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How is the Canadian Biotechnology Evolving: A Comparison of the 1997 and 1999 Biotechnology Use and Development Surveys

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Canada

HOW IS THE CANADIAN BIOTECHNOLOGY EVOLVING: A COMPARISON OF THE 1997 AND 1999 BIOTECHNOLOGY USE AND DEVELOPMENT SURVEYS

A JOINT-PAPER

BETWEEN

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Working Papers

The Working Papers publish research related to science and technology issues. All papers are subject to internal review. The views expressed in the articles are those of the authors and do not necessarily reflect the views of Statistics Canada.

The Science and Innovation Information Program

The purpose of this program is to develop **useful indicators of science and technology activity** in Canada based on a framework that ties them together into a coherent picture. To achieve the purpose, statistical indicators are being developed in five key entities:

- **Actors**: are persons and institutions engaged in S&T activities. Measures include distinguishing R&D performers, identifying universities that license their technologies, and determining the field of study of graduates.
- **Activities**: include the creation, transmission or use of S&T knowledge including research and development, innovation, and use of technologies.
- **Linkages**: are the means by which S&T knowledge is transferred among actors. Measures include the flow of graduates to industries, the licensing of a university's technology to a company, co-authorship of scientific papers, the source of ideas for innovation in industry.
- **Outcomes**: are the medium-term consequences of activities. An outcome of an innovation in a firm may be more highly skilled jobs. An outcome of a firm adopting a new technology may be a greater market share for that firm.
- **Impacts**: are the longer-term consequences of activities, linkages and outcomes. Wireless telephony is the result of many activities, linkages and outcomes. It has wide-ranging economic and social impacts such as increased connectedness.

The development of these indicators and their further elaboration is being done at Statistics Canada, in collaboration with other government departments and agencies, and a network of contractors.

Prior to the start of this work, the ongoing measurements of S&T activities were limited to the investment of money and human resources in research and development (R&D). For governments, there were also measures of related scientific activity (RSA) such as surveys and routine testing. These measures presented a limited picture of science and technology in Canada. More measures were needed to improve the picture.

Innovation makes firms competitive and we are continuing with our efforts to understand the characteristics of innovative and non-innovative firms, especially in the service sector that dominates the Canadian Economy. The capacity to innovate resides in people and measures are being developed of the characteristics of people in those industries that lead science and technology activity. In these same industries, measures are being made of the creation and the loss of jobs as part of understanding the impact of technological change.

The federal government is a principal player in science and technology in which it invests over five billion dollars each year. In the past, it has been possible to say only *how much* the federal government spends and *where* it spends it. Our report **Federal Scientific Activities, 1998 (Cat. No. 88-204)** first published socio-economic objectives indicators to show *what* the S&T money is spent on. As well as offering a basis for a public debate on the priorities of government spending, all of this information has been used to provide a context for performance reports of individual departments and agencies.

As of April 1999, the Program has been established as a part of Statistics Canada's Science, Innovation and Electronic Information Division.

The final version of the framework that guides the future elaboration of indicators was published in December, 1998 (**Science and Technology Activities and Impacts: A Framework for a Statistical Information System,** Cat. No. 88-522). The framework has given rise to **A Five-Year Strategic Plan for the Development of an Information System for Science and Technology** (Cat. No. 88-523).

It is now possible to report on the Canadian system on science and technology and show the role of the federal government in that system.

Our working papers and research papers are available at no cost on the Statistics Canada Internet site at http://www.statcan.ca/cgi-bin/downpub/research.cgi?subject=193.

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ACKNOWLEDGEMENTS

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The authors are grateful to Antoine Rose, Special Advisor in Biotechnology, Science, Innovation and Electronic Information Division (SIEID), (Statistics Canada), Mario Perek and Neil MacIntosh from Industry Canada, for their helpful comments and suggestions. The authors are, however, responsible for any errors and omissions that may remain.

Executive Summary

Using data from two Statistics Canada's Biotechnology Use and Development surveys, the present report shows how Canadian biotechnology companies have evolved in recent years.

SNAPSHOT OF CANADIAN BIOTECHNOLOGY

Results show that biotechnology companies in Canada are experiencing rapid growth and that more biotechnology activity is now being captured by Statistics Canada. For example, between 1997 and 1999, Canadian biotechnology firms grew in number with core biotechnology firms increasing from 282 firms to 358, respectively. They brought in $1.9 billion in biotechnology revenues in 1999, as compared to $813 million in 1997, and spent around $827 million on biotechnology R&D in 1999 compared to $494 million in 1997.

FEATURE TRENDS

Our analytical results show that a significant number of new biotechnology products and processes are now reaching the market (6,597 products were on the market in 1999, compared to 1,758 in 1997). This is reflected in the upward trend of Canadian biotechnology revenues over the last few years. There is also an increasing return on research and development investment on biotech activities. Indeed, the ratio of biotech revenues to biotech R&D expenditures grew from 1.65 in 1997 to 2.36 in 1999. This implies that past R&D investment is resulting in current revenues that more than offset current R&D spending needs. This also points to an increasing ability of Canadian biotech firms to finance their own R&D, instead of relying on external sources of financing capital.

As measured by biotechnology revenues and R&D spending, the increase in biotechnology activity in Canada between 1997 and 1999 is largely attributable to large firms (over 150 employees). In 1999, large firms' revenues from biotechnology product sales were more than 3.5 times their 1997 level ($1.4 billion in 1999 compared to $398 million in 1997). In this respect, large firms seem to have been successful in transforming basic research into products in the market over the last few years. They have also been successful in expanding their presence on international markets, with biotechnology exports revenues going from $167 million in 1997 to $589 million in 1999. Moreover, large biotechnology firms expanded significantly their research activity over the 1997-1999 period, contributing 86% to the overall increase in biotechnology R&D expenditures. We can see from these trends that large, diversified Canadian companies are starting to adopt biotechnology. On the other hand, increases in biotechnology activities among small firms (less than 50 employees) are mainly due to additional firms being captured by Statistics Canada in 1999 rather than small firms having more biotechnology products registering sales. Indeed, our results show that small biotechnology firms in Canada face a serious commercialization challenge. Most of them are low revenues earners and not yet at a manufacturing/revenue generating

stage. The biggest challenge for these firms is to bring more products onto the market and record, as in many cases R&D expenditures exceed revenues.

Revenues and R&D expenditures of Canadian biotechnology companies are concentrated in the Human Health sector and the Agriculture and Food Processing sector. Sectoral comparisons show that both sectors had more than double their 1997's biotechnology revenues levels in 1999. However, the Human Health sector remains the dominant sector in biotechnology in Canada. It is in this particular sector that we find the highest biotechnology revenues with more than $1 billion in 1999 and the highest number of firms with biotechnology revenues (97 out of 225 firms had biotech revenues in 1999). However, with 542 products on the market (mostly diagnostics products), the Human Health sector lag behind other sectors along the commercialization path.

Human Health has the lion's share (85% or $294 million) of R&D expenditures on biotechnology in Canada. The increase in overall biotechnology R&D over the last two years came mainly from this sector. The ratio of R&D-to-revenues is also high (around 68%) in this sector, reflecting both the high cost of R&D relative to marketable products, and the greatest potential of this sector in the future. Firms in the Agriculture and Food Processing sector also experienced a significant growth over the 1997-1999 period. In particular, firms in this sector expanded their activities in international biotechnology product markets by more than 2.5 times ($284 million of exports in 1999 compared to $101 million in 1997). Despite this recent progress, there has not been a high level of investment on research and development in this area compared to the Human Health sector. This could be explained, in part, by the low cost (relative to the Human Health sector) of developing biotechnology products in this particular field. It also means that much of the R&D capability on biotechnology in the Agri-food sector is still located in government and universities. For example, in 2000-2001, Agriculture and Agri-Food Canada was one of the largest supporter of biotechnology expenditures in the agri-food sector with $57 million, which were only for intramural activities[1].

Results also show that biotechnology also has applications in industrial processing and in almost all resource-based sectors. For example, biotechnology revenues from the OTHER group (Bioinformatics, Aquaculture, Mining/Energy/Petroleum/Chemicals, and Forest Products) went up by six-fold from 1997 to 1999; that is from $25 million in 1997 to $158 million in 1999. Revenues have been growing faster in this group than in any other type of biotechnology, although from a very small initial base.

In terms of geographic concentration, biotechnology companies are located mainly in Quebec, Ontario, and British Columbia. Biotechnology revenues are on the rise in all these provinces. Most R&D expenditures also take place in these provinces. It is interesting to note that biotechnology R&D spending in Quebec in 1999 was almost twice its 1997 level. Quebec companies are now Canada's leader in terms of R&D spending on biotechnology with $337 million spent on research in 1999. Biotechnology

[1] Statistics Canada. The Service Bulletin, Science Statistics. Vol. 26, No. 2. April 2002.

companies are nonetheless found in all the other Canadian provinces, some of which have also significant biotechnology activities. For example, a third of the increase in biotechnology revenues between 1997 and 1999 came from firms in Saskatchewan. This significant increase in Saskatchewan is mainly due to increases in firms' export activities.

When looking at the evolution of human resources, biotechnology personnel saw a decrease of 1,324 people, going from 9,019 in 1997 to 7,695 in 1999. This decrease took place mostly in medium and large firms, in all sectors, and across all provinces. However, in the midst of losing employees, firms were able to retain key personnel related to activities such as R&D and management/licensing/administration activities. Furthermore, findings suggest that the loss of personnel might be mainly a transfer of service personnel which took place between biotechnology firms and service companies, e.g. contracting research organizations (CROs).


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Introduction

New ground-breaking developments in genomics, bioinformatics, and proteomics are affecting many sectors, such as pharmaceuticals, medical care, agriculture, life insurance, consumer products, environment, and information technology. Not only are these transformative technologies new, but their impacts are taking place at an increasing pace, thus making Canadian biotechnology firms important economic players[2]. However biotechnology[3] as an economic activity is still in its infancy: on average, biotechnology firms are no more than 12 years old. The use of biotechnology throughout the economy, even though wide spread, is quite recent, with the longest average usage being less than 11 years.

Between 1997 and 1999, Canadian biotechnology firms grew in number with core biotechnology firms increasing from 282 firms to 358, respectively. They brought in $1.9 billion in biotechnology revenues in 1999, as compared to $813 million in 1997. They spent $827 million on biotechnology R&D in 1999 and $494 million in 1997 and the number of new products developed went from 8,924 in 1997 to 17,574 in 1999.

The present report will show how Canadian biotechnology has evolved in recent years using data collected through Statistics Canada's bi-annual surveys[4]. In so doing, our goal is 2-fold: 1) document and analyze the evolution of biotech activities by paying special attention to changes due to differences in survey methodology between 1997 and 1999 as opposed to real changes, and 2) extends the analytical work underway in the Science, Innovation and Electronic Information Division (SIEID) of Statistics Canada and in the Life Sciences Branch (LSB) of Industry Canada to highlight the main features and evolution of Canadian biotechnology activities. Specifically, this is achieved by comparing and analyzing data from the 1997 and 1999 Statistics Canada's Biotechnology Use and Development surveys (BUDS).

The organization of the current study is as follows: in the next section, the 1997 and 1999 BUD surveys are presented with special emphasis on their differences. In section 3, changes in the distribution of biotechnology firms are the main focus. Section 4 looks into the trends in biotechnology revenues. Section 5 explores the evolution in biotechnology firms' exports. Section 6 focuses on the evolution of biotechnology R&D expenditures. Changes in human resources are the topic of section 7.

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[2] Rose 1998, Arundel 1999, Arundel and Rose 1999, McNiven 2001 a, b, Niosi 2000, Niosi and Bas 2001, Traoré 2001, Traoré and Rose 2002, Traoré 2002, Byrd 2001, Statistics Canada 2001

[3] The Canadian Biotechnology Advisory Committee defines biotechnology as "a collection of technical knowledge about living organisms or the elements they are composed of", and applied biotechnology as "those aspects of biotechnology that are used to manufacture products or advance processes serving social, scientific, or economic purposes". Canadian Biotechnology Advisory Committee (2000), 1999-2000 Annual Report of the Canadian Biotechnology Advisory Committee.

[4] Canada recently started collecting information under the Biotechnology Use and Development Survey (BUDS) – Statistics Canada. The first survey of 1996 was followed by the 1997 and 1999 surveys. The 2001 BUDS is presently underway with preliminary results to be available in the fall/winter of 2002.

II The 1997 and 1999 Biotechnology Use and Development Surveys (BUDS)

This section of the report will focus on the differences between the 1997 and 1999 BUD surveys[5]. These differences may be regrouped into two categories: the sample of respondents and the concerns for respondents' burden. It also highlights the methodology used in this report in order to compare the two surveys.

2.1 Sample of Respondents

The 1997 BUDS sample of respondents was based on a list of 475 firms. Their names and addresses were obtained from: Industry Canada, the 1998 Canadian Biotechnology Directory maintained by Contact Canada, and the Statistics Canada Research and Development in Canadian Industry Survey. In the 1999 BUDS, the sample of respondents was obtained by doing two things. First, a must-take-all list of firms was developed in a similar fashion to the 1997 survey. This list was then supplemented with a sample of firms from Statistics Canada's Business Register in selected North American Industry Classification System (NAICS) codes. Given that biotechnology is a pervasive technology, the selection of these NAICS codes was guided by two considerations: i) only NAICS codes where the use of biotechnology was likely were selected, ii) the selection of the firms took into account firm size, sector of activity, and province so as to obtain a representative sample.

2.2 Concerns for Respondents' Burden

To alleviate respondents' burden, i.e. the time spent in answering the questionnaire, the 1999 BUDS excluded firms with less than 5 employees and spending less than $100,000 on R&D. The 1997 BUDS did not include any such restriction.

2.3 Data

In this report, to make sure it is appropriate to compare the 1997 results to the 1999 results, the two surveys were harmonized by the Life Sciences unit of the Science, Innovation and Electronic Information Division (SIEID) of Statistics Canada.

2.3.1 Differences and Similarities between the 1997 and 1999 BUDS

The 1997 questionnaire was sent to 475 firms; and the 1999's to 3377. Both surveys excluded not-for-profit organizations, universities, government laboratories, hospitals. Companies in the service sector such as Contract Research Organizations (CROs) were also excluded. In addition, as mentioned earlier, the 1999 BUDS excluded firms employing less than 5 people and spending less than $100,000 on R&D. These exclusions are not expected to affect the quality of the data for two main reasons. First, universities, hospitals, and government laboratories, even though active in biotechnology R&D which

[5] For a detailed description of the surveys, readers can refer to Traoré (2001) and McNiven (2001 a, b, 2002).

may have given rise to spin-offs biotechnology firms, do not fit into the main goal of the Biotech surveys which is to provide information on the main characteristics of firms that use biotechnology to produce and/or develop commercial products and processes. The same holds true for CROs even though they offer R&D research services to biotech firms. Second, companies that use traditional biotechnology techniques and those who employ less than 5 employees and spend less than $100,000 on R&D are a small percentage of the biotechnology firms and it was deemed appropriate to omit them from the survey.

After accounting for non-responses and applying post-stratification techniques[6], the number of the Canadian biotechnology dedicated firms (or core firms[7]) was estimated at 282 firms in 1997 and 358 in 1999.

2.3.2 Additional Firms

As noted above, the 1997 questionnaire was sent to 475 firms and that of 1999, to more than 7 times these many, i.e. 3,377. The end result of this larger pool of respondents is a larger number of biotechnology firms being captured in 1999. Of the 1999 estimate, 206 firms took part in the 1997 BUDS. These 206 firms are hereafter referred to as Common Firms. The distribution of Common Firms, shown in Annex 1, closely follows that of the general population of firms in both surveys. The additional firms captured in the 1999 BUDS should not be taken as meaning only "new entries or creation of new biotechnology firms" in the 1997-1999 period. It could also include biotechnology firms that existed in 1997 but which, for different reasons, were not covered by the list. Because of data limitations, no distinction could be made between new entries, creation of new biotechnology firms, and existing firms in 1997 that were not surveyed then. Therefore, the reader should keep in mind that one has to be careful when explaining the growth of Canadian biotechnology firms over the last few years. One way to overcome this problem is to look at the evolution of the average figures during the 1997-1999 period. The average figures, among other things, give the average biotechnology revenues per firm, the average biotechnology R&D expenditures per firm. Therefore, the average figures indicate whether an increase in the total figures is only the result of a larger number of firms being captured by the 1999 BUDS or reflects a real increase of the economic activity of Canadian biotechnology firms. Average figures are used in this report to compare key economic indicators.

2.4 Data Strata

In both surveys, firms are categorized in 3 strata: size; sector of activity; and province of location. Firms with 50 employees or less are referred to as small; those employing between 51 and 150 people are medium-sized firms; and those with more than 150 employees are large. The current analysis, group firms into four sectors: Human Health; Agriculture and Food Processing; Environment; and OTHER. Bio-informatics,

[6] Lohr, 1999 pp.269-274

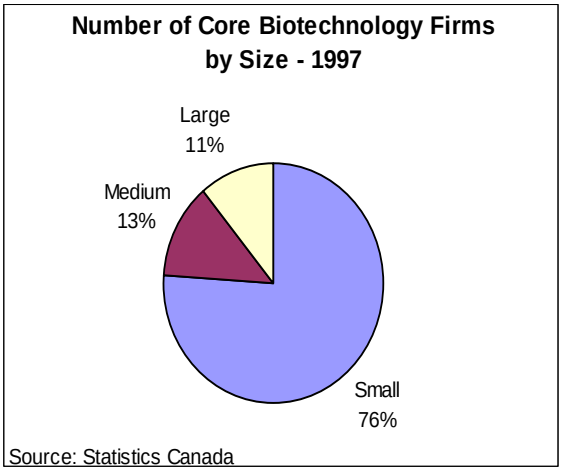
[7] Statistics Canada defines core biotechnology companies as those firms that develop biotechnology products/processes and that consider biotechnology an essential component of their activities.

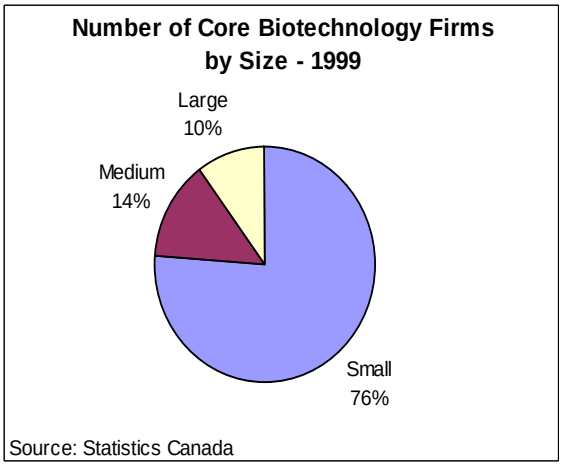
Aquaculture, Mining/Energy/Petroleum/Chemicals, and Forest Products make the OTHER sector. The provincial division is made of the individual provinces, except for the Atlantic region where the 4 provinces (New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland) are grouped under The Maritimes. These groupings are intended to limit the extent of statistical information suppression because of confidentiality clauses.

III Changes in Biotechnology Firms Distribution

Canada had 358 core biotechnology companies[8] in 1999, which represents an increase of 27% over the 282 companies identified in 1997. Figure 1 shows that Canadian biotechnology companies are dominated by small companies (1 to 50 employees), who make up over 75% of the total. Most additional firms[9] captured in 1999 were small firms (see Table 1).

FIGURE 1



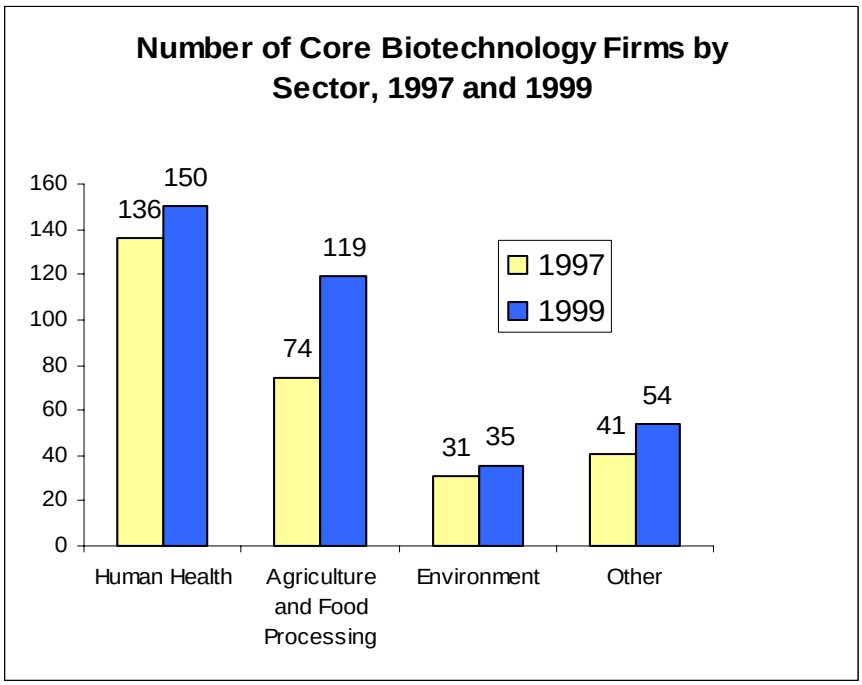


[8] See section 2 for a definition of core biotechnology firms.

[9] **Note to the Readers**: As noted in section 2, the term "additional firms" in the current study should not be taken as meaning only "new entries or creation of new biotechnology firms" in the 1997-1999 period. It also includes biotechnology firms that existed in 1997 but which, for different reasons, were not covered by the list. Because of data limitations, no distinction could be made between new entries in biotechnology activities, creation of new biotechnology firms, and existing firms in 1997 that were not surveyed then. Hence, the use of "additional firms", instead of "new firms" throughout the report.

Canadian biotechnology companies are concentrated in the Human Health sector with more than 40% of companies, followed by the Agriculture and Food Processing sector with 33% of companies in 1999[10]. We notice, for instance, that traditional sectors such as the pharmaceutical and agri-food industries are concentrating increasingly on genetic research to develop new products. The latter sector saw a significant increase in its number of biotechnology firms over the last two years with 45 additional firms in 1999 (Figure 2). This indicates that biotechnology companies are beginning to emerge around new technologies coming off the laboratory benches.

FIGURE 2

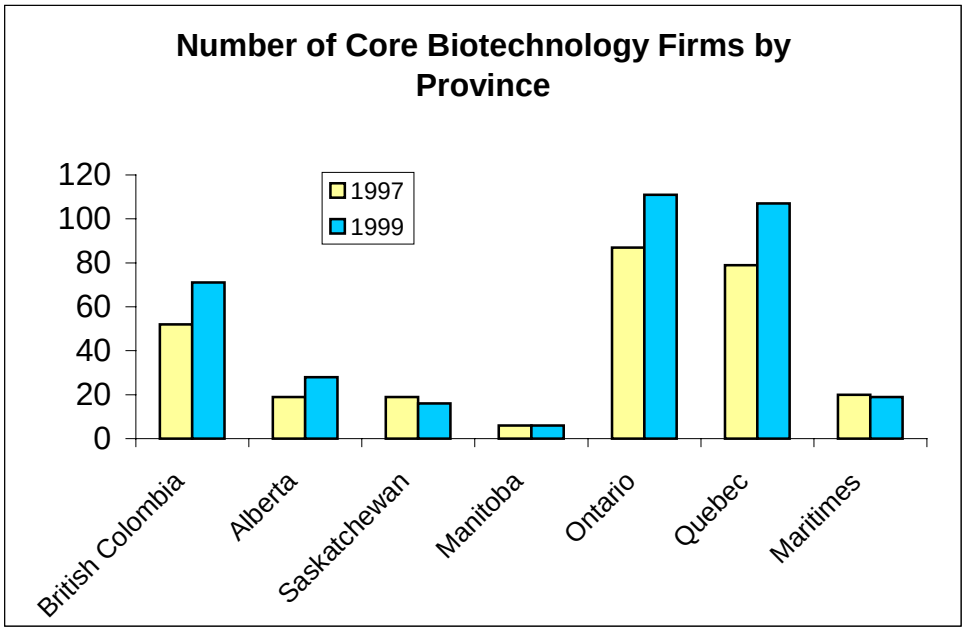


Source: Statistics Canada

In terms of geographic concentration, biotechnology companies are located mainly in Quebec, Ontario, and British Columbia. As shown in Figure 3, biotechnology companies are nonetheless found in all the other Canadian provinces, some of which have also significant biotechnology activities. All the provinces, except the Maritimes and Saskatchewan, experienced an increase in the number of biotechnology firms: Quebec had 28 more firms in 1999 than in 1997; Ontario followed with 24 additional firms, British Columbia at 19, and Alberta at 9. This increase in the number of biotech firms may originate from two factors: 1) the creation of new biotech firms between 1997 and 1999 and 2) the change in the survey methodology which may have allowed more firms to be captured in 1999. However, data limitations prevent us from documenting the share of the increase attributable to each individual factor.

[10] See Annex 2 for a detailed definition of the sectors.

FIGURE 3



Source: Statistics Canada

Table 1: Changes in Biotechnology Firms Distribution by Size, Sector, and Province, 1997 to 1999

			Change	
	1997	**1999**	**1999-1997**	**%**
A) Size				
Small Firms (50 employees or less)	214	270	56	26%
Medium Firms (51-150 employees)	37	51	14	38%
Large Firms (over 150 employees)	31	37	6	19%
Total	**282**	**358**	**76**	**27%**
B) Sector				
Human Health	136	150	14	10%
Agriculture and Food Processing	74	119	45	61%
Environment	31	35	4	13%
Other	41	54	13	32%
Total	**282**	**358**	**76**	**27%**
C) Province				
British Columbia	52	71	19	37%
Alberta	19	28	9	47%
Saskatchewan	19	16	-3	-16%
Manitoba	6	6	0	0%
Ontario	87	111	24	28%
Quebec	79	107	28	35%
Maritimes	20	19	-1	-5%
Total	**282**	**358**	**76**	**27%**

Source: Statistics Canada

IV Trends in Biotechnology Revenues

Biotechnology revenues more than double between 1997 and 1999, going from $813 million to a little over $1.9 billion in 1999. Table 2 summarizes changes in biotechnology revenues by firm size, sector and region over the 1997-1999 period. In 1999 there were 49 additional firms declaring biotechnology revenues, bringing the number of such firms up by 28%. The product pipeline, i.e. products in development for the marketplace, reveals that an increasing number of Canadian biotechnology companies have products on the market and are recording revenues. There were 6,597 biotechnology products and processes on the market in 1999 compared to only 1,758 in 1997, an increase of 275%. This high percentage is clearly an indication of growth in Canadian biotechnology.

Table 2: Changes in Total Revenues and Biotech Revenues by Size, Sector and Province, 1997 to 1999

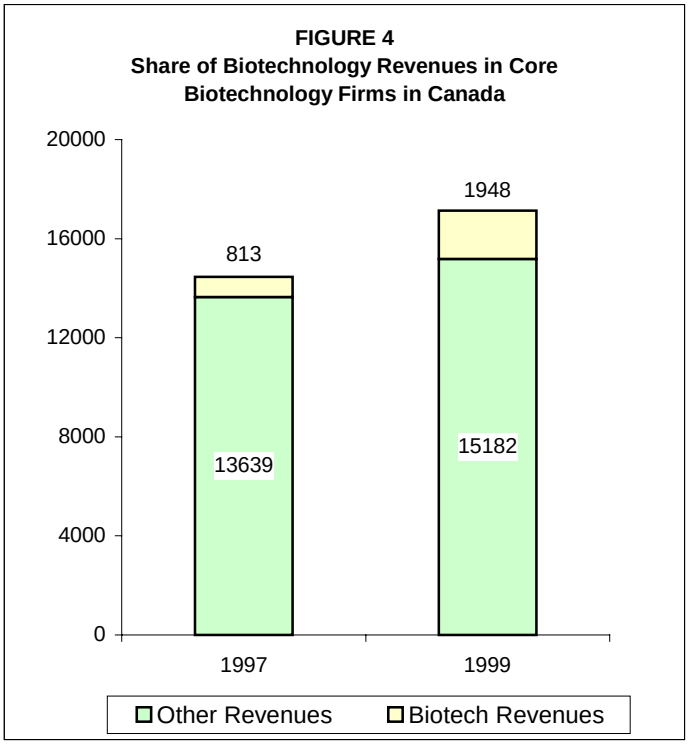
	Total Revenues (000,000)				Biotech Revenues (000,000)			
			Change				Change	
	1997	1999	1999-1997	%	1997	1999	1999-1997	%
A) Size								
Small Firms (50 employees or less)	1,756	590	-1166	-66%	214	249	35	16%
Medium Firms (51-150 employees)	685	849	164	24%	201	295	94	47%
Large Firms (over 150 employees)	12,011	17,291	5280	44%	398	1,404	1006	253%
Total	**14,452**	**18,730**	**4,278**	**30%**	**813**	**1,948**	**1,135**	**140%**
B) Sector								
Human Health	3,397	3,185	-212	-6%	417	1,036	619	148%
Agriculture and Food Processing	9,792	7,153	-2639	-27%	322	709	387	120%
Environment	1,090	287	-803	-74%	49	45	-4	-8%
Other	173	8,105	7932	4585%	25	158	133	532%
Total	**14,452**	**18,730**	**4,278**	**30%**	**813**	**1,948**	**1,135**	**140%**
C) Province								
British Columbia	118	1,880	1762	1493%	47	138	91	194%
Alberta	248	392	144	58%	56	90	34	61%
Saskatchewan	5,644	..	..	..	56	433	377	673%
Manitoba	1,908	123	-1785	-94%	33	69	36	109%
Ontario	2,665	8,121	5456	205%	363	635	272	75%
Quebec	3,805	3960	155	4%	224	554	330	147%
Maritimes	61	..	..	..	34	28	-6	-18%
Total	**14,452**	**18,730**	**4,278**	**30%**	**813**	**1,948**	**1,135**	**140%**

Source: Statistics Canada

.. Figures not available

Note: Due to rounding, figures may not add to totals

When looking at the evolution of biotechnology revenues in relation to total revenues over the last two years (Figure 4), it is interesting to see that a larger proportion of revenues is now derived from biotechnology. Indeed, the share of biotech revenues on overall revenues grew from 6% in 1997 to 10% in 1999. This might indicate, in part, that long and costly research and development (R&D) effort made by Canadian biotechnology firms are starting to pay off as new biotechnology products and processes are reaching the market.



Source: Statistics Canada

The upward trend of Canadian biotechnology revenues over the last few years could also be explained by an increase in access to capital for core biotechnology firms. Indeed, Canadian biotechnology firms were successful in raising financing capital between 1997 and 1999. The total amount of capital raised went from $467 million in 1997 to $2.1 billion in 1999, a 4.5 times increase for the period. All firm categories increased the amounts of financing raised. This upward trend held for the average amount of capital raised with larger firms leading the way.

Biotechnology products and processes take longer to develop as compared to other sectors because of the higher emphasis on research and the need to follow rigorous government health and environment regulatory processes. For example, according to the US Office of Technology Assessment, development costs for one health related product range from US$300-$350 million over a 7-10 year period. This raises unique financing challenges where companies need access to financing over the long development times, while investors are looking to recoup their investment within shorter timelines. Therefore, access to financing remains one of the biggest hurdles to commercialization and revenue growth.

4.1 Biotechnology Revenues by Firm Size

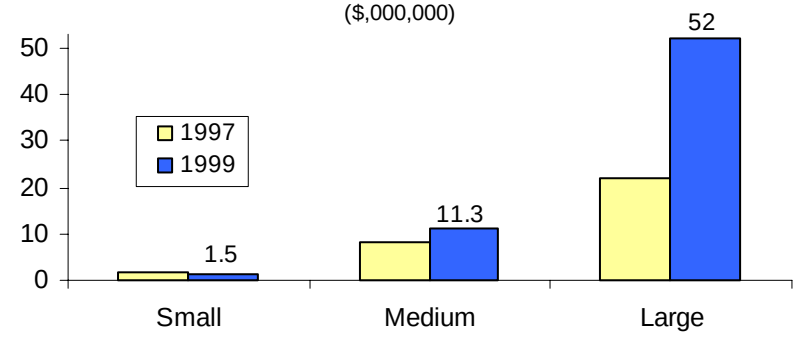
All firm categories contributed to the significant increase in biotechnology revenues from 1997 to 1999, with larger firms capturing the largest share. Specifically, large firms' revenues from biotechnology product sales were more than 3.5 times their 1997 level ($1.4 billion in biotech revenues in 1999 compared to $398 million in 1997).

Although it is interesting to look at real increases in biotechnology revenues, it is somewhat more telling to look at the evolution of the average biotechnology revenues during that period. Figure 5 suggests that increases in larger firms' biotechnology revenues are due to increases not only in the number of firms declaring revenues but also in their average biotechnology revenues. Therefore, large firms seem to have been successful in transforming basic research into products in the market over the last few years. Around 89% of large Canadian biotechnology firms were making over $3.3

million in biotechnology revenues in 1999. Product development largely depends on the resources and strategies of individual companies as well as their technical and market forces. A number of arguments to large-firm advantages with respect to commercialization of biotechnology have been offered in the literature. One is that large firms have better access to capital, human as well as monetary. A lack of access to capital and a lack of skilled human resources are among the biggest obstacles to the commercialization of biotechnology identified by Canadian companies of all size. On average, large biotechnology firms raised 5 times more capital than smaller firms ($66 million of capital raised in 1999 for large firms compared to $14 million for small ones). Also, large firms have usually access to larger markets, which facilitate the commercialization of biotechnology. Finally, large firms, through formal departments that handle staffing and training issues, are often better able to have access to manufacturing and regulatory expertise necessary at the commercialization stage.

Our results also show that there were 37 additional small firms with revenues in biotechnology in 1999 (out of the total 49). The increase in revenues for this size category between 1997 and 1999 was around 16% ($249 million in biotech revenues in 1999). However, when looking at Figure 5, we notice that smaller firms experienced a fall (-9%) in average biotechnology revenues. The 16% increase in biotechnology revenues noted above is probably due to additional firms declaring revenues being captured and not to, perhaps, having more biotechnology products registering sales. Most of small biotechnology firms in Canada are low revenue earners (less than $2.2 million in biotechnology revenues) since they are mostly R&D intensive and not yet at a manufacturing/revenue generating stage.

Figure 5
Average Biotech Revenues by Firms Size, 1997 and 1999



Source: Statistics Canada

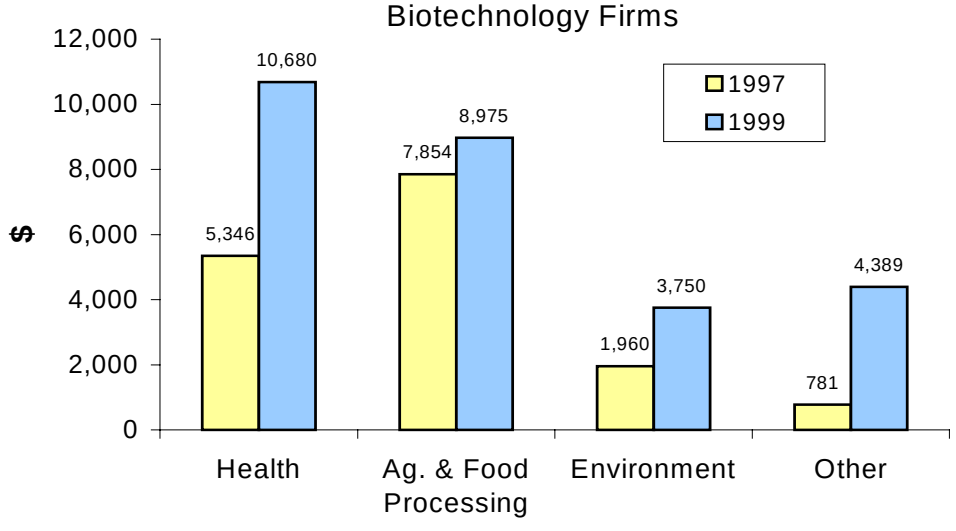
Small biotechnology firms in Canada face a serious commercialization challenge. For these firms to realize the benefits of their R&D investments in biotechnology, they need to increase their commercialization rate. Around 42% of total revenues is derived from biotechnology activities among small firms compared to only 8% for large firms. Therefore, their own survival is dependent on their ability to bring new biotechnology products or processes to the market over the next few years.

Looking at the correlation between firm size and biotechnology revenues in Annex 3, we see that revenues earning capacity and firm size are positively and monotonically associated. This means that larger firms are more likely to earn revenues from biotechnology activities than smaller firms. This makes several biotechnology activities experts question whether the current number of small biotechnology companies in Canada is sustainable. If small firms are unable to increase their revenues over the next few years, there will likely be continued pressure for consolidation, strategic alliances or outlicensing of technology. For example, strategic alliances with large companies could enable small firms to share the high costs and risks associated with biotechnology and tap into the managerial and regulatory expertise, marketing strengths and manufacturing capabilities of their larger partner (Anderson, McNiven, and Rose 2002).

4.2 Biotechnology Revenues by Sector

Revenues from biotechnology exceeded $1.9 billion in 1999, with the highest revenues emanating from the Human Health field (53% of total biotechnology revenues), followed by the Agriculture and Food Processing sector (36%). Sectoral comparisons show that the Human Health sector and the Agriculture and Food Processing sectors each had more than double their 1997's biotechnology revenues levels and that these upward trends also hold when looking at average biotechnology revenues (Figure 6).

FIGURE 6
Average Biotech Revenues by Sector from Core Biotechnology Firms



Source: Statistics Canada

Firms in the Human Health sector seem to be more involved in biotechnology since 33% of their overall revenues is derived of biotechnology sales. It is also in this particular sector that we find the highest number of firms with biotechnology revenues in 1999, 97 out of 225 as compared to 79 in the Agriculture and Food processing sector, 36 in the Other sector, and 12 in the Environment sector. Historically, firms in the Human Health sector have been more successful due to high consumer demand and high levels of government funding for basic biomedical research. They also have had more support from the capital markets. This certainly explains, in part, the increasing number of firms with product on the market in this particular sector. However, looking at the correlation in Annex 3, one cannot conclude statistically to the existence of a clear linear association between revenue earning capacity and sector of activity. Therefore, being in a particular sector alone doesn't increase firm chances to commercialize biotechnology. The commercialization capacity of a firm is more dependent on its own characteristics such as its size and its R&D expenditures. It is nevertheless interesting to note the significant rise in the number of firms declaring biotechnology revenues in this particular sector. On the other hand, with 542 products on the market, the Human Health sector laid behind both the Agriculture and Food processing and the Other sector. Products on the market are mostly diagnostics products (410 diagnostics kits). There are also some therapeutics products (132) on the market[11]. It is expected that about three-quarters of world biotechnology demand will continue to be in the health sector as its medicines, vaccines and other health-related devices and products will help reduce or eradicate many diseases and improve life expectancy.

Figure 6 also shows a rise in average biotechnology revenues of firms in the Agriculture and Food Processing sector. The recent success of Canadian biotechnology firms in this particular sector can largely be attributed to different government support programs. Canada is now a global leader in agriculture biotechnology. However, biotechnology companies in this sector still face a commercialization challenge, as they do not attract significant amounts of venture capital necessary to bring new products to the market.

Biotechnology does not only have applications in Human Health or agriculture, but in industrial processing, and in almost all resource-based sectors. Results indicate the presence of biotechnology activities in a diversity of sector. For example, biotechnology revenues from the OTHER[12] sector went up by six-fold from 1997 to 1999 (from $25 million in 1997 to $158 million in 1999) and the average biotechnology revenues saw similar trends (Table 4). This is not surprising since Canada has seen several scientific

[11] According to BIOTECanada, which represents Canadian health care, agricultural, food, research and other organizations that are involved in biotechnology, Human Health products approved in Canada include treatments for infectious diseases such as AIDS, treatments for wounds, burns and ulcers, and vaccines. Pharmaceutical products tailored to respond to the characteristics of individual patients (biopharmaceuticals) produced by Canadian companies are not on the market yet.

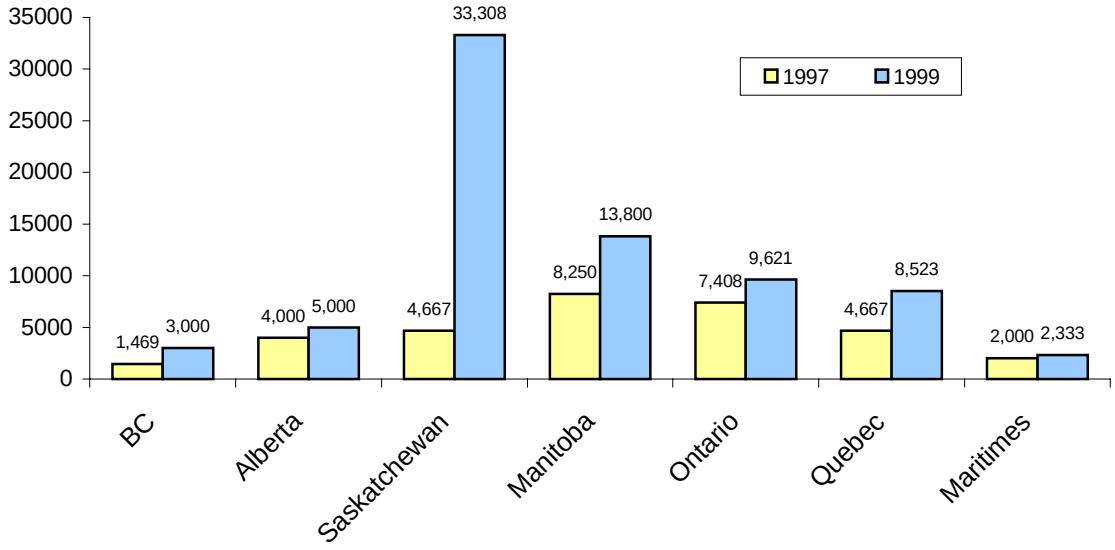
[12] Other consists of: Bioinformatics, Aquaculture, Mining/Energy/Petroleum/Chemicals, and Forest Products

breakthroughs reaching the market over the recent years, in particular in bioinformatics[13]. Bioinformatics is becoming increasingly important in being able to collect, manage, mine and analyse biological data. This sector indicates great potential in Canada, with over 3,000 products/processes at the R&D stage. The time frame to pass through the life cycle tends to be shorter for this area than for others (for example, not all bioinformatics products will be subject to regulation). Therefore, we may see a significant increase in revenues in this sector over the next few years.

4.3 Biotechnology Revenues by Region

Ontario leads the nation with 33% ($635 million) of Canadian biotechnology revenues in 1999, followed closely by Quebec with 28% ($554 million) of total biotechnology revenues. Saskatchewan ranks third with 22% ($433 million) of the total. A third of the increase in biotechnology revenues between 1997 and 1999 came from firms in Saskatchewan. This significant increase in Saskatchewan is not necessarily due to an increase in the number of firms captured by the survey but rather an increase of the average biotechnology revenues per firm (Figure 7).

Figure 7
Average Biotechnology Revenues from Core Biotechnology Firms by Province



Source: Statistics Canada

Firms in this province seem to have been very successful in transforming their R&D spending into sales. They also increased significantly their export activities between 1997 and 1999 (see section 5). Biotechnology firms in Saskatchewan are mainly in the Agriculture and Food Processing sector. The Province's success can be explained in part by the recent agriculture cluster in Saskatoon. This cluster builds on the strengths of the University of Saskatchewan and the federal and provincial agencies in and

[13] Bioinformatics includes molecular modeling, gene databases, etc.

immediately adjacent to Innovation Place, an industrial research park. Saskatoon has become in only a few years one of the world's leading centers for bio-agriculture.

The other large contributors to this increase are British Columbia, Quebec, and Manitoba. As shown in Figure 7, average revenues are on the rise in all these provinces. This indicates that biotechnology revenue increase derives from the increase in both the number of firms and the average of biotechnology revenues. Contributions from Ontario and Alberta were however more moderate.

V Trends in Biotechnology Exports

Because of its limited domestic market, Canada is driven by international trade. Revenues from biotechnology were nearly $2 billion in 1999, of which $718 million (37%) was from exports. Biotechnology exports revenues were up by $407 million, or 131% between 1997 and 1999. This finding outlines the vitality of Canadian biotechnology as expansion into international markets has been found to a source of rapid growth (Niosi, 2000). Table 3 summarizes trends in biotechnology exports between 1997 and 1999.

Table 3: Changes in Total Export Revenues and Biotech Export Revenues by Size, Sector and Province, 1997 to 1999

	Total Export Revenues (000,000)				Biotech Export Revenues (000,000)			
			Change				Change	
	1997	1999	1999-1997	%	1997	1999	1999-1997	%
A) Size								
Small Firms (50 employees or less)	810	150	-660	-81%	67	78	11	16%
Medium Firms (51-150 employees)	183	131	-52	-28%	77	51	-26	-34%
Large Firms (over 150 employees)	2,338	2,249	-89	-4%	167	589	422	253%
Total	**3,331**	**2,530**	**-801**	**-24%**	**311**	**718**	**407**	**131%**
B) Sector								
Human Health	484	578	94	19%	177	410	233	132%
Agriculture and Food Processing	2,073	1,433	-640	-31%	101	284	183	181%
Environment	750	..	..	..	24	..	..	..
Other	24	..	..	..	9	..	..	..
Total	**3,331**	**2,530**	**-801**	**-24%**	**311**	**718**	**407**	**131%**
C) Province								
British Columbia	26	290	264	1015%	24	60	36	150%
Alberta	52	101	49	94%	49	..	..	..
Saskatchewan	441	763	322	73%	2	208	206	10300%
Manitoba	1,130	53	-1077	-95%	2	43	41	2050%
Ontario	540	709	169	31%	153	164	11	7%
Quebec	1,116	612	-504	-45%	59	227	168	285%
Maritimes	26	2	-24	-92%	22	..	..	..
Total	**3,331**	**2,530**	**-801**	**-24%**	**311**	**718**	**407**	**131%**

Source: Statistics Canada

.. Figures not available

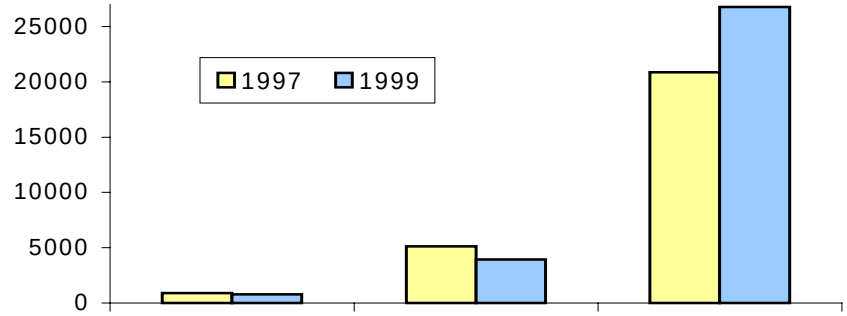
Note: because of rounding, figures may not add to totals

This rise was possible thanks to smaller and larger firms. Both firm categories expanded their presence on international biotechnology markets. However, when looking at the average biotech export revenues (Figure 8), we see that the rise in biotechnology export revenues from smaller firms results from an increase in their number. Therefore, the expanded presence of this firm category on international markets is mainly due to

additional firms being captured by the 1999 BUDS, rather than small firms registering more sales from foreign markets. On the other hand, Figure 8 suggests that increases in larger firms' biotechnology export revenues are due to increases not only in the number of firms declaring exports but also in their average biotechnology export revenues. This indicates that there are an increasing number of leading-edge biotechnology companies (mainly large firms) in Canada with worldwide markets.

FIGURE 8

Average Biotechnology Export Revenues from Core Biotechnology Firms by Size



Source: Statistics Canada

Canadian biotechnology exports are composed primarily of Human Health products (57% of total biotech exports or $410 million) and Agriculture and Food Processing products (40% of total biotech exports or $284 million). In 1999, biotechnology export revenues were much greater in these two sectors than in 1997. Both sectors expanded their activities in international biotechnology product markets by more than 2.5 times.

As shown in Table 3, the two Canadian provinces with the most export activity are Quebec (32% of total biotech export revenues) and Saskatchewan (29%). It is not surprising since these two provinces are home to the majority of companies operating in the Human Health and agriculture sectors, respectively. Biotechnology export revenues grew in all provinces between 1997 and 1999, with the largest growth taking place in Saskatchewan. Saskatchewan exports mainly agricultural biotechnology products primarily to the United States. We suspect that this strong growth is mainly due to the recent introduction on the market of canola genetically engineered for herbicide tolerance and superior oil qualities, as well as genetically engineered potatoes for insect resistance. These two products seem to have captured a significant share of Saskatchewan's export market of the conventional variety.

VI Trends in Biotechnology Research and Development (R&D)

By and large, biotechnology activities are intensive in R&D and this requires a long-term commitment. A large number of core Canadian biotechnology companies have been built on discoveries originating in Canadian universities, research hospitals and government laboratories[14]. As shown in Table 4, R&D expenses allocated to biotechnology by core biotechnology firms rose to $827 million in 1999, reflecting an increase of 67% over the $494 million spent in 1997. Nearly 68% of total R&D expenditures in the core group of Canadian firms was devoted to biotechnology in 1999, compared to 53% in 1997. However, we notice an increasing return on research and development investment over the 1997-1999 period. Indeed, the ratio revenues-to-R&D indicates that each dollar spent on biotechnology R&D in years past resulted in $2.36 of biotechnology revenues in 1999, compared to $1.65 in 1997, implying an increase capability of biotech firms to finance some of their activities, in particular, biotech R-D expenditures from their own resources, instead relying of external sources of funding.

Federal government spending on biotechnology R&D activities is also growing rapidly in all of the federal government departments and agencies that have a significant role in this sector. According to Statistics Canada, the federal government spent more than $378 million on biotechnology R&D in 2000/2001, an increase of 22% over the 1998/1999 level. The Canada Foundation for Innovation, Canada Research Chairs, Network Centres of Excellence, as well as the Canadian Institutes of Health Research (CIHR) have all contributed to the upward trend of biotechnology R&D spending in Canada over the recent years.

[14] Byrd (2002) finds that spin-off firms are important as they made up over 34% of the core group of firms from the 1999 biotechnology survey. They also made up over 112 of the 270 small size firms, by far the largest group of core biotechnology firms, and half of the Human Health related firms, the largest sector of biotechnology firms.

Table 4: Changes in Total R&D Expenditures and Biotech R&D Expenditures by Size, Sector and Province, 1997 to 1999

	Total R&D Expenditures (000,000)				Biotech R&D Expenditures (000,000)			
			Change				Change	
	1997	1999	1999-1997	%	1997	1999	1999-1997	%
A) Size								
Small Firms (50 employees or less)	307	294	-13	-4%	193	256	63	33%
Medium Firms (51-150 employees)	171	184	13	8%	124	106	-18	-15%
Large Firms (over 150 employees)	448	733	285	64%	177	465	288	163%
Total	**926**	**1,210**	**284**	**31%**	**494**	**827**	**333**	**67%**
B) Sector								
Human Health	733	917	184	25%	409	703	294	72%
Agriculture and Food Processing	93	124	31	33%	53	73	20	38%
Environment	42	13	-29	-69%	10	..	..	..
Other	57	156	99	174%	22	..	..	..
Total	**926**	**1210**	**284**	**31%**	**494**	**827**	**333**	**67%**
C) Province								
British Columbia	88	158	70	80%	77	131	54	70%
Alberta	28	102	74	264%	20	81	61	305%
Saskatchewan	35	43	1	50%	19	28	9	47%
Manitoba	14	31	17	121%	12	20	8	67%
Ontario	364	423	59	16%	220	223	3	1%
Quebec	383	448	65	17%	132	337	205	155%
Maritimes	14	6	0	0%	14	6	-8	-57%
Total	**926**	**1,210**	**284**	**31%**	**494**	**827**	**333**	**67%**

Source: Statistics Canada

.. Figures not available

Note: Due to rounding, figures may not add to totals

6.1 Biotechnology R&D by Firm Size

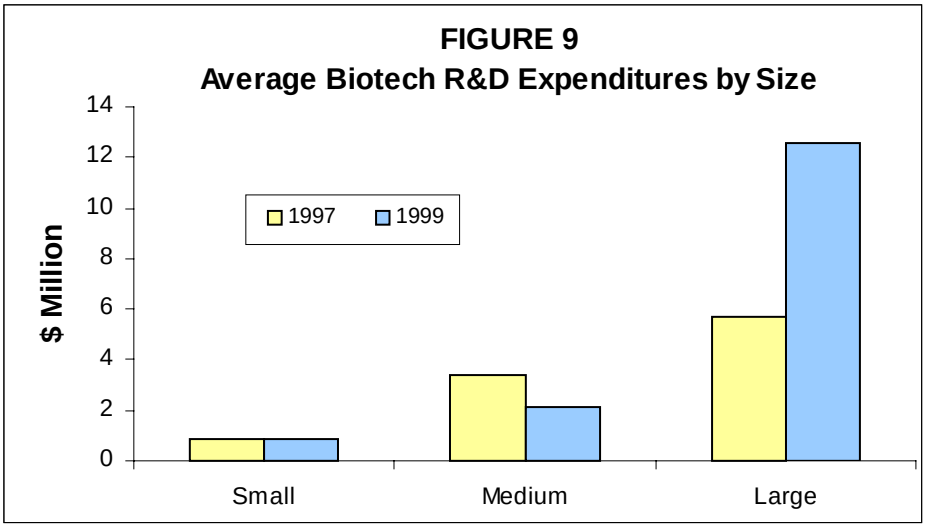
The increase in biotechnology R&D expenditures between 1997 and 1999 is largely attributable to large firms, which increased their spending on biotechnology research almost three-fold ($465 million), contributing 86% to the overall increase. This indicates the high interest of large firms into biotechnology. Firms in this size category spent $12 million on average on biotechnology R&D, more than twice the level spent by these same firms in 1997 (Figure 9). Larger firms are able to afford larger amount on biotechnology R&D and so, almost half of them spent more than $3 million on biotech R&D in 1999. Moreover, large firms are better able to finance their biotechnology innovation through financing markets. Large core biotechnology firms raised, on average, $66 million in capital for biotechnology in 1999 compared to $14 million for small firms.

Small biotechnology firms also increased their spending in biotechnology R&D, from $193 million in 1997 to $256 million in 1999. However, this increase is mainly due to the rise in the number of small firms captured by the 1999 BUDS rather than an increase of spending by small firms. It should be noted that among large businesses, investment in biotechnology R&D represents about half of the revenues from biotechnology, while among small businesses, spending on biotechnology R&D exceeded income in 1999. This underlines the intense level of research activities in small businesses. The biggest challenge for small biotechnology firms is to have products on the market and generate revenues, as in many cases R&D expenditures exceed revenues.

It is clear from the above observations that firm size is likely to influence positively the amount a firm spends on biotechnology R&D as shown in Annex 3. As firms grow larger, they are likely to increase the amount they spend on biotechnology R&D. Since R&D expenditures are positively correlated with revenues (i.e. the more a firm spend on biotechnology R&D, the more likely it is to earn biotechnology revenues), large firms seem to have a net advantage over small firms.

Another interesting finding from Annex 3 is that being a spin-off company is negatively correlated to biotechnology R&D spending. In other words, a spin-off firm is less likely to spend more on biotechnology R&D than its counterparts. A possible explanation is that these firms are able to benefit from R&D spill- their parent company or share in part of the R&D expenditures necessary to pursue a project. The end result being smaller amounts being spent on biotechnology R&D at the firm level.

FIGURE 9
Average Biotech R&D Expenditures by Size



Source: Statistics Canada

6.2 Biotechnology R&D by Sector

Human Health has the lion's share (85% of R&D spending by core firms in 1999) of R&D expenditures on biotechnology in Canada. The increase in overall biotechnology R&D over the last two years came mainly from this sector which spent $703 million in 1999, an increase of 72% over the $409 million figure of 1997. This increase is the compounded effects of the rise in both number of firms in Human Health and the average spending in biotechnology R&D of firms in this sector. Most firms in this sector (44% of them) spent more than $3 million in biotechnology R&D in 1999. When looking at the ratio of revenues-to-R&D in the health sector, we see that one dollar spent on biotechnology R&D in 1999 resulted in $1.47 of biotechnology revenues in 1999. Therefore, the return on R&D investment in the Human Health sector is inferior to the overall average ($2.36). This reflects both the high cost of R&D relative to marketable products, and the concentration in the area of greatest potential and interest to Canadians.

Government commitment to biotechnology in the Human Health field is also significant with, for example, the creation of Genome Canada in 2000 to fund research activity in genomics across the country. Universities and research hospitals have also played a significant role in the increase of Canadian biotechnology firms spending on biotechnology R&D in the Human Health sector. In 1999, of the 150 biotechnology firms operating in Human Health sector, 75 were from spin-off from universities, hospitals or government labs. Among all the sectors, Human Health accounted the largest percentage of biotech spin-off firms.

On the other hand, although the Agriculture and Food Processing sector accounts for 33% of the biotechnology companies and 36% of biotechnology revenues, it only accounts for 9% of R&D spending ($73 million in 1999). The increase of 38% of biotech R&D spending in this sector is only explained by a greater number of firms being captured in 1999 than in 1997. Firms in this sector are mostly low spenders on biotechnology R&D: almost half of firms spent less than $475,000 in 1999. In contrast to Human Health products, we suspect that Agriculture and Food Processing development costs are relatively low. Our results show that average R&D costs per biotechnology products in the Agriculture and Food Processing sector are around $16,000 as compared to more than $250,000 in the Human Health sector. This result also indicates that, in the Canadian agri-food sector, much of the R&D capability is still located in government laboratories and universities. Indeed, Canada has a strong base in agricultural biotechnology as a result of research conducted by the universities of Guelph and Saskatchewan, the National Research Council's Plant Biotechnology Institute and Agriculture and Agri-Food Canada. For example, in 2000-2001, Agriculture and Agri-Food Canada was one of the largest supporter of biotechnology expenditures in the agri-food sector with $57 million, which were only for intramural activities[15].

6.3 Biotechnology R&D by Region

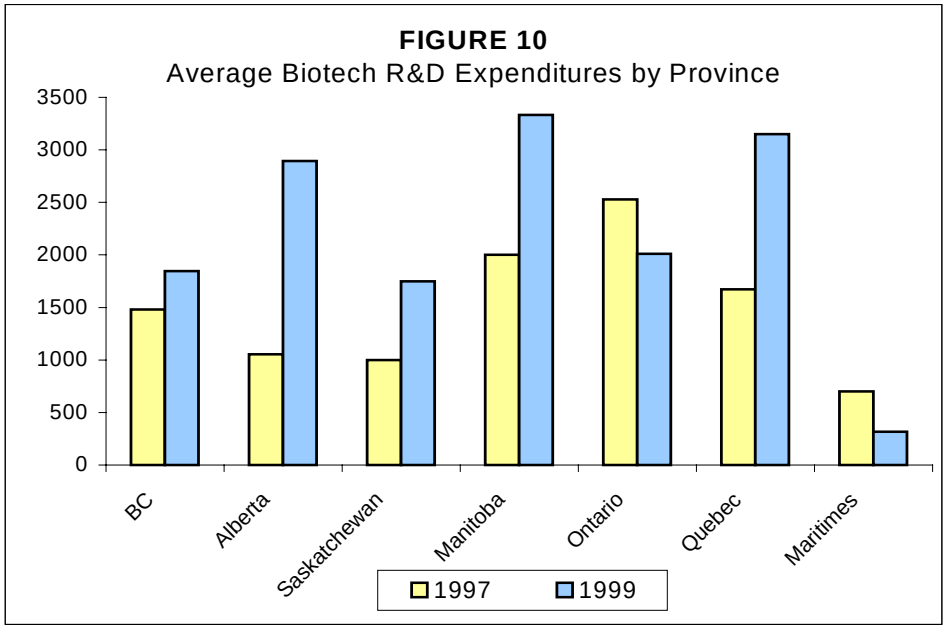
Most R&D expenditures take place in Quebec and Ontario. This is not surprising since the bulk part of the Canadian biotechnology companies is in these two provinces. However, despite having a similar number of companies, there are important differences between these two provinces regarding investment in R&D. Quebec companies spent $337 million on R&D in 1999 compare to the $223 million spent in Ontario. This is a radical shift from the 1997 portrait where Ontario was leading the way with $220 million (45%) of biotechnology R&D expenditures compared to the $132 million spent by Quebec firms. In 1999, biotechnology R&D spending in Quebec was almost twice its 1997 level. This rise in biotechnology R&D expenditures in Quebec is the results of the increase in both the number of firms and average spending on biotechnology R&D (Figure 10). On the other hand, biotechnology R&D expenditures in Ontario remained at their 1997 level. Most firms in Ontario (44%) were in the low spending group in 1999 with expenditures less than $475,000, where over one third of Quebec firms were high spenders with over $3 million in R&D expenditures. As explained by Hall and Bagchi-Sen (2002), the province of Quebec has established itself as a leader in biotechnology, in particular in the bio-pharmaceutical sector. This success can be the result of a focused

[15] Statistics Canada. The Service Bulletin, Science Statistics. Vol. 26, No. 2. April 2002.

provincial strategy to link the resources, infrastructure, and technical knowledge of government, universities, and industry players in support of industry growth. While Ontario is larger in size in terms of number of firms and biotech revenues than Quebec. However, provincial initiatives are being implemented to solidify relationships between biotechnology leaders and university or government research institutes toward the common goals of industry cohesion and growth. Ontario government has set the ambitious goal of making Ontario one of the top three jurisdictions for biotechnology in North America.

British Columbia has also a strong research base and ranks third in Canada in terms of R&D spending in biotechnology with $131 million in biotechnology R&D expenditures in 1999. British Columbia is home to one of Canada's fastest growing biotechnology community. A lot of biotechnology companies in British Columbia are the result of spin-offs from B.C. universities (Byrd, 2002).

Finally, it is important to note the significant increase in both total biotechnology R&D expenditures and average biotechnology R&D expenditures in Alberta. Biotechnology firms in this province spent $81 million in biotechnology R&D in 1999. Biotechnology firm primary focus in Alberta is on the Agriculture and Food Processing sector. Alberta recent success can be explain in part by the establishment of the Alberta Agricultural Research Institute to fund, coordinate and promote strategic agricultural research initiatives and technology transfer in the agriculture and food sector.



Source: Statistics Canada

VII Evolution of Human Resources

During the 1997-1999 period, biotechnology personnel fell by 1,324 people, going from 9,019 in 1997 down to 7,695 in 1999 (Table 5). This 15% decrease in employment is attributed to medium-sized and large firms. The former category experienced a 42% decrease in biotechnology personnel and the latter 9% loss. Employment by small firms was steady for the period. This loss in employment is surprising since Canadian biotechnology firms have grown in number over the last few years.

Except for the Environment sector, which experienced an 11% increase, employment in all the Other sectors was down. The Human Health led the way with 847 fewer biotechnology employees, i.e. 13% fewer than in 1997. The OTHER sector followed with 290 fewer people, and the Agriculture and Food Processing sector with 219. Again, this is surprising since companies in the Human Health sector and the OTHER sector have experienced growth in terms of revenues, R&D spending and number of firms.

Table 5: Changes in Biotech Employment by Size, Sector, and Province, 1997 to 1999

	Number of Biotech Employees			
			Change	
	1997	1999	1999-1997	%
A) Size				
Small Firms (50 employees or less)	2,895	2,902	7	0%
Medium Firms (51-150 employees)	2,299	1,323	-976	-42%
Large Firms (over 150 employees)	3,825	3,470	-355	-9%
TOTAL	**9,019**	**7,695**	**-1,324**	**-15%**
B) Sector				
Human Health	6,280	5,433	-847	-13%
Agriculture and Food Processing	1,542	1,323	-219	-14%
Environment	291	323	32	11%
Other	906	616	-290	-32%
TOTAL	**9,019**	**7,695**	**-1,324**	**-15%**
C) Province				
British Columbia	1,042	1,191	149	14%
Alberta	789	574	-215	-27%
Saskatchewan	351	289	-62	-18%
Manitoba	209	357	148	71%
Ontario	3,416	2,547	-869	-25%
Quebec	2,722	2,557	-165	-6%
Maritimes	490	181	-309	-63%
TOTAL	**9,019**	**7,695**	**-1,324**	**-15%**

Source: Statistics Canada

All provinces lost biotechnology employees between 1997 and 1999 except British Columbia and Manitoba, which gained 149 and 148 more people, respectively. Firms in Ontario lost the largest number of biotechnology employees, 869. The lost of employment seemed to be felt almost everywhere in Canada.

Because of the counter-intuitive nature of the results, we further investigated the downward trend in biotechnology employment by estimating the correlation coefficients between loss of employment and a number of factors. This enabled us to investigate the relationship between various biotechnology firm characteristics. Results are shown in Annex 4.

Four main factors are positively and significantly correlated with employment decline: 1) being a spin-off firm; 2) contracting out of regulatory/clinical affair; 3) contracting out of marketing/distribution activities; and, 4) forming a joint-venture. In other words, spin-off firms were more likely than their counterparts to have experienced a loss of biotechnology personnel. Likewise, firms that formed joint-ventures, or contracted out regulatory/clinical affairs, and marketing/distribution activities were more likely to have seen personnel leave in 1999. These findings suggest that biotechnology personnel that left in 1999 were mostly involved in marketing/distribution activities and

regulatory/clinical affairs and that this can be seen as a shift in employment as opposed to clear looses of jobs. This contention is supported by the facts that i) contracting out R&D activities and loss of biotechnology personnel are not correlated and ii) contracting out management/licensing/administration activities and loss of employment are also not correlated. Further support to our contention is provided by the facts that i) spin-off firms do not contract out R&D activities as implied by the negative and significant correlation coefficient between the two variables and ii) firms that form joint-ventures are not involved in contracting out R&D activities.

The above results lead to two main conclusions. First, in the midst of the loss of personnel, biotechnology firms were able to retain personnel related to important activities such as R&D and management/licensing/administration. Given that these activities are key to their survival as economic units and the related personnel is the source of specific knowledge with a high content of tacitness, an important factor of production and performance, it may be inferred that core biotechnology activities were not affected by the loss of personnel in 1999. Secondly, given that contracting out is found to be a major reason why personnel left biotechnology firms in 1999, the loss of employment seems to be a transfer of service personnel and have taken place between biotechnology firms and most likely service companies (such as contracting research organizations (CROs)) which were not covered by either the 1997 nor the 1999 surveys. Has such entities been surveyed we might have seen an increase in their employment levels during the 1997-1999 period.

CONCLUSION

In this paper we investigate how Canadian biotechnology companies have evolved in recent years, using Statistics Canada's Biotechnology Use and Development bi-annual surveys.

Our comparison shows that biotechnology companies in Canada are experiencing extremely rapid growth. New Canadian biotechnology products and processes are now reaching the market. There is also an increasing return on research and development investment in biotechnology. However, although the sector is fairing a nice evolution, commercialization of biotechnology products remains a concern.

Our analysis points out to some interesting findings. For example, the increase of biotechnology activity in Canada between 1997 and 1999 as measured by biotech revenues and R-D expenditures, is largely attributable to large firms. Large, diversified Canadian companies are starting to adopt biotechnology. They now invest greatly in biotechnology research and development and introduce more and more biotechnology products to the market. On the other hand, small firms face a serious commercialization challenge. Most of them are low revenues earners and have not yet reached the manufacturing/revenue generating stage in the two-year period studied. Our analytical results show that both biotechnology revenue earning and biotechnology R&D spending capacities are directly and positively associated to firm size. In other words, as firms

grow larger, they are likely to increase the amount they spend on biotechnology R&D and earn more revenues from biotechnology than smaller firms. Therefore, there will likely be continued pressure on small biotechnology firms for consolidation or strategic alliances.

The Human Health sector remains the dominant sector in biotechnology in Canada. Firms in this sector have the highest revenues and devote significant resources to research and development. However, they have less products on the market than biotech firms in other sectors. We find important activities in the Agriculture and Food Processing sector, with Canada now being a world leader in this field. Our results also show biotechnology activities in a diversity of sector such as bioinformatics, aquaculture, and forest products. Revenues have been growing faster in these sectors than in any other type of biotechnology, although from a very small initial base.

Biotechnology activities are found in all Canadian provinces, with Quebec showing the greatest promises with biotechnology R&D expenditures on the rise. Our comparison also shows that core biotechnology firms saw a decrease in biotechnology personnel over the two-year period studied. However, findings suggest that the loss of personnel was more a transfer of service personnel, which may have taken place between biotechnology firms and service companies such as CROs. Firms retained key personnel related to R&D and management/licensing/administration activities.

From our results, we can conclude that much more biotechnology activity is now being captured in Canada. With a rate of growth much higher than that of the general economy, Canadian biotechnology holds considerable promise and is likely to experience strong growth in the coming years. Statistics Canada is currently working on its 2001 BUDS and results should come out by the end of 2002. This will improve our understanding of the evolution of the Canadian biotechnology activities.

ANNEX 1

Distribution of Common firms, by Size, Sector, and Province, 1999

	Number of Firms	
	Actual Count	**Percentage Count**
A) Size		
Small Firms (50 employees or less)	156	76%
Medium Firms (51-150 employees)	28	14%
Large Firms (over 150 employees)	22	11%
Total	**206**	**100%**
B) Sector		
Human Health	83	40%
Agriculture and Food Processing	69	33%
Environment	23	11%
Other	31	15%
Total	**206**	**100%**
C) Province		
British Columbia	42	20%
Alberta	19	9%
Saskatchewan	10	5%
Manitoba	..	..
Ontario	67	33%
Quebec	51	25%
Maritimes	..	..
Total	**206**	**100%**

Source: Statistics Canada

.. Figures not available

ANNEX 2

Biotechnology Sector	
Human Health	**Diagnostics** (e.g. biosensors, immunodiagnostics, gene probes**)** **Therapeutics** (e.g. vaccines, immune stimulants, biopharmaceuticals, rational drug design, drug delivery, combinatorial chemistry)
Agriculture Biotechnology	**Plant Biotechnology** (e.g. tissue culture, embryogenesis, genetic markers, genetic engineering) **Animal Biotechnology** (e.g. diagnostics, therapeutics, embryo transplantation, genetic markers, genetic engineering) **Non-food Agriculture** (e.g. fuels, lubricants, commodity and fine chemical feedstocks, cosmetics)
Natural Resources	**Energy** (e.g. microbiologically enhanced petroleum recovery, industrial bioprocessing, biodesulphurization) **Mining** (e.g. microbiologically enhanced mineral recovery, industrial bioprocessing, biodesulphurization) **Forest Products** (e.g. biopulping, biobleaching, biopesticides, tree biotechnology, industrial bioprocessing)
Environment	**Air** (e.g. bioremediation, diagnostics, phytoremediation, biofiltration) **Water** (e.g. biofiltration, diagnostics, bioremediation, phytoremediation) **Soil** (e.g. biofiltration, diagnostics, bioremediation, phytoremediation)
Aquaculture	Fish health, broodstock genetics, bioextraction
Bioinformatics	**Genomics & Molecular Modelling** (e.g. DNA/RNA/protein synthesizing & databases for humans, plants, animals, and micro-organisms) **Gene Therapy** (e.g. gene identification, gene constructs, gene delivery)
Food Processing	**Bioprocessing** (e.g. using enzymes and bacterial cultures) **Functional Foods/Nutraceuticals** (e.g. probiotics, unsaturated fatty acids)
Other	

ANNEX 3

Correlation Coefficients, Biotech Revenues, 1999

	Size	Sector	Province	Collaborative Agreements	Spin-off	1999 Biotech R&D Expenditures	1999 Biotech Revenues
Size	1						
Sector	0.048	1					
Province	0.124*	0.073	1				
Collaborative Agreements	0.223**	(.14**)	0.033	1			
Spin-off	.250**	.259**	0.068	(0.067)	1		
1999 Biotech R&D Expenditures	.181**	(0.427**)	-0.023	.295**	(0.259**)	1	
1999 Biotech Revenues	.233**	-0.067	-0.021	0.09	0.013	.349**	1

* Correlation coefficient is significant at the 1% level (2-tailed)

** Correlation coefficient is significant at the 5% level (2-tailed)

ANNEX 4

Correlation Coefficients, Loss of Employees, 1999

	Collaborative Agreements	Spin-off	Contract out R&D Activities	Contract out Regulatory/ Clinical Affairs	Contract out Marketing/ Distribution Activities	Contract out Management/ Licensing Administration/ Activities	Firm Forms Joint-venture	Biotech Personnel left firm in 1999
Collaborative Agreements	1							
Spin-off	(0.067)	1						
Contract out R&D Activities	(0.214**)	(-0.128)**	1					
Contract out Regulatory/ Clinical Affairs	(0.033)	0.022	0.255**	1				
Contract out Marketing/ Distribution Activities	(0.102)	0.14*	0.133**	0.294**	1			
Contract out Management/ Licensing/Administration Activities	0.038	0.105	0.165**	0.364**	0.246**	1		
Firm Forms Joint-venture	.222**	0.045	-0.047	0.018	-0.035	-0.056	1	
Biotech Personnel left firm in 1999	0.094	**0.194****	-0.092	**0.148****	**0.26****	0.069	**.131***	1

* Correlation coefficient is significant at the 1% level (2-tailed)

** Correlation coefficient is significant at the 5% level (2-tailed

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