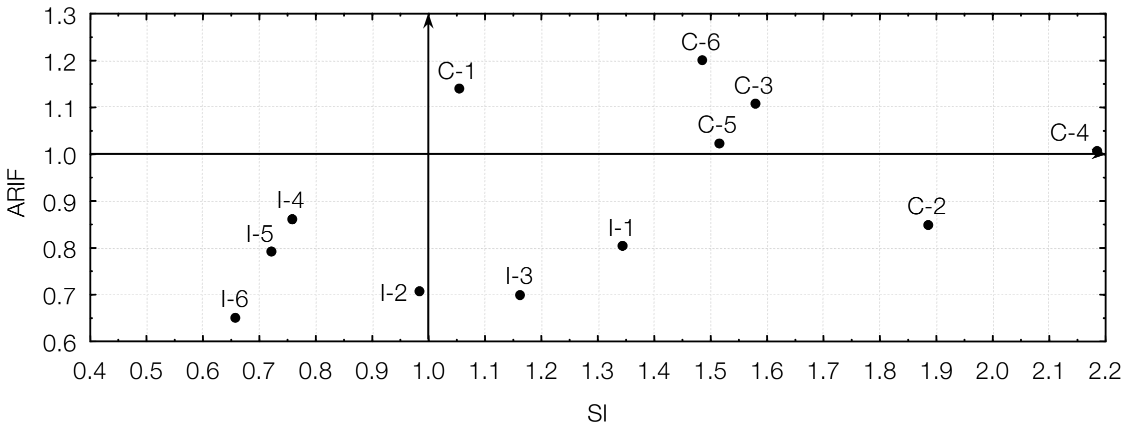
LEGEND			
Subfields	**Symbol**	**Subfields**	**Symbol**
Addictive diseases	1	Nephrology	18
Allergy	2	Neurology & neurosurgery	19
Anesthesiology	3	Obstetrics & gynecology	20
Arthritis & rheumatism	4	Ophthalmology	21
Cancer	5	Orthopedics	22
Cardiovascular system	6	Otorhinolaryngology	23
Dentistry	7	Pathology	24
Dermatology & venereal disease	8	Pediatrics	25
Endocrinology	9	Pharmacology	26
Environmental & occupational health	10	Pharmacy	27
Fertility	11	Psychiatry	28
Gastroenterology	12	Radiology & nuclear medicine	29
General & internal medicine	13	Respiratory system	30
Geriatrics	14	Surgery	31
Hematology	15	Tropical medicine	32
Immunology	16	Urology	33
Miscellaneous clinical medicine	17	Veterinary medicine	34
Countries	**Symbol**		
Canada	C		
India	I		

Figure 6 Map of India and Canada's strengths and weaknesses in clinical medicine by subfield, 1990-2001

Source: Compiled by Science-Metrix from data prepared by the OST from SCI.

1.5.5 Strengths and weaknesses in earth & space sciences

In earth and space science, there is room for collaboration in astronomy and astrophysics as well as in environmental science (Figure 7).



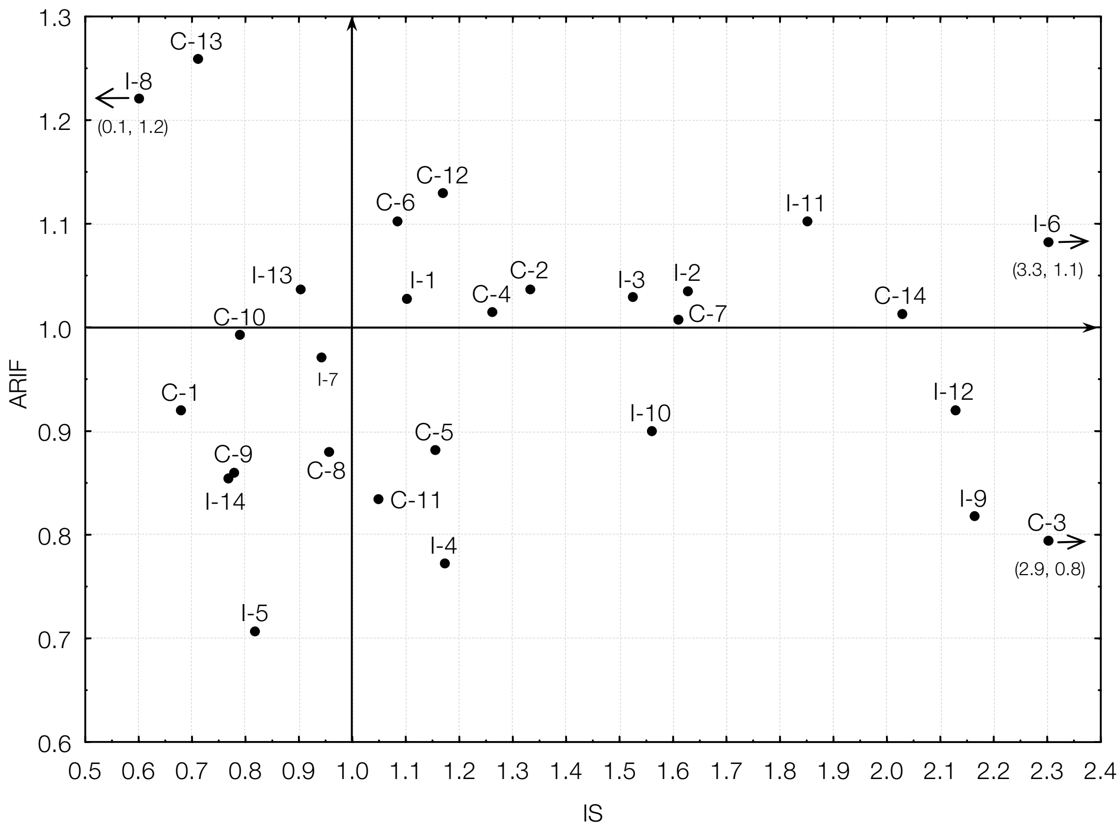
LEGEND			
Subfields	**Symbol**	**Subfields**	**Symbol**
Astronomy & astrophysics	1	Geology	4
Earth & planetary science	2	Meteorology & atmospheric science	5
Environmental science	3	Oceanography & limnology	6
Countries	**Symbol**		
Canada	C		
India	I		

Figure 7 Map of India and Canada's strengths and weaknesses in earth & space sciences by subfield, 1990-2001

Source: Compiled by Science-Metrix from data prepared by OST from SCI.

1.5.6 Strengths and weaknesses in engineering & technology

Figure 8 shows that within the field of engineering & technology India and Canada could collaborate in chemical engineering, civil engineering, metals & metallurgy and nuclear technology, given their complementary strengths.



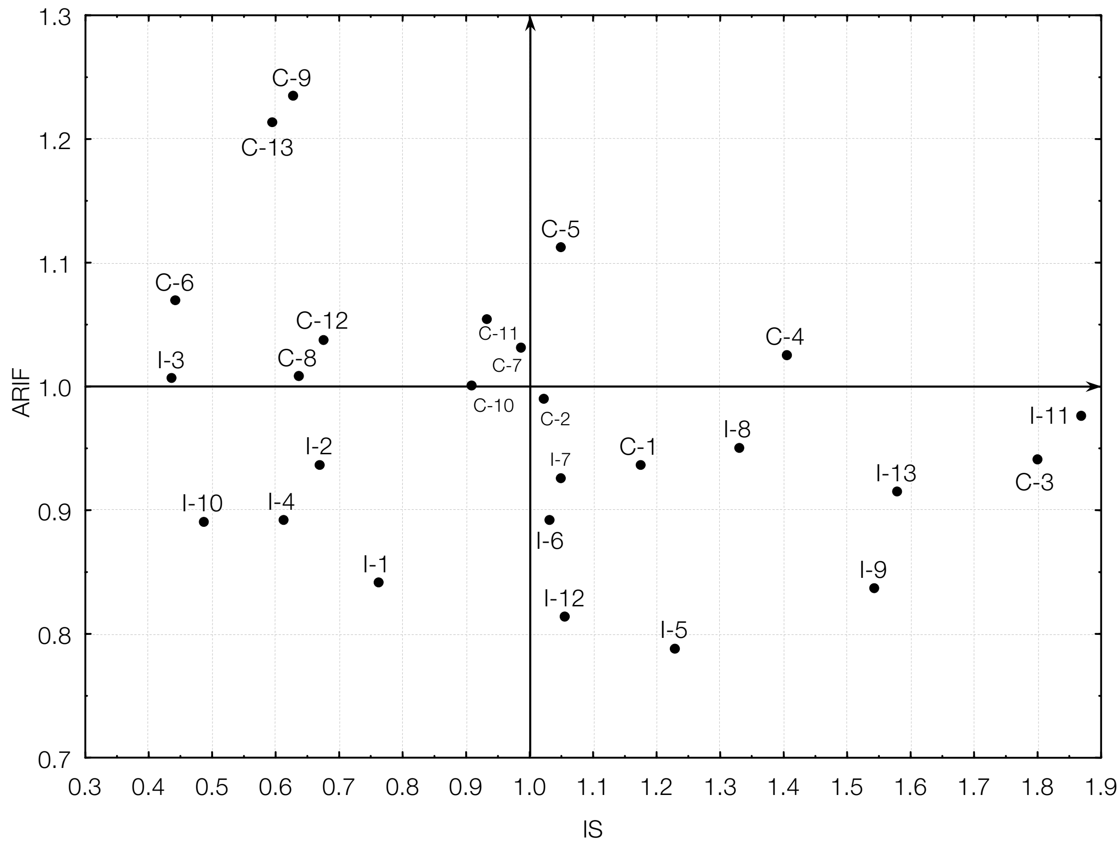
LEGEND			
Subfields	Symbol	Subfields	Symbol
Aerospace technology	1	Library & information science	8
Chemical engineering	2	Materials science	9
Civil engineering	3	Mechanical engineering	10
Computers	4	Metals & metallurgy	11
Electrical engineering & electronics	5	Miscellaneous engineering & technology	12
General engineering	6	Nuclear technology	13
Industrial engineering	7	Operations research	14
Countries	Symbol		
Canada	C		
India	I		

Figure 8 Map of India and Canada's strengths and weaknesses in engineering and technology by subfield, 1990-2001

Source: Compiled by Science-Metrix from data prepared by the OST from SCI.

1.5.7 Strengths and weaknesses in mathematics and physics

Finally, figure 9 shows Canadian and Indian strengths and weaknesses in the fields of mathematics and physics. The greatest potential for collaboration lies in solid states physics, and there is also some potential in optics.



LEGEND			
Subfields	**Symbol**	**Subfields**	**Symbol**
Applied mathematics	1	Fluids & plasmas	8
General mathematics	2	General physics	9
Miscellaneous mathematics	3	Miscellaneous physics	10
Probability & statistics	4	Nuclear & particle physics	11
Acoustics	5	Optics	12
Applied physics	6	Solid state physics	13
Chemical physics	7		
Countries	**Symbol**		
Canada	C		
India	I		

Figure 9 Map of India and Canada's strengths and weaknesses in mathematics & physics by subfield, 1990-2001

Source: Compiled by Science-Metrix from data prepared by the OST from SCI.

PART II
CANADA-INDIA
SCIENTIFIC COLLABORATION

2 Scientific Collaboration between India and Canada

Few studies emphasize Canada-India collaboration in science and technology. As mentioned before, India science does not regularly publish in mainstream scientific journals, therefore reducing its chances to enter networks of international collaboration. Nonetheless, we will see in this part of the study that Canada and India have a growing number of scientific collaborations. Indeed many Indian scientists studied in Canada and continue to have links with their *alma mater* and homeland when they obtain a professorial position or the equivalent in non-academic fields. This helps in the development of international collaboration networks. Combined with the important scientific policies implemented by the Indian government, these developments surely contribute to the growing number of collaborations between Canada and India, but also make collaboration very dependent on particular individuals because of the small number of partners. This section will look at how this collaboration is distributed among scientific fields, institutional sectors, institutions and researchers.

2.1 Scientific collaboration at the country level

Table V presents Canada-India collaboration by field by year. The number of publications grew somewhat steadily from 1990, where it was at the lowest level of the years covered by this study (1990-2001), to 2001, where it reached its maximum. The average annual growth in collaboration hovers around 8%, with the biggest yearly increases occurring between 1990 and 1991 (31%), between 1994 and 1995 (16%), between 1999 and 2000 (16%) and between 2000 and 2001 (24%). There was a marked decrease in collaboration between 1995 and 1998. The small collaboration drop that occurred in 1997 and 1998 corresponds to the political setback between the two countries, caused by the Indian nuclear tests. Over the 11 years covered by this study, physics was the field in which most collaboration was done (365), followed by engineering & technology (219), mathematics (171) and chemistry (167). Although physics is the field where there is most collaboration, it is showing the least growth in collaboration among the four leading fields. Of this top four, chemistry is the demonstrating the largest average annual growth (28%), indicating great potential as a field for collaboration between the two countries. Biomedical research is the field experiencing the largest average annual increase (54%), which could mean that there is a large potential for collaboration here too; however, caution must be used here, especially since the number of publications in this fields is relatively low.

Table V Number of Canada-India scientific papers by field, 1990-2001

Years	Biology	Biomedical Research	Chemistry	Clinical Medicine	Earth & Space	Engineering & Tech	Mathematics	Physics	Others & Unknown	TOTAL
1990	7	2	11	3	7	17	11	25	10	**93**
1991	15	8	4	6	13	16	10	36	14	**122**
1992	14	12	12	11	10	20	16	31	12	**138**
1993	12	9	7	12	8	22	26	27	12	**135**
1994	6	12	13	13	8	12	20	37	14	**135**
1995	7	8	10	11	10	22	21	40	27	**156**
1996	14	9	11	15	7	22	14	24	20	**136**
1997	7	3	19	14	10	20	10	22	12	**117**
1998	10	9	14	9	14	7	4	30	25	**122**
1999	5	12	16	12	8	23	11	30	22	**139**
2000	12	10	20	17	5	17	14	37	29	**161**
2001	5	21	30	30	18	21	14	26	34	199
TOTAL	**114**	**115**	**167**	**153**	**118**	**219**	**171**	**365**	**231**	**1,653**

Source: Compiled by Science-Metrix from SCI Expanded.

2.2 Canada-India collaboration by institutional sector

Table VI shows the collaborations between the Indian and Canadian research sectors. Of the Indian sectors, universities are responsible for the largest part of collaborations (73.1%), followed by the governmental sector (18.5%). The pattern is similar in Canada. Universities are again the leading collaborating sector (89.0%), also followed by governments (6.5%). Indian universities principally collaborate with Canadian universities (66.9% of the total amount of collaborations) and then with the Canadian government (3.8% of total collaborations). The Indian government sector also collaborates principally with Canadian universities (16.1% of the total amount of collaborations) and governments (2.0% of the total amount of collaborations). The amount of collaboration involving the clinics and hospitals sector (both Indian and Canadian) represents 4.7% of the total amount of collaborations, which is about twice as much as for private companies (2.5% for Indian companies and 2.7% for Canadian companies).

Table VI Number and percentage of Canada-India collaborations by institutional sector, 1990-2001

Institutional Sectors (Canada / India)	Universities	Clinics and Hospitals	Companies	Governments	Others	Unknown	N
Universities	1,106 (66.9%)	42 (2.5%)	35 (2.1%)	266 (16.1%)	91 (5.5%)	10 (0.6%)	1,471 (89.0%)
Clinics and Hospitals	36 (2.2%)	36 (2.2%)	1 (0.1%)	8 (0.5%)	3 (0.2%)	2 (0.1%)	77 (4.7%)
Companies	26 (1.6%)	5 (0.3%)	3 (0.2%)	13 (0.8%)	2 (0.1%)	0 (0.0%)	45 (2.7%)
Governments	63 (3.8%)	2 (0.1%)	3 (0.2%)	33 (2.0%)	8 (0.5%)	0 (0.0%)	108 (6.5%)
Others	3 (0.2%)	4 (0.2%)	1 (0.1%)	2 (0.1%)	1 (0.1%)	1 (0.1%)	10 (0.6%)
Unknown	16 (1.0%)	5 (0.3%)	3 (0.2%)	8 (0.5%)	0 (0.0%)	0 (0.0%)	29 (1.8%)
N	1,209 (73.1%)	77 (4.7%)	43 (2.5%)	306 (18.5%)	99 (6.0%)	11 (0.7%)	1,653

Source: Compiled by Science-Metrix from SCI Expanded.

2.3 Canada-India collaborations by institutions

Table VII presents the collaboration between Indian and Canadian institutions. Only the institutions with twelve or more collaborations (i.e. one publication per year on average) are presented in this table.

The Indian Institute of Science is the most active Indian institution in Canada-India collaboration (76 collaborations in 12 years). It is followed by the Indian Institute of Technology in Kanpur (70 collaborations) and Panjab University (59 collaborations). McMaster University strongly collaborated with the Banaras Hindu University (18 collaborations), the Institute of Mathematical Sciences (15 collaborations) and the Indian Statistical Institute in Delhi (13 collaborations). As for the Indian Institute of Science, it does not collaborate specifically with a particular Canadian institution; instead, the institute seems to collaborate less intensely with a large number of Canadian institutions (McMaster University and Institut de recherche en Cardiologie de Montréal being the most important collaborators with nine collaborations each). McMaster University is the most active Canadian institution in Canada-India collaboration (114 collaborations). It is followed by the University of Toronto (107) and McGill University (97).

The largest number of collaborations between two institutions is between the University of New Brunswick and the Center for Advanced Technology with 24 publications in 12 years. This important collaboration is mainly due to the collaboration between Ronald M. Lees of the University of New Brunswick and Dr. Mukhopadhyay of the Center for Advanced Technology; their collaborations accounts for 19 papers over the twelve years covered by this study. In general, it seems that Canadian collaboration is more concentrated in a small number of institutions. This is illustrated by the fact that the most important Canadian collaborating institutions collaborate more intensely (more collaboration per institution) than their Indian counterparts, who seem to collaborate less intensely (fewer collaboration per institution), do.

Table VII Inter-institutional Canada-India collaborations, 1990-2001

Institution or Country	Canada	McMaster University	University of Toronto	McGill University	University of Alberta	University of Waterloo	University of Calgary	University of British Columbia	University of Victoria	Université de Montréal	Dalhousie University	University of Saskatchewan	University of Manitoba	Concordia University	University of New Brunswick	University of Windsor	Memorial University of Newfoundland	Ottawa University	University of Guelph	National Research Council Canada	Simon Fraser University	University of Western Ontario	York University	Queen's University	Royal Military College of Canada (RMC)	Université Laval	Carleton University	Agriculture and Agri-food Canada	St. Francis Xavier University	Lakehead University	Université du Québec à Trois-Rivières (UQTR)	Institut de Recherche Clinique de Montréal (IRCM)
India	1,653	114	107	97	90	72	72	64	63	61	60	58	53	53	53	50	48	47	45	42	42	40	38	33	29	27	25	21	21	18	16	12
Indian Institute of Science	76	9		4	2	5	7	7	3	4	5		2	6			1		1	1	7					1	1					9
Indian Institute of Technology Kanpur	70	1	7	15	5	3	12	4		1	2	1	5	3	6					1	5											
Panjab University	59		4		7					1		1			2	3			3	9	8	1			14		1			4		
Tata Institute of Fundamental Research	57	3	4	6	10	1	1	2	7		2						3	2	1		1	1		7		2	7					
Indian Institute of Technology Roorkee	56	9	1	2	6	1	1							3		2			3				15	10			1				1	
Indian Institute of Technology Bombay	55	3	4	2	1	1	3	3	1		7		7	15	1	2	1				2	1		1		3					3	
Indian Institute of Technology Delhi	52	2	1		2	1	4	1	2		1	1	11	2		9	1	1			2											
Institute of Mathematical Sciences	46	15	3	1		6	1		2	4									7		13						1					
University of Delhi	44	4	2		2	8	2		1		3	3	8			1	1	3	1					2	1				2	2	1	
Indian Institute of Technology Kharagpur	42		2		2	2		1		1	12				2			2	1	2		5			12							
Banaras Hindu University	37	18	2	3	3			1	1			1			1	1	1		2								4	1				
Indian Statistical Institute Calcutta	35			1		3		1					1	1		5	1	9	1				12				2					
Indian Statistical Institute Delhi	34	13	8		4	2		2	3										1													
Physical Research Laboratory	28	1	8			9		1		1			1					3				1	1			1						
Centre for Advanced Technology	27				1			4							24		2			9												
Bhabha Atomic Research Centre	26	1	1	4	1			1	1	1	1	1	3		1		2		2	1		2				1						
Calcutta University	24	1	1	2		1			1	3						2	7	1								3	1					
All India Institute of Medical Sciences	23	9	1	2									1									2		2		1						1
University of Hyderabad	22									6		3						1				3									1	
Indian Association for the Cultivation of Science	21		3		1										1		7			3	1		4			1					2	
Indian Institute of Technology Madras	21	2			1	2		2	3			1		1			4	1		1					1		2					
University of Madras	20	1		10							1	5		2																		
Indian Space Research Organisation	20						11	1		8														3								
Jawaharlal Nehru University	20		6	2		5		1				1	1														1					1
Council of Scientific and Industrial Research, Regional Research Laboratory Trivandrum	19				1			12																							6	
University of Pune	18	1	2		2	2							1	1	1		1		1											8		
University of Rajasthan	16			1					2				1							10												
Visva-Bharati University	16					1												14								1						
Jawaharlal Nehru Technological University, College of Engineering Hyderabad	15					1					12																					
Guru Nanak Dev University	14		1	4			5	1				4					2															
Punjab Agricultural University	14				4							2				3			1									4				
Punjabi University	13		1		2	1	1											1		1		4			1					2		
Institute of Physics	12	7								4		1						1	4													
Meerut University	12					1		2							2		1	1				7						2				
Aligarh Muslim University	12				2																						1		10			
National Chemical Laboratory	12					1				2		1				2				2						3						
University of Jammu	12						1													10												

Source: Compiled by Science-Metrix from SCI Expanded.

2.4 Canada-India collaborations by researcher

Table VIII presents collaboration between Indian and Canadian researchers between 1990 and 2001. Only the researchers with 12 or more collaborations are presented in this table. As mentioned above, the most intense occurrence of collaboration between two researchers is between Dr. Mukhopadhyay of the Indian Center for Advanced Technology and Dr. Lees of the University of New Brunswick. Dr. Mukhopadhyay is the Indian researcher participating in the highest number of collaborations (26), while Dr. H.M. Srivastava is the most active Canadian collaborating with India (34). In general, Indian researchers collaborate with one Canadian researcher on one project. Canadian researchers collaborate principally with one Indian researcher but can also collaborate with other Indian researchers and have a tendency do diversify their collaboration projects. It is also worth mentioning that Indian collaborators have often studied in Canada and that their collaboration is principally with past colleagues and professors. Some Canadian collaborators studied in India but most of them were trained in Canada.

Table VIII Canada-India collaborations between researchers, 1990-2001

		Indian researchers	Mukhopadhyay, I	Pathak, KN	Murthy, MVN	Srivastava, R	Balasubramanian, K	Dutt, R	Sarkar, U	Srinivas, V	Dubey, PK	Gupta, UC	Nair, V	Parthasarathy, R	Sood, PC	Yadav, VK
		Total number of collaborations	Centre for Advanced Technology	Panjab University	Institute of Mathematical Sciences	Indian Institute of Technology Roorkee	Indian Statistical Institute	Visva-Bharati University	Physical Research Laboratory	Indian Institute of Technology Kharagpur	Jawaharlal Nehru Technological University College of Engineering Hyderabad	Indian Institute of Technology Kharagpur	Council of Scientific and Industrial Research	Institute of Mathematical Sciences	Sri Sathya Sai Institute of Higher Learning	Indian Institute of Technology Kanpur
Canadian researchers	Total number of collaborations	1,656	26	20	15	15	14	14	14	13	12	12	12	12	12	12
Srivastava, HM	University of Victoria	34														
Bhaduri, RK	McMaster University	25			15											
Varshni, YP	Ottawa University	24						14								
Dunlap, RA	Dalhousie University	19								13						
Lees, RM	University of New Brunswick	19	19													
Ranganathan, S	Royal Military College of Canada	16		15												
Balakrishnan, N	McMaster University	15					12									
McEachran, RP	York University	15				15										
Stauffer, AD	York University	15				15										
Bector, CR	University of Manitoba	14														
Meath, WJ	University of Western Ontario	14														
Drake, JE	University of Windsor	13														
Chaudhry, ML	Royal Military College of Canada	12										12				
Eigendorf, GK	University of British Columbia	12											12			
Grossert, JS	Dalhousie University	12									12					
Kumar, A	University of Western Ontario	12														
Paranjape, VV	Lakehead University	12		5												
Parvez, M	University of Calgary	12														11
Viswanathan, KS	Simon Fraser University	12												12		

Source: Compiled by Science-Metrix from SCI Expanded.

2.5 Canada-India memoranda of understanding, bilateral agreements and collaborative projects

Many Canadian and Indian institutions have, over the years, signed memoranda of understanding (MoU), bilateral agreements and collaborative projects. Agreements presented in Table IX are grouped by type: government; commercial and university. These agreements were collated from an extensive search of the worldwide web.

The MoU and other agreements involving the government of at least one of the two countries involved several agreements in the field of earth and space science: eight MoU were signed with the aim of facilitating collaboration between the two countries in the fields of energy, environment, geomatics and space sciences. For instance, an MoU in the field of earth & space science was signed in 2003 between the Canadian Space Agency and Indian Space Research Organization (ISRO): "The Memorandum will foster the study of cooperative programs in satellite communications and satellite remote sensing as well as encouraging cooperation in the field of exploration and use of space by the private sector and academia in both countries."[8]

There are three important MoU to do with environmental science and energy efficiency issues. All these agreements are aimed at the industry sector, either to increase its capacity to incorporate environmental and social issues into doing business or to promote innovation and information exchange to advance energy-efficient techniques. The 1994 Eco-Friendship was signed between the Government of India and the Government of Canada in October 1994. This MoU led to a project with a CDN$6.7-million budget that began in 1996 and was scheduled to continue until December 2001. The overall goal of the project was to contribute to the capacity of Indian industry and government to promote environmentally sustainable industrial development. To date, principal achievements are[9]:

Policy Achievements

- *More rational and effective application by GOI of the Basel Convention in the Indian lead and zinc recycling industry*
- *Modernization of hazardous waste classification system*
- *Improvement of GOI procedures for environmental impact assessments*
- *More influence on GOI stance on climate change and so-called Clean Development Mechanism*
- *Re-formulation of an eco-labelling program*
- *Greater openness of GOI to voluntary, market-based approaches to environmental management, to complement command- and-control-based regulation*

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[8] http://www.space.gc.ca/asc/eng/media/press_room/news_releases/2003/030327.asp, visited October 7, 2003.

[9] http://www.ciionline.org/services/70/default.asp?Page=Indo-Canadian%20Eco-Friendship%20.htm, visited October 7, 2003.

Table IX List of Canada-India memoranda of understanding, bilateral agreements and collaborative projects, 1991-2003

Date	Sector	Title of agreement or partnership	Indian Institution	Indian representant	Canadian Institution	Canadian representant
2003	Governmental	Canada-India Geosciences Memorandum of Understanding	India's Minister Responsible for Mines	Shri Ramesh Bais	Natural Resources Canada	Honourable Herb Dhaliwal
2003	Governmental	Memorandum of Understanding on International Space Cooperation	Indian Space Research Organization (ISRO)	Dr.Kasturirangan	Canadian Space Agency (CSA)	Dr. Marc Garneau
2003	Governmental	India-Canada MoU for socio-environmental project	Joint Secretary, Ministry of Finance	U.K. Sinha	Deputy High Commissioner of Canada in India	Brian Dickson
2003	Governmental	Memorandum Of Understanding offers masters degree in aviation with specialisation in airport management and engineering.	Gao Government		Concordia University	
2002	Governmental	Canada–India Cooperation In Geomatics and Spatial Information	Indian Minister of State for Rural Development	Shri Shanta Kumar	Natural Resources Canada	Honourable Herb Dhaliwal
2002	Governmental	Canada–India Cooperation on Energy Efficiency	Federation of Indian Chambers of Commerce and Industry	R S Lodha	Natural Resources Canada	Irwin Itzkovitch
2002	Governmental	Canada-India Cooperation on Geospatial Information Technology	State of Andhra Pradesh		Natural Resources Canada	
2002	Governmental	Memorandum of Understanding on Geomatics	Centre for Spatial Database Management and Solutions (CSDMS)	Sanjay Kumar	Geomatics Industry Association of Canada	Ed Kennedy
1999-present	Governmental	Canada-India Institute Industry Linkage Project (CIIILP) - a bilateral technical education project	Indian Department of Economic Affairs (DEA) and Ministry of Human Resource Development(MHRD), Directorates of Technical Education in the five Indian states and Indian industries		Government of Canada - CIDA & Canadian industries	
1993	Governmental	Indo-Canadian Eco-Friendship - Memorandum Of Understanding				
2002	Commercial	Memorandum of Understanding on the Master License to operate the TalXchange Network	ABC Consultants		Talware Networx Inc.	
2002	Commercial	Memorandum of understanding to provide steel panel and stud framing systems to build homes faster and more efficiently.	Orchid Group of Companies		Minaean Ventures Inc.	
2002	Commercial	Memorandum of understanding to work together on projects associated with waste water and municipal water treatment.	Mahindra Acres Consulting Engineers Ltd.		Process Research Ortech Inc.	
2002	Commercial	Memorandum of understanding to introduce hybrid seed genetic lines to India.	Summit Seeds India Limited		Agricultural Environment Renewal Canada Inc. (AERC)	
2002	Commercial	Memorandum of understanding to carry out a feasibility study on the social, environmental and economic impact of using wetlands for treating municipal wastewater.	Punjab State Council for Science and Technology of Chandigarh, Punjab		CH2M Hill Canada Limited	
2002	Commercial	Memorandum of understanding to provide training and knowledge-based forensic information systems for the purpose of automating and networking all law enforcement agencies in 25 state and central forensic science laboratories in India.	Lab Systems (I) Pvt. Ltd.		Forensic Technology (WAI) Inc.	
2002	Commercial	Contract to carry out a feasibility study to set up an integrated hazardous waste collection, transportation, treatment and disposal facility.	Udaipur Chamber of Commerce and Industry		Vaughan International Limited	
2002	Commercial	Memorandum of understanding to integrate existing technologies in an effort to develop new solutions in the field of disaster relief management.	Intergraph Consulting		Maxsys Engineering Solutions	
2002	University	Memorandum Of Understanding in Engineering	Oil and National Gas Corporation Limited, Institute of Reservoir Studies		University of Calgary	
2002	University	Memorandum Of Understanding in Environment	Dr.Dharmambal Government Polytechnic for Women, Chennai	K.S.Babai	Georgian College, Barrie	John Bobbette
1998-2003	University	Boiler Emissions Upgrade Project - India	Bengal Engineering College Deemed University National Power Training Institutes at Durgapur, Nagpur, Badarpur, Neyveli, and Faridabad West Bengal Power Development Corporation Limited Central Electricity Authority, Ministry of Power Central Mechanical Engineering Research Institute Madhya Pradesh State Electricity Board		Dalhousie University	Prof. Prabir Basu
1998-2001	University	Managing Environmental Risks: An Analysis of India's Regulatory Policies and Programmes on the Use of Harmful Household Products	Harcourt Butler Technological Institute	Rakesh K. Trivedi	University of Guelph	Clive Southey
1997	University	Memorandum of Understanding, 1997, Mechanical engineering	Periyar Maniammi College of Technology for Women		Memorial University	Prof. J.J. Sharp
1994-1996	University	Waste Management for Sustainable Development in India: Policy, Planning and Administrative Dimensions	Harcourt Butler Technological Institute	Shailendra K. Awasthi	University of Guelph	Nonita T. Yap
1994-1996	University	Sustainable Development Of Mountain Environments In India And Canada	University of Delhi	Dr. R.B. Singh	University of Manitoba	Dr. F. Berkes
1994-1996	University	Role of Women in Domestic Energy Systems in Rural Areas of India	Tata Energy Research Institute (TERI)	Mr. V. Ramana	University of Waterloo	Dr. M. Chandrashekar
Unspecified	University	Multi Purpose Recycling Project	Indian Institute of Technology, Kharagpur	Dr. S. Tripathy	University of Western Ontario	Dr. Michael A. Powell
2003	College	Memorandum of Understanding on collaboration on the development education	Periyar Society	K. Veeramani	College of the North Atlantic	P. Walsh
2003-2007	College	Project INDIA - Environmental Education	Nachimuthu Polytechnic in Tamil Nadu, India		College of the North Atlantic	
2003-2007	College	Project INDIA - Environmental Engineering Technology Progams	Periyar Maniammai College of Technology for Women (Vallam, India)		College of the North Atlantic	

Source: Compiled by Science-Metrix from the Internet.

Achievements in Indian industry so far are:

- *Over 1,000 Indian industry managers, regulators and environmental consultants trained directly by Canadian trainers in 17 areas of environmental management, each a complex, technically demanding field;*
- *Over 2,500 Indian industry managers, regulators and environmental consultants subsequently trained by EMD staff using project training modules;*
- *Documented improvements in environmental performance of nearly 150 companies through CII-EMD training and advisory services;*
- *An additional 4,000 Indian managers trained in ISO 14001 using tools supplied in part by this project;*
- *Over 100 Indian companies trained by CII-EMD using project inputs have received ISO 14001 certification;*
- *Awareness of environmental management in Indian industry now much higher.*

A follow-up agreement was signed in 2003 to develop eco-efficient collaboration instruments. As part of this agreement, Canada will contribute CDN$ 9 million to India for a five-year project to support the implementation of environmentally and socially sustainable initiatives within industry and governments. The project would be implemented by the Confederation of Indian Industry's (CII) Environment Management Division in partnership with the Ministry of Environment and Forests and the Ministry of Commerce's Department of Industry Policy and Promotion[10].

Another bilateral technical education project is supported by the governments of Canada and India: the Canada-India Institute Industry Linkage Project (CIIILP)[11]. Initiated in 1999, This $8.4 million (CDN) initiative intends to enhance the efficiency and effectiveness of the technical education system in the five Indian states of Chhattisgarh, Goa, Gujarat, Madhya Pradesh and Maharashtra.. The project goals are to: 1. develop sustainable models of effective interaction and linkage between technical institutions and industry; 2. ensure sustainability and promote replication of the project initiatives; 3. promote private sector participation in human resource development issues, focusing on technical education as an entry point. The principal stakeholders are Canadian International Development Agency (CIDA), the Indian Department of Economic Affairs (DEA) and Ministry of Human Resource Development (MHRD), Directorates of Technical Education in the five Indian states, Canadian & Indian industries. The Association of Canadian Community Colleges (ACCC) serves as the executing agency.

Also worthy of interest, the College of the North Atlantic is involved in cooperative environmental programs with Indian institutions. A MoU on collaboration on the development education were signed with the Periyar Society. The Periyar Society includes the Periyar Maniammai Institute of Science and Technology (PMCTW), the Periyar Self-Respect Propaganda Institution and the Periyar Research Organisation for Bio-Technic and Ecosystem. In particular, two projects were funded in 2003 by the Association of Canadian Community Colleges (ACCC). The first four-year educational project, which involves the collaboration of College of the North Atlantic as well as Cambrian

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[10] http://www.cidaindia.org/cida-india-news4.htm, visited October 7, 2003.

[11] http://www.ciiilp.org/, visited October 7, 2003.

College (Ontario) together with Nachimuthu Polytechnic in Tamil Nadu, aims to develop an effective program review process for industry-educational institute collaboration[12]. This project also tackles technology transfer and curriculum development for several environmental courses. The second project also spans four years and aims to develop an environmental engineering technology program with the Periyar Maniammai College of Technology for Women[13].

The Indian government has also put forth initiatives and agreements such as the agreement between the Goan government and Concordia University. This MoU aims at facilitating the transfer of knowledge and technology between Indian institutions and Concordia University in the field of airport management and engineering.

In the energy sector, an MoU on Cooperation on Energy Efficiency was signed in 2003. The Canadian Industry Program for Energy Conservation (CIPEC) and the Indian Industrial Programme for Energy Conservation (IIPEC) signed the MoU with a view to developing and improving energy efficiency in India. Together, CIPEC and IIPEC will work to demonstrate the link between energy-efficient actions, enhanced productivity and competitiveness and the reduction of greenhouse gas emissions. Canada and India will share information and progress from their programs, including annual reports and energy data, and promote innovation and information exchange to advance energy-efficient approaches in industry[14].

MoU and other agreements involving universities of at least one of the two countries are also of noticeable importance and many of them also address environmental issues. India is a country facing many interesting environmental challenges which makes it an understandable partner in environmental research for many Canadian universities. The Shastri Indo-Canadian Institute (SICI), an organization with a membership that includes most of the major Canadian universities, played an important role in many of these agreements. Founded in 1968 with the participation of the Indian and Canadian governments, this organization, located in Calgary, sought to promote Canadian teaching and research on India. While originally interested in social sciences and humanities, it has expanded its field of action to multidisciplinary approaches involving the humanities and science and technology. Exchange of knowledge and technology in the field of engineering is also important, whether as part of broader environmental science exchange or on its own, such as the MoU in mechanical engineering between the Periyar Maniammi College of Technology for Women in India and Memorial University in Canada.

A Boiler Emissions Upgrade Project, led by the Consortium of Dalhousie University and Greenfield Research Incorporated with financing from the Canadian International Development Agency (CIDA) with a budget of CDN$2.6 million, started in December 1998 and will continue until December 2003. The project involves several collaborators from different sectors in India and aims

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[12] http://www.cna.nl.ca/administration/international/showproject.asp?id=26, visited January 12, 2004.

[13] http://www.cna.nl.ca/administration/international/showproject.asp?id=20, visited January 12, 2004.

[14] http://www2.nrcan.gc.ca/india-inde/mou-ee.cfm?lang=eng, visited October 7, 2003.

to assist the government and industries in India to meet the challenges of growing energy demands and the associated degradation of the environment by revitalising old polluting power plants with a fuel-flexible and environment-friendly technology, to facilitate the transfer of technology between Canadian and Indian private sector firms and to support the development of academic and research organizations in India[15].

Numerous commercial MoU and agreements have been reached between Indian and Canadian enterprises, some of which involve technological and scientific transfer. Just as in government and university MoU, environment plays a central role, more specifically in the area of waste management. With India being the second most populated country in the world, it is easy to understand its need for efficient waste-management technologies. Other areas in which agreements have been signed cover the transfer of housing technologies, biotechnologies, forensic information system technologies and disaster relief management technologies. Most of these agreements were reached during the Canada Trade Mission to India in 2002, showing a marked warming-up of the scientific and economic relations between India and Canada.

[15] http://www.dal.ca/~lpi/projects/India.htm, visited October 7, 2003.

PART III
INDIAN & CANADIAN
TECHNOLOGICAL INVENTIONS

3 Technological Inventions in India and in Canada

Table X clearly shows that there is a large difference between the number of patents in India and Canada and that both countries show growth in the number of yearly patents. India produces on average only 3.5% of the Canadian patent output with a very small amount of 1,439 patents in 13 years compared to the 41,393 Canadian patents produced during the same period. However, it is important to notice that Indian output is growing faster than Canadian output since the former grew from 1.6% of the Canadian output in 1990 to 7.8 % in 2002. This Indian growth is probably due to the fact that India changed its policies towards patent and intellectual property in 1998-1999. This shift in policy created a bigger incentive for Indians to patent their inventions[16].

Table X Number of USPTO patents and share of total USPTO patents of Canada and India, 1990-2002

Year	Total Canadian inventions	% of total USPTO	Total Indian inventions	% of total USPTO	Total USPTO inventions
1990	2,193	2.21%	36	0.04%	99,197
1991	2,438	2.29%	33	0.03%	106,266
1992	2,359	2.20%	43	0.04%	107,035
1993	2,404	2.20%	41	0.04%	109,361
1994	2,553	2.25%	41	0.04%	113,235
1995	2,587	2.28%	64	0.06%	113,552
1996	2,830	2.34%	62	0.05%	121,135
1997	3,064	2.48%	73	0.06%	123,572
1998	3,831	2.36%	130	0.08%	162,218
1999	4,001	2.38%	156	0.09%	168,017
2000	4,301	2.46%	184	0.11%	174,821
2001	4,465	2.44%	234	0.13%	182,858
2002	4,367	2.38%	342	0.19%	183,538
Grand Total	41,393	2.35%	1,439	0.08%	1,764,805

Source: Compiled by Science-Metrix from the USPTO database.

Although Indians increased their patent output, Table XI clearly shows that they still have a huge deficit in terms of intellectual property (IP). Their global net flow of IP is -33.3%, meaning that a third of Indian patented inventions are the property of non-Indian interests. This demonstrates a clear "technological outflows". This deficit flow of IP reached its zenith in 1993 with -60.7% and was at its smallest in 1997 with -23.0%. As for Canada, its global net flow of IP is negative too, but on a smaller scale at around -8.0%. Its worst year was in 1996 with -10.7%, and its best year was in 2001 with -6.1%.

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[16] Ramanna, Anitha, "Policy Implications of India's Patent Reforms: Patent Applications in the Post-1995 Era", Economic and Political Weekly, May 25, 2002, p. 2065.

Table XI Number of inventions, intellectual property (IP) and net flow of IP for Canada and India, 1990-2001

Year	Canada			India		
	Inventions	IP	Net Flow of IP	Inventions	IP	Net Flow of IP
1990	2,193	1,934	-8.0%	36	19	-29.4%
1991	2,438	2,142	-7.4%	33	14	-36.2%
1992	2,359	2,068	-8.3%	43	12	-58.4%
1993	2,404	2,058	-9.3%	41	13	-60.7%
1994	2,553	2,220	-8.5%	41	19	-37.2%
1995	2,587	2,244	-9.0%	64	26	-42.2%
1996	2,830	2,383	-10.7%	62	28	-35.7%
1997	3,064	2,571	-10.1%	73	42	-23.0%
1998	3,831	3,297	-7.9%	130	72	-28.7%
1999	4,001	3,474	-6.7%	156	89	-28.6%
2000	4,301	3,712	-6.4%	184	100	-34.1%
2001	4,465	3,857	-6.1%	234	141	-29.5%
Grand Total	41,393	35,686	-8.0%	1,439	789	-33.3%

Source: Compiled by Science-Metrix from the USPTO database.

International collaboration in patenting practices between India and Canada is fairly rare. In fact, only eleven patents in the USPTO patent database show at least one Canadian and one Indian inventor. Table XII presents an information summary of the patents invented in collaboration. No clear trend can be observed due to the diversity of subjects covered and the small number of patents produced in collaboration.

Table XII Canada-India patents information summary, 1990-2002

4933052	Title:	Process for the preparation of continuous bilayer electronically-conductive polymer films
	Inventors:	O'Brien; Robert N. (Victoria, CA) and Santhanam; Kalathur S. V. (Bombay, IN)
	Assignee:	University of Victoria (CA)
5051157	Title:	Spacer for an electrochemical apparatus
	Inventors:	O'Brien; Robert N. (Victoria, CA) and Santhanam; Kalathur S. V. (Bombay, IN)
	Assignee:	University of Victoria (Victoria, CA)
5415638	Title:	Safety syringe needle device with interchangeable and retractable needle platform
	Inventors:	Novacek; Laurel A. (Vancouver, CA); Sharp; Fraser R. (Vancouver, CA); McLean; Donald A. (Vancouver, CA)
	Assignee:	Inviro Medical Devices, Ltd. (Bridgetown, Barbados, IN)
5428011	Title:	Pharmaceutical preparations for inhibiting tumours associated with prostate adenocarcinoma
	Inventors:	Sheth; Anil R. (Bombay, IN); Garde; Seema (Bombay, IN); Panchal; Chandra J. (Lambeth, CA)
	Assignee:	Procyon Biopharma, Inc. (CA)
5798523	Title:	Irradiating apparatus using a scanning light source for photodynamic treatment
	Inventors:	Villeneuve; Luc (Montreal, CA); Miller; Gerard (Dorval, CA); Bernier; Robert (Dorval, CA); Laurendeau; Claude (Boucherville, CA); Pal; Prabir Kumar (Calcutta, IN)
	Assignee:	Theratechnologies Inc. (Montreal, CA)
5900145	Title:	Liquid crystal stationary phases for chromatography
	Inventors:	Naikwadi; Krishnat P. (Sydney, CA); Wadgaonkar; Prakash P. (Pune, IN)
	Assignee:	J & K Environmental Ltd. (Sydney, CA)
5956252	Title:	Method and apparatus for an integrated circuit that is reconfigurable based on testing results
	Inventors:	Lau; Lee K. (Don Mills, CA); Bicevskis; Robert P. (Richmond Hill, CA)
	Assignee:	ATI International (IN)
6084373	Title	Reconfigurable modular joint and robots produced therefrom
	Inventors:	Goldenberg; Andrew A. (Toronto, CA); Kircanski; Nenad (North York, CA); Kircanski; Manja (North York, CA); Seshan; Ananth (Pune, IN)
	Assignee:	Engineering Services Inc. (Toronto, CA)
6208620	Title	TCP-aware agent sublayer (TAS) for robust TCP over wireless
	Inventors:	Sen; Sanjoy (Plano, TX); Joshi; Atul Suresh (Maharashtra, IN); Kumar; Apurva (Lucknow, IN); Umesh; M. N. (Kerela, IN)
	Assignee:	Nortel Networks Corporation (Montreal, CA)
6291598	Title	Process for the production of a polymerized material and the product produced thereby
	Inventors:	Williams; Michael C. (4736 - 151 Street, Edmonton, Alberta, CA); Li; Nai-Hong (3608 - 117 B Street, Edmonton, Alberta, CA); Sankholkar; Yatin (B-24 T, Off Veer Savarkarmarg, Prabhadevi, Bombay 400 025, IN)
	Assignee:	NULL
6458590	Title	Methods and compositions for treatment of restenosis
	Inventors:	Mukherjee; Anil B. (Brookeville, MD); Kundu; Gopal C. (Maharashtra, IN); Panda; Dibyendu K. (Montreal, CA)
	Assignee:	The United States of America, as represented by the Department of Health

Source: Compiled by Science-Metrix from the USPTO database.

Conclusion

Although India is thought to be a part of the developing world, its scientific output is surprisingly high. A scientometric analysis shows that, since its revolution, India managed to implement a strong scientific community, making it the only developing nation present among the top fifteen most important scientific producers. Indian science specializes principally in physics, chemistry and engineering, but does not publish in mainstream international journals that are highly cited. Since India is the second most populated country in the world, millions of Indian students embark on higher education studies, producing more PhD per capita than any other country in the world[17], thus making India a very appealing place with which to create scientific collaboration links. Canada should take advantage of this fact. Since the two countries are clearly embarking on a period of warm relations with each other (as shown by the recent increase in the number of MoUs signed between the two countries), Canada is in an excellent position for collaborating with India. Canada already collaborates with India in many different sectors, notably physics and engineering, and scientometric data also show that Canada has complementariness with India in these scientific fields (physics, engineering & technology and also chemistry) due to both countries' tradition of quality scientific production in those fields. This complementariness could translate into a higher rate of publication for Canadian scientists and a greater scientific impact for Indian ones, making them logical scientific partners.

As for its technology production, India's late nineties shift in patenting policy makes India a more appealing place to develop new technologies and processes. This is clearly shown by the fact that Indian patenting, although very small right now, is on an explosive trajectory. Many big international corporations, like Microsoft[18], have decided to establish a branch in India, taking advantage of the country's high number of qualified workers and scientists. Canada should continue to promote collaboration between Indian and Canadian enterprises, since many Canadian companies could profit from the large Indian market and workforce, and India in turn could profit from Canadian expertise in many fields such as geomatics or environmental management.

In brief, even if there are important differences between India and Canada in terms of scientific and technological production, both countries could profit from intensified collaboration.

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[17] http://www.educationindia-online.com/ei/student/ov.asp, visited on October 9, 2003.

[18] Microsoft press release, "Microsoft opens new product development center in India", Hyderabad, India, March 8, 1999.