Bibliometric analysis of Korean scientific and technological activities and collaboration with Canada

Final Report

Prepared for the
Department of Foreign Affairs and International Trade, Canada

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31 March 1997

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Executive summary

This report contains three parts. Part 1 presents an overview of the evolution of the Republic of Korea scientific and technological (S-T) papers and patents (1980-1995) and a more detailed analysis of the recent evolution (1991-1995). Part 2 analyses the scientific collaboration of Korea with other countries while Part 3 focuses on the collaboration with Canada. This report uses the metric system and Korea, Korean and South Korea refer to the Republic of Korea.

- Between 1980 and 1995, the number of scientific papers by authors from the Republic of Korea grew at 23% per year meaning that the number doubled every 3,4 years. During that period, the number of U.S. patents granted to South Korean inventors grew at 39% per year and the number of patents doubled every 2,1 years.
- *Given these trends and those observed for Canada, the level of U.S. patents granted to Korean inventors will equal that of Canada in 1997 while the number of scientific papers will reach the same level by 2006.*
- The scientific production of South Korea emphasises papers in the fields of engineering and technology, chemistry and physics. By comparison, Canada emphasises the fields of earth and space, biology and mathematics.
- In the domains of invention and technology, as measured by patent data, South Korea concentrates her activities in information and communication technology and this could be turned into a competitive advantage in the growing multimedia sector. The sectors emphasised by South Korea comprise radio and television, electrical components as well as communication equipment. By comparison, Canada emphasises industrial machinery as well as motor vehicles and equipment.
- *All those trends considered, the Republic of Korea should be able to reach her target to enter the G7 of leading countries in science and technology in the early 21st. century.*
- Canada occupies rank 9 and accounts for 2,5 % of all scientific collaborations with Korea. This percentage is lower than the 4,2 % share of scientific papers by Canada in the SCI database between 1991 and 1995. The rate of growth of collaboration between Canada and Korea is the lowest among the most important collaborating countries.
- The collaboration between Canada and South Korea is more concentrated in the fields of earth and space, clinical medicine and, to a lesser extent, biomedical research and chemistry. If we exclude a series of 27 papers in the field of high energy physics (project HERA), there is no real pattern of sustained growth in the period 1991-1995, except in clinical medicine.
- *Given these trends, Canada is likely to become one of the more marginal collaborators of Korea.*

Introduction

This report contains three parts. Part 1 presents an overview of the evolution of South Korea scientific and technological (S-T) papers and patents (1980-1995) and a more detailed analysis of the recent evolution (1991-1995). Part 2 analyses the scientific collaboration of South Korea with other countries while Part 3 focuses on the collaboration with Canada.

In Part 1, the time-series of the scientific papers and U.S. patents granted to South Korean inventors show exponential growth patterns. This is an indication that South Korean S-T has "taken-off". The data show that Korean scientific activities can be decomposed in two subsystems, with four disciplines in each one. The core disciplines in terms of the quantity of papers are: chemistry; physics; engineering and technology; clinical medicine. The peripheral disciplines are: biomedical research, biology, earth and space, and mathematics. The index of specialisation reveals that, relative to world average, South Korea puts more emphasis on engineering and technology, chemistry, and physics.

Part 2 analyses the patterns of scientific collaboration of South Korea. The analysis reveals the presence of a two-tier system, with a group of countries that can be considered as the core group of collaborators of South Korea while a second group is composed of her peripheral collaborators. Canada is the ninth collaborators of South Korea in term of the frequency of collaborative papers between 1991 and 1995. This rate is consistent with Canada's world share of scientific papers. It is important to note that within the countries in the core group of collaborators that displayed a significant rate of exponential growth in their collaborations with South Korea, Canada has the lowest growth factor. If these trends do not change, Canada is bound to slip behind other countries in the core group of collaborators of South Korea.

Finally, Part 3 considers the patterns of scientific collaboration between Canada and South Korea. The exponential growth in collaboration between Canada and South Korea is due to the growth of the activity in physics, and this level of activity is mainly due to the presence of these two countries in the HERA large scale project in high energy physics. The rate of collaboration in engineering and technology, the second most important discipline during the period, appears to be lowering over time. Collaborations in chemistry started well in 1992 but fell abruptly in 1995.

Sources of data

The bibliometric data on scientific activity were extracted from the Science Citation Index (SCI) database on CD-ROM (Institute for Scientific Information). Among the many different databases accessible to locate scientific publications, the SCI is one of the few that contain the address of all authors of a given publication; most other databases list only the addresses of the first author. This factor explains why the SCI is widely used for bibliometric studies of scientific collaboration between countries. This database — like all others for that matter — do not survey all the world scientific journals, but only about 3500 journals considered as the most important and influential. This number varies over the years to take into account new journals, disappearing ones and the fact that some may have become less important in their field. Papers published in journals not covered are thus 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 accepts that the probability of having a really influential journal not covered by SCI is low, and that we are less interested in knowing the exact number of total articles than in establishing trends in international collaboration.

The study also uses patent data from the U.S. VISIITT (Opus Publications & Chadwick-Healey) and CASSIS (U.S. Patent and Trademark Office) databases on CD-ROM as well as data from the National Science Foundation's Science and Engineering Indicators (SEI). Patent data from the U.S. are a common, albeit imperfect, indicator of technological capability. Patents should be seen as indicators of inventive capability. Many inventions and many patents are never developed and used on a large scale, hence a patent cannot be considered as a reliable indicator of innovative capability. Despite this caveat, patent data in the U.S. are useful to identify the more creative institutions as well as the domains of specialisation of a given country.

Part 1
Scientific and technological production of South Korea

This part analyses the scientific and technological production of South Korea. A first section analyses the rate of growth between 1980 and 1995 of scientific papers in the SCI database and the number of patents granted by the U.S. to South Korean inventors. A second section analyses the scientific output by discipline as well as the technological sectors where South Korea has put more emphasis between 1991 and 1995. Finally, the third section presents the leading Korean scientific and technological institutions.

1. Evolution of South Korean science and technology 1980-1995

Figure 1 shows the rapid growth of the world share of scientific papers by Korean scientists since the beginning of the 1980s while Figure 2 shows the Korean share of U.S. patents granted to foreign inventors. The observed rates of growth are coherent with Korean S&T policy of strong commitment to raising investments in basic research and increasing R&D expenditures. For example, between 1993 to 1995, the Government doubled its investment in basic research at universities, that is, from 581 U.S. millions to 1 073 U.S. millions dollars. It is expected to be at the level of 4 500 U.S. millions dollars by year 2001 (MOST, 1996: 31). In terms of R&D expenditures, Korea's has moved from 0,7% of GDP in 1980 to about 2,3% in 1994 thereby joining countries like Germany (OECD, 1996: 141). This annual growth rate of 20% is similar to that of the South Korean scientific papers for the same period, which is 23%. The annual rate of growth of the U.S. patents granted to South Korean inventors is higher, at 39%. Given these trends, the number of scientific papers doubles every 3,4 years while the number of U.S. patents given to Korean inventors doubles every 2,1 years (see Figure 3). If we project these trends and those of Canada, one sees that Korean production of scientific papers will equal that of Canada in year 2006 while South Korea will obtain as much patents in the U.S. as Canada in 1997 (Figures 1 and 2). This shows that South Korea is catching up more rapidly in technology, which is consistent with the findings on the specialisation of South Korea by disciplines where it is shown to specialise in chemistry and engineering.

Figure 1 Evolution of world share of scientific papers by Korean and Canadian scientists

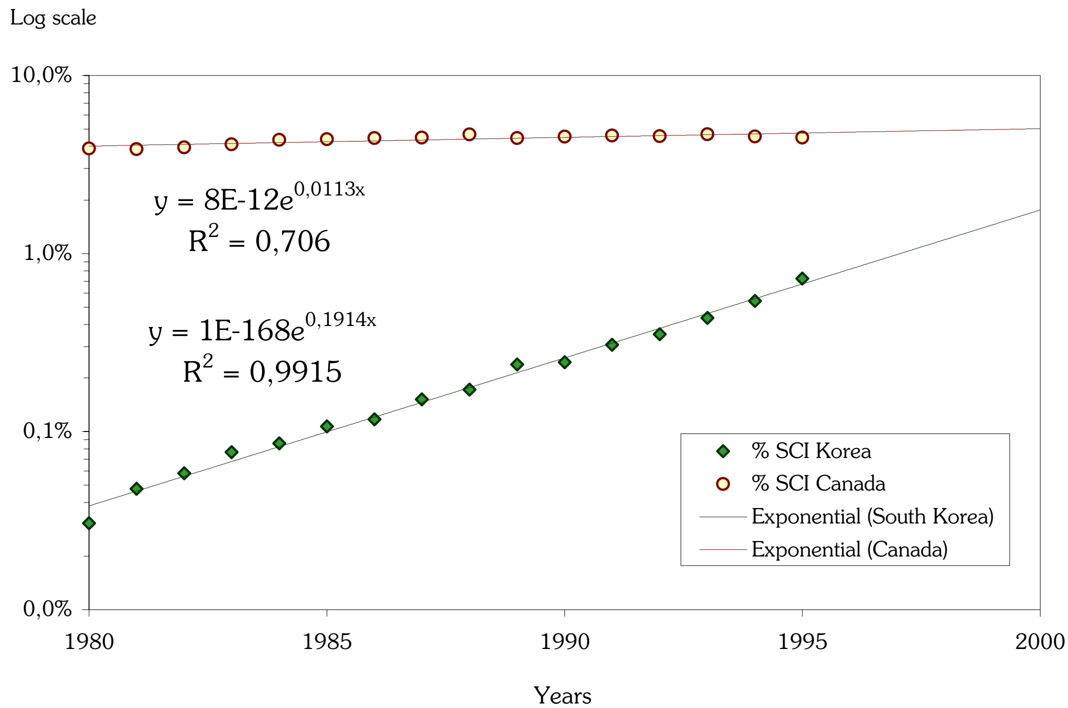
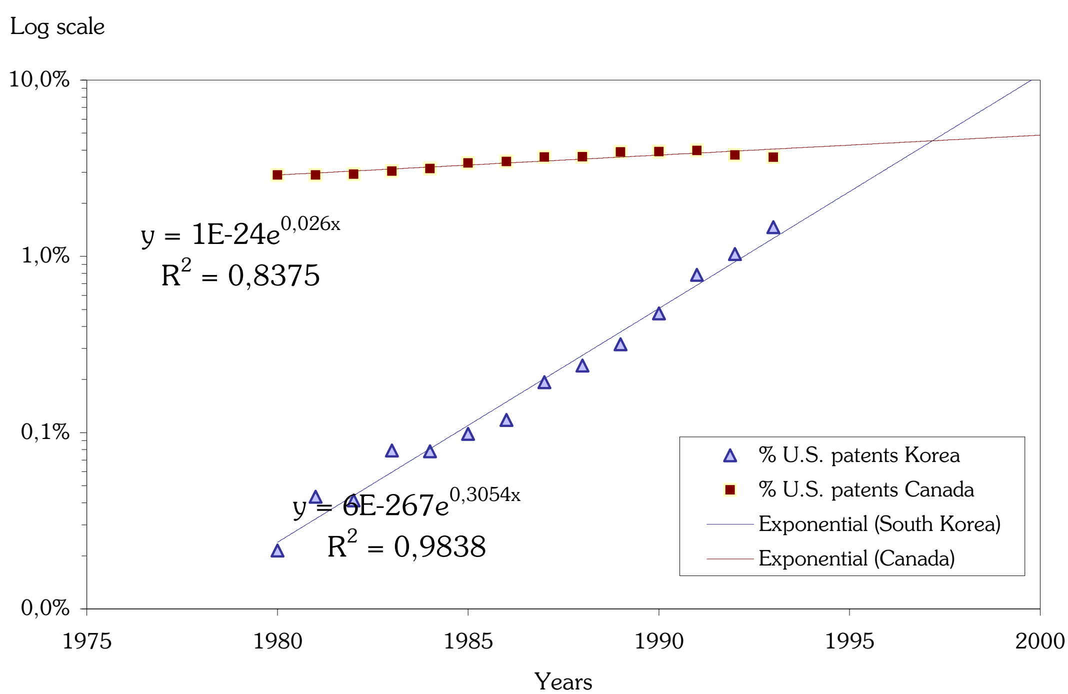


Figure 2 Evolution of Korean and Canadian share of U.S. patents granted to foreign inventors



Source: Calculated by CIRST-UQAM & INRS using data from Science Citation Index (1991-1995) and from Science & Engineering Indicators (1996)

Figure 3 Exponential growth of scientific papers and U.S. patents from South Korea 1980-1995

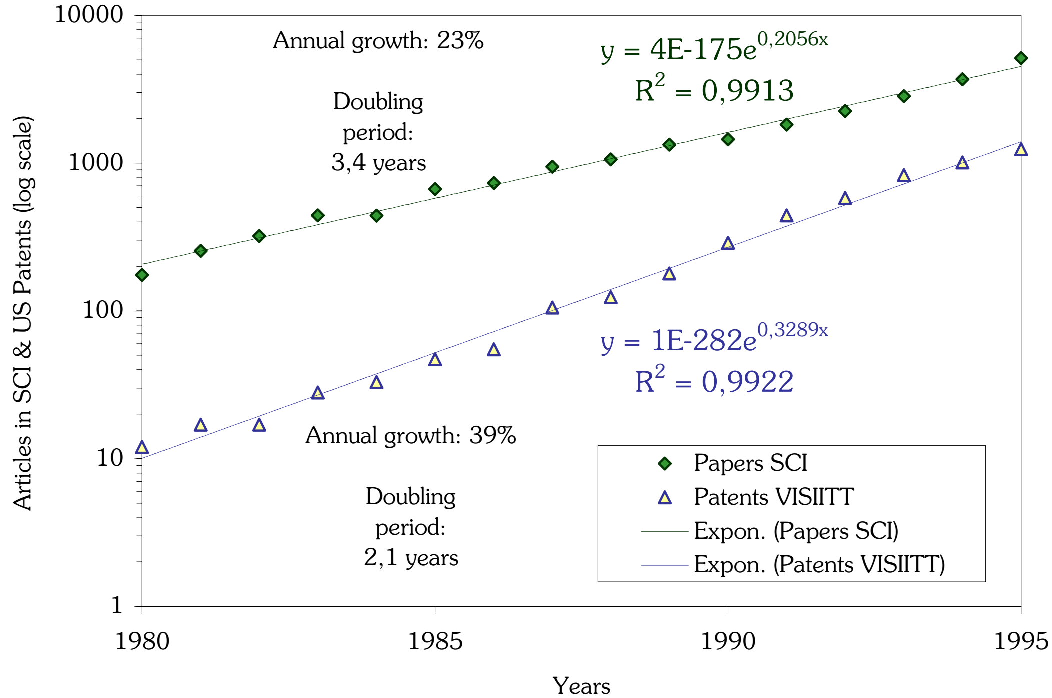
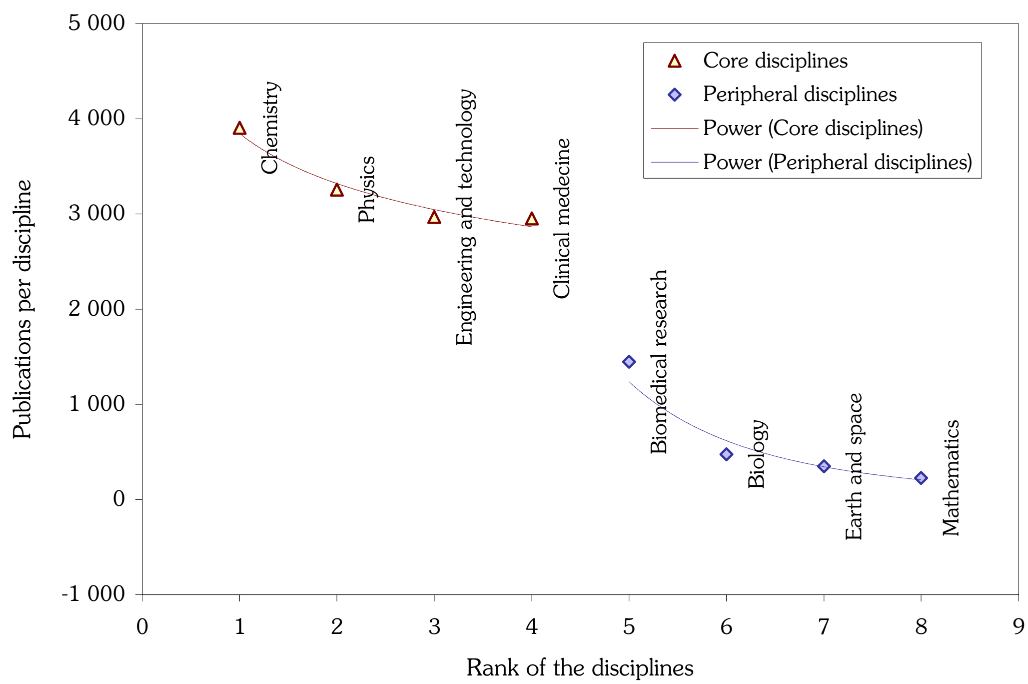


Figure 4 Distributions of South Korean scientific publications by discipline 1991-1995



Source: Calculated by CIRST-UQAM & INRS using data from VISITT (1969-1995) and Science Citation Index (1991-1995)

Assuming that the current rates of growth are sustained over a few years, South Korea will be in the group of leading S-T nations very soon. The high rate of exponential growth and the high level of correlation of these regressions suggest that South Korean science and technology has "taken-off"[1]. Given these trends, Korea is highly likely to reach its aim "to reach the level of the G-7 countries in science and technology by the early 21st century" (MOST, 1996: 14).

2. Scientific and technological fields of specialisation of South Korea

Figure 4 shows that South Korean scientific activities can be decomposed in two subsystems, with four disciplines in each one[2]. In terms of quantity of papers, the core disciplines are chemistry, physics, engineering and technology, and clinical medicine whereas South Korea has lower levels of activities in biomedical research, biology, earth and space, and mathematics.

Table 1 is divided in two parts: A- Scientific production of South Korea by discipline 1991-1995; B- Index of specialisation of South Korea 1991-1995. The index of specialisation is a measure of the relative presence in each discipline as compared to the world average. An index value that is less than one indicates a weaker emphasis on a discipline than the world average for that field and an index above one, a stronger emphasis on a discipline than the world average for that field. This index thus indicates the fields of specialisation of a country. It is important to note that this is not an index of quality but an indicator of specialisation or concentration in various disciplines.

Table 1-A reveals the sustained growth of every discipline in South Korea - with the exception of a small drop in the field of mathematics between 1994 and 1995, growth is sustained for all disciplines and for every year. Table 1-B reveals that Korea puts a strong emphasis on engineering and technology as well as on chemistry. However, one must note

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1 See Rostow (1960) for a study on the growth of nations and Foster (1986) for a study on the growth of innovative firms.

2 Each of these subsystems can be represented by a statistically significant ($\alpha<0,05$) hyperbolic regression curve. The rupture is statistically significant (since F = 49,65 and $F_{0,99}$ (2,4) = 18) when tested with a generalised Chow test of structural change or test of differential regressions (Archambault, 1996: 56; Johnston, 1984: 207, 219).

that the index of specialisation dimishes over time in both disciplines, probably due to a diversification of her investments in a broader range of disciplines. Korea also puts a strong emphasis on physics and there is an upward trend in this discipline. A weaker emphasis is placed on biology, biomedical research, clinical medicine as well as on earth and space.

Table 1 Evolution of scientific production and index of specialisation of South Korea by discipline

A- Scientific production of South Korea by discipline 1991-1995

Disciplines	1991	1992	1993	1994	1995	Total
Biology	67	74	79	85	116	421
Biomedical research	147	193	237	325	379	1 281
Chemistry	478	565	677	826	910	3 456
Clinical medicine	340	356	458	561	899	2 614
Earth and space	29	58	57	81	83	308
Engineering & tech.	391	419	515	615	688	2 628
Mathematics	24	39	40	50	48	201
Physics	340	382	544	690	927	2 883
Total 8 disciplines	1 816	2 086	2 607	3 233	4 050	13 792
Unknown, multidisciplinary	89	113	349	561	674	1 786
Grand total	1 905	2 199	2 956	3 794	4 724	15 578

B- Index of specialisation of South Korea 1991-1995

Disciplines	1991	1992	1993	1994	1995	1991-1995
Biology	0,55	0,53	0,45	0,39	0,43	0,46
Biomedical research	0,44	0,50	0,49	0,54	0,51	0,50
Chemistry	2,14	2,20	2,11	2,08	1,83	**2,04**
Clinical medicine	0,50	0,45	0,47	0,46	0,59	0,50
Earth and space	0,36	0,63	0,49	0,57	0,46	0,50
Engineering & tech.	3,04	2,84	2,79	2,68	2,40	**2,69**
Mathematics	0,86	1,21	1,00	1,00	0,77	0,95
Physics	1,60	1,56	1,78	1,82	1,96	**1,79**

Source: Calculated by CIRST-UQAM & INRS using data from Science Citation Index (1991-1995)

Table 2 shows the number of papers, their percentage and the index of specialisation for South Korea and for Canada. Although the rate of growth of South Korea is rapid, one can see that between 1991 and 1995 the total number of papers for these eight disciplines is about ten times greater in the case of Canada. South Korean and Canadian science are complementary since these countries do not emphasise the same fields. The ratio of the percentage, or of that of the index of specialisation, of the Korean articles by disciplines to that of Canadian articles provides a synthetic figure that allows a comparison of the domains of specialisation of both countries. When the value of the ratio is higher than one, then South Korea is more specialised than Canada in a discipline and, conversely, a score lower than one signifies that Canada is more specialised in that field. This ratio reveals that, relative to Canada's pattern of specialisation, Korea emphasises papers in chemistry nearly three times as much as Canada, albeit, as noted before, there is a downward trend in the level of emphasis on chemistry in South Korea (analytical, applied, general, inorganic and nuclear, and physical chemistry as well as polymers). Again this is probably due to a diversification of her investments in a broader range of disciplines. South Korea also emphasises articles in the fields of physics as well as engineering and technology (chemical, civil, electrical and electronic, general, industrial as well as mechanical engineering; aerospace, computers, information science, metal and metallurgy, material science, nuclear technology and operational research).

Table 2 Level of production per discipline, percentage and index of specialisation for South Korea and Canada 1991-1995

Countries	Korea			Canada			
Disciplines	Articles	Per cent	Index of specialisation	Articles	Per cent	Index of specialisation	Ratio %Korea/ %Canada
Biology	421	3%	0,46	14 412	11%	**1,60**	0,28
Biomedical res.	1 281	9%	0,50	25 450	19%	1,02	0,49
Chemistry	3 456	25%	**2,04**	11 483	9%	0,69	**2,94**
Clinical medicine	2 614	19%	0,50	46 579	35%	0,92	0,55
Earth and space	308	2,23%	0,50	10 238	8%	**1,72**	0,29
Engineer. & tech.	2 628	19%	**2,69**	11 548	9%	**1,21**	**2,22**
Mathematics	201	1,46%	0,95	2 687	2%	**1,30**	0,73
Physics	2 883	21%	**1,79**	12 110	9%	0,77	**2,32**
Total 8 disciplines	13 792	100%		134 507	100%		

Source: Calculated by CIRST-UQAM & INRS using data from Science Citation Index (1991-1995)

However, the emphasis on mathematics is slightly higher in Canada. The percentage of articles in biomedical research and in clinical medicine is about twice as high in Canada. Finally, Canada emphasises articles in biology and earth and space about four times as much as South Korea. In order words, South Korea is more oriented towards technology and chemistry whereas Canada is more oriented than South Korea towards health and life sciences.

Table 3 presents the patent classes most emphasised by South Korean inventors patenting in the U.S. for patents granted in 1993[3]. A plot on a doubly logarithmic scale reveals that this dataset is composed of three subgroups, the ruptures being represented by a line in Table 3. The evidence shows that many fields in which South Korea put more emphasis can be brought under either of the “multimedia” or the “information and communication technologies” umbrellas. For example, South Korea has many patents in pictorial communication and television, magnetic and static information storage or retrieval, semiconductor device manufacturing (process) and electrical audio signal processing systems and devices. Albeit at a lower level, South Korea is also active in telephonic communications, coded data generation, active solid state devices such as transistors, electrical transmission or interconnection systems and recorders. Finally, there is a noteworthy emphasis on telecommunications, sheet feeding or delivering (useful for printers and photocopiers), image analysis, superconductor technology, optic systems and elements including communication, and cryptography. All these patents are signs of the build up of a strong technological capability in fields that have grown steadily in the G7 countries since the mid-1980s and which are expected to constitute the enabling technologies of the future.

Using patent data from the U.S., Choung (1995: 25) provided an index of specialisation for South Korea using 34 standard industrial classes. His analysis reveals that, during the period 1990-1992, the South Korean specialised highly in semiconductors (index of 4,59 which is how many times more patents in this fields that Korea receives compared to the world share). This is followed by the image and sound class (4,22) and at some length by electrical devices and systems (2,30) and by general, non-electrical, industrial equipment (2,25). South Korea is also notably specialised in the calculators, computers and other office equipment class (1,46), that of telecommunications (1,18) and that of assembling and material handling apparatus (1,10).

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3 Listing is limited to Patent and Trademark Office classes that have received at least 200 patents from all countries in 1993.

Table 3 Patent classes most emphasised by inventors from South Korea patenting in the U.S.

Title	Index of specialisation
Electric lamp and discharge devices	12,58
Pictorial communication; television	7,40
Dynamic magnetic information storage or retrieval	6,64
Refrigeration	5,86
Semiconductor device manufacturing: process	5,56
Static Information storage and retrieval	5,15
Electric lamp and discharge devices: systems	5,08
Electrical audio signal processing systems and devices	4,47
Telephonic communications	3,50
Electricity: motive power systems	3,27
Coded data generation or conversion	3,14
Winding and reeling	2,76
Dynamic information storage or retrieval	2,54
Active solid state devices (e.g., transistors, solid state)	2,50
Electrical transmission or interconnection systems	2,44
Recorders	2,28
Synthetic resins or natural rubbers – part of the class 520 series	2,26
Metal fusion bonding	2,25
Telecommunications	2,16
Sheet feeding or delivering	2,12
Electric heating	1,80
Image analysis	1,77
Music	1,59
Superconductor technology: apparatus, material, process	1,58
Optics: systems (including communication) and element	1,52
Coating apparatus	1,29
Synthetic resins or natural rubbers – part of the class 520 series	1,22
Cryptography	1,17
Organic compounds – part of the class 532-570 series	1,15
Adhesive bonding and miscellaneous chemical manufacture	1,13
Typewriting machines	1,10
Organic compounds – part of the class 532-570 series	1,08
Pumps	0,99
Amusement devices: games	0,97
Machine element or mechanism	0,97
Error detection/correction and fault detection/recover	0,95
Electricity: electrical systems and devices	0,94
Heat exchange	0,91
Food or edible material: processes, compositions, and products	0,90
Pulse or digital communications	0,84
Organic compounds – part of the class 532-570 series	0,77
Photocopying	0,75
Compositions: ceramic	0,75
Chemistry: electrical current producing apparatus, product, and process	0,75
Photography	0,74
Conveyors: power-driven	0,71
Chemical apparatus and process disinfecting, deodorizing, preserving, or sterilizing	0,67
Chemistry: electrical and wave energy	0,61
Specialized metallurgical processes	0,57
Surgery	0,56
Synthetic resins or natural rubbers – part of the class 520 series	0,56
Electrical generator or motor structure	0,54

Source: Science & Engineering Indicators (1996) Appendix table 6-12.

Table 4 shows that within a group of six strategic technological fields (about a quarter of the US patents for the period), South Korean inventors are emphasising patents in radio and television technologies as well as in electrical components and communication equipment. Given the tendency towards the integration of computers, telecommunications and audiovisuals technologies, that is, the rise of multimedia technologies, South Korea appears to be preparing well for the future, albeit, it is only marginally more specialised than Canada in the computer field. Similarly, Choung (1995: 19) found that, between 1990 and 1992, large numbers of patents were granted to South Korea in the fields of television and facsimile, semiconductors, calculators, computers, data processing systems, telecommunications equipment as well as electrical and electronic instruments. Choung (1995: 24) suggested that the level of emphasis on image and sound equipment was rising as well as that in the fields of semiconductors, calculators, computers and other office equipment. However, this author observed a falling level of emphasis in telecommunications.

Table 4 Number of patents in the U.S., percentage and index of specialisation in six strategic technological fields. South-Korea and Canada 1980-1993

Sectors	World*	Per cent	South Korea	Per cent	Index spec.	Canada	Per cent	Index spec.
Radio and television	12 562	5%	159	13%	**2,7**	122	3%	0,6
Computers	38 445	14%	144	11%	0,8	331	8%	0,6
Industrial machinery	51 464	19%	130	10%	0,5	1 082	26%	**1,4**
Aircraft and parts	11 800	4%	13	1%	0,2	154	4%	0,8
Motor vehicle & equip	22 618	8%	36	3%	0,3	458	11%	**1,3**
Electrical compon. and communication equip.	129 638	49%	781	62%	**1,3**	1 980	48%	1,0
Total 6 sectors	266 528	100%	1 263	100%		4 126	100%	

*Sum of patents from Asia, North and South America, European Union.

Source: Calculated by CIRST-UQAM & INRS using data from Science & Engineering Indicators (1996)

All these data essentially confirm the suggestion that South Korea seems to be concentrating in the field of information and communication technologies. It is interesting to note that despite a strong emphasis on chemistry in the scientific papers, and despite the strategic role of patenting in the chemical industry, the emphasis of South Korea in patents do not comprise the chemical sector. This might be due to her willingness to abandon the smokestack industries in favour of the more information intensive ones.

3. Leading scientific and technological institutions in South Korea

A graphical analysis on doubly logarithmic scale revealed that South Korean institutions have three levels of production. Table 5 shows the number of scientific papers published by institutions in the two most productive tiers. These account for around 85% of the total number of articles per discipline. The number of papers per institution is greater than the total number of papers since many papers are counted more than once when they comprise more than one institution. Clearly, the National University in Seoul and the Korean Advanced Institute for Science and Technology (KAIST) are the two most important sources of Korean scientific papers and are followed by the Pohang University of Science and Technology (POSTECH) and Yonsei University. The vast majority of the leading scientific institutions are universities. Nonetheless, there are also two chaebol (Samsung #24 and Lucky Goldstar #29) which shows that these companies behave like other multinational entreprises. This strong linkage between science and technology can be seen as another sign of the take-off of the South Korean industrial structure.

Table 6 presents the index of specialisation of these institutions. Again, this is obtained by dividing the percentage of articles by an institution in a given discipline by the percentage of the world share in that discipline. A figure higher than one denotes a strong emphasis whereas one lower than one denotes a weaker emphasis on a discipline. Generally, most universities put a stronger emphasis on applied and physical sciences (engineering, chemistry and physics) and a weaker emphasis on life and natural sciences (medicine, biology, earth and space) and mathematics. In contrast, Seoul National University's research activities are more evenly distributed among the eight fields. There seems to be no strong institution devoted to biomedical research or biology. When one considers the index of specialisation and the number of papers, mathematics is important at four universities (Kyungpook National University; Korea University; Pusan National University; Postech) and, similarly, clinical medicine is concentrated in three university hospitals (Catholic University Seoul; Seoul National University Hospital; the University of Ulsan's ASAN Medical Centre).

Established in 1971 to train postgraduate students and to carry out advanced research project (MOST, 1996: 33; Embassy of Canada, Seoul, 1994: 32-3), KAIST is strongly oriented toward engineering, though present in chemistry and physics. The presence of other governmental organisations is also noteworthy. These include the Korean Institute of

Science and Technology (KIST) which is devoted to large scale national projects and applied research, this is corroborated by the high level of emphasis of KIST in engineering, chemistry and physics (see institution #7 in Table 6). The Korea Research Institute of Standards and Science (KRISS) is specialised in physics as well as engineering and technology as one would expect since it incorporates the KAO or Korea Astronomy Observatory (Embassy of Canada, Seoul, 1994: 32 *ff*.).

Table 5

Number of scientific articles by discipline for most productive institutions in South-Korea 1991-1995

	Institutions	Total*	Chemistry	Physics	Engineering & techno.	Clinical medecine	Biomedical research	Biology	Earth & space	Maths
1	SEOUL-NATL-UNIV	3 523	593	674	389	784	442	108	66	40
2	KAIST	3 411	864	742	1 043	79	304	17	26	21
3	POHANG-UNIV-SCI-&-TECHNOL-POSTECH	1 229	335	349	313	17	78	9	0	25
4	YONSEI-UNIV	1 209	130	186	112	491	104	16	25	14
5	KOREA-UNIV	593	135	178	41	63	25	18	15	13
6	PUSAN-NATL-UNIV	553	230	55	70	56	28	9	25	11
7	KIST	476	129	99	89	19	77	19	1	4
8	KYUNGPOOK-NATL-UNIV	406	132	42	45	44	44	13	4	11
9	KOREA-RES-INST-STAND-&-SCI	388	64	176	60	2	5	4	25	0
10	CHONBUK-NATL-UNIV	381	53	92	34	66	53	7	6	0
11	CHUNGNAM-NATL-UNIV	378	129	48	43	43	40	18	28	4
12	CHONNAM-NATL-UNIV	375	75	62	45	74	27	23	9	4
13	HANYANG-UNIV	358	70	50	66	69	30	6	4	0
14	UNIV-ULSAN (ASAN Med Ctr)	332	31	18	17	210	31	2	2	1
15	KAERI	331	36	53	130	56	9	4	3	3
16	CATHOLIC-UNIV-SEOUL	324	1	2	1	277	20	0	0	0
17	KYUNG-HEE-UNIV	305	41	69	16	90	24	5	5	2
18	GYEONGSANG-NATL-UNIV	290	63	61	10	51	40	23	1	2
19	INHA-UNIV	285	127	37	27	14	16	2	4	5
20	ELECTR-&-TELECOMMUN-RES-INST	280	30	143	65	1	0	0	0	2
21	KOREA-RES-INST-CHEM-TECHNOL	277	202	18	9	11	21	3	1	0
22	SOGANG-UNIV	277	100	81	24	0	1	1	4	2
23	CHUNGBUK-NATL-UNIV	256	68	48	22	29	26	9	9	1
24	SAMSUNG	223	18	64	73	24	1	1	0	1
25	KANGWEON-NATL-UNIV	215	61	52	13	7	24	13	3	1
26	SEOUL-NATL-UNIV-HOSP	210	1	0	0	186	11	1	1	0
27	EWHA-WOMANS-UNIV	209	63	48	5	25	18	4	3	3
28	SUNG-KYUN-KWAN-UNIV	206	84	45	25	7	11	5	0	8
29	GOLDSTAR	204	51	61	38	8	20	1	0	0
30	YEUNGNAM-UNIV	186	82	12	34	15	14	10	1	3
31	WONKWANG-UNIV	180	32	46	7	48	20	6	1	1
32	AJOU-UNIV	165	35	43	26	21	9	1	2	2
33	KWANGWOON-UNIV	157	17	98	32	0	2	0	0	0
34	HALLYM-UNIV	144	33	12	1	63	19	1	0	3
35	AGCY-DEF-DEV	143	51	10	52	4	8	0	2	1
36	KEIMYUNG-UNIV	134	17	4	3	84	8	0	0	5
37	SOON-CHUN-HYANG-UNIV	127	21	4	2	83	4	5	2	0
38	CHUNG-ANG-UNIV	126	22	19	10	45	14	4	0	2
39	DONGGUK-UNIV	125	35	47	13	6	2	2	0	1
40	INJE-UNIV	125	27	22	3	38	7	1	1	1
41	DONG-A-UNIV	116	23	27	23	12	7	3	2	2
42	KON-KUK-UNIV	114	10	24	8	22	15	13	2	1
43	CHOSUN-UNIV	105	24	12	16	30	4	0	0	1
44	DANKOOK-UNIV	99	33	10	8	23	12	1	0	1
	Per cent of the total Korean papers per institution	85%	87%	88%	84%	85%	88%	69%	74%	83%

* The total number of articles also comprise unknown papers and those in the multidisciplinary categories

Source: Calculated by CIRST-UQAM & INRS using data from Science Citation Index (1991-1995)

Table 6

Index of specialisation for most productive institutions in South-Korea 1991-1995

	Institutions	Chemistry	Physics	Engineer & techno.	Clinical medecine	Biomedical research	Biology	Earth & space	Maths
1	SEOUL-NATL-UNIV	1,56	1,86	1,77	0,67	0,77	0,52	0,48	0,84
2	KAIST	2,27	2,05	4,75	0,07	0,53	0,08	0,19	0,44
3	POHANG-UNIV-SCI-&-TECHNOL-POSTECH	2,42	2,65	3,92	0,04	0,37	0,12	0,00	1,44
4	YONSEI-UNIV	0,98	1,47	1,47	1,21	0,52	0,22	0,52	0,84
5	KOREA-UNIV	2,25	3,12	1,19	0,34	0,28	0,55	0,70	1,73
6	PUSAN-NATL-UNIV	3,87	0,97	2,04	0,31	0,31	0,28	1,17	1,47
7	KIST	2,40	1,94	2,87	0,12	0,95	0,65	0,05	0,59
8	KYUNGPOOK-NATL-UNIV	3,21	1,07	1,90	0,35	0,71	0,58	0,27	2,13
9	KOREA-RES-INST-STAND-&-SCI	1,55	4,48	2,52	0,02	0,08	0,18	1,68	0,00
10	CHONBUK-NATL-UNIV	1,39	2,53	1,54	0,56	0,92	0,34	0,44	0,00
11	CHUNGNAM-NATL-UNIV	2,97	1,16	1,72	0,32	0,61	0,76	1,79	0,74
12	CHONNAM-NATL-UNIV	1,91	1,66	1,99	0,61	0,46	1,08	0,64	0,81
13	HANYANG-UNIV	1,93	1,45	3,16	0,62	0,55	0,30	0,31	0,00
14	UNIV-ULSAN (ASAN Med Ctr)	0,81	0,49	0,77	1,78	0,54	0,10	0,14	0,21
15	KAERI	1,00	1,54	6,24	0,50	0,17	0,20	0,23	0,66
16	CATHOLIC-UNIV-SEOUL	0,03	0,06	0,05	2,44	0,36	0,00	0,00	0,00
17	KYUNG-HEE-UNIV	1,32	2,34	0,90	0,95	0,51	0,30	0,45	0,51
18	GYEONGSANG-NATL-UNIV	2,04	2,08	0,56	0,54	0,86	1,37	0,09	0,52
19	INHA-UNIV	4,45	1,36	1,64	0,16	0,37	0,13	0,39	1,40
20	ELECTR-&-TELECOMMUN-RES-INST	1,01	5,07	3,81	0,01	0,00	0,00	0,00	0,54
21	KOREA-RES-INST-CHEM-TECHNOL	6,20	0,58	0,48	0,11	0,43	0,17	0,09	0,00
22	SOGANG-UNIV	3,82	3,25	1,59	0,00	0,03	0,07	0,42	0,61
23	CHUNGBUK-NATL-UNIV	2,61	1,93	1,46	0,36	0,66	0,63	0,96	0,31
24	SAMSUNG	0,80	3,00	5,66	0,35	0,03	0,08	0,00	0,36
25	KANGWEON-NATL-UNIV	2,85	2,55	1,05	0,11	0,74	1,11	0,39	0,37
26	SEOUL-NATL-UNIV-HOSP	0,04	0,00	0,00	2,46	0,30	0,07	0,11	0,00
27	EWHA-WOMANS-UNIV	3,03	2,43	0,42	0,39	0,58	0,35	0,40	1,15
28	SUNG-KYUN-KWAN-UNIV	3,70	2,08	1,91	0,10	0,32	0,40	0,00	2,81
29	GOLDSTAR	2,32	2,91	3,00	0,12	0,60	0,08	0,00	0,00
30	YEUNGNAM-UNIV	3,90	0,60	2,81	0,23	0,44	0,87	0,13	1,14
31	WONKWANG-UNIV	1,62	2,44	0,61	0,79	0,67	0,56	0,14	0,40
32	AJOU-UNIV	2,05	2,64	2,64	0,40	0,35	0,11	0,33	0,93
33	KWANGWOON-UNIV	0,93	5,62	3,03	0,00	0,07	0,00	0,00	0,00
34	HALLYM-UNIV	2,03	0,78	0,11	1,26	0,78	0,11	0,00	1,47
35	AGCY-DEF-DEV	3,24	0,67	5,73	0,08	0,34	0,00	0,35	0,51
36	KEIMYUNG-UNIV	1,14	0,28	0,35	1,84	0,36	0,00	0,00	2,68
37	SOON-CHUN-HYANG-UNIV	1,41	0,28	0,23	1,82	0,18	0,62	0,37	0,00
38	CHUNG-ANG-UNIV	1,54	1,40	1,22	1,03	0,65	0,51	0,00	1,12
39	DONGGUK-UNIV	2,69	3,79	1,73	0,15	0,10	0,28	0,00	0,61
40	INJE-UNIV	2,20	1,88	0,42	1,01	0,38	0,15	0,23	0,65
41	DONG-A-UNIV	1,89	2,33	3,28	0,32	0,38	0,45	0,46	1,31
42	KON-KUK-UNIV	0,86	2,16	1,19	0,61	0,85	2,04	0,48	0,68
43	CHOSUN-UNIV	2,24	1,18	2,60	0,91	0,25	0,00	0,00	0,75
44	DANKOOK-UNIV	3,05	0,97	1,28	0,69	0,74	0,17	0,00	0,74

Source: Calculated by CIRST-UQAM & INRS using data from Science Citation Index (1991-1995)

The Korean Atomic Energy Research Institute (KAERI) strongly emphasises papers in engineering and technology. With an index value of 6,24, this is the institutions that displays the highest rate of specialisation in Table 6. This level of specialisation in engineering can be explained given the mission of this institution: "KAERI carries out extensive R&D programs related to nuclear fuel design, nuclear safety, reactor engineering, and RI [radioisotopes] applications as well as fundamental research" (MOST, 1996: 45).

The level of specialisation of KAERI can also be explained given the South Korean Government policy to endogenise nuclear plant design and production. It is noteworthy that South Korea is already operating power plants from nearly all the leading nuclear reactor manufacturers: Alsthom and Framatome, GE, GEC, Westinghouse and, importantly, AECL (*Ibid*.: 47). This level of diversification cannot be understood in terms of economies of scale and economies of learning. Rather, they can be understood within the realm of the classical import substitution strategy used by the South Korean Government (Archambault, 1991: 9-11; Enos and Park, 1988: 232-4). It is noteworthy that AECL and GE are working with KHIC and that this firm is building the Unit 3 and 4 at Ulchin (Framatome and Alsthom are building Unit 1 and 2). This expertise and that of KAERI are instrumental in the development of South Korea own nuclear reactors: "Ulchin Units 3&4, which are now under construction, will be the first Korean nuclear standard nuclear power plants designed and built with technology on hand. Through the improvement of the existing PWRs, Korea will develop the next-generation reactor technology by 2001" (*Ibid*.: 46). At Wolsong, AECL is collaborating with one company and one country that is highly likely to become a competitor.

In the case of patent data, the contribution of the chaebol, that is, the South Korean variant of the Japanese Keiretsus or conglomerate, is much stronger. For example, Table 7 reveals that 2,5% of the assignees to South Korean patents granted in the U.S. have been assigned 86% of the patents. Samsung is clearly the leader with nearly twice as many patents as the Lucky Goldstar chaebol. Hyundai has traditionally been larger than Lucky Goldstar (now known as LG) but Hyundai is more active in heavy industries such as shipbuilding whereas Lucky was active in chemicals and Goldstar was active in electronics. Daewoo, Cheil and SKC have lesser importance. The governmental institutions are not so important, with ETRI leading the group (Electronics Telecommunications Research Institute) followed by the KIST, the KAIST and the KRISS (Korea Research Institute of Chemical Technology).

Table 7 Top ten assignees for U.S. patents issued to South Korean inventors 1978-1996

Assignees	Assignments	Cum% assignees	Cum% assignments
Samsung	2 468	0,2%	44,1%
Lucky Goldstar (LG Group)	1 271	0,5%	66,8%
Hyundai	418	0,7%	74,3%
Daewoo	214	1,0%	78,1%
Korean Telecommunication Authority & ETRI	146	1,2%	80,7%
Korea Institute of Science and Technology	116	1,5%	82,8%
Korea Advanced Institute of Science and Technology	62	1,7%	83,9%
Korea Research Institute of Chemical Technology	54	2,0%	84,8%
Cheil	41	2,2%	85,6%
SKC Limited	38	2,5%	86,2%

Source: Calculated by CIRST-UQAM & INRS using data from VISIITT database (1969-1996)

Conclusion

The data in this part shows that the rate of growth of Korean science and technology is rapid and sustained over the period 1980-1995. Between 1991 and 1995, South Korea produced a large number of papers in chemistry, physics, engineering and technology as well as clinical medicine. During this interval, South Korea emphasised papers in engineering and technology, chemistry, and to a lesser extent, physics. South Korea is also actively patenting in the U.S. and emphasises inventions in information and communication technologies and appears to be well positioned to enter the rapidly growing multimedia sector. Given these trends, South Korea should be able to reach her target to enter the G7 of S-T in the early 21-st century. The next section analyses South Korea's scientific collaborations with foreign countries.

Part 2
Scientific collaborations of South Korea with foreign countries

This section analyses firstly the distribution of collaborations between South Korea and her scientific collaborators and secondly the rate of growth of her scientific collaborations. A "collaboration" is a paper with affiliations in two countries or more, hence the numbers of collaborations per institution and of collaborators are higher than the number of papers.

An analysis of the distribution of collaborations per country on a doubly logarithmic scale reveals two subsystems (see Figure 5). South Korea has a core group of 27 core collaborators and a group of 56 more peripheral collaborators. The core group includes 35% of the collaborating countries and those countries account for more than 95% of the collaborations. The four leading countries in terms of collaborations with South Korea (less than 5% of the collaborating countries) account for nearly 70% of the collaborations, which is typical of scientometric distributions in which a small number of actors produces the majority of activities.

It is also useful to study whether there is exponential rate of growth in the collaborations between South Korea and her core collaborators in order to locate that of Canada (see Figure 6 and Table 8). During the time interval 1991-1995, six countries had a highly significant ($\alpha<0{,}01$) exponential rate of growth in collaborative papers while eleven countries also had a significant exponential rate of growth, albeit at a lower level of significance ($\alpha<0{,}05$). Again, the significant exponential regressions can be seen as indications of a take-off of scientific collaborations of South Korea, in particular with the G7 countries as well as Russia, China and eight smaller countries that belong to South Korea's core group of collaborators. Not all of those collaborators have a steady rate of growth though. Indeed, ten of the core collaborating countries do not have a significant exponential rate of growth in their collaboration with South Korea, most of them have a low level of collaborations.

Figure 5 Hyperbolic distributions of scientific collaborations with South Korea 1991-1995

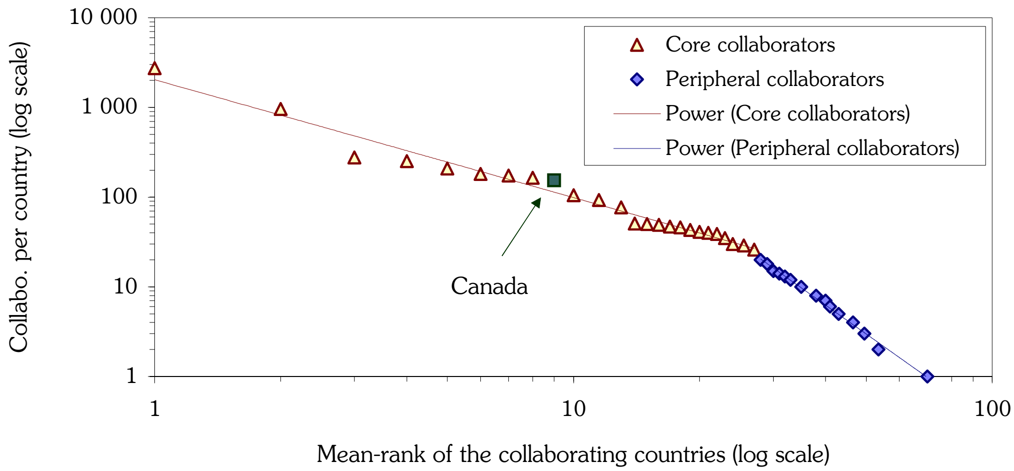
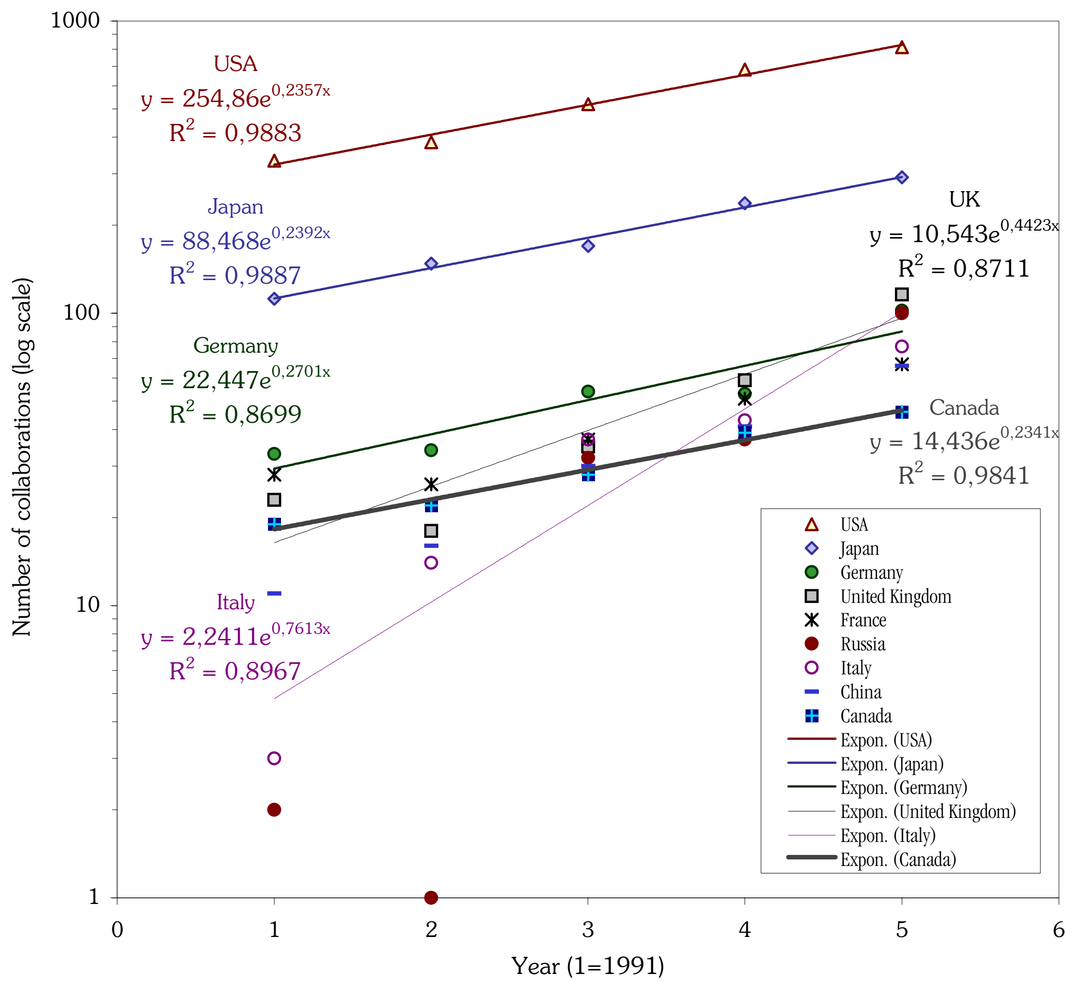


Figure 6 Nine leading countries in scientific collaborations with South Korea 1991-1995



Source: Calculated by CIRST-UQAM & INRS using data from Science Citation Index (1991-1995)

Globally, the rate of growth for the major collaborating countries are essentially the same, except for Italy. In particular, the rate of growth of Canada's scientific collaborations with South Korea is similar to that of the U.S., Japan, France and to a lesser extent that of Germany and Australia.

Table 8 Patterns of collaboration of South Korea with her core group of scientific collaborators 1991-1995

Countries	1991	1992	1993	1994	1995	Total	Growth rate	α
U.S.	333	385	519	682	813	2732	0,236	0,01
Japan	112	148	170	238	292	960	0,239	0,01
Germany	33	34	54	53	102	276	0,270	0,05
U.K.	23	18	35	59	116	251	0,442	0,05
France	28	26	37	51	67	209	0,242	0,05
Russia	2	1	32	37	100	181	1,143	0,05
Italy	3	14	37	43	77	174	0,761	0,05
China	11	16	30	41	66	164	0,452	0,01
Canada	**19**	**22**	**28**	**39**	**46**	**154**	**0,234**	**0,01**
Spain	2	9	22	20	52	105	0,731	0,05
Netherlands	2	8	22	17	44	93	0,694	0,05
Switzerland	1	8	18	25	41	93	0,857	0,05
India	4	10	21	10	32	77	0,416	ns
Hungary		8	18	11	14	51	0,119	ns
Taiwan	1	4	12	12	21	50	0,719	0,05
Australia	6	6	8	9	20	49	0,281	0,05
Poland	2	1	8	10	26	47	0,743	0,05
Denmark	7	2	5	12	20	46	0,778	0,01
Israel	3	4	10	4	22	43	0,398	ns
Bulgaria		6	15	6	14	41	0,163	ns
Sweden	5	6	4	12	13	40	0,260	ns
Austria	6		1	12	20	39	1,498	ns
Cyprus		5	12	5	13	35	0,199	ns
Greece			3	10	17	30	0,867	ns
Brazil	1	1	7	3	17	29	0,677	ns
Romania	1	9	7	6	15	29	0,501	ns
Finland	1	2	2	7	14	26	0,653	0,01

Source: Calculated by CIRST-UQAM & INRS from Science Citation Index (1991-1995)

Though the order of frequency of collaboration with Korea does not match the order of world share of scientific paper, it is worth noting that the first five countries in terms of scientific collaboration with Korea are the very ones, and in the same order, from which Korea imports its technology (OECD, 1996: 64 Table 8.4). For example, the strong presence of the U.S. is no surprise and is coherent with the Korean government decision to create, in 1996, a Science Cooperation Centre in this country in order to facilitate scientific exchanges with the world's most important producer of science (*Ibid.*: 60). The strong presence of China can also be related to technology transfer for this country is the most important in terms of technological import from Korea. China's importance can also be related to the more global Korea's Asia-Pacific economic strategy. The importance of Russia is also consistent with Korean data about her most important international collaborative agreements, for the last seven years (*Ibid.*: 63 Table 8.3). We have however no particular explanation for the importance of the collaborations with Italy.

From the strict proportionality of world output, one would have expected Canada to be in the seventh position. The evidence shows that Canada is the ninth collaborator chosen by Korea in terms of total number of joint papers between 1991 and 1995, all disciplines included. These 154 collaborative papers account for around 2,5% of the total number of collaborations between South Korea and other countries. From the comparison, one sees that Korea collaborates less with Canada than with countries like China and Italy, despite the fact that they are minor producers of papers. Furthermore, the position of Canada is not insured since all the countries with lower levels of collaboration have higher rates of growth. In fact, of all the countries with a significant growth rate, Canada has the slowest growth factor. This means that unless there is a change in these tendencies, Canada is bound to slip behind other countries in the ranks of South Korea's groups of collaborators.

In order to identify the major fields of collaboration for G7 countries, we have calculated an index of collaboration, for each discipline (Table 9). This index is the ratio of the percentage of one country's share in a discipline divided by the percentage of collaboration of South Korea with the world. Whereas U.S. is important in most fields except biology, Italy and France are important only in that latter field. Collaboration with UK is strong only in earth and space. Collaboration with Japan is strong essentially in physics, chemistry and engineering. The collaboration between Canada and South Korea emphasises earth and space as well as clinical medicine and, to a lesser extent, biomedical research, three disciplines which are not among the fields emphasised by South Korea. Nonetheless, the collaboration also emphasise chemistry, one discipline where South Korea puts a strong emphasis.

Table 9 Index of collaboration of G7 countries with South Korea

Disciplines	U.S.	Japan	Germany	UK	France	Italy	Canada
Chemistry	**1,11**	**1,66**	**1,12**	0,54	0,63	0,30	**1,21**
Physics	**1,12**	**1,50**	0,92	0,99	0,86	0,19	0,96
Engineering & tech..	**1,22**	**1,63**	0,88	0,72	1,00	0,34	0,91
Mathematics	**1,32**	0,85	0,67	0,94	0,18	0,35	0,79
Clinical medicine	**1,32**	0,84	0,85	0,41	1,02	0,61	**2,26**
Biomedical research	**1,46**	**1,14**	0,52	0,92	0,47	0,19	**1,22**
Earth and space	**1,33**	0,60	0,94	**1,71**	0,00	0,38	**2,61**
Biology	0,60	0,70	**1,32**	**1,19**	**1,55**	**1,97**	0,83

Source: Calculated by CIRST-UQAM & INRS using data from Science Citation Index (1991-1995)

Part 3
Scientific collaboration between South Korea and Canada

According to data in the VISIITT database, there is no joint patent between Canada and South Korea. In fact, there is only one jointly assigned patent by South Korea in the U.S., and this patent is shared with the Netherlands. This kind of figure could be expected since, contrary to scientific publications where knowledge is non-proprietary and, therefore, where joint-authorship is frequent, inventions are appropriable and so do not lend themselves to joint patenting.

This part analyses in greater details the scientific collaborations between South Korea and Canada between 1991 and 1995. For those years, there are 154 papers in the SCI database on CD-ROM with an affiliation in South Korea and in Canada. Two of those are single authors with an affiliation in both countries. Since it is not possible to distinguish whether a paper that comprises affiliations in Canada and in South Korea is a collaboration between nationals from both countries or whether one of the collaborators has an affiliation in both countries, it was decided to keep these two papers in the dataset.

This part analyses successively the distribution of collaborations by disciplines and the distribution of collaborations by Canadian and by South Korean institutions. An important consideration is the presence of a set of 27 articles published by nearly 400 co-authors from the HERA international project in high energy physics. The study of the collaborations by Canadian and by South Korean shows that growth in this system comes from the collaborations in physics, otherwise, the growth of collaborations is close to nil.

1. Collaborations per discipline

Table 10 shows that the number of collaborations is greater in physics, while engineering, clinical research, chemistry, biomedical research as well as earth and space have lesser collaborations. The level of collaboration in biology and in mathematics is low. When the papers from the HERA project are excluded, the collaborations in physics become equal to those in engineering and technology (n=23).

Table 10 Collaborations per discipline between South Korea and Canada 1991-1995

Disciplines	1991	1992	1993	1994	1995	Total
Physics	2	2	5	14	26	49
Physics excluding HERA	2	2	1	10	8	23
Engineering and technology	7	5	6	2	3	23
Clinical medicine	1	3	2	2	8	16
Chemistry	0	2	4	7	1	14
Biomedical research	3	2	3	3	2	13
Earth and space	2	2	2	4	3	13
Biology	3	2	1	1	0	7
Mathematics	0	2	1	2	1	6
Non identified	1	2	4	4	2	13
Total excluding HERA	19	22	24	35	28	128
Total including HERA	19	22	28	39	46	154

Source: Calculated by CIRST-UQAM & INRS from Science Citation Index (1991-1995)

Time series of collaborations reveal an orderly exponential rate of growth ($\alpha<0,01$) only in physics and this pattern only holds when papers from HERA are included. When the remaining disciplines are considered together, there is no significant pattern of growth. Hence, the exponential growth in scientific collaborations between Canada and South Korea is due to the growth of the activity in physics, and this activity is mainly due to the presence of these two countries in the HERA project. This suggests that the rate of growth of close collaborations between Canada and South Korea is either quite low or even non-significant. The rate of collaboration in engineering and technology, the second most important discipline during the period, appears to be lowering over time. Collaborations in chemistry started well in 1992 but fell abruptly in 1995.

2. Collaborations per institution

The study of the collaborations between Canadian and South Korean institutions shows distinctive patterns for both countries when all the dataset is considered but they display remarkably similar patterns when the institutions that collaborate in HERA are excluded. There are around 50 institutions from South Korea as well as around 50 collaborators from Canada. Table 11 presents a list of South Korean and Canadian institutions with more than one collaboration.

Table 11 Institutions from South Korea and Canada with more than one scientific collaboration with the other country 1991-1995

South Korean institutions	Collaborations with Canada	Collaborations in HERA	Canadian institutions	Collaborations with Korea	Collaborations in HERA
Korea-Univ	38	27	Univ Toronto, Ontario	45	26
Seoul-Natl-Univ	19		Mcgill Univ, Québec	41	27
POSTECH (Pohang)	11		Univ Manitoba	34	27
Yonsei-Univ	10		York Univ, Ontario	30	27
Pusan-Natl-Univ	7		Univ Saskatchewan	17	
KAIST	6		Univ Alberta	8	
Chonnam-Natl-Univ	5		Univ Ottawa, Ontario	8	
Chungnam-Natl-Univ	5		Mc Master Univ, Ontario	7	
Kangnung-Natl-Univ	4		Univ Western Ontario	7	
Kyungpook-Natl-Univ	4		Univ British Columbia	6	
Kyungsung-Univ	4		Univ Waterloo, Ontario	6	
KAERI	3		AECL	5	
Chungbuk-Natl-Univ	3		Simon Fraser Univ, B.C.	5	
Kyung-Hee-Univ	3		Univ Calgary, Alberta	5	
Pai-Chai-Univ	3		Univ Victoria, B.C.	5	
Samsung	3		NRC	4	
Wonkwang-Univ	3		Triumf, British Colombia	4	
Andong-Natl-Univ	2		Agriculture Canada	3	
Chonbuk-Natl-Univ	2		Concordia Univ, Québec	3	
Chonnam-Nat-Univ-Hosp	2		Queens Univ, Ontario	3	
ETRI	2		Vancouver Gen. Hosp, B.C.	3	
Gyeongsang-Natl-Univ	2		Xerox Canada Ltd, Ont.	3	
Kon-Kuk-Univ	2		Dominion Radio Astro., B.C.	2	
Korea-Inst-Energy-Res	2		Maisonneuve Hosp, Qué.	2	
Korea-Natl-Housing-Corp	2		Montreal Neurol Hosp, Qué.	2	
Natl-Fisheries-Univ-Pusan	2		Univ Montreal, Québec	2	
Natl-Inst-Hlth	2		Univ Sherbrooke, Québec	2	
Seoul-Natl-Univ-Hosp	2		Univ Windsor, Ontario	2	
Soong-Sil-Univ	2				
Yeungnam-Univ	2				

Source: Calculated by CIRST-UQAM & INRS from Science Citation Index (1991-1995)

Conclusion

The scientific production of South Korea emphasises papers in the fields of engineering and technology, chemistry and physics. By comparison, Canada emphasises the fields of earth and space, biology and mathematics. With the present rate of growth of scientific activity in both countries, the annual number of papers by Korea will equal that of Canada in 2006.

In the domains of invention and technology, as measured by patent data, South Korea concentrates her activities in information and communication technology and this could be turned into a competitive advantage in the growing multimedia sector. Within a set of inventions in major industrial sectors comprising around 25 % of the U.S. patents, the sectors emphasised by South Korea are radio and television, electrical components as well as communication equipment. By comparison, Canada emphasises industrial machinery as well as motor vehicles and equipment. With the actual rate of growth of patenting activity in both countries, Korea will reach the level of Canada in 1997. Given these trends, South Korea should be able to reach her target to enter the G7 of S-T in the early 21-st century.

Canada occupies rank 9 and accounts for 2,5 % of all scientific collaborations with Korea. This percentage is lower than the 4,2 % share of scientific papers by Canada in the SCI database between 1991 and 1995. The rate of growth of collaboration between Canada and Korea is the lowest among the most important collaborating countries. The collaboration between Canada and South Korea is more concentrated in the fields of earth and space, clinical medicine and, to a lesser extent, biomedical research and chemistry. If we exclude a series of 27 papers in the field of high energy physics (project HERA), there is no real pattern of sustained growth in the period 1991-1995, except in clinical medicine.

It should be noted that this analysis has only looked at the pattern of scientific activity and has not proposed indicators of the quality of Korean research in the fields identified. This could be done by means such as using the impact factors of the journals in which Korean scientists publish, peer reviews as well as qualitative and quantitative surveys. Nonetheless, the type of bibliometric analysis used in this study offers a global map of the scientific activities of a given country and her pattern of collaborations with other countries that is useful to situate Canada within the global market of international scientific research.

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Annex 1 Assignees with more than one U.S. patent granted to South Korean inventors 1978-1996

Assignees	Assignments	Cum% assignees	Cum% assignments
Samsung	2468	0,2%	44,1%
Lucky Goldstar (LG Group)	1271	0,5%	66,8%
Hyundai	418	0,7%	74,3%
Daewoo	214	1,0%	78,1%
Korean Telecommunication Authorithy & ETRI	146	1,2%	80,7%
Korea Institute of Science and Technology (KIST)	116	1,5%	82,8%
Korea Advanced Institute of Science and Technology (KAIST)	62	1,7%	83,9%
Korea Research Institute of Chemical Technology (KRICT)	54	2,0%	84,8%
Cheil	41	2,2%	85,6%
SKC Limited	38	2,5%	86,2%
Sindo Ricoh Co., Ltd.	18	2,7%	86,6%
Agency for Defence Development	15	3,0%	86,8%
Pohang Iron & Steel Co., Research Institute of Industrial S-T	14	3,2%	87,1%
Silver Star Co., Ltd.	13	3,5%	87,3%
American Standard Inc.	12	3,7%	87,5%
Kolon Industries, Inc.	12	4,0%	87,7%
Pacific Chemical Co., Ltd.	12	4,2%	88,0%
Lotte Confectionery Co., Ltd.	11	4,5%	88,2%
Miwon Co., Ltd.	11	4,7%	88,4%
Tong Yang	10	5,0%	88,5%
J & L Importers, Inc.	9	5,2%	88,7%
Kia	9	5,5%	88,9%
Korea Chemical Co., Ltd.	9	5,7%	89,0%
Korea Measures Co., Ltd.	9	6,0%	89,2%
Kumho & Co, Inc.	9	6,2%	89,3%
Pacific Corporation	9	6,5%	89,5%
Sunkyong	9	6,7%	89,7%
Sam Yang Co., Ltd.	8	7,0%	89,8%
Yukong Limited	8	7,2%	89,9%
Bando	7	7,5%	90,1%
Mando	7	7,7%	90,2%
Bloxwich Korea Co., Ltd.	6	8,0%	90,3%
Korea Institute of Machinery & Metals (KIMM)	6	8,2%	90,4%
Korea Research Institute of Standards & Science (KRISS)	6	8,5%	90,5%
Samick Music Corporation	6	8,7%	90,6%
Yoshinaga Prince Company Limited	6	9,0%	90,7%
ALZA Corporation	5	9,2%	90,8%
Daesaeng Corporation	5	9,5%	90,9%
Dong Yang Industrial Co., Ltd.	5	9,7%	91,0%
EHWA Diamond Ind. Co., Ltd.	5	10,0%	91,1%
Inkel Corporation	5	10,2%	91,2%
Korea Atomic Energy Research Institute (KAERI)	5	10,4%	91,3%

These 15 assignees (4% of the group) have four assignments each (1% of the assignments):

Asia Motors Co., Inc.; Bae Jin Corporation; Dongyang Jonghap Corporation; Hae Sung Engineering Co., Ltd.; Korea Food Research Institute; Korea Green Cross Corporation; Logos Co., Ltd.; Metex Corporation; Michael & Park's Trading and Sales, Inc.; Poongsan Corporation; Ra, Jong Oh Lim, Joon Young; Samhwa Electric Industrial Co., Ltd.; Tae Lim Electronics Co., Ltd.; TriGem Computer, Inc.; Yuhan Corporation, Ltd.

These 18 assignees (4% of the group) have three assignments each (1% of the assignments):

AT&T Corp.; Ben Clements & Sons, Inc.; Dae Young Packing Co., Ltd.; Dong A Electric Parts Co., Ltd.; Dong Kook Pharmaceutical Co., Ltd.; General Electric Company; Hitachi, Ltd.; Ilya Co., Ltd.; International Business Machines Corporation; Korea Kumho Chemical Co., Ltd.; Korea Tarpaulin Inc.; Kyungdook National University; Mercury International Trading Corp.; Nae Wae Semiconductor Co., Ltd.; Shinhan Kongki Co. Ltd.; Top Qua; Westinghouse Electric Corp.; Woo Kyong Industrial Co., Ltd.

These 48 assignees (12% of the assignees) have two assignments each (2% of the assignments):

Anico Co. Ltd.; Banpo Corporation; Boam R&D Co., Ltd.; Bultina; Byong Duk Choi; Changmin Technology Co., Ltd.; Colibri Corporation; Cosmetech International Inc.; DADA Corp.; Dae Sam Co., Ltd.; Daewood (sic); Daeyang Optical Co., Ltd.; Dong Hwa; Dong Sung Chemical Ind. Co., Ltd.; Dong-A Pharmaceutical Co., Ltd.; Dong-Il Commerce & Co., Ltd.; Dongkook Pharmaceutical Co. Ltd. Kwon, Ki Beom; E. I. Du Pont de Nemours and Company; Franklin Sports Industries, Inc.; Haidon Industrial Co., Ltd.; Han Baek Trading Co., Ltd.; Hanil Industrial Co., Ltd.; Hankook Tire Mfg. Co., Ltd.; Han-Mi Mold & Tool Co., Ltd; Interport International, Inc.; Kencho Kobe Co., Ltd.; Komelon Corporation Ltd.; Kookje Elec. Ind. Co., Ltd.; Korea Advanced Energy Research Institute; Korea Crown Co., Ltd.; Korea Heavy Industries & Construction Co., Ltd.; Korea Steel Chemical Co., Ltd.; Namsung Electronics Corp. (sic); Nong Shim Co., Ltd.; Office of Monopoly; Poong San Metal Corporation; Pop Limited; Robert Bosch GmbH; Sam I1 Pharmaceutical Manufacturing Co., Ltd.; Sam Jung Co., Ltd.; Samwoo Far Infra-Red Ray Co., Ltd.; Sanko' Industry Corporation; Seoil Industrial Co., Ltd.; Starlight Industries, Inc.; Timex Corporation; Woobang Land Co., Ltd.; Yohan Electronics Co., Ltd.; Zebco Corporation.

The group above thus comprises 123/402 assignees and produces 5319/5598 assignments. The remaining 279 assignees (<70% of the group) have one assignment (5% of assignments).

Annex 2 Leading Korean institutions by disciplines

Chemistry

KAIST	864
Seoul-Natl-Univ	593
POSTECH	335
Pusan-Natl-Univ	230
Korea-Res-Inst-Chem-Technol	202

Physics

KAIST	742
Seoul-Natl-Univ	674
POSTECH	349
Yonsei-Univ	186
Korea-Univ	178
Korea-Res-Inst-Stand-&-Sci	176
Electr-&-Telecom-Res-Inst	143

Engineering and technology

KAIST	1043
Seoul-Natl-Univ	389
POSTECH	313
KAERI	130
Yonsei-Univ	112
KIST	89
Samsung	73
Pusan-Natl-Univ	70

Clinical medecine

Seoul-Natl-Univ	784
Yonsei-Univ	491
Catholic-Univ	277
Univ-Ulsan (Asan Med Ctr)	210
Seoul-Natl-Univ-Hosp	186

Biomedical research

Seoul-Natl-Univ	442
KAIST	304
Yonsei-Univ	104
POSTECH	78
KIST	77
Chonbuk-Natl-Univ	53
Kyungpook-Natl-Univ	44
Chungnam-Natl-Univ	40
Gyeongsang-Natl-Univ	40

Biology

Seoul-Natl-Univ	108
Chonnam-Natl-Univ	23
Gyeongsang-Natl-Univ	23
KIST	19
Chungnam-Natl-Univ	18
Korea-Univ	18
Natl-Fisheries-Univ-Pusan	18
KAIST	17
KORDI	16
Yonsei-Univ	16

Earth and space

Seoul-Natl-Univ	66
Chungnam-Natl-Univ	28
KAIST	26
Korea-Res-Inst-Stand-&-Sci	25
Pusan-Natl-Univ	25
Yonsei-Univ	25

Mathematics

Seoul-Natl-Univ	40
POSTECH	25
KAIST	21
Yonsei-Univ	14
Korea-Univ	13
Pusan-Natl-Univ	11
Kyungpook-Natl-Univ	11