DIFFUSION OF BIOTECHNOLOGIES IN CANADA:

RESULTS FROM THE SURVEY OF BIOTECHNOLOGY USE IN CANADIAN INDUSTRIES - 1996

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THE INFORMATION SYSTEM FOR SCIENCE AND TECHNOLOGY PROJECT

The purpose of this project is to develop useful indicators of activity and a framework to tie them together into a coherent picture of science and technology in Canada.

To achieve the purpose, statistical measurements are being developed in five key areas: innovation systems; innovation; government S&T activities; industry; and human resources, including employment and higher education. The work is being done at Statistics Canada, in collaboration with Industry Canada and with 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 and potentially misleading picture of science and technology in Canada. More measures were needed to improve the picture.

Innovation makes firms competitive and more work has to be done to understand the characteristics of innovative, and non-innovative firms, especially in the service sector which dominates the Canadian Economy. The capacity to innovate resides in people and measures are being developed of the characteristics of people in those industries which 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 how much the federal government spends and where it spends it. The current report, Federal Scientific Activities (Catalogue 88-204), released early in 1997, begins to show what the S&T money is spent on with the new Socio-Economic Objectives indicators. As well as offering a basis for a public debate on the priorities of government spending, all of this information will provide a context for reports of individual departments and agencies on performance measures which focus on outcomes at the level of individual projects.

By the final year of the Project in 1998-99, there will be enough information in place to report on the Canadian system on innovation and show the role of the federal government in that system. As well, there will be new measures in place which will provide a more complete and realistic picture of science and technology activity in Canada.

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Executive Summary

Biotechnology is widely seen as a pervasive new technology with current or potential applications in a large number of industries. Yet, if biotechnology is as pervasive as expected, we should start to see its diffusion to firms that use biotechnology in their production processes, as part of their products, or in their pollution control systems. The Survey of Biotechnology Use in Canadian Industries - 1996 focuses on the diffusion of biotechnology in a limited number of resource and manufacturing sectors where biotechnology has proven or potential applications. The survey asks respondents about their firm's use of 22 carefully defined biotechnologies, ranging from recombinant DNA to classical and traditional breeding of plants and animals. These biotechnologies are organised into three technology classes: eight selection and modification technologies, five environmental technologies, and nine culture and biological material technologies.

The survey was sent to all firms in Canada with more than five million dollars in sales in 1995 and which fell within 17 industrial sectors. For most analyses, these 17 sectors are combined into eight sectors: four in resources (mining, crude petroleum extraction, petroleum refining, wood, pulp & paper), and four in manufacturing (food, pharmaceuticals, non-pharmaceutical chemicals, and other manufacturing). Responses were received from 2,010 firms, or 88% of the original sample. The questions on investment, benefits, and information sources are only asked of 271 firms that use one or more biotechnologies (bio-users).

The strength of the survey lies in its coverage of the application of biotechnology by mid and large firms. It is especially useful for evaluating the diffusion of environmental applications.

Basic characteristics of firms that use biotechnology

Overall, 14% of the respondent firms use one or more biotechnologies. The two most important predictors of whether or not a firm uses biotechnology are its size and its industrial sector. The percentage of users increases with firm size, from 8% of firms with less than 50 employees to 44% of firms with more than 1,000 employees. Biotechnology use is concentrated in only a few of the 17 sectors. Two sectors, food and paper & allied products, account for 52% of firms that use biotechnology, while eight sectors account for 95% of all bio-user firms. At the eight-sector level, the percentage of firms that use biotechnology ranges from 2% for other manufacturing to 31% in pharmaceuticals. Bio-user firms have a higher level of technical expertise than non-user firms: an average of 17% versus 13% of employees are university graduates, 72% versus 52% of firms perform R&D, and 55% versus 21% of firms participated in alliances for R&D.

Use of specific biotechnologies

The food and pharmaceutical sectors dominate the use of selection & modification and culture & biological material technologies, with these two sectors accounting for 81% of users of selection and modification technologies. In contrast, environmental biotechnologies have diffused more broadly, although their use is still dominated by firms in the resource sectors. Approximately 25% of all resource firms use an environmental biotechnology, compared to only 6% of firms in the food sector and 6% of firms in non-pharmaceutical chemicals.

Utilization stage for specific biotechnologies

The questionnaire asks bio-user firms to indicate the utilization stage reached for each biotechnology in use. Four options are given: research, part of the production process, part of the product sold, and for pollution control. The last three are all applications. Firms active in one or more of the selection and modification technologies are least likely to have moved to an application stage, with only 66% in at least one application, compared to 96% of firms that use environment biotechnologies and 83% of firms that use culture and biological material technologies.

There are no notable differences in the average years of use of a biotechnology by firm size. In contrast, there are large differences by sector, ranging from an average of 17 years for firms in the food sector to 2.8 years for mining firms.

Future plans to use biotechnology

Very few firms plan to adopt biotechnology within two years. For both bio-users and non-users combined, only 12 plan to adopt a selection & modification technology, 40 plan to adopt an environmental technology, and 29 plan to adopt a culture & biological material technology. The greatest potential for future adoption, once firms that state that they do not plan to adopt because biotechnology is currently too expensive are included, is for environmental biotechnology. Here, 67 firms (3% of the total) are potential adopters.

The majority of potential adopters are existing bio-users that plan to adopt a different biotechnology than the ones in current use. However, most of the planned or potential adoption is within the same class of biotechnologies already used by the firm, with very little potential adoption of biotechnologies from a different technology class.

Barriers to acquiring and implementing biotechnology

Both non-user and bio-user firms were asked about the importance of 19 impediments to biotechnology acquisition. The results for non-users point to a problem either with information on biotechnologies or with a lack of commercially applicable biotechnologies. The most important impediments for bio-users are high equipment costs (cited by 43%), government regulations or standards (38%), lack of financial justification (35%), insufficient development of biotechnology (33%), and a lack of equity capital (30%). Four of these factors concern the relative cost of biotechnology compared to alternative technical solutions. Three impediments linked to the availability of skills are notably less frequent, cited by less than 21% of the firms. Only 19% cite an insufficient market for the product, indicating that biotechnology use will increase as acquisition costs decline.

Bio-user firms were also asked if each of nine factors had a ‘particular significance’ as a barrier to the implementation of biotechnologies in each of the three technology classes. The most prevalent response is ‘no barriers to implementation’ (cited by 44%), followed by regulatory constraints (29%). The next three most frequently cited barriers are linked to the availability of expertise: the need for advice and information (27%), training (27%), and skill availability (27%). There are very few differences in the importance of these barriers by sector, except that a higher percentage of mining firms (46%) and pharmaceutical firms (56%) cite a lack of skill availability.

Generally, firms in the resource sectors are more concerned about regulation than firms in manufacturing, with the exception of small pharmaceutical firms. Since resources firms are major users of environmental technologies, this suggests that regulation could be impeding the diffusion of environmental biotechnology. Food firms and large pharmaceutical firms are much less concerned about regulation than firms in other sectors.

Investment in biotechnology equipment and software

Only 12% of bio-user firms made no investment in biotechnology in 1996. Of the remaining firms, over 60% invested less than 0.1 million dollars. The data permit a crude estimate of the average investment per employee. This is highest in pharmaceuticals, at over 4,000 dollars, and lowest in mining, at less than 200 dollars per employee. The highest level of investment in the resource sector is for the wood, pulp & paper industry at 1,600 dollars per employee. A lack of cost-effective environmental biotechnologies is the most probable explanation of the low levels of investment in several resource sectors.

Average investment per employee for environmental biotechnology is similar across all firm sizes. In contrast, average investment in selection & modification and culture & biological material technologies is considerably higher among firms with less than 50 employees, averaging over 19,000 dollars per employee compared to less than 5,000 dollars for firms with 50 or more employees. These results highlight the importance of small firms in the development of the most technically-advanced biotechnologies.

Benefits of biotechnology

The survey asks respondents to indicate which of 15 possible benefits have resulted from their firm's use of biotechnology. A reduction in environmental damage is reported by 72% of firms that use environmental biotechnology. The use of environmental biotechnology appears to have substantial secondary benefits in terms of lower costs or an improvement in productivity: 45% of firms that cite a reduction in environmental damage from the use of environmental biotechnology also report lower costs, while 36% report an increase in quality or productivity.

The most commonly cited benefits from the use of selection & modification and culture & biological material technologies is an improvement in product quality, cited by over 43% of these two groups. This is followed by a group of several benefits concerned with higher efficiency, cited by 25% to 37% of the firms.

A high percentage of users of all three types of biotechnology find that the use of biotechnology increases the need for skilled labour and capital. For all firms combined, 27% report an increase in the need for skilled labour versus 5% who report a decline, and 23% report an increase in the need for capital versus 12% who report a decline.

The negative benefit of 'no improvements' was reported most frequently by pharmaceutical and food firms (26% and 22% respectively). This suggests that biotechnology is riskier and more experimental in these two sectors than in the other sectors.

Internal and external information sources

The single most important influence on the use of eight internal sources for learning about biotechnology is whether or not the firm performs R&D. R&D performers are more likely to cite research, experimental development, design, production engineering, and the corporate head office as important internal sources. The size of the firm and the sector of activity has very little influence on the use of internal sources.

The most frequently cited 'principal' external sources, out of a list of 14 options, are publications followed by consultants & service firms, supplier firms, trade fairs & conferences, and universities. The principal sources for firms active in selection & modification technologies are very similar to those for firms active in culture & biological material. Firms that use environmental biotechnologies differ from these other two groups, particularly in their use of consultant and service firms. These are cited as a principal information source by 58% of environmental firms compared to less than 34% of firms active in the other two technology classes. R&D performing firms cite a significantly higher number of external sources than non R&D performers.

On average, 49% of firms cite at least one of four public organizations: universities, provincial research organizations, federal information programs, and federal research organizations. Two publicly-funded sources, provincial research organizations and federal information programs, are infrequently cited but their use is equally distributed across all types of firms by size and sector. Provincial research organizations are most frequently cited by firms in the Prairies (31%) and least frequently cited by firms in BC and Ontario. There is no difference in the use of three other publicly-funded organizations by region. Universities, a source of advanced biotechnology, are most likely to be cited by R&D performing firms that are active in a number of biotechnologies. Firm size has no effect on the use of all public information sources, except for environmental technologies, where larger firms are more likely to cite universities.

Conclusions

The diffusion of biotechnology in Canada is limited, with relatively low potential adoption rates in the near future of a few percent a year. Neither regulation, with the exception of the resource sectors, nor the high cost of biotechnology equipment, are major factors in preventing the diffusion of biotechnology. The most important factors are the need for technical and scientific expertise both within and outside of the firm, a lack of information about biotechnology by non-users, and, perhaps most importantly, a lack of commercially viable applications.

1. Introduction

Biotechnology is widely seen as a pervasive new technology with current or potential applications in a large number of industries. These include pharmaceuticals, chemicals, mining, forestry, fisheries, agriculture and food processing. Broadly defined, biotechnology includes “a range of techniques dealing with recombinant DNA, cell fusion, plant and animal cell cloning, monoclonal antibodies, tissue culture, and bioprocess engineering”. This definition from the Science Council of Canada is used in the 1996 Research and Development Survey, which estimates that 348 firms in Canada conducted R&D in biotechnology in 1995[1].

Most economic research on biotechnology similarly focuses on firms that are involved in the discovery and development of new biotechnology, particularly genetic engineering[2]. Yet, if biotechnology is as pervasive as expected, we should start to see its diffusion to firms that use biotechnology in their production processes, as part of their products, or in their pollution control systems. The Canadian Survey of Biotechnology Use, which is the focus of this report, differs from previous research in Canada and abroad by focusing on the diffusion of biotechnology in a limited number of resource and manufacturing sectors where biotechnology has proven or potential applications.

An accurate appraisal of the diffusion of biotechnology requires careful definitions of what is meant by biotechnology. It is not sufficient to simply ask firms if they use ‘biotechnology’ because there are two main definitions of biotechnology in widespread use. A narrow definition is limited to the use of genetic engineering to develop novel plant, animal, or microbial varieties. The recent interest and excitement over biotechnology is due to the possibilities of genetic engineering, which dates back to the early 1970s, and other recent discoveries such as cell fusion, tissue culture, and monoclonal antibodies.

For a variety of reasons, the modern interpretation of the term ‘biotechnology’ has been broadened, after the discovery of genetic engineering, to include plant breeding and bioprocesses such as brewing or basic industrial fermentation processes[3]. These technologies have a long development history measured in centuries or millennia. This conflicts with the widespread impression of biotechnology as a high technology sector with many completely new applications.

We are left with two common but conflicting definitions of biotechnology. One refers to a group of recent technologies such as genetic engineering, while the second includes a wide range of both traditional and modern technologies. The 1996 Survey of Biotechnology Use in Canadian

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[1] See Statistics Canada, November 1997: Biotechnology Research and Development (R&D) in Canadian Industry, 1995; Science Statistics, catalogue 88-001-XPB.

[2] For example, the various Ernst & Young reports provide annual estimates of the number of biotechnology firms in North America and Europe that are active in biotechnology R&D. Other research on biotechnology, such as a recent collection of studies on the European biotechnology industry, similarly focuses on R&D and dedicated biotechnology firms (Senker J (ed), *Biotechnology and Competitive Advantage: Europe’s Firms and the US Challenge*, Edward Elgar, 1998).

[3] A major source of the confusion over the meaning of biotechnology was public opposition to genetic engineering in the 1970s and 1980s. The proponents of new biotechnologies attempted to reduce public concerns by stressing the similarities between modern biotechnology and familiar techniques such as classical breeding methods. They also attempted to reduce opposition to genetically engineered organisms by altering the name to the less fearsome rubric of genetically *modified* organisms. For a history of the public controversy over new biotechnologies and its effect on the definition of biotechnology, see Hubbard, R., Ward E. *Exploding the Gene Myth*, Beacon Press, Boston, 1993; Krimsky S., *Genetic Alchemy: The Social History of the Recombinant DNA Controversy*, MIT Press, Cambridge, 1982.

Industries avoids these definitional problems by asking respondents about their firm's use of 22 carefully defined biotechnologies, ranging from recombinant DNA to classical and traditional breeding of plants and animals. The survey also asks how each biotechnology is used, using four development stages: as part of research, in the production process, part of the product sold, or for pollution control.

This report provides an overview of the results of the Canadian Survey of Biotechnology Use. As much as possible, each chapter is written to be understandable on its own, without the need to refer to other chapters. There is one exception. Chapter 2, which discusses the survey methodology, must be read to be able to fully understand the other chapters. In order to keep each chapter as brief as possible, supplementary results are provided in Appendix A. A glossary of definitions is also provided immediately before the Appendix.

Chapters 3 and 4, plus parts of Chapters 6 and 7, focus on the use, adoption, and impediments to the adoption of biotechnology. These chapters include results for 1,739 firms that do not use any biotechnologies. The other chapters are limited to questions that were only answered by 271 firms that used one or more of the 22 biotechnologies listed in the questionnaire.

2. Survey and Methodology

The 1996 Survey of Biotechnology Use in Canadian Industries surveyed all firms in Canada that met two criteria:

- Annual sales in 1995 exceeded 5 million Canadian dollars.
- The firm's main sector of activity fell within a limited list of 17 industrial sectors, defined at the two-digit SIC level. These sectors were chosen because they were believed to be the most likely users of biotechnology. The eligible industrial sectors and their industrial classification code are listed in Table 2.1.

Table 2.1 Sectors covered by the 1996 Canadian Survey of Biotechnology Use

Sector	SIC	Sector	SIC	Sector	SIC
Fishing	3	Tobacco	12	Printing & publishing	28
Forestry services	5	Leather products	17	Fabricated metal products	30
Mining	6	Primary textiles	18	Refined petroleum & coal	36
Crude petroleum and gas	7	Textile products	19	Chemicals	37
Food	10	Wood products	25	Other (includes instruments)	39
Beverages	11	Paper & allied products	27		

Due to these two selection criteria, the survey will underestimate the number of firms active in the pharmaceutical and agricultural applications of biotechnology, especially in research. There are three reasons for this. First, many biotechnology firms that are active in these two areas are small firms with annual sales below 5 million dollars. Second, agricultural and pharmaceutical services are not covered by the survey. The effect is to exclude firms that are active in developing biotechnology products, but which only sell research services to other firms or which have not yet brought a new product to market. The latter is especially important because the majority of Canadian firms active in pharmaceutical biotechnology had not yet marketed a product[4]. Third, two sectors that include plant breeding firms are excluded from the survey[5].

The strength of the survey lies in its coverage of the use of biotechnology by mid-sized and large firms, rather than on research activities. The survey is especially useful for the diffusion of environmental applications in the natural resource sectors, and in its coverage of the food processing sector and mid to large chemical firms.

As is apparent from Table 2.1, many manufacturing sectors are not covered by the survey, such as transport equipment, electronic and telecommunications equipment, and machinery. These sectors were not included because there was little evidence to indicate that they are extensive users of biotechnology. This is probably a reasonable assumption, particularly in the light of the very low diffusion of biotechnology to many of the manufacturing sectors covered by the survey, as shown in Chapter 3 below.

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[4] Canadian Biotechnology Strategy Taskforce, *Health and Health Industries*, December 16, 1997.

[5] These are sectors 016 (horticultural specialties) and 0239. In addition, the survey does not cover services to petroleum and minerals (09), but this is unlikely to make much of an impact on the results since the main petroleum and mining sectors are included.

2.1. Survey Response Rate

The biotechnology diffusion survey was sent to 3,397 establishments of 2,298 firms that met the two selection criteria. The results cannot be analyzed at the establishment level because many firms with multiple establishments completed a representative questionnaire for the entire firm. The results for multi-establishment firms were therefore aggregated to the firm-level. Responses are available for 2010 firms, or 88% of the original sample.

2.2. Data Analysis

All of the results in this report use the firm level data[6]. Most of the analyses give results based on both the number of firms and after weighting by the number of employees. Both methods have their advantages.

2.3. Number of firms

Simple counts or percentages of the number of firms that use a specific biotechnology, particularly for single establishment firms, provide a measures of the diffusion of biotechnology expertise, under the assumption that each firm must have one or more individuals that are familiar with the technology. An example is the percentage of firms in the wood products sector that have adopted one or more environmental biotechnologies. Many policy actions, such as programs to inform firms about the available technological options, benefit from count data to identify and define the target population. The results based on count data use the full set of up to 2,010 firms.

2.4. Employee-weighting

Firms vary enormously in size. This means that a handful of very large firms can account for most of a sector's production. Under these conditions the percentage of firms that use a specific biotechnology can be misleading if most of the user firms are very small and account for only a very small percentage of the sector's output. This can be particularly misleading for an evaluation of the use of environmental technologies. For instance, the potential benefits of a cleaner production technology will be substantially greater if two firms that account for 50% of the sector's entire output adopt the technology than if ten firms that account for 5% of the output adopt it.

The employee-weighted results are equal to the percentage of all employees in firms that use a specific biotechnology out of the total number of employees among all of the firms that responded to the survey. For example, assume that there are 100 responding firms with a total of 100,000 employees in the food sector and that five of these firms, with a combined employment of 20,000, use a specific biotechnology. The employee-weighted result is 20%, which is the percentage of all employees in this sector that are employed by firms that use the biotechnology [7]. This is four times higher than the percentage of firms that use the biotechnology.

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[6] A comparison of the results based on an analysis of the mixed establishment/firm data and the firm data show few notable differences. This is because approximately 96% of the firms have only one or two establishments.

[7] The results are not adjusted to account for differences in the non-response rates. The amount of bias from different response rates should be acceptable, given the generally high response rates.

There is one potential drawback to the use of employee-weighted results. The method assumes that there is a direct correlation between the number of employees in a firm and a characteristic of interest, such as the use of a specific biotechnology. However, a firm with many different establishments might only use this biotechnology in one of them - which could even be the smallest establishment. In general, the employee-weighted results will tend to bias upwards the true use of a biotechnology. In order to limit the extent of this bias, 12 firms with 10 or more establishments are excluded from the employee-weighted results. These firms are, however, included in the firm-level results.

2.5. Regression analyses

As will be apparent in Chapter 3, a large number of factors influence the use of biotechnology. In some cases it may be difficult to tell which of a range of factors has a real influence and which is confounded by another factor. Where relevant, regression analyses are used to control for the effect of several different factors on a variable of interest. Many of these variables are based on a yes or no response. For example, firms are asked whether or not they use each of 13 external sources of information about biotechnology. Logistic regression is the appropriate statistical technique to use when the dependent variable is limited to two possible outcomes.

There is an important drawback to the use of regression techniques to analyze the biotechnology survey data. All regressions assume that there is a clear cause and effect relationship between the factors (or independent variables) and the outcome (the dependent variable). This means that the independent variables must occur before the outcome. However, the survey only obtains cross-sectional data, which means that both the influential factors and the outcome are measured at the same point in time. In order to interpret the regression results, we must assume that our estimates of the independent variables have remained relatively constant and could have influenced the outcome of interest.

2.6. Definition of the Industrial Sector

The firm’s sector of activity has a crucial influence on the use of specific biotechnologies. For this reason many of the analyses calculate separate results by sector. This introduces problems because there are often too few cases to provide meaningful results or to overcome confidentially constraints. In order to overcome this problem, sectors at the two-digit level are aggregated into groups of similar activities. There is one exception. Pharmaceutical firms are classified separately from other chemical firms.

Two different aggregation levels are used: one based on eight sectors and another based on two sectors. The sectors included in each level of aggregation are shown in Table 2.2. The aggregation of sectors was based on a preliminary analysis of the patterns of biotechnology use to ensure that only sectors with similar use patterns were combined.

2.7. Definition of Biotechnology

The 22 different biotechnologies are grouped into several classes of similar technologies. The questionnaire uses three classes. Many of the survey questions, such as on investment or the difficulties in implementing a biotechnology, ask about all biotechnologies within one of these three

Table 2.2. Definition of the sector of activity

Two-digit SIC level	Aggregation to eight sectors	Aggregation to two sectors
Fishing		
Food	1. Food	
Beverages		
Tobacco		
Pharmaceuticals	2. Pharmaceuticals	
Non-pharmaceutical chemicals	3. Non pharmaceutical chemicals	1. Manufacturing
Primary textiles		
Textile products		
Leather products		
Fabricated metal products	4. Other	
Printing and publishing		
Other (includes instruments)		
Mining	5. Mining	
Crude petroleum and gas	6. Crude petroleum	
Refined petroleum and coal	7. Refined petroleum	2. Resources
Forestry services		
Wood products	8. Wood, paper and pulp	
Paper and allied products		

classes. This considerably reduces the ability to recombine biotechnologies into different classification systems. The three classes used in the questionnaire are as follows:

- *Selection and modification of biological material*: Includes eight biotechnologies that are used in genetic engineering and in pharmaceutical applications.

- *Environmental biotechnologies*: Includes five biotechnologies that are used to remove noxious compounds from solids, air or liquids. These are generally end-of-pipe environmental technologies.

- *Culture and or use of biological material*: Includes nine biotechnologies that are used in a variety of applications, including agriculture, industrial processes, and clean environmental biotechnologies in contrast to end-of-pipe technologies[8].

An additional group of biotechnology classes is also used, based on both existing knowledge about the use of biotechnology and preliminary analyses of the types of firms that use specific biotechnologies. This additional system is as follows:

- *Genetic engineering*: This class includes five technologies that are required for genetic engineering or which are frequently used in combination with genetic engineering: recombinant DNA, peptide synthesis, gene probes, gene therapy, and DNA amplification. All five are included under 'selection and modification of biological material'.

- *Agriculture*: Includes five technologies that are used in agricultural applications: tissue culture, somatic embryogenesis, bio-pesticides, classical/traditional breeding, and

[8] End-of-pipe technologies clean up pollution after the pollution has already occurred. An example is scrubbers to remove sulfur dioxide from the smokestacks of smelters or coal-burning electrical plants. Clean environmental technologies prevent pollution from occurring in the first place. An example is the use of micro-organisms instead of harmful chemicals to bleach wood pulp (Tils C., Sorup P. Biotechnology as a cleaner technology in pulp and paper, *IPTS Report*, July 16, 1997).

microbio-inoculants. All five are listed in the questionnaire under ‘culture and or use of biological material’.

- *Process*: Includes two technologies that are used in industrial production: bio-processing and bio-sensing. Both are listed under ‘culture and or use of biological material’. Although this class contains only two biotechnologies, preliminary analyses showed that they were distinctly different from other groups, such as the environmental technologies.

These additional classes do not include all 22 biotechnologies listed in the survey. Three technologies that are primarily used by pharmaceutical firms are excluded: antibodies/antigens, rational drug design, and monoclonal antibodies; and two clean biotechnologies that are used by eight firms are excluded: bio-leaching and bio-bleaching.

Other classification systems are also plausible and of equal validity. For example, biotechnologies can be divided into first, second, and third generation technologies that approximate the historical development of these technologies, or the classification system can be based on the ability to manage genetic material.

2.8. Confidentiality

Some results based on count data are not given in order to meet the confidentiality requirements of the Statistics Canada Act. This is indicated in the Tables and Figures with the symbol ‘<‘. Employee-weighted results for all groups are always provided where relevant. However, the total number of employees is never given to preserve the confidentiality of the employee-weighted results.

2.9. Evaluation of the Questionnaire

The Survey of Biotechnology Use is an innovative and experimental questionnaire that has never been used before. During the analyses, several ways of improving future questionnaires on biotechnology were identified. The results are given in Appendix B.

2.10. Comparison with Other Reports

Other reports based on the results of the *Survey of Biotechnology Use in Canadian Industries* are available or in preparation. In some cases, the numbers used in this report can vary slightly from the numbers available in other reports. However, these variations are small and do not alter the results in any substantive way. The variations are caused by minor changes to the data set since the analyses for this report were completed in late February of 1998 and differences in the inclusion and exclusion criteria for specific analyses.

3. The Use of Biotechnology

A fundamental question of interest to both government and industry is: who uses biotechnology? The 'who' refers to the characteristics of firms, such as their size, sector of activity, or level of technical expertise. A good understanding of the types of firms that use biotechnology can assist the design of government programs to get different types of information to firms that use and do not use biotechnology. Firm managers can use this information to predict the size of the future market or for their marketing strategies.

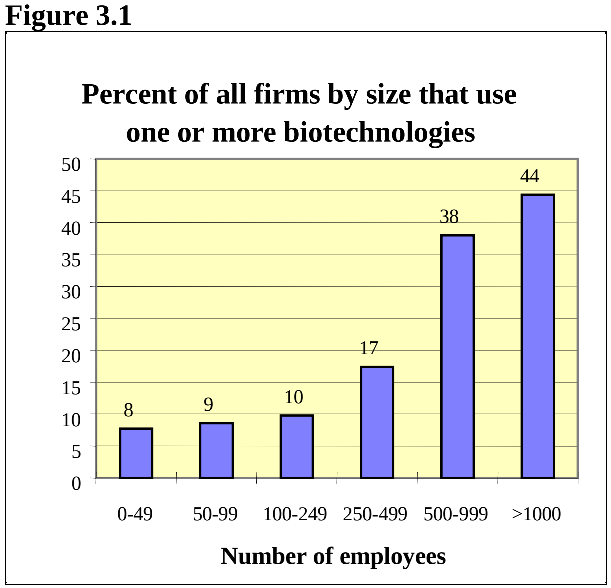
This chapter evaluates some of the factors that are correlated with the use of one or more of the 22 biotechnologies included in the survey questionnaire. A firm is defined as a 'bio-user' if it uses one or more of these technologies and as a 'non-user' if it uses none of them. Overall, 14% of the 2,010 firms that responded to the questionnaire use one or more biotechnologies.

The questionnaire obtained information, for all responding firms, on seven characteristics that could be linked to the use of biotechnology: firm size, measured by the number of employees; the sector of activity, the percentage of total sales due to exports, the self-reported state of the firm's production technology, the percentage of all employees with a university education, whether or not the firm performs R&D[9], and participation in alliances for R&D. The last three factors are indicators of the firm's level of technical expertise.

3.1. Firm Size

Figure 3.1 shows that the percentage of firms that use one or more of the 22 biotechnologies listed in the questionnaire increases with firm size, from 8% of firms with less than 50 employees to 44% of firms with more than 1000 employees. The percentage of firms that use biotechnology is relatively flat up to 250 employees, after which it increases rapidly for the next two size classes. This is followed by only a slight increase from the second largest to the largest size class.

Figure 3.1



3.2. Industrial Sector

Two aspects of the firm's sector of activity are of interest: the distribution of biotechnology users across sectors and the percentage of firms and employees that use biotechnology within each sector. The former shows where biotechnology is most frequently used while the latter shows the intensity of use in each sector.

[9] The results for firm size, R&D performance, and exports are summarized in Table A-1 of Appendix A.

Table 3.1 gives the distribution, across sectors, of the 271 firms that use biotechnology. The sectors are listed in order of the percentage of all employees in firms that use biotechnology. Biotechnology use is concentrated in only a few sectors, defined at the two-digit level. Two of the 18 sectors, food and paper & allied products, account for 52% of the firms that use biotechnology and for 56% of the total employment in bio-user firms. The first eight sectors account for 95% of the firms and 97% of the employees.

The results of Table 3.1 show that there are very few bio-user firms in over half of the sectors. For this reason, the percentage of all firms within each sector that use biotechnology are given for eight aggregated sectors. These results, shown in Figure 3.2, are listed in order of the employee-weighted results[10].

Table 3.1. Distribution of 271 firms that use biotechnology by sector

Sector	Number of user firms	% of 271 user firms	% of user employees
Paper & allied products	48	18	33
Food	92	34	22
Beverages	23	8	12
Mining	13	5	7
Refined petroleum & coal	11	4	7
Crude petroleum & gas	33	12	7
Pharmaceuticals	19	7	5
All other chemicals	18	7	4
Printing & publishing	x	-	1
Primary textiles	x	-	1
Wood products	x	-	1
Forestry services	x	-	--
Textile products	x	-	--
Fabricated metal products	x	-	--
Other	4	2	--
Fishing	x	-	--
Tobacco	0	-	--
Leather products	0	-	--
Total	*271*	*100*	*100*

x: Confidential to meet secrecy requirements of the Statistics Act

-: Nil or zero

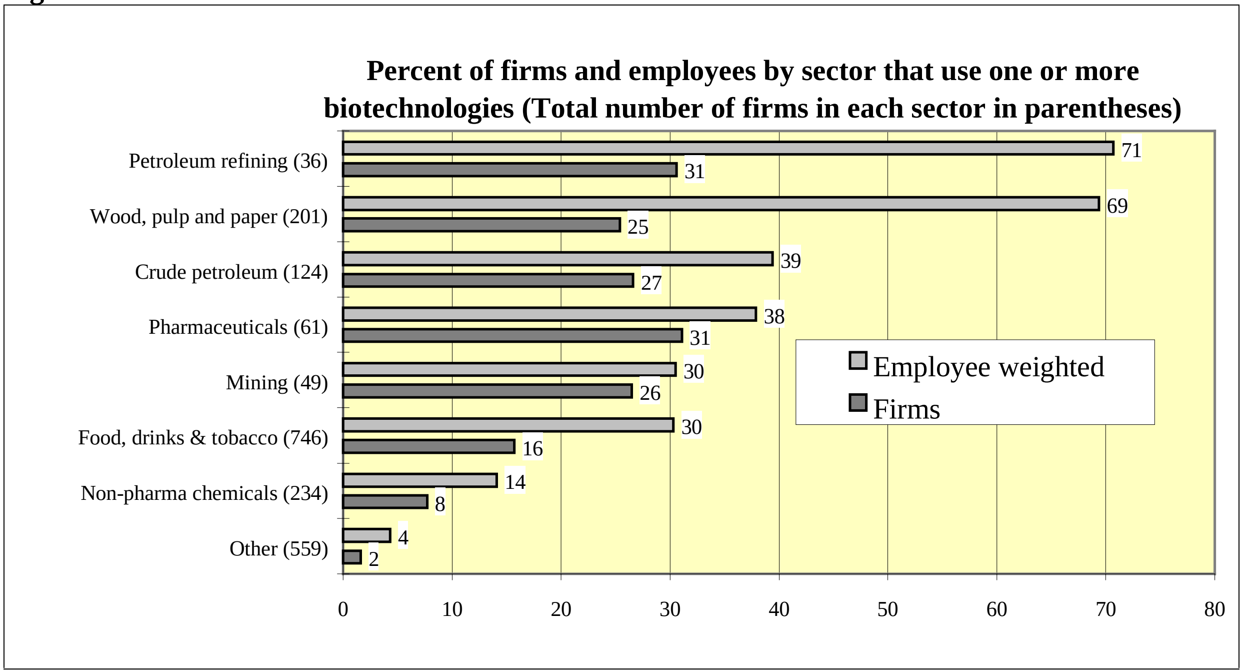
--: Amount too small to be expressed.

The percentage of all firms in a sector that use biotechnology is comparable for all of the four resource sectors, ranging from 27% of mining firms to 31% of petroleum refining firms. In contrast, there is considerably more variation in the manufacturing sectors, where the percentage of firms that use biotechnology ranges from a low of 2% for ‘other’ manufacturing to a high of 31% for pharmaceutical firms. Of interest, the use rate of 8% for non-pharmaceutical chemical firms is considerably lower than the rate of 31% for pharmaceutical firms.

[10] Table A-2 of Appendix A gives the percentage of firms and employees that use biotechnology at the two-digit SIC level.

The employee-weighted results show much greater variation for the resource sectors. Approximately 70% of employees in petroleum refining and in wood, pulp and paper work for a firm that uses biotechnology compared to 39% of crude petroleum firms and 30% of mining firms. The percentage of employees in the food sector that work for a firm that uses biotechnology is also twice the percentage of food firms that use biotechnology.

Figure 3.2



The differences by sector in the percentage of firms that use biotechnology is not due to higher average firm sizes in sectors with high rates of biotechnology use. Furthermore, bio-user firms are larger than non-users in each of the eight sectors. There is one anomaly. The higher average number of employees for bio-user firms in the pharmaceutical sector (513 versus 380) is due to a few very large bio-user firms. Closer inspection of the size distribution for pharmaceutical firms shows that 74% of bio-user firms have less than 100 employees, compared to only 26% of non-user firms[11]. This is probably caused by the importance of new start-up firms in the development of pharmaceutical applications of biotechnology.

3.3. Export Share

Bio-user firms derive a higher percentage of their total sales from exports: 52% compared to 43% for non-users. The results for exports are not as reliable as the results for firm size because the majority of firms, 64%, did not answer the survey question on export share. The largest difference

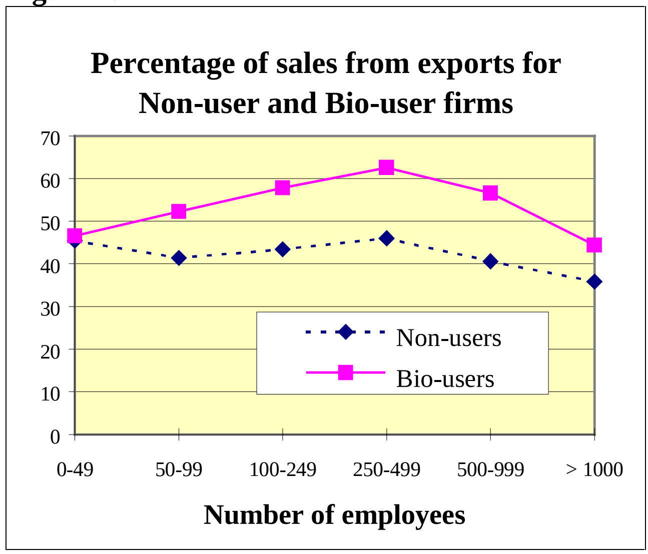
[11] The average size of bio-user and non-user firms by sector is given in Table A-3 of Appendix A.

in the export share between bio-user and non-user firms is for mid-sized firms, as shown in Figure 3.3. Mid-sized firms also have the highest export share for both groups.

3.4. State of Production Technology

All firms were asked to compare their production technology with "that of their most significant competitors in Canada and outside Canada". Five options were given: much less advanced, less advanced, about the same, more advanced, and much more advanced. There are no differences in the self-reported state of production technology between non-user and bio-user firms, both compared to other firms in Canada and with firms outside of Canada. This is shown in Table 3.2. Approximately 60% of both non-users and bio-users report that their production technology is 'about the same' as that used by their competitors in Canada and abroad.

Figure 3.3



There is no difference in the state of production technology compared to Canadian competitors between bio-users and non-users in each of the eight sectors (results not shown), except for pharmaceuticals firms, where the distribution of responses for bio-users is much flatter than the distribution for non-users. Considerably fewer pharmaceutical firms that use biotechnology report that their production technology is 'about the same' (28% compared to 65% for non-users) while more bio-users report that their production technology is more or much more advanced than their Canadian competitors (56% compared to 30%) and less advanced (17 versus 5%).

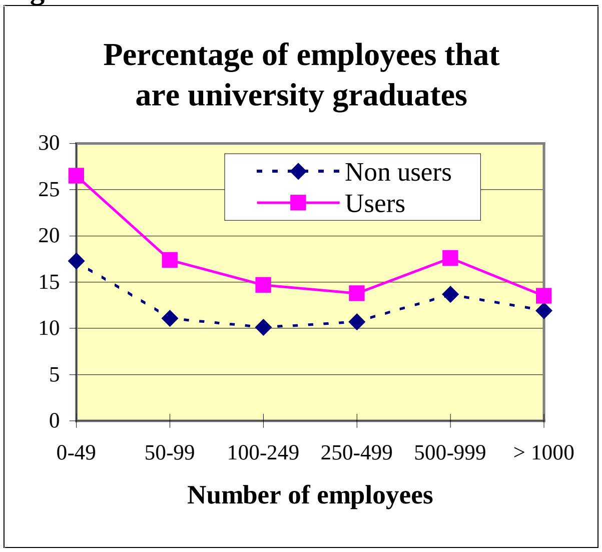
Table 3.2. Self-reported state of production technology for bio-user and non-user firms

Compared to:	Other Canadian producers		Foreign producers	
	Non-users	Bio-users	Non-users	Bio-users
Much less advanced	1	2	2	4
Less advanced	7	10	12	12
About the same	59	55	61	58
More advanced	25	28	21	21
Much more advanced	7	5	4	6
	100%	100%	100%	100%
Number of responding firms	*1450*	*258*	*1391*	*250*
P value ($\chi 2$) (non-users vs users)	0.29		0.20	

3.5. Educational Qualifications

The percentage of employees in bio-user and non-user firms that are college graduates is similar, at 11% and 10% respectively. In contrast, a significantly higher percentage of the employees of bio-user firms than non-user firms are university graduates: 17% versus 13%. The employee-weighted results follow the same pattern, with a smaller difference in the percentage of college graduates among bio-users than non-users (10% compared to 9%) and a larger difference for university graduates (13% versus 11%). As shown in Figure 3.4, bio-user firms have a higher average percentage of university employees across all size classes, although it is largest for the smallest firms with less than 50 employees and declines with firm size[12].

Figure 3.4

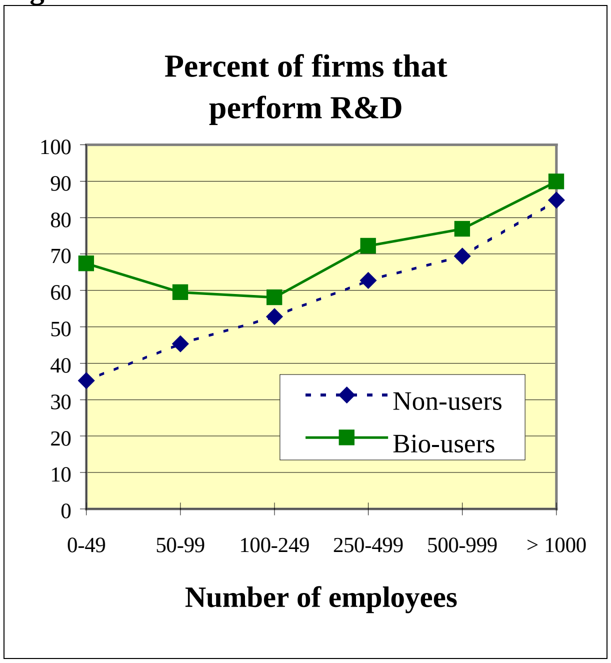


By sector, the percentage of university graduates among bio-user firms ranges from 8% of all employees in wood and paper firms to 37% of employees in pharmaceutical firms. In most sectors, a higher percentage of all employees are university or college graduates in bio-user firms than in non-user firms. The exceptions are wood and paper, where non-user firms have a higher percentage of university graduates, and pharmaceuticals, where 37% of employees in both bio-user and non-user firms are university graduates[13].

3.6. R&D Performance Status

Overall, 72% of bio-user firms perform R&D, compared to 52% of non-user firms. Figure 3.5 gives the percentage of bio-user and non-user firms by firm size that perform R&D. There is only a small difference in the percentage of bio-user and non-user firms that perform R&D for most size classes, but substantially more bio-user than non-user firms with less than 100 employees perform R&D.

Figure 3.5



[12] Table A-4 of Appendix A gives full results for university graduates, college graduates, and both combined.

[13] The lack of a difference in the pharmaceutical sector does not hold for firm-level averages, where the average for bio-user firms is 48.2% compared to 33.3% for non-user firms. This is due to a high percentage of university graduates in small pharmaceutical firms. Table A-5 of Appendix A provides firm-level percentages of graduate employees for each sector while Table A-6 gives employee-weighted results.

3.7. Alliances for R&D

Firms that performed R&D were asked if they were part of an R&D alliance. More than twice as many bio-user than non-user firms were engaged in an alliance for R&D in 1996: 55% versus 21%[14]. Firms that participated in an R&D alliance were asked about the type and location of their partners. The results are given in Table 3.3.

A significantly higher percentage of bio-user than non-user firms that participate in alliances for R&D have alliances with competitors, consultants, governments, universities, and research institutes within Canada. Non-users are more likely to have alliances with suppliers and clients, but the difference is not statistically significant. Since all respondents to this question had at least one R&D alliance, the higher percentage of several types of alliances among the bio-user firms is due to a higher average number of alliances among the bio-user compared to non-user firms.

For both non-user and bio-user firms, alliances with partners in Canada are consistently more common than alliances with partners outside of Canada. For example, 47% of bio-user firms that participated in an alliance for R&D had an alliance with a research institute in Canada, compared to 12% that had an alliance with a research institute outside of Canada. The only exception is for other firms within the same group, where 24% of bio-users have R&D alliances with firms in and outside of Canada[15].

Table 3.3. Percent of bio-user and non-user firms that engaged in R&D alliances that had each of the following alliances with partners in Canada and abroad

	Canada		Abroad	
Partners	**Non-user**	**Bio-user**	**Non-user**	**Bio-user**
Competitors	**9**	**18**	**4**	**10**
Suppliers	39	36	19	21
Clients	25	20	15	17
Consultants	**28**	**45**	**9**	**18**
Other firms within group	20	24	**16**	**24**
Other firms not listed above	11	12	7	9
Government	**16**	**43**	2	4
University	**30**	**62**	**6**	**13**
Research Institutes	**23**	**47**	8	12

The results for each type of alliance exclude firms that did not answer the question. Statistically significant differences between bio-users and non-users ($p < 0.05$) are marked in **bold** type.

3.8. Conclusions

The two most important predictors of whether or not a firm uses biotechnology are its size (measured by the number of employees) and its sector of activity. The effect of firm size is expected because large firms are more likely than small firms to be involved in a range of activities, some of which could use biotechnology. This result must be interpreted cautiously because the ques-

[14] Excludes six non-user firms that stated that they participated in R&D alliances but which did not check any of the nine types of R&D alliance partners.

[15] Further information on the alliances of bio-user firms is given in Chapter 10.

tionnaire does not identify the importance of biotechnology to the firm's business strategy. It is possible that biotechnology is only a minor part of the business activities of some of the large biotechnology users. The concentration of biotechnology in a few sectors reflects the range of possible applications of biotechnology. It is most likely to be used in the food processing and chemical sectors and for environmental applications. The types of biotechnology in use are examined in Chapter 4.

The results for two of the three indicators of technical expertise, educational qualifications and R&D performance, show that the greatest difference between non-user and biotechnology user firms occurs in small firms with less than 100 employees. The biotechnology user firms in this size group are much more likely to perform R&D and to have a high proportion of university graduates in their total staff. Among larger firms, slightly more biotechnology users than non-users perform R&D and the bio-users have a higher percentage of university graduates. The results for alliances show that a higher percentage of bio-users than non-users participate in R&D alliances and they participate, on average, in a larger number of different types of alliances.

These results strongly suggest that a higher than average level of technical expertise and skill is required to be able to use biotechnology. This conclusion conflicts with the finding that there is no difference in the state of the production technology used by bio-users and non-users. There are at least two possible explanations. First, biotechnology could serve as an alternative to existing methods, without offering immediate technical advantages. This is most likely in areas where biotechnology is a relatively new option. A related possibility is that the biotechnology users have not yet fully applied new biotechnologies to their production processes. Second, the non-users may give an inaccurate assessment of their comparative standing, particularly if they are unfamiliar with the advantages conferred by biotechnology.

4. Use of Specific Biotechnologies

As noted in the Introduction, the term 'biotechnology' is a misnomer. There is, in fact, a wide range of biotechnologies, ranging from the most recent and technologically advanced genetic engineering technologies to plant breeding and bioprocessing, both with ancient pedigrees. The development of government policy to assist the use and development of biotechnology requires a thorough understanding of the types of biotechnology in use. This information can also assist biotechnology firms in estimating the size and structure of their current market.

The biotechnology questionnaire asks about the use of 22 different biotechnologies, grouped into three classes of similar technologies: eight technologies used to select and modify biological material, five environmental technologies, and nine technologies used in the culture and/or use of biological material. A firm is defined as a user of a specific technology class if it uses one or more of the relevant technologies. For example, a firm is classified as a user of environmental biotechnologies if it reports using at least one of the five environmental technologies. The questionnaire's definition of each biotechnology is given in the glossary.

The 22 biotechnologies are also recombined, for analysis, into an additional three classes. A firm is classified as using *genetic engineering* if it uses one or more of five technologies used for or in combination with genetic engineering. Similarly, it is defined as a user *of agricultural biotechnology* if it uses at least one of five technologies used in agriculture, and as a *process* user if it uses one of two technologies used in industrial production. The process and agriculture classes are a subset of the nine 'culture and/or use of biological material' technologies while the genetic engineering class is a subset of the eight 'selection and modification' technologies. Chapter 2 provides additional details on the three biotechnology classes included in the questionnaire and the three additional classes.

4.1. Biotechnology Use by Sector

The employee-weighted results for the use of each of 22 biotechnologies in eight sectors are given in Table 4.1. To make the table easier to read, the results are lightly shaded when between 10% and 25% of the employee-weighted firms use the biotechnology. A darker shading is used when over 25% of the employee-weighted firms use the biotechnology. There are several clear patterns of use[16].

With one minor exception, none of the eight selection and modification technologies are used by firms in the four resource-based sectors, with the exception of some use in the wood, pulp and paper sector (WPP). The main users of these eight technologies are in the food (F) and pharmaceutical (P) sectors.

The highest rate of diffusion is reached for the environmental biotechnologies. The resource sectors are the primary users of this biotechnology class, particularly bioremediation to break down hazardous substances. The use rate for this technology ranges from a low of 25% in mining (M) to a high of 64% in petroleum refining (PR). All five environmental biotechnologies are widely used in the petroleum refining sector.

[16] The weighted results are given in preference to the firm-level data because confidentiality constraints reduce the amount of information that can be displayed at the firm level. The results at the firm level are very similar to the weighted results. The firm-level results are provided (when possible given confidentiality constraints) in Table A-7 of Appendix A.

Table 4.1. Employee-weighted percentages for the use of 22 biotechnologies in eight sectors[1]

	Resource-based sectors				Manufacturing sectors			
	M	CP	PR	WPP	F	P	NPC	O
Number of respondent firms	49	124	36	201	746	61	234	559
Selection and modification biotechnologies								
Recombinant DNA	-	-	-	--	8	14	1	--
Antibodies/antigens	-	-	-	-	5	15	--	--
Peptide synthesis	-	-	-	-	--	14	--	-
Rational drug design	-	-	-	-	--	13	--	--
Monoclonal antibodies	-	-	-	-	2	15	1	--
Gene probe	-	-	-	-	7	14	2	--
Gene therapy	-	-	-	-	-	-	--	-
DNA amplification	-	-	-	-	7	14	--	--
Environmental biotechnologies								
Bioaugmentation	9	12	48	26	11	--	2	-
Bioremediation	25	39	64	52	10	-	11	2
Bio-reactors	16	-	53	40	9	--	3	-
Phytoremediation	15	14	26	3	--	-	-	-
Biological gas cleaning	-	5	48	-	1	-	2	-
Culture and biological material technologies								
Tissue culture	-	-	-	1	6	15	2	--
Somatic embryo genesis	-	-	-	-	--	--	1	-
Bio-pesticide	-	-	-	7	1	8	1	-
Classical/traditional breeding	3	-	-	3	8	4	1	-
Bioprocessing	-	-	28	1	15	15	--	--
Bio sensing	3	-	-	1	11	28	1	--
Bio-bleaching	-	-	-	1	--	-	-	-
Bio-leaching	14	-	-	-	-	-	-	2
Microbio-inoculants	-	2	-	1	1	--	1	-

[1]: Excludes 12 firms with ten or more establishments. M: mining, CP: crude petroleum, PR: petroleum refining, WPP: wood, paper, and pulp, F: food, beverages and tobacco, P: pharmaceuticals, NPC: non-pharmaceutical chemicals, O: other manufacturing.

Light-shaded squares: > 10% - 24.9%, darker shaded squares: > 25%.

The use rates for environmental biotechnologies drops substantially in the manufacturing sector. The largest user of these technologies is the food sector (F), although the highest use rate is only 11% for bioaugmentation. The use rate for all environmental technologies is below 2% in the pharmaceutical and ‘other’ manufacturing sectors.

The final group of nine culture and biological material technologies is rarely used in the resource sectors, with the exception of bioprocessing in petroleum refining and bio-leaching in mining. The greatest use of these technologies is in the food and pharmaceutical sectors.

The resource sector that uses the widest range of different biotechnologies is wood, pulp and paper. In manufacturing, the food and pharmaceutical sectors are the most diversified users of biotechnology. Very little use of any biotechnology is made by firms in non-pharmaceutical chemicals (NPC) and in ‘other’ manufacturing (O), with the exception of bioremediation in the non-pharmaceutical chemical sector.

4.2. Biotechnology Use by Technology Class

Table 4.2 gives the percentage of both firms and employees that use at least one biotechnology in each of four biotechnology classes: genetic engineering, and environmental, agricultural, and process applications. For example, 24% of the 49 mining firms use at least one of the five environmental biotechnologies.

Table 4.2. Use of any biotechnology within each of four biotechnology classes by sector: Firm and employee-weighted[1] percentages

	Resource-based sectors				Manufacturing sectors			
	M	CP	PR	WPP	F	P	NPC	O
Number of respondent firms	49	124	36	201	746	61	234	559
Genetic engineering								
Firms	-	-	-	x	2	12	x	x
Employees	-	-	-	--	11	14	3	--
Environment								
Firms	24	27	28	24	6	x	6	x
Employees	30	39	70	68	18	--	12	2
Agriculture								
Firms	x	x	-	3	4	26	2	1
Employees	3	2	-	10	8	24	2	--
Process								
Firms	x	-	x	x	9	21	2	x
Employees	3	-	28	2	21	30	1	--

1: Excludes 12 firms with ten or more establishments. M: mining, CP: crude petroleum, PR: petroleum refining, WPP: wood, paper, and pulp, F: food, beverages and tobacco, P: pharmaceuticals, NPC: non-pharmaceutical chemicals, O: other manufacturing.

Definition of biotechnology classes: **Genetic engineering**: uses one or more of recombinant DNA, peptide synthesis, gene probes, gene therapy, and DNA amplification. **Environment**: uses one or more of bioaugmentation, bioremediation, bioreactors, phytoremediation, and biological gas cleaning. **Agriculture**: uses one or more of tissue culture, somatic embryo genesis, bio-pesticides, classical/traditional breeding, and microbial inoculants. **Process**: uses one or more of bioprocessing and bio-sensing.

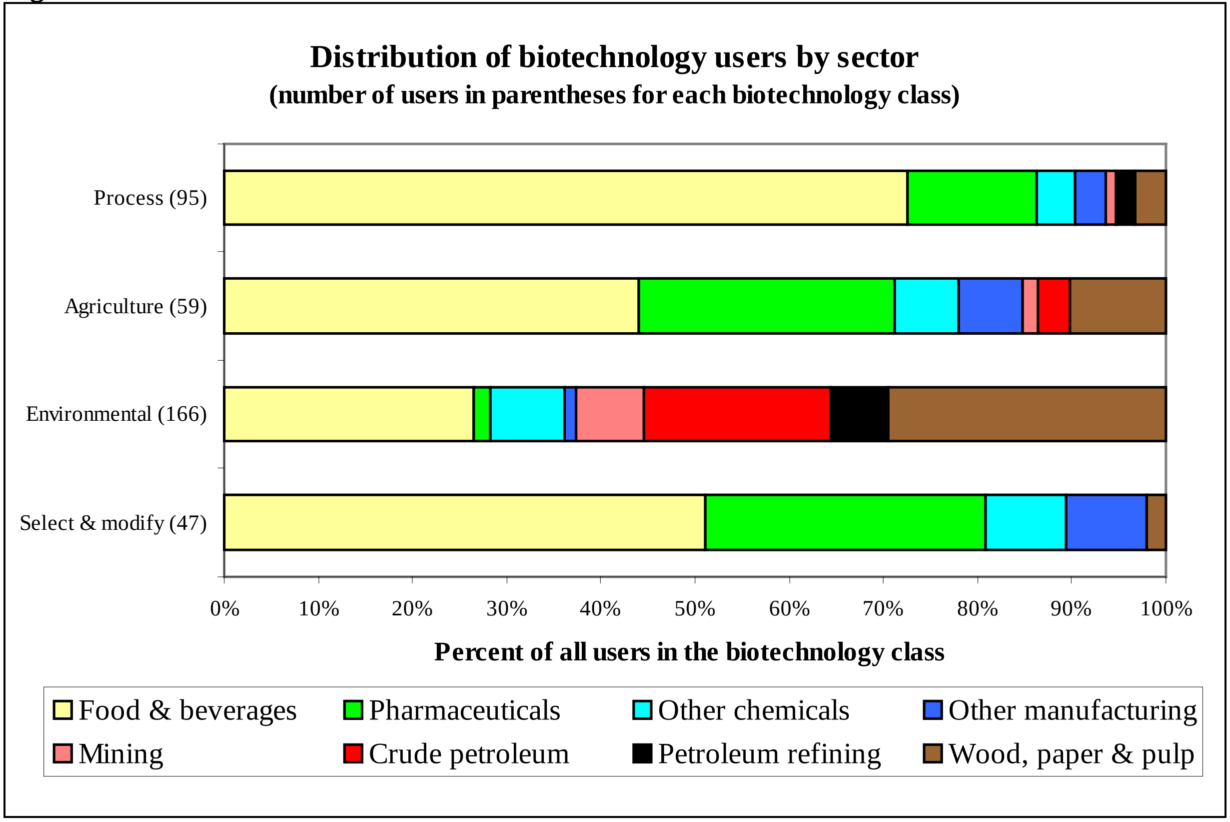
The patterns of use by sector are very similar to those described above for Table 4.1, although Table 4.2 provides a clearer picture of the use of genetic engineering and agricultural technologies. The core group of genetic engineering technologies is used by only a small number of firms. They are most extensively used by pharmaceutical firms, even though only 12% of pharmaceutical firms use one or more of them. Agricultural and process applications are also largely limited to food and pharmaceutical firms.

4.3. Distribution of Biotechnology Users by Sector

Tables 4.1 and 4.2 above give the percentage of all firms or employees within a specific sector that use each type of biotechnology. The location of biotechnology expertise is better examined through an evaluation of the distribution by sector of all users in a specific biotechnology class, as shown in Figure 4.1. The distribution of all firms by biotechnology class sums across the rows to 100%. The group of all eight selection and modification technologies is used instead of the five genetic engineering technologies because of confidentiality constraints. The distribution of users for genetic engineering and selection and modification technologies are very similar.

The results shown in Figure 4.1 are similar to the results of Tables 4.1 and 4.2. The process, agricultural, and genetic engineering biotechnologies are dominated by firms within the pharmaceutical and food sectors. These two sectors account for 86% of all firms active in process applications, 71% of all firms active in agricultural applications, and 81% of all firms active in selection and modification technologies. The largest differences is for the use of environmental biotechnologies. As shown in Table 4.2, only 6% of food firms use environmental technologies. However, as shown in Figure 4.1, these firms account for 26% of all users of environmental technologies.

Figure 4.1



See Table 4.2 for a description of the first three biotechnology classes.

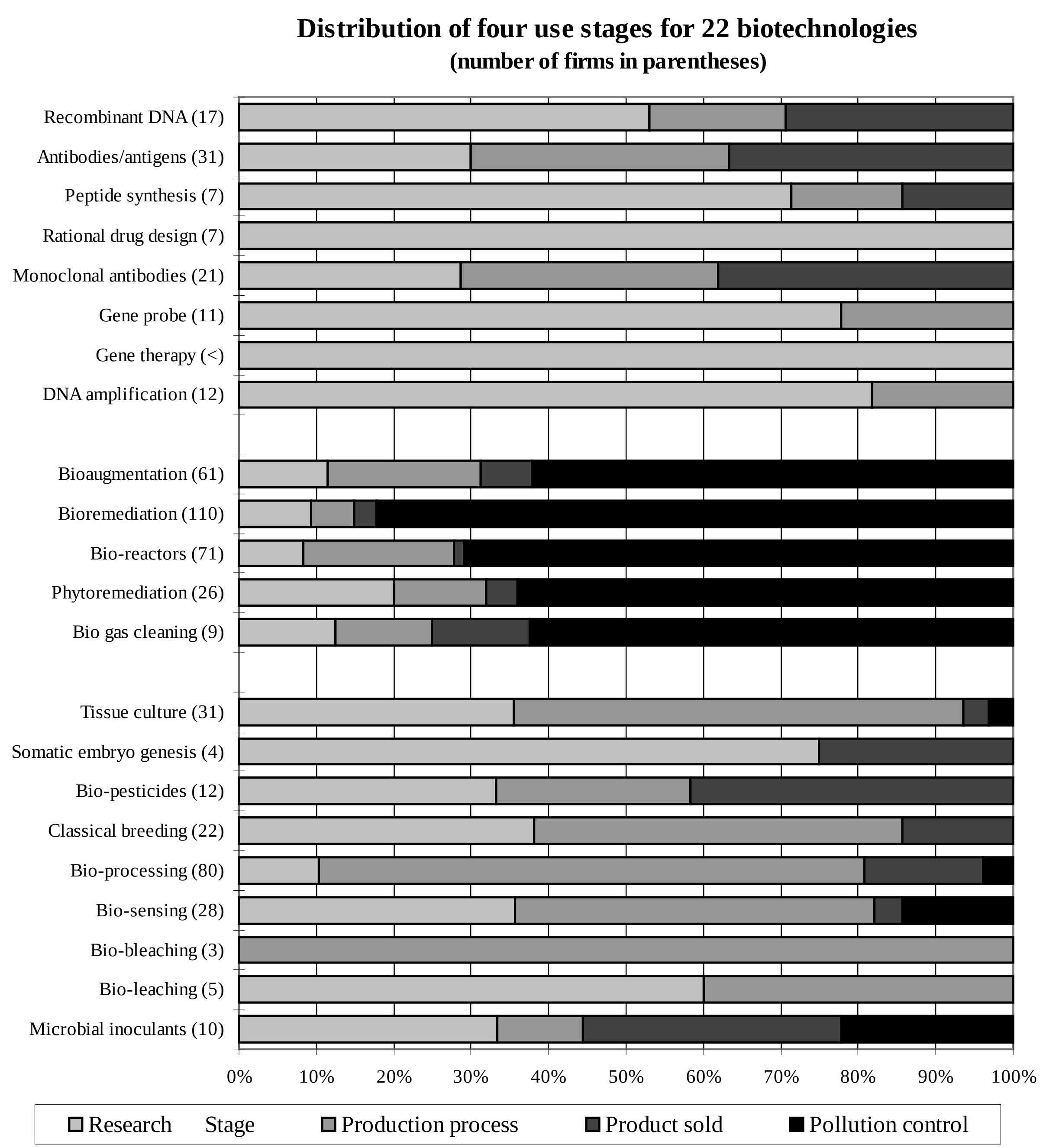
4.4. Conclusions

The food and pharmaceutical sectors dominate the use of selection and modification biotechnologies and the use of culture and biological material technologies. This holds for the percentage of firms and employees in each sector that use these technologies and the percentage of all relevant users that are in these two sectors. In contrast, the use of environmental biotechnologies is considerably more diverse, although the diffusion of environmental biotechnology is considerably more extensive in the four resource sectors than in the four manufacturing sectors. Chemical firms that are not active in pharmaceuticals and the 'other manufacturing' sectors have the lowest use rates for all biotechnologies.

5. Utilization Stage for Specific Biotechnologies

Technology is developed through a long interactive process of continual improvements in response to experience or to new demands. In the early days of development, almost all use of a technology can be concentrated on research, while a well-understood technology can reach the status of an 'off the shelf' item that can be purchased and immediately introduced into existing

Figure 5.1



production or pollution control systems. Examples of the latter include some new computer equipment and components and sensor devices.

A main step forward in the development of a technology is from a focus on research and development to the ability to use the technology in a practical application. A lack of applications, or at least commercially successful ones, can form a major barrier to the adoption of a new technology. The survey partly addresses these issues by asking the 271 firms that use one or more biotechnologies to indicate the utilization stage that has been reached for each biotechnology in use. Four options are given: research, part of the production process, part of the product sold, and for pollution control. The latter three options are all biotechnology applications.

The question on the utilization stage has two major limitations that must be clearly understood. First, the results cannot be used to determine the percentage of all firms that are active in biotechnology research, since a firm that both conducts research and uses the technology in an application stage is classified in the latter stage. Second, we do not know if a firm that is in the application stage currently conducts or ever conducted research on biotechnology. These two limitations reflect the questionnaire's focus on the application and diffusion of biotechnology rather than on research and development.

Figure 5.1 gives the percentage of users of each biotechnology that are in each of the four stages[17]. The most frequent stage for the selection and modification technologies is research. Only antibodies/antigens and monoclonal antibodies have the majority of firms active in applications such as production or part of the product sold. None of the eight technologies are used for pollution control.

The most frequent use stage for every environmental biotechnology is in pollution control, with the percentage of firms using each biotechnology for this purpose ranging from approximately 62% for both bioaugmentation and biological gas cleaning to 82% for bioremediation. The culture and modification technologies show the most diverse range of stages, although the most frequent use is as part of the production process.

Very few of the firms in this survey sell biotechnology as part of a product. The biotechnologies with the highest percentage of firms active in product sales are antibodies/antigens (37%), monoclonal antibodies (38%), bio-pesticides (42%), and microbial inoculants (33%).

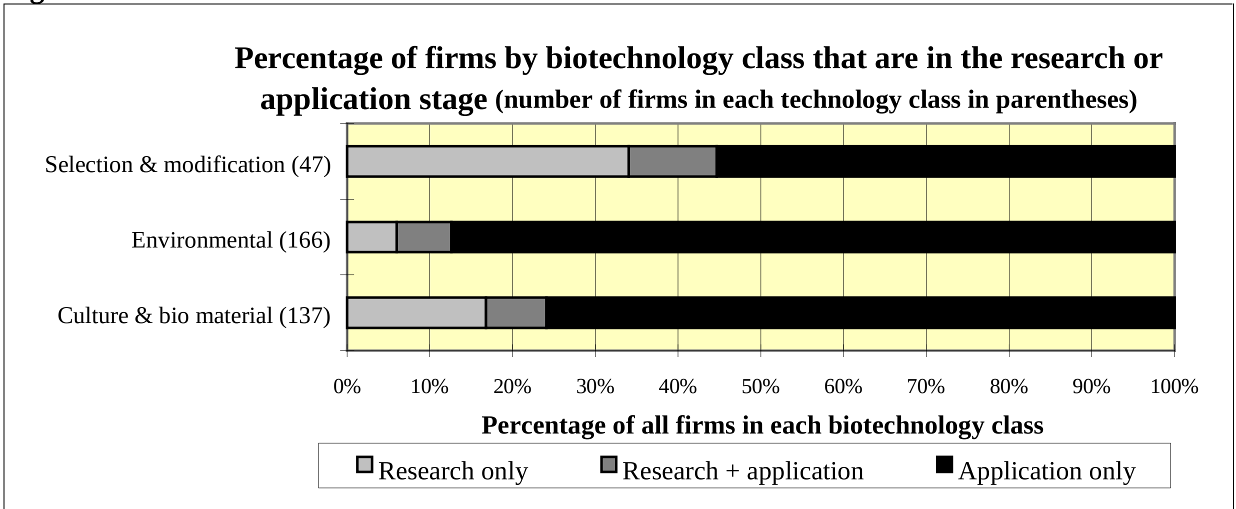
5.1. Research Versus Applications

As noted above, a main division between the four use stages is between the research stage and the three other options, all of which require the application or commercialisation of biotechnology. Figure 5.2 gives the percentage of firms in each of the three main biotechnology classes that are in the research stage only, in the research stage for one biotechnology and in the applied stage for another, or only in one of the three application stages.

Firms active in one or more of the selection and modification technologies are least likely to have moved to the application stage, with 34% only in research and another 11% in both research and the application stage. In contrast, only 6% of firms active in environmental biotechnology are in the research stage only with another 7% involved in both research and applications. The percent-

[17] See Table A-8 of Appendix A for full results for the percentage of firms in each use stage for each biotechnology.

Figure 5.2



age of firms that are active in culture and biological materials that are in the research stage is intermediate, with 17% in the research stage only and another 7% involved in both.

The percentage of firms by sector that are in the application stage for one or more biotechnologies is as follows: 62% in mining, 94% in crude petroleum, 100% in refined petroleum, 94% in wood, pulp and paper, 92% in food, 90% in pharmaceuticals, 83% for other chemicals, and 78% for other manufacturing. There are too few firms in each sector for a breakdown of the percentage of firms in the application stage by biotechnology class. An analysis of the two main sectors, resources and manufacturing, by biotechnology class shows application rates of 80% or higher for both sectors for all technology classes, with the exception of genetic engineering. Only 65% of manufacturing firms that use these technologies have progressed to at least one application. This matches the results shown in Figure 5.2.

5.2. Average Years of Use

These differences in the percentage of firms that are still in the research stage is partly related to the average years of use for each biotechnology. The selection and modification technologies have been in use for a shorter time period than many of the other biotechnologies. This is shown in Table 5.1. The maximum number of years of use of selection and modification biotechnologies ranges between 3 and 30 years, compared to between 30 and 75 years for environmental biotechnologies and 3 and 99 years for the culture and use biotechnologies.

The five genetic engineering technologies have the shortest mean years of use, ranging from 4.8 years for recombinant DNA to 6.4 years for peptide synthesis. In comparison, antibodies and monoclonal antibodies have been used for a longer period of time, with a mean of 10.1 and 7.3 years respectively. This partly explains the relatively high percentage of firms that are active in these two technologies that sell products based on them.

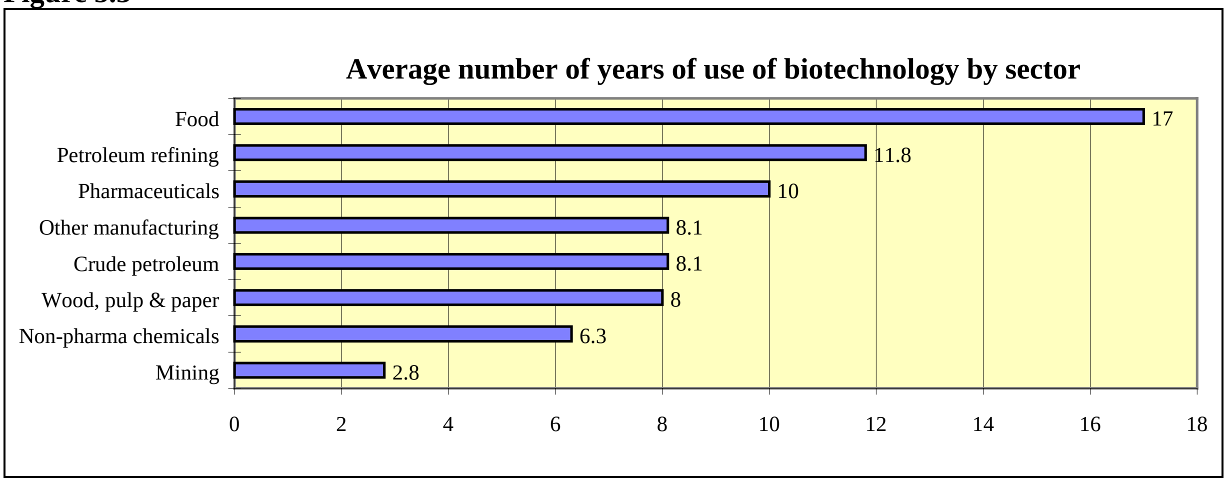
The genetic engineering group is, on average, newer than most other technologies, with the exception of somatic embryo genesis, with a mean of two years. The low number of years of use for

Table 5.1 Average years of use for specific biotechnologies

Technology	Number of users[1]	Minimum	Maximum	Mean	Std Deviation
Selection and Modification					
Recombinant DNA	15	1	15	5	4
Antibodies	29	1	30	10	8
Peptide synthesis	7	-	20	8	8
Rational drug design	5	3	29	13	11
Monoclonal antibodies	18	1	20	7	5
Gene probe	8	3	15	7	4
Gene therapy	x	-	-	-	-
DNA Amplification	9	3	15	6	4
Environmental					
Bioaugmentation	50	1	30	10	8
Bioremediation	97	1	40	9	9
Bio-reactors	68	1	75	10	13
Phytoremediation	21	-	50	12	14
Biological gas cleaning	6	1	32	8	12
Culture and Use					
Tissue culture	26	1	30	9	8
Somatic embryo genesis	4	1	3	2	1
Bio pesticides	10	1	12	4	3
Classical breeding	18	2	20	10	6
Bio-processing	70	1	99	30	30
Bio-sensing	25	1	35	7	9
Bio-bleaching	5	3	11	6	4
Bio-leaching	4	1	11	6	5
Microbio-inoculants	8	3	39	11	12

1: Excludes firms that did not reply to the question on the number of years of use for each technology.

Figure 5.3



classical breeding techniques, with a maximum of 20 years, is probably due to the fact that the survey does not cover most plant and animal breeding firms.

Analyses of the average number of years that a firm has used any biotechnology showed no significant differences by firm size[18]. In contrast, there are significant differences in the average years of use for firms by sector, as shown in Figure 5.3. Firms active in the food and pharmaceu-

18 These results could be confounded by the number of years that a firm has been in existence. Unfortunately, no data on the date of establishment or another method of determining firm age is available. Instead, the size of the firm is used as a proxy for firm age. The average number of years of use for each firm is determined from the average for all biotechnologies used by the firm, or only for those biotechnologies in a specific technology class, depending on the circumstances. Correlation analyses of average firm size by average years of use were not significant for all firms or for correlations limited to firms active in specific technology classes.

tical sectors have used biotechnology for the longest average number of years, while firms in the mining sector are relatively recent users, with an average of only 2.8 years.

5.3. Conclusions

Each of the three main biotechnology classes is dominated by one major stage. This is research for the selection and modification technologies, pollution control for the environmental technologies, and use in the production process for the culture and use of biological material technologies. Very few firms sell biotechnologies as part of their product line. This is partly due to the types of firms that were surveyed, which excludes firms in equipment manufacturing. Several of the environmental technologies, such as bio-reactors, could be constructed in this sector and then sold to the large resource firms. Nevertheless, the fact that the most frequent application of biotechnology is in the production process or part of pollution control equipment emphasizes that biotechnology is predominantly a process technology. It is primarily used as an input into existing production processes. This can create problems for its future diffusion, since firms will often be able to draw on alternative production or pollution control methods.

6. Future Plans to Use Biotechnology

Chapters 3 and 4 give the percentage of firms that currently use biotechnology. Another question of interest is the number of firms that plan to use biotechnology in the near future. The answer to this question is of value for estimates of the future economic and social impacts of biotechnology, as well as providing a measure of the market for biotechnologies over the short-term future.

All firms that did not use a specific biotechnology, including non-users and firms that used a different biotechnology, were asked if they planned to use the technology within the next two years. If not, they were asked if there was no application for the technology or if the technology was not cost effective. The results to these two questions provide two measures of the future adoption of biotechnology. The first measure is the percentage of firms that state that they plan to adopt within two years. The second measure includes firms that do not plan to adopt a biotechnology because it is too expensive. These firms form an additional group of possible future users because they could decide to adopt the technology if the cost falls or the benefits rise compared to the costs. Firms that plan to adopt a specific biotechnology within two years plus firms that reply that the biotechnology is too expensive are combined into a group of potential adopters.

Very few firms plan to adopt biotechnologies within two years or are potential adopters. The results for the three biotechnology classes used in the questionnaire plus the most advanced group of genetic engineering technologies (a subset of the selection and modification technologies) are given in Table 6.1[19].

Table 6.1. Future plans to adopt biotechnology

Biotechnology class	Within 2 years		All potential adopters[1]	
	Current users[2]	Non-users[3]	All firms[4]	Employee weighted
Selection & modification	8 (3%)	4 (0,2%)	19 (1%)	0,4%
genetic engineering	6 (2%)	x	15 (1%)	0,3%
Environmental	22 (8%)	18 (1%)	67 (3%)	11%
Culture and biological material	18 (7%)	11 (0,6%)	45 (2%)	5%

[1]: Firms that plan to adopt within two years plus firms that state that the technology is too expensive.

[2]: A current user is a firm that uses any of the 22 biotechnologies. The percentage is the proportion of the 271 current users of at least biotechnology that plan to adopt one or more technologies within the technology class.

[3]: The percentage is the proportion of the 1,739 firms that do not use any biotechnology at the time of the survey that plan to adopt one or more technologies within the technology class.

[4]: Percent of all potential adopters out of the 2,010 responding firms.

The majority of firms that plan to adopt a biotechnology within two years are current users of at least one other biotechnology. For example, 3% of current users of at least one biotechnology plan to adopt a selection and modification biotechnology within the next two years, compared to only 0.2% of firms that do not currently use any biotechnology. Including firms that currently find biotechnology too expensive among the potential adopter pool increases the number of potential users by between 55% for culture and use technologies to 88% for genetic engineering. However, the percentage of potential adopters out of all responding firms remains low, ranging from 0.7% for genetic engineering to 3% for environmental biotechnologies. The employee-

[19] Results for each of the 22 biotechnologies are given in Table A-10 of Appendix A.

weighted results gives a maximum rate for potential adopters of 11% for environmental technologies.

6.1. Diffusion from One Technology Class to Another

An interesting question is if the use of one biotechnology increases the ability of firms to use or adopt another biotechnology. This is possible if experience with the techniques and advantages of one biotechnology increases the ability and interest of a firm in adopting another biotechnology. This type of analysis requires grouping the technologies by related skills. Results are given here for three technology classes: the five genetic engineering technologies, the five environmental technologies, and the five agricultural technologies[20].

Table 6.2 gives the percentage of firms that currently use any biotechnology in each of these three technology classes and that also use a biotechnology in one of the other two classes. The majority of the 24 firms that use genetic engineering are also active in at least one of the other two technology classes, with only 4 firms (17%) not using one of the other two technologies. This is not surprising since genetic engineering is a core capability. In contrast, only 5% of the 166 firms that use environmental biotechnologies also use genetic engineering, while 145 (87%) do not use a technology from the other two technology classes. These results suggest that there are few flows from environmental technology to genetic engineering, while firms active in genetic engineering are able to use other technologies.

Table 6.2 Firms that use technologies in more than one biotechnology class

		Percent of firms that use one or more technology in:			
	N	Genetic Eng	Environmental	Agricultural	None of the two
Genetic engineering	24	-	38	71	17
Environmental	166	5	-	11	87
Agricultural	59	29	30	-	51

An analysis of the potential to adopt another biotechnology in the future, outside of the firm's current class, requires limiting the analysis to firms that are only active in one of these three biotechnology classes. For example, a user of agricultural technology cannot currently use either genetic engineering or an environmental technology. There are 4 eligible firms for genetic engineering, 145 for environmental technologies, and 30 for agricultural technologies. Results are given in Table 6.3 for both methods of estimating planned future use: firms that plan to use another technology within two years and firms that are potential adopters. None of the four genetic engineering firms plan to adopt a technology from the other two classes and therefore these firms are not included in Table 6.3.

The results show that there is very little planned adoption of a biotechnology in another class within two years. Most of the planned adoption is by current users of environmental biotechnology who plan to use a different environmental technology from the ones that they currently use.

[20] The five genetic engineering technologies are recombinant DNA, peptide synthesis, gene probes, gene therapy, and DNA amplification. The five environmental technologies are bioaugmentation, bioremediation, bioreactors, phytoremediation, and biological gas cleaning. The five agricultural technologies are tissue culture, somatic embryogenesis, bio-pesticides, classical/traditional breeding, and microbio-inoculants.

Table 6.3 Planned and potential adoption of biotechnology

Current use	N	Planned Use Genetic E	Environmental	Agriculture
Plan to use within two years				
Environmental	145	x	17 (12%)	x
Agricultural	30	3 (10%)	3 (10%)	3 (10%)
Potential adopters (in two years plus too expensive)				
Environmental	145	x	28 (19%)	6 (4%)
Agricultural	30	3 (10%)	4 (13%)	3 (10%)

For example, 17 firms that currently use an environmental biotechnology, or 12% of current users, plan to use a different environmental technology within two years. Similar patterns are observed for the potential adopters. Current users of environmental biotechnology are most likely to adopt another environmental biotechnology (19%) while very few see any potential use for either genetic engineering or agricultural biotechnology.

These results show that these three technology classes are comparatively distinct. Firms that currently use one biotechnology are unlikely to adopt a biotechnology from a different technology class.

6.2. Conclusions

The results on the future diffusion of biotechnology are based on conditions in mid to large firms and exclude many firms active in pharmaceutical applications or in primary agriculture. However, the findings should provide a reasonably accurate picture of the short-term potential for the diffusion of biotechnology in the resource sectors, the food products sector, and for non-pharmaceutical chemical firms in Canada.

The short-term potential for the further diffusion of biotechnology to non-users is very limited, with only 18 non-users planning to adopt an environmental biotechnology within the next two years and only 11 non-users planning to adopt a culture & biological material technology in the same period. The employee-weighted results for both bio-users and non-users combined shows that the greatest potential for future adoption, once firms that currently find biotechnology too expensive are included, is for environmental biotechnologies. But even here only 11% of the employee-weighted firms are potential adopters. Only 2% of all firms (5% after employee-weighting) are potential adopters of the culture and biological material technologies that are used in the food and agricultural sectors.

These low, albeit short-term estimates of the future diffusion of biotechnology, contrast sharply with some recent estimates that biotechnology is likely to diffuse rapidly, particularly in the agricultural and food sectors[21]. Nor is the difference between the low diffusion rates found in this survey and the optimistic estimates in other studies due to different scenarios for the fall in the cost of biotechnology compared to alternative techniques. The estimates given above for potential adopters includes all firms that state that the technology is 'too expensive'. The greatest obstacle to future adoption is the high percentage of firms that report 'no application'.

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[21] For example, a report for EuropaBio recently estimated that steady growth in the use of biotechnology would result in an almost four-fold increase in the value of biotechnology in food and agriculture in Europe, from 40 billion ECUs in 1995 to 150 billion in 2005 (Burke JF, Thomas SM. Agriculture is biotechnology's future in Europe, *Nature Biotechnology* 15:695-696, August 1997).

The majority of potential adopters are existing bio-users that plan to adopt a different biotechnology than the ones in current use. Furthermore, most of the planned or potential adoption is likely to occur within the same technology class that the firm already uses, with very little adoption of technologies from different technology classes.

There are two complementary explanations for these results. The first is that the future diffusion of biotechnology, over the short term, is limited not so much by high costs, although this is a factor, as by a limited range of commercially feasible applications. In this respect, the widespread enthusiasm for biotechnology could be ahead of reality (at least outside of the pharmaceutical sector). Overcoming a lack of applications will require more basic and applied research to expand the range of commercially feasible uses for biotechnology[22]. A second explanation is due to information failure: many firms, particularly non-users, could be unaware of the potential applications of biotechnology in their firm. Some support for this explanation is shown in Table 6.1. A considerably higher percentage of current users plan to adopt a biotechnology than non-users. This could be due to a better understanding among the users of the benefits and potential applications of biotechnology.

[22] Several of the sector reports of the Canadian Biotechnology Taskforce comment on a lack of suitable applications. One relevant example is the use of bio-oxidation to recover minerals in mining. Existing applications of this technology are best suited to warm climates, whereas commercial applications to Canada require research to develop commercially viable biotechnologies that can function in a cold climate.

7. Barriers to Acquiring and Implementing Biotechnology

A major question of interest to policy is to identify the factors that act as impediments to the acquisition and implementation of biotechnology and to measure the importance of these factors. Several potential barriers to the development and use of biotechnology are amenable to government intervention, including the supply of skilled technicians and scientists, government regulations, and scientific and technical information services. Other potential barriers, such as a lack of a market or equity capital, can also be influenced by government policy, for example through public information programs or tax incentives.

The biotechnology survey asks all firms about the importance of 19 impediments to acquiring biotechnology. These are grouped into four categories: cost-related, availability of inputs, organizational problems, and a miscellaneous group. Firms that use biotechnology are also asked if nine separate factors, plus an 'other category', caused difficulties for the implementation of biotechnology processes. They could also respond that 'there were no barriers'.

7.1. Impediments to Biotechnology Acquisition

The question on impediments gives firms two response options. Firms could reply that each impediment was 'not applicable' or they could rate its importance on a five-point scale: insignificant, slightly significant, moderately significant, very significant, and crucial. The question also gives firms the option of noting that there were no impediments or that there were 'other' impediments not included in the question. However, very few firms used either of the latter two categories. Therefore, results for these two questions are not reported[23].

7.2. Non-user firms

The results to this question are difficult to interpret for firms that do not use biotechnology. Between 94% and 96% of non-user firms gave a response of 'not applicable' to each of the 19 impediments[24]. There are two possible interpretations of this result. The first explanation is that the vast majority of non-users do not find any of the 22 listed biotechnologies of relevance to their firm. This interpretation matches the fact that only 2% of non-users that answered any of the impediment questions are potential adopters of any biotechnology, as defined in Chapter 6. The second explanation is that many of the non-user firms did not find the question of great relevance and therefore did not take the time to answer the question[25].

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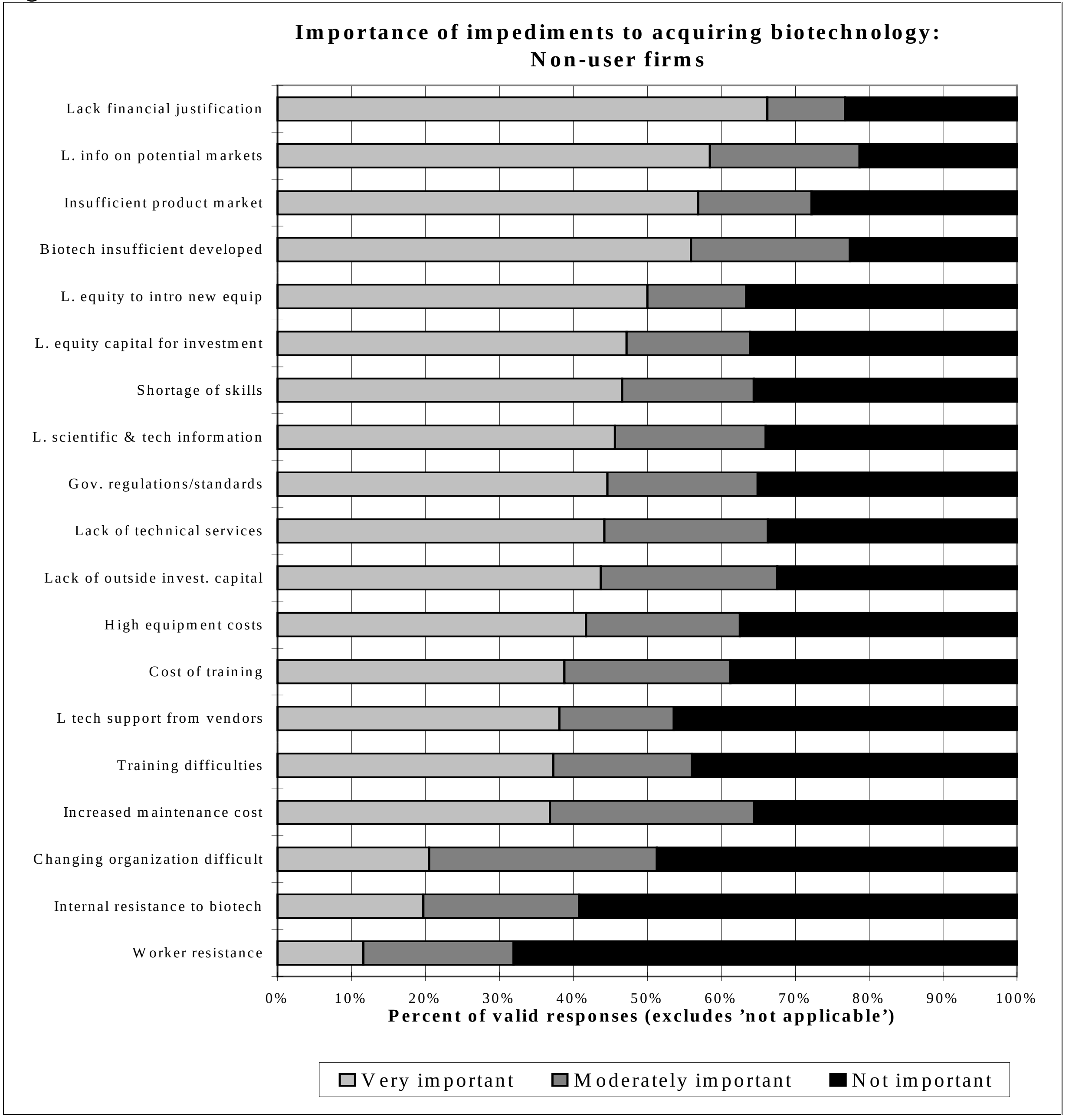
[23] Only 3.3% of the 2,010 firms gave a response other than 'not applicable' to the 'other' category while less than 0.2% responded that there were no impediments.

[24] In addition, 39 non-user and 12 bio-user firms did not answer any of the 21 questions on impediments. These firms are excluded from all of the analyses.

[25] There is some support for this explanation. The percentage of 'not applicable' responses is higher than expected, given the comparatively high use rates of over 25% of firms in the petroleum refining, wood, pulp and paper, crude petroleum, pharmaceuticals, and mining sectors, which suggests that biotechnology does have some value in these sectors.

Figure 7.1



We proceed here on the assumption that the first explanation has some validity. This permits an evaluation of impediments among non-users firms that gave a response other than 'not applicable' to each question. The importance given to each impediment by these firms is assumed to represent conditions among non-user firms that are aware of a biotechnology application in their sector[26]. The results are given in Figure 7.1. The importance scale is aggregated into three categories of 'not important' (insignificant and slightly), 'moderately important', and 'very important' (very important and crucial). The number of valid responses per impediment ranges from 71 to 103[27].

The impediments in Figure 7.1 are listed in descending order by the percentage of valid respondents that state that the factor is very important. This percentage exceeds 50% for four impediments: a lack of financial justification, a lack of information on potential markets, an insufficient market for the product, and an insufficient development of biotechnology. All of these impediments point to a problem either with information or with a lack of commercially applicable biotechnologies. None of these four factors concern the cost of investment or acquiring equity capital, although the fifth factor in order of importance is a lack of equity capital to implement biotechnology acquisitions. The least important impediments concern organizational problems within the firm. Less than 21% of the respondents reply that these three impediments are very important.

Several factors of great interest to policy, including a shortage of skills and government regulations and standards, are in the mid-range of importance. It would be of interest to divide the results by sector, since we would expect pharmaceutical and food firms to have different views on impediments than firms involved in the resource sectors. Unfortunately, there are too few responses to provide meaningful results by sector or area of activity. In addition, the results will be questionable, since an evaluation of skills or the impact of government regulation is best made by firms with some experience with them. For this reason it is worth turning to the results for firms that use one or more biotechnologies.

7.3. Importance of impediments for biotechnology user firms

The interpretation of the results for the questions on impediments is more complex for the bio-user firms than for the non-users. For the latter group the question refers to the importance of impediments to the acquisition of any biotechnology. In contrast, bio-user firms can interpret the question in two different ways: the effect of each impediment on the acquisition of a technology that has already been adopted, or the effect on the acquisition of a technology that the firm has not (or not yet) adopted. It is not possible to determine from the questionnaire results which interpretation has been used. It is only possible to assume that the results for bio-users are based on some experience with acquisition, although this will be a retrospective judgement for firms who interpret the question as referring to biotechnologies that it has already acquired.

A first comparison was made between the distribution of responses between the small number of non-user and bio-user firms that did not answer 'not applicable' to every question. For 14 of the 19 impediments, bio-users were significantly less likely than non-user firms to find the impediment of importance. The percentage of 'very important' responses among non-users was also over two times the percentage for bio-users for 11 impediments. As an example, 47% of non-users state that skill shortages are a very important barrier to acquiring biotechnology, versus only

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[26] An alternative is to limit the analyses to non-user firms who replied to this question and who are also potential adopters of one or more technologies, as defined in Chapter 6. However, these results are not very useful because only 41 non-users are in this group. The average percent of 'not applicable' responses for the 19 impediment questions for this group of non-users is 52.8%.

[27] See Table A-10 of Appendix A for full details.

13% of bio-users. These results suggest that a general lack of experience with biotechnology, rather than any specific impediment, is one of the largest barriers to their acquisition by firms that do not currently use biotechnology[28].

Table 7.1 gives results for each impediment for 259 bio-users that answered at least one of the 19 questions. These results are not directly comparable with those given in Figure 7.1 for non-users because of different methods of aggregation. The table for bio-users includes the not-applicable

Table 7.1 Importance of impediments to adopting biotechnology for 259 bio-user firms

Impediment	Not applicable	Not important	Important
Cost-related problems			
High equipment costs	42	14	43
Lack of equity capital to implement new equipment	52	18	30
Lack of financial justification	47	18	35
Cost of training	50	31	20
Increased maintenance expenses	49	27	23
Insufficient market for product	63	18	19
Government regulations/standards	45	17	38
Availability of inputs			
Lack of equity capital for investment	53	21	26
Lack of outside capital for investment	59	22	19
Shortage of skills	48	32	21
Training difficulties	50	32	19
Organizational problems			
Difficulties in introducing organizational changes	50	33	18
Internal resistance to biotechnologies	49	38	13
Worker resistance	49	43	8
Other problems			
Lack of scientific and technical information	41	32	27
Lack of technical services (consulting, testing)	44	32	23
Lack of technical support from vendors	46	33	21
Biotechnologies not sufficiently developed	44	23	33
Lack of information about potential markets	59	18	22

Note: The rows sum to 100%.

option plus two other categories. Responses of insignificant or slightly important are combined into a 'not important' category, while responses of moderately important, very important, and crucial are combined into an 'important' category.

The five impediments with the highest percentage of 'important' responses are high equipment costs (43%), government regulations or standards (38%), lack of financial justification (35%), insufficient development of biotechnology (33%), and a lack of equity capital to implement new biotechnology acquisitions (30%). Four of these factors concern the cost of acquiring new equipment based on biotechnology. For example, high equipment costs will make it difficult to justify the adoption of a biotechnology if an alternative technology is already available, while more de-

[28] The comparison is based on the three categories used in Figure 7.1 (very important, moderately important, and not important). The results for the percentage of 'very important' responses for non-users, bio-users, and the p value (based on the distribution across all three classes) are as follows: high costs (42, 44, .066), lack of equity capital (50, 40, .182), lack of financial justification (66, 36, .000), cost of training (39, 8, .000), increased maintenance cost (37, 8, .000), insufficient market for product (57, 27, .000), government regulations (45, 39, .289), lack of equity capital for investment (47, 30, .048), lack of outside capital (44, 18, .001), shortage of skills (47, 13, .000), training difficulties (37, 8, .000), difficulties in introducing organizational change (20, 12, .054), internal resistance (20, 11, .068), worker resistance (12, 4, .018), lack of scientific or technical information (46, 21, .000), lack of technical services (44, 16, .000), lack of technical support from vendors (38, 16, .000), biotechnology insufficiently developed (56, 32, .000), and lack of information on potential markets (58, 24, .000).

velopment of the technology would reduce costs both by improving the reliability of the technology and through production scale factors. The relatively low percentage of firms that cite an insufficient market for the product (19%) suggests that biotechnology use will increase among these firms as acquisition costs decline.

Three impediments that are linked to labour skills (skill shortages, training costs, and training difficulties) are less important than cost factors. Less than 21% of the respondents find each skill factor to be an important impediment. A lack of information appears to be more important than a lack of skilled labour, as shown by over 20% of respondents citing as important a lack of information on potential markets (22%), technical services (23%), and scientific or technical information (27%). The group of organizational problems are the least likely to impede the acquisition of biotechnology.

The effect of the size of the firm, measured by the number of employees, on the 'importance' of each impediment was evaluated through linear trend analyses using six size classes[29]. The percentage of firms that found an impediment to be of importance declined with firm size for five impediments, four of which are financial: lack of equity capital for the implementation of new biotechnology acquisitions, the cost of training, lack of equity capital for investment, and a lack of outside capital for investment. The fifth factor that declines in importance with firm size is an insufficient market for the product. Only one impediment increases in importance with firm size: internal resistance to biotechnologies. For all other impediments, including government regulation, skill shortages, and a lack of various information sources, there is no difference in importance by firm size.

7.4. Differences in the importance of impediments by sector

There are enough respondents among the bio-users to investigate differences by sector. Table 7.2 gives the percentage of firms in each of eight sectors that find an impediment of importance. The most important impediments in each sector, based on an evaluation of both the firm-level and employee-weighted results[30], are summarized below.

Mining: The most frequently cited impediment for mining firms is a lack of appropriate biotechnologies, followed by a lack of information and a shortage of skills. This combination of impediments hinges on problems in the supply of suitable biotechnologies. The employee-weighted results also point to the importance of a lack of financial justification, which suggests that the available biotechnologies are uncompetitive with the alternatives. Government regulations are also a commonly cited impediment.

Crude petroleum and petroleum refining: These two sectors are discussed together because of the similarity of the results. The most commonly cited impediment is government regulations, followed by high equipment costs and the insufficient development of biotechnologies. All other impediments are relatively unimportant, both within these two sectors and compared to other sectors. The use of biotechnology by firms in both of these sectors is almost entirely limited to

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[29] The six size classes are: 0 - 49 employees, 50 - 99 employees, 100 - 249 employees, 250 - 499 employees, 500 - 999 employees, and over 1000 employees.

[30] The equivalent employee-weighted results are given in Table A-11 of Appendix A.

environmental biotechnology. This suggests that the concern over government regulation is related to environmental regulation.

Wood, pulp and paper: The most important impediments in this sector are high equipment costs, a lack of financial justification, and a lack of sufficient development of biotechnologies, while firms in this sector are moderately concerned about maintenance costs and a lack of equity capital for investment. This combination suggests that biotechnologies are not yet fully competitive with alternatives, once the high cost of replacing large existing investment in capital equipment is factored in. Government regulation and a lack of information are of moderate concern. Market conditions and a shortage of skills are a minor problem.

Food: High equipment cost is the most commonly cited impediment in the food sector for both the firm and employee-weighted results. Other important impediments are a lack of financial justification and a lack of finance among the smaller food firms. Surprisingly, government regulations are less commonly cited in this sector than in all other sectors at the firm level and they are also relatively unimportant for the employee-weighted results. In contrast, concern over internal resistance to biotechnologies is relatively more common among food firms. This could be due to a more traditional attitude to food production, although this is not reflected by a high level of concern over product markets.

Table 7.2 Percentage of bio-user firms by sector that find each impediment of importance[1] (maximum number of responding firms per sector in parentheses)

	M (12)	CP (33)	PR (9)	WPP (48)	F (111)	P (19)	NPC (18)	O (8)
Cost-related problems								
High equipment costs	33	33	33	54	44	42	33	62
Lack of equity capital to impl equip	8	12	11	38	34	37	17	62
Lack of financial justification	25	21	33	53	35	21	39	25
Cost of training	8	12	-	23	19	42	11	38
Increased maintenance expenses	17	24	11	36	20	32	6	38
Insufficient market for product	-	12	-	11	23	21	44	12
Government regulations/standards	42	46	44	36	34	47	39	38
Availability of inputs								
Lack of equity capital for investment	-	12	-	34	29	37	17	62
Lack of outside capital for investment	8	12	-	17	19	32	17	62
Shortage of skills	42	12	11	19	16	42	28	38
Training difficulties	33	12	11	13	19	37	17	25
Organizational problems								
Difficulties in organizational changes	-	12	11	17	20	26	22	13
Internal resistance to biotechnologies	-	6	11	13	15	5	22	25
Worker resistance	-	3	3	13	10	10	-	-
Other problems								
Lack of scientific & tech information	58	24	22	38	22	21	28	12
Lack of technical services	33	19	-	34	22	26	17	12
Lack of tech support from vendors	17	18	11	30	21	32	11	12
Biotechnologies not developed	75	30	33	43	26	32	39	12
Lack of info about potential markets	8	15	-	17	24	35	33	50

[1]: Includes firms that responded 'not applicable'. Importance is defined as a moderately important, very important, or crucial response. M: mining, CP: crude petroleum, PR: petroleum refining, WPP: wood, paper, and pulp, F: food, beverages and tobacco, P: pharmaceuticals, NPC: non-pharmaceutical chemicals, O: other manufacturing.

Pharmaceuticals: There is a large difference between the firm-level and employee-weighted results for this sector. This is caused by a sharp difference in concerns over impediments between the large percentage of small pharmaceutical firms in the survey and the small proportion of very large firms. The consequence of this division is that the firm-level results represent conditions among small pharmaceutical firms while the employee-weighted results represent large firms. The large firms show a minimal level of concern for most impediments, with almost all values below 10%. The only important impediments are a lack of technical support from vendors and a lack of information on potential markets. The smaller pharmaceutical firms display the greatest level of concern over impediments relative to all other sectors. This high level of concern applies to almost all impediments except for a lack of financial justification. This could be caused by a heightened awareness of the problems, due to a very strong reliance on the development of competitive, new biotechnology products. Concern over government regulations is highest among small pharmaceutical firms compared to all other sectors, although it is not notably higher compared to mining, crude petroleum, and petroleum refining. Large pharmaceutical firms are considerably less likely to be concerned about regulation.

Non-pharmaceutical chemicals: This sector shows some of the division noted for pharmaceutical firms between large and small firms. Two impediments that attract a moderate level of concern for both the firm-level and employee-weighted results are government regulations and a lack of sufficient development of biotechnologies. This sector also has the highest percentage of firms that are concerned about product markets.

Other manufacturing: The results for this sector are unreliable, both because less than 2% of firms in this sector use biotechnology and because there are very few respondents to the question on impediments. Consequently, no conclusions about impediments are drawn for these firms.

7.5. Barriers to the Implementation of Biotechnology Processes

Users of biotechnology were asked if each of nine factors had ‘particular significance’ as a difficulty for the implementation of biotechnology processes. The question also includes an ‘other’ option and the option of ‘there were no barriers’ (listed in last place). There are two notable differences between this question and the question on impediments to biotechnology acquisition. First, the respondent can only check if each factor had ‘particular significance’ as a barrier, whereas the impediment question provides an importance scale. Second, the question is asked separately for the three main technology classes: selection and modification of biological material, culture and/or use of biological material, and environmental biotechnologies.

The results given below for each of the three biotechnology classes are limited to firms that use one or more technologies in the relevant class[31]. Results are also provided for the use of any biotechnology, based on a positive response to a barrier in one or more of the three biotechnology classes.

The results are presented in Figure 7.2 at the firm level for each of the three biotechnology classes plus all three classes combined[32]. The results are ordered by the percentage of firms that cite each barrier for any of the three biotechnology classes.

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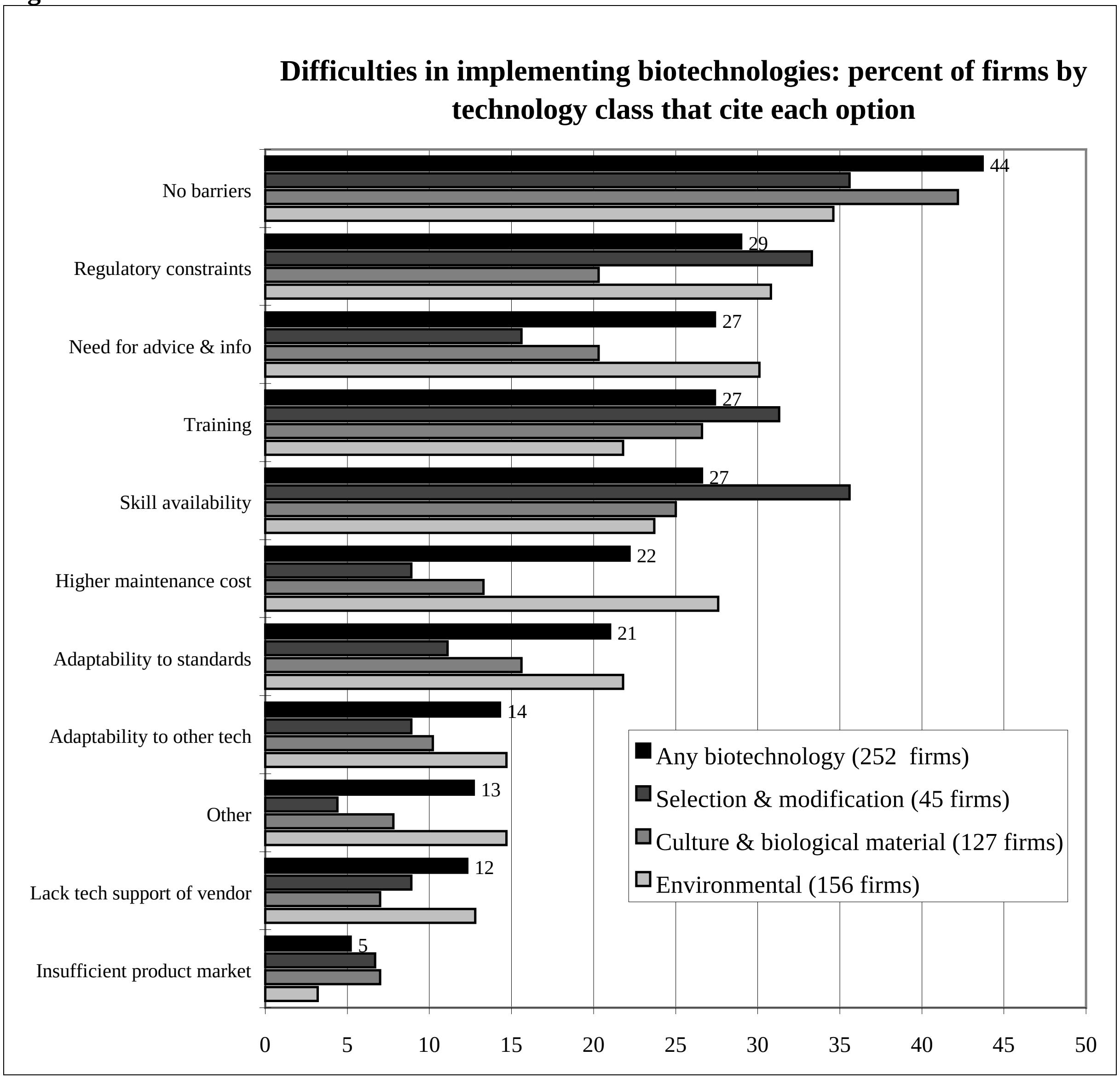
[31] Nineteen bio-user firms are excluded from all of the results because they did not answer any of the questions, leaving valid responses for a maximum of 252 firms.

[32] Table A-12 of Appendix A provides full firm and employee-weighted results.

Figure 7.2



Under most conditions, firm level results are preferable to employee-level results as a measure of the problems with implementation because the problems will be similar regardless of the size of the firm or the number of establishments that it has. One possible exception to this assumption is if the degree of difficulty increases with the scale of production. If true, the percentage of firms that report difficulties should increase with the average firm size. Linear trend analysis of each of the 11 barriers for each of the three technology classes found that the firm's size had no effect for the implementation of selection & modification and for culture & biological material technologies. However, the percentage of firms that reported difficulties due to training, the need for advice and information, and regulatory constraints increased with firm size for users of environmental technologies. The first two suggest problems with the expertise required to implement biotechnology on a large scale. The problem with regulatory constraints could reflect differences in the types of activities of small versus large users of environmental biotechnologies.

Figure 7.2 shows that the most prevalent response is 'no barriers' to implementation, which is reported by 44% of the firms for at least one of the technology classes and by 33% or more of the firms in each technology class. The most common barrier is regulatory constraints, followed by three factors that are linked to the availability of expertise: the need for advice and information, training, and skill availability. The prevalence of each difficulty is similar between the three technology classes, with the culture and biological material group occupying the middle ground, with correlation coefficients (R2) of 0.74 with the selection and modification class and 0.85 with the environmental class. The differences between the selection and modification and environmental classes is much greater, with an R2 value of 0.41. The most visible differences between the three classes is for the need for outside advice and high maintenance costs, which are much more prevalent for firms that use environmental technologies.

7.6. Differences by sector

Differences by sector were compared for the prevalence with which a difficulty was noted in any biotechnology class. Very few significant differences occur for either comparisons between the eight sectors or between the resource and manufacturing sectors. The only notable difference among the eight sectors is for the availability of skills, which is cited by 46% of mining firms and 56% of pharmaceutical firms but only by 7% of crude petroleum and 10% of petroleum refining firms[33]. The comparisons based on all resource sectors versus all manufacturing sectors show that a significantly higher percentage of resource firms cite regulatory constraints than manufacturing firms: 38% versus 23% respectively.

7.7. Conclusions

The available results on the impediments faced by firms that do not use biotechnology are limited. However, three pieces of evidence point to a major role of either a lack of information on biotechnology or a lack of applications. First, the very high percentage of non-users that gave responses of 'not applicable' suggests that the non-users either lacked an adequate level of knowledge about biotechnologies or that biotechnology was not applicable to their firm. Second, non-users that did reply to the impediment questions emphasized factors that are linked to a lack of information or commercially suitable applications. Third, a much higher percentage of non-user than bio-user firms found the impediments to be 'very important'. This suggests that a lack of first-hand experience with biotechnology increases the level of concern over the potential impediments to acquisition.

The most important impediments to acquisition faced by bio-users are cost-related factors. This suggests that the use of biotechnology will increase as the costs fall in response to further development work on these technologies. Concern over cost also declines with firm size. Factors related to skills and training do not appear to be an important impediment, except for small pharmaceutical firms. The most important impediments for firms in the resource sectors concern a lack of suitable, cost-effective biotechnologies. This is also emphasized by the relatively high percentage of users of environmental biotechnologies that cite high maintenance costs as a barrier to the implementation of biotechnology.

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[33] See Table A-13 of Appendix A for full details of differences by sector for any biotechnology class.

Results on the importance of regulation, although always of great concern to government policy, are notoriously difficult to interpret. This is because regulation can work both ways: it can encourage the adoption of a technology or hinder it, but survey respondents often give negative responses, perhaps instinctively, to questions on regulation. Unfortunately, the question on regulation is not detailed enough to provide good results on the role of regulation as an impediment to acquisition or as a barrier to implementation. Nevertheless, two main conclusions can be drawn.

First, firms in the resource sectors are more concerned about regulation as an impediment to the acquisition and implementation of biotechnology than firms in manufacturing, with the exception of small pharmaceutical firms. Since resource firms are major users of environmental biotechnology, this indicates that environmental regulations are acting as an impediment to the use of biotechnology. The problem here is that it is not clear if the negative appraisal of regulation concerns environmental regulation per se or if these environmental regulations do, in fact, hinder the use of biotechnology.

Second, food firms and large pharmaceutical firms are much less concerned about regulation than firms in other sectors. This should moderate concerns that strict regulation in these sectors is inhibiting the use of biotechnology. One explanation is that firms in these two sectors accept regulation as a necessary part of business.

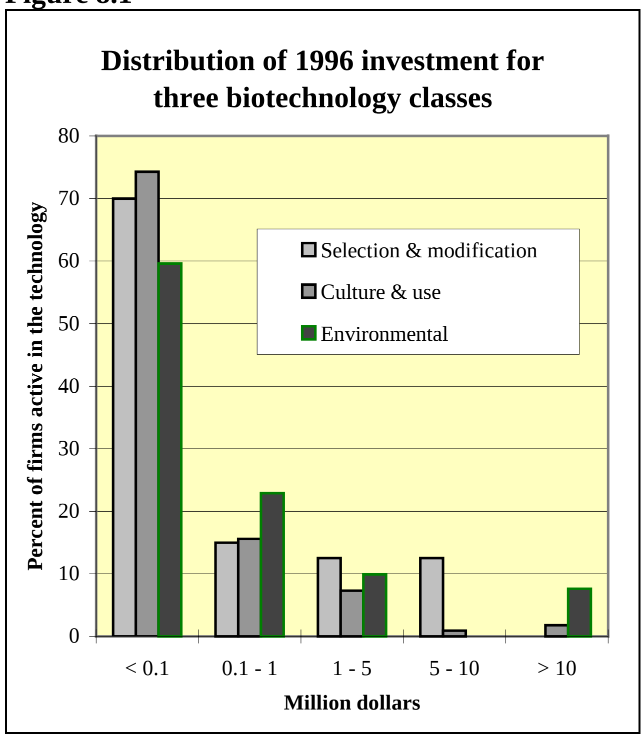
8. Investment in Biotechnology Equipment & Software

The results for the impediments to biotechnology acquisition presented in Chapter 7 identify high equipment costs as a major impediment for firms that currently use biotechnology, although it is less of a barrier for non-users. High investment costs are of policy concern because they could act as entry barriers for new firms or block the diffusion of beneficial technologies.

The questionnaire obtains rough estimates of investment in biotechnology equipment and software, for one year, in the three technology classes: selection and modification technologies, environmental technologies, and the culture and use of biological material. These results permit a snap-shot view of the amount of investment in different sectors and by technology. Although suggestive, they do not allow a thorough investigation of the effect of investment costs on biotechnology acquisition because the data are only available for one year. Data on cumulative investment over time are required for a complete picture of investment costs.

Each firm that used one or more biotechnologies was asked to estimate their 1996 investment in the three main technology groups. Six options are provided: less than 0.1 million dollars, 0.1 to 1 million, 1 to 5 million, 5 to 10 million, over 10 million dollars, and 'not applicable'. The latter option was valid for firms that are not active in a specific technology class. Firms that are active in a specific technology but which marked 'not applicable' are assumed to have made zero investments in the technology during 1996[34].

Figure 8.1



8.1. Distribution of Investment by Technology Class

The distribution of the amount of investment in each biotechnology class is given in Figure 8.1, limited to 225 firms that made some investment: 40 in selection and modification technologies, 109 in the culture and use of biological material, and 131 in environmental technologies. Over 60% of firms invested less than 0.1 million dollars in each technology class, with very few firms investing more than 10 million dollars. The highest level of investment is for environmental technologies.

Only 12% of the firms made no investments in biotechnology in 1996. Almost all of these firms (28 out of 30) were only active in one of the three biotechnology classes. The majority of firms,

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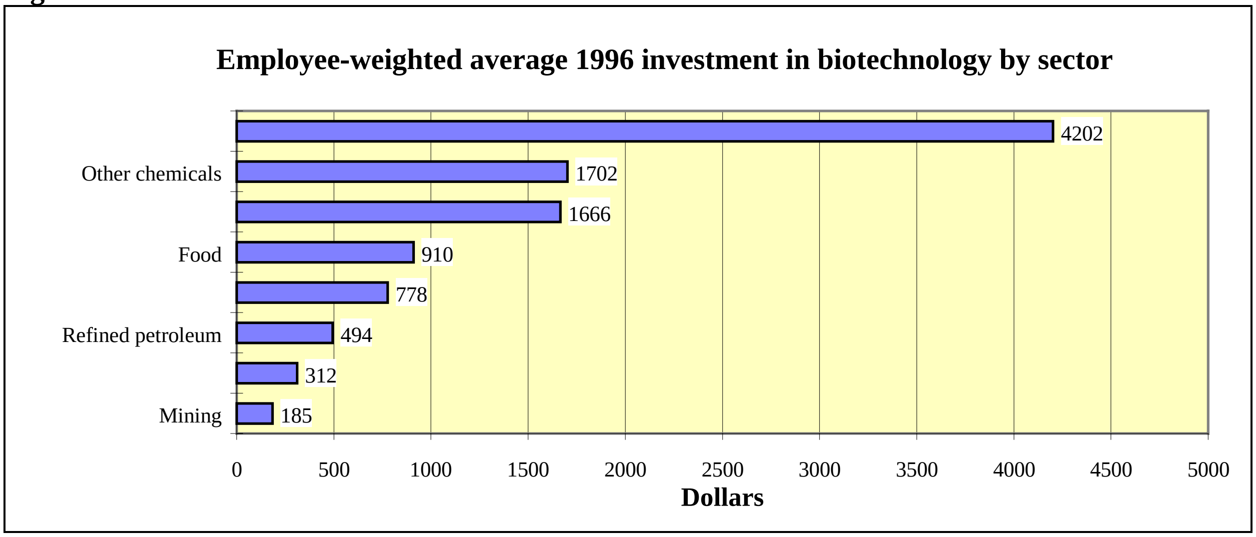
[34] Sixteen firms did not answer any of the questions and are excluded from the analyses, leaving useable results for 255 bio-user firms.

69%, invested in one biotechnology class, 17% in two classes, and 2% in three. This is slightly less than the percentage of firms that were active in one, two or three biotechnology classes (74%, 22%, and 4% respectively).

8.2. Average Investment by Sector

The mid-point of each investment level is used to calculate the average investment by firms in each sector[35]. Investment is summed across the three technology classes for 46 firms that were active in two or three classes. The average investment per employee in 1996 in each sector is given in Figure 8.2.

Figure 8.2



The average investment per employee in pharmaceuticals of 4,202 dollars is over twice as high as in any other sector. In contrast, average investment levels per employee are lowest in the three resource sectors of petroleum refining, crude petroleum, and mining. The highest level of investment in resources is for the wood, pulp and paper industry.

8.3. Investment Costs as a Barrier to Acquiring Biotechnology

The employee-weighted percentage of firms in each sector that find the high cost of biotechnology equipment to be an important impediment to acquiring biotechnology does not correlate well with the average employee-weighted 1996 investment. If anything, there is a negative relationship, with a higher percentage of firms with low investment levels reporting that high equipment costs are an important impediment. For example, only 4% of the employee-weighted firms in the pharmaceutical sector, which has the highest average investment per employee, find equipment costs to be an important barrier compared to 90% of firms in petroleum refining, with an average investment of about 500 dollars. In addition, the average investment per firm in biotechnology in

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[35] A response of 'not applicable' is set to zero, while investment over 10 million dollars is set equal to 10 million. The latter will underestimate averages where large investment amounts are common.

some of the resource sectors is comparatively low. This is shown in Table 8.1. The lowest average investment is in the crude petroleum and mining sectors. These results suggest that high equipment costs, by themselves, are not an important impediment to investment in biotechnology. Instead, a lack of cost-effective environmental biotechnologies is a more probable explanation of the low levels of investment in the mining and crude petroleum sectors.

Table 8.1 Firm and Employee-weighted average investment in biotechnology in 1996: by sector (in thousands of Canadian dollars)

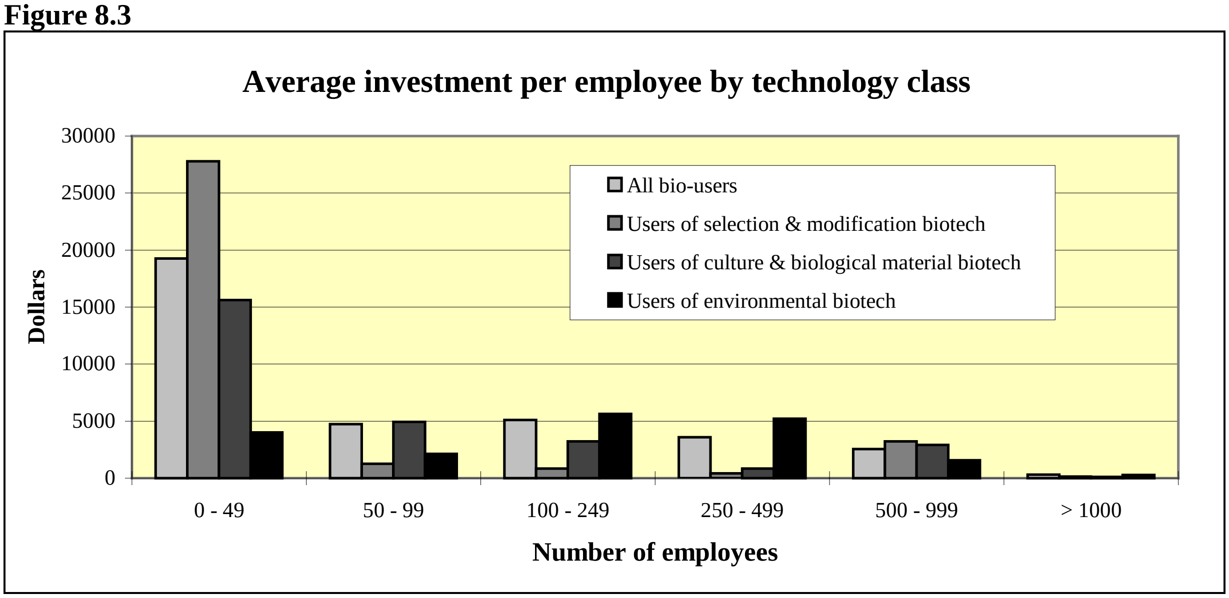
Sector	N	Firm-level average	Employee-weighted[1]
Mining	12	229	291
Crude petroleum	31	120	175
Petroleum refining	11	1,581	1,712
Wood, pulp & paper	48	2,318	2,097
Food	111	616	832
Pharmaceuticals	17	1,891	3,342
Non-pharmaceutical chemicals	17	720	611
Other manufacturing	8	431	1,106

[1]: Excludes firms with 10 or more establishments.

8.4. Average Investment by Size and Technology Class

Figure 8.3 gives employee-weighted average investment per employee for six size classes. The results are given for all bio-users and for bio-users that are active in each technology class[36]. The figure shows a clear difference in investment patterns between firms active in environmental

Figure 8.3



biotechnology and in the other two technology classes. Average investment per employee for environmental biotechnology is comparatively flat across all size classes, except for firms with more than 1000 employees, where it falls to 268 dollars. In contrast, average investment levels per employee in selection & modification biotechnology and in culture & biological material is considerably higher among firms in the smallest size class. This effect is greatest for selection and modification, which includes genetic engineering. These results highlight the importance of small firms in the development of technologically-advanced biotechnologies.

8.5. Conclusions

The majority of firms active in biotechnology invested less than 0.1 million dollars in 1996 in biotechnology equipment and software. Although this is not very high, firms in the smallest size class invested considerably more per employee than larger firms, particularly in the non-environmental biotechnologies. However, this does not appear to form an entry barrier because the importance of high equipment costs as an impediment to the use of biotechnology declines with the actual amount of investment made by firms. This is because investment patterns are strongly influenced by the sector of activity, with consistently high levels of investment per employee or firm in the pharmaceutical and wood, pulp & paper sectors and consistently low levels of investment in mining and in crude petroleum. Whether or not a level of investment is unacceptably high or not is likely to depend more on the cost-effectiveness of the technology than on the absolute costs.

These results also suggest that investment in biotechnology in mining and crude petroleum is lagging, particularly given the high potential for environmental biotechnology in these sectors[37]. However, our ability to use the results to determine whether or not investment is adequate is severely constrained by a lack of comparable data for other countries and by the lack of data for more than one year.

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[36] See Table A-14 of Appendix A for the full results. The average investment by technology class excludes investment made by a firm in a different technology class.

[37] Biotechnology has a wide range of applications in both mining and energy extraction, including bio-leaching and biooxidation of ore, bioupgrading of crude oil quality, and bioremediation and phytoremediation for environmental management. See the Canadian Biotechnology Strategy report on the Mining and Energy Sectors, November, 1997.

9. Perceived and Actual Benefits of Biotechnology

What factors influence the decision to use biotechnologies? And once adopted, what benefits do firms gain from them? One set of survey questions asks bio-users if each of eight factors, plus an 'other' category, had a positive influence on their decision to adopt biotechnology. A second set of questions asks firm if their use of biotechnology led to each of 15 benefits, plus an 'other' category and a 'no improvements' category. Each set of questions is asked separately for the three main biotechnology classes. A better understanding of the benefits of biotechnology is of value both for policies to encourage the use of biotechnology and for firms that might be considering their adoption.

The policy implications of these two question groups largely lie with the second question on the results of using biotechnology. The first question on the factors influencing the decision to use biotechnology is ambiguous. It could either refer to the expectations held by firms in the past or to the factors that cause the firm to continue to use biotechnology[38]. In either case, the perception of actual benefits is likely to have a larger impact on future expectations. Therefore, the results of the second question is more relevant to the future diffusion of biotechnology and is given more attention below.

9.1. Influences on the Decision to Use Biotechnology

Figure 9.1 gives the percentage of firms that find each of nine factors to have influenced their decision to use biotechnology[39]. The results are given separately for all classes of biotechnology combined and for each of the three biotechnology classes separately. For example, a factor is counted as having influenced the decision for 'any biotechnology' if it was a factor in one or more of the three separate technology classes. The results for each biotechnology class, in contrast, are limited to firms that use at least one technology within the class.

The three most commonly cited factors for any biotechnology are to lower production costs, develop new products and processes, and internal familiarity with the technology. Very few firms decided to use a technology because of the expectation of faster delivery times.

[38] One problem with the question on the decision to adopt is that an interpretation based on past conditions could be influenced by current outcomes. For example, a firm that managed to significantly reduce production costs as a result of a biotechnology that was introduced ten years earlier could respond that 'lower production costs' influenced the decision to use biotechnology. Furthermore, as shown in Table 5.1, many biotechnologies have been in use for between 10 and 30 years. It is possible that the respondent does not know or remember the original reasons to adopt the technology. The effect of the number of years that a technology has been in use was checked by dividing all users of any technology in one of the three biotechnology classes into 1) firms that had used any technology within the class for more than five years and 2) firms that had used none of them for more than five years. The frequencies of firms in each group that gave a 'yes' response to each of the 27 decision to adopt questions were compared. There were four statistically significant differences, two of which were for 'internal familiarity with the technology'. This was a more frequent influence on the decision to adopt among firms that had been using biotechnology for more than 5 years. For the majority of questions, there was very little difference in the frequencies. These results indicate that the findings (with the one exception) are not biased by the length of time that the firm has used a biotechnology within the technology class.

[39] See Table A-15 of Appendix A for the full results.

Figure 9.1

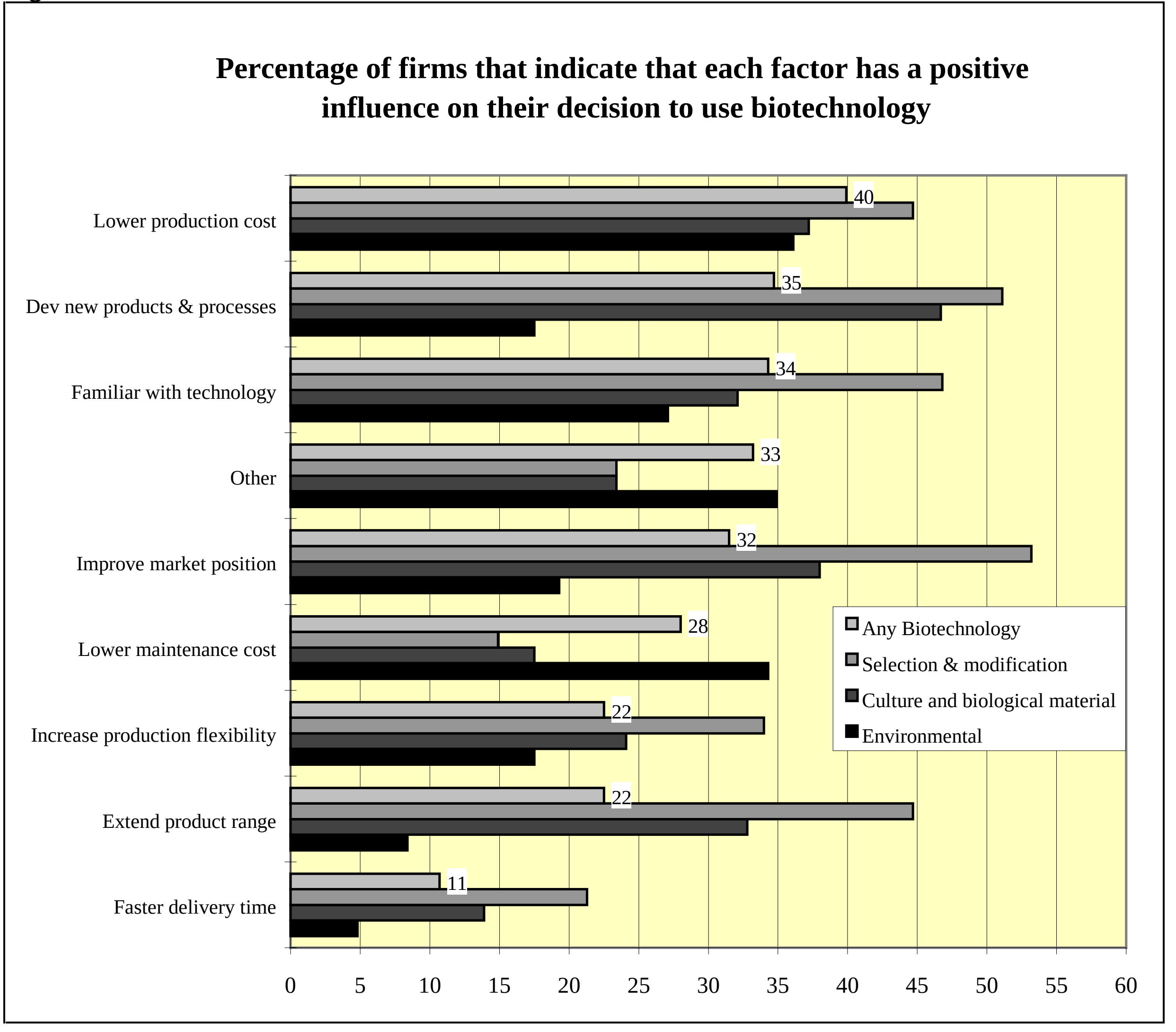
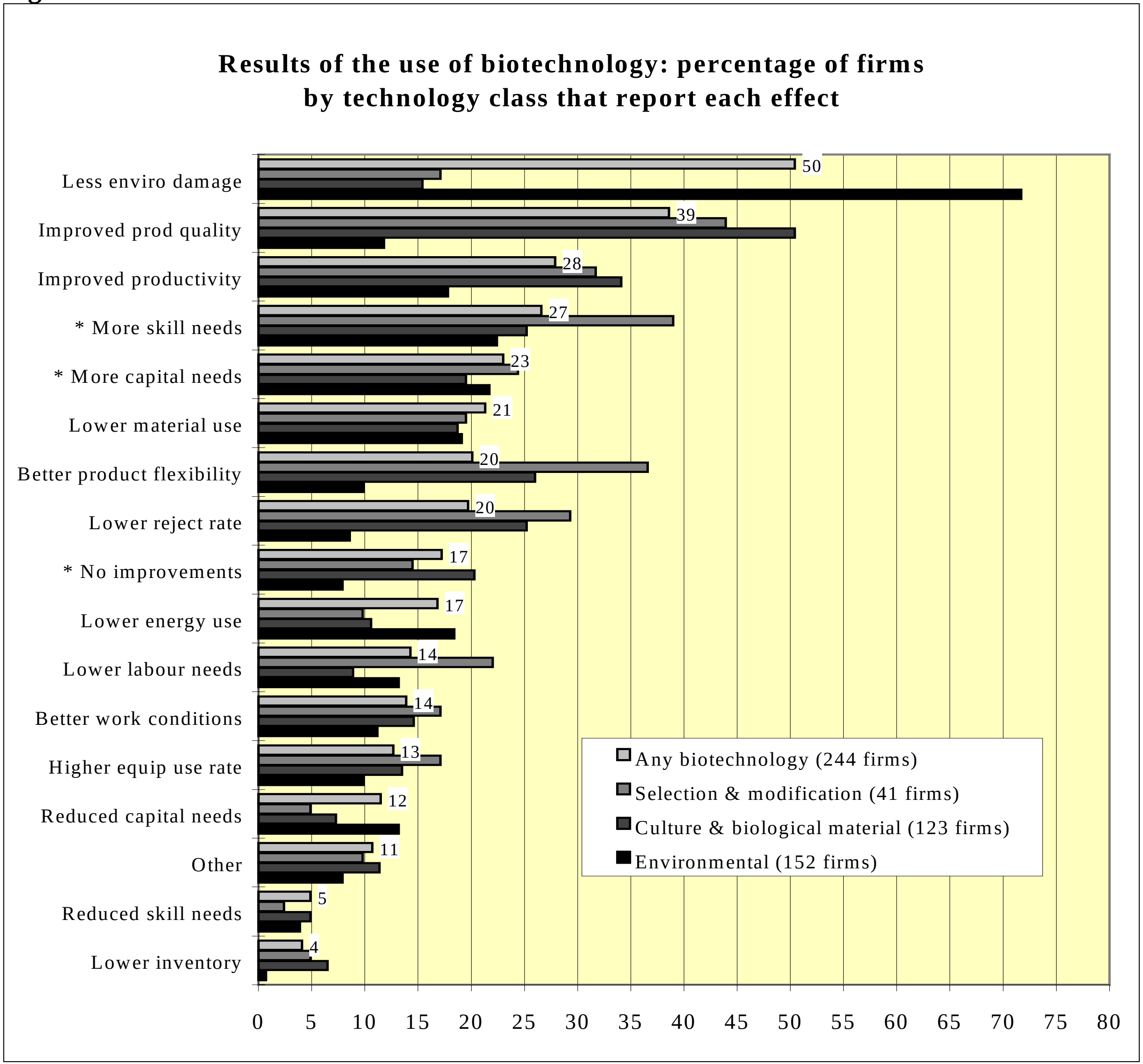


Figure 9.1 shows that there are large differences in the factors among the three technology classes. First, firms active in the selection and modification technologies have the widest variety of factors influencing their decision to adopt, as shown by the above average frequencies for many different factors. A high percentage of these firms are also influenced by factors related to product markets, such as improving their market position, extending their product range, and developing new products and processes. In contrast, the frequencies for users of environmental technologies are much lower across most of the factors. The most frequently cited factors for these firms are lower production costs, lower maintenance costs, and the 'other' category, all of which are cited by approximately 35% of these firms. The 'other' category could be cited to indicate environmental reasons for using biotechnology, since this reason is not included among the list of nine factors. All other factors, with the exception of familiarity with the technology, are cited by less than 20% of the users of environmental biotechnologies.

Figure 9.2



The results for users of culture and biological material technologies lie between the two other technology classes. The most frequently cited factor is the development of new products and processes.

9.2. Benefits of Biotechnology Use

The second question asks about the results of biotechnology use for each of the three main technology classes. Fifteen results are provided, plus an 'other' category and a 'no improvements' category. Of the fifteen, 13 are benefits, such as reduced labour requirements or an increased equipment use rate, while two are possibly disadvantages because they could increase costs: increased skill requirements and increased capital investments. The results for the firm-level are given in Figure 9.2 for each biotechnology class plus all three combined into 'any biotechnology'[40]. An asterisk '*' is used to mark outcomes that are not benefits.

The results for the selection & modification and culture & biological material technologies are very similar, with a strong correlation coefficient (R2 equals 0.77). In contrast, the results for environmental technologies differ substantially[41]. The most frequent outcome for users of environmental biotechnology, not surprisingly, is a reduction in environmental damage, with 72% of the users reporting this outcome. All other beneficial outcomes for environmental users are considerably less prevalent. The next most frequent benefit is 'lower energy use', reported by 18% of these firms.

The most commonly cited benefit for the users of the other two technology classes is an improvement in product quality, cited by 50% of the users of culture & biological material technologies and by 44% of the users of selection and modification technologies. This is followed by a group of outcomes for higher efficiency: improved productivity, better product flexibility, and a lower rejection rate, all of which are cited by between 37% and 25% of the firms. All other beneficial outcomes are cited by less than 20% of the firms.

A higher percentage of users in all three technology groups find that the use of biotechnology increases the need for skilled labour and capital than reduces the need for these two inputs. For all firms combined, 27% report an increase in the need for skilled labour versus 5% who report a decline, and 23% report an increase in the need for capital compared to 12% who report a decline. The outcome of the need for more skilled labour is highest in the selection and modification group, at 39%, where the most advanced biotechnologies are under development. R&D performing firms in each group also reported the highest increases in the need for skilled labour[42].

9.3. Benefits of Environmental Biotechnologies

The goal of innovation in many environmental areas is to develop clean production techniques that are both better for the environment and reduce costs by requiring fewer inputs or less expensive inputs. The outcome from using environmental biotechnology is investigated further to identify the percentage of firms that use these technologies and benefit from lower costs. A basic reduction in costs is assumed to occur if the user identifies one or more of the following outcomes: lower labour costs, lower material consumption, lower energy consumption, or a lower product rejection rate. A firm could also benefit from environmental technologies that improve productivity (through an increased equipment utilization rate) or product quality.

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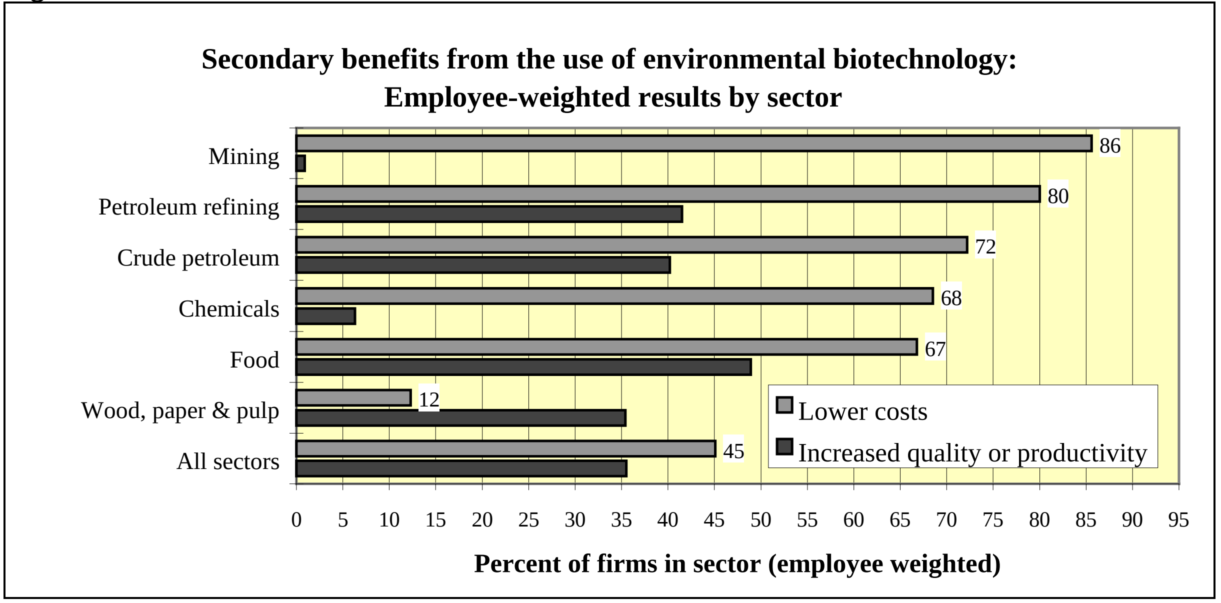
[40] See Table A-16 of Appendix A for the full results.

[41] The correlations use the results for all 17 questions shown in Figure 9.1. The coefficients between the outcomes for environmental biotechnology and each of the other two biotechnology classes are 0.0 when 'less environmental damage' is included and only slightly better, with R^2 coefficients of 0.09 and 0.20, when this outcome is excluded from the correlation.

[42] The difference in the percentage of R&D performers and non-R&D performers that report an increase in skill requirements is statistically significant for all three technology classes. No other result consistently differed in prevalence between R&D performers and non-R&D performers.

Figure 9.3 provides employee-weighted results for six sectors, limited to 109 firms that noted that the use of environmental biotechnology had reduced environmental damage. There are no pharmaceutical firms in this group and too few ‘other manufacturing’ firms to be able to provide separate results for this sector[43]. For all sectors combined, the percentage of firms that report lower production costs from the use of environmental biotechnologies is 45%, while 36% report an increase in quality or productivity. Unexpectedly, a reduction in cost is most prevalent in mining

Figure 9.3



(which has one of the lowest use rates for environmental technologies), and lowest in wood, pulp and paper, (which has one of the highest use rates). In all sectors except wood, paper & pulp, considerably more firms note secondary benefits from a reduction in costs than they do from an increase in quality or productivity. These results show that the environmental biotechnologies have noticeable secondary benefits for firms, particularly for reducing costs.

9.4. Differences in the Prevalence of Outcomes by Firm Size

The prevalence of each outcome from the use of any of the three biotechnology classes was determined for each of six firm size classes. The goal is to determine if some outcomes were more prevalent among small, medium or large firms. Statistically significant differences by size class were found for four effects of the use of biotechnology: an improvement in productivity, a lower product rejection rate, an increase in product quality, and reduced environmental damage. The results are given in Figure 9.4.

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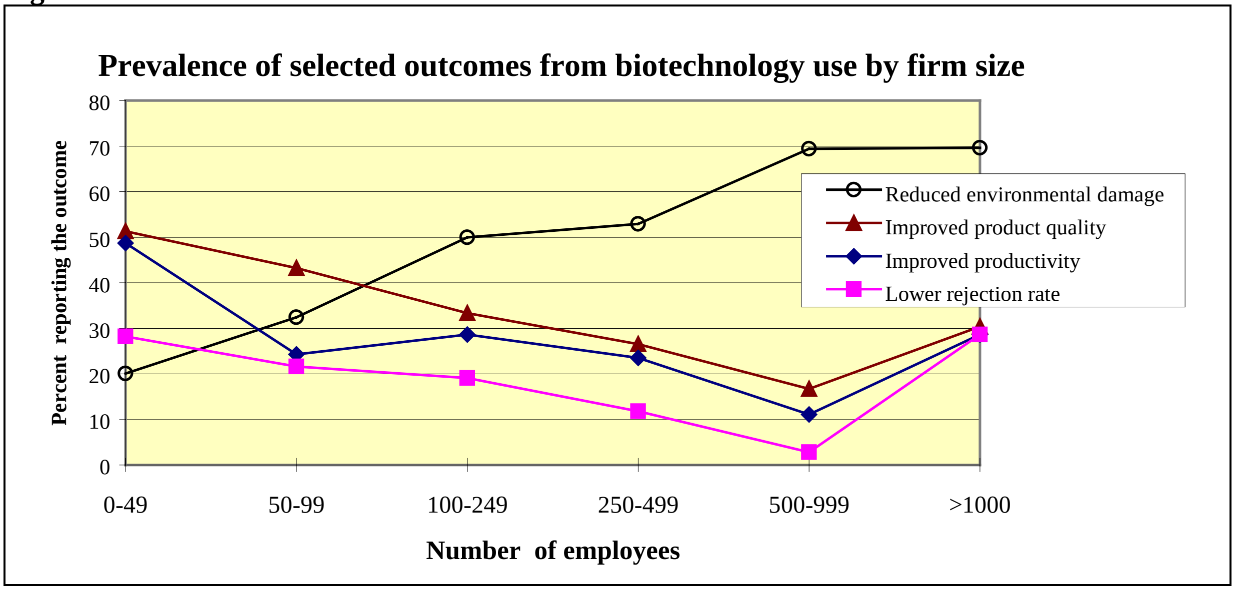
43 See Table A-17 of Appendix A for full results, including at the firm-level.

The frequency with which firms report a reduction in environmental damage from the use of biotechnology shows a highly significant linear trend, with an increase in the prevalence for this outcome with firm size. The other three trends, two of which concern products, decline with firm size, except for the largest size class. All of these results are partly due to sectoral differences. The high outcome rates for small firms are due to small biotechnology firms that are active in the development of new products, while the trend for environmental damage reflects their increasing use by large firms in the resource sector[44].

Figure 9.4



9.5. Differences by Sector

The percentage of firms in each sector that report each outcome from the use of any of the three biotechnology classes closely follows the patterns observed in Figure 9.2[45]. This is because of the dominance of the resource sectors in the use of environmental technologies and the food and pharmaceutical sectors in the other two biotechnology classes. The only interesting result that cannot be derived from Figure 9.2 is for 'no improvements'. This outcome was reported most frequently by pharmaceutical and food firms (26% and 22% respectively). It is not due to firms that are still in the research phase because 90% of pharmaceutical and food firms that noted 'no improvement' are in the application phase for at least one biotechnology. This suggests that biotechnology is riskier and more experimental in these two sectors than in the other sectors.

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[44] The results for the improvement in productivity is due to high prevalence rates for this outcomes among food and pharmaceutical firms, the results for a lower rejection rate is partly due to food firms, product quality for both food and pharmaceutical firms, and environmental reduction among resource firms, particularly in wood, paper and pulp.

[45] The results by sector are given in Table A-18 of Appendix A.

9.6. Conclusions

The benefits of biotechnology use are similar between firms that use selection and modification technologies and those that use culture and biological use technologies. For both, the most frequently cited benefits concern product characteristics such as quality, flexibility, and a lower rejection rate. The primary benefit from using environmental biotechnology is to reduce environmental damage. In addition, almost half of all firms that use environmental biotechnology also report cost savings through lower energy or other input requirements. Approximately a quarter of the firms reported that biotechnology increased the need for skilled labour and for more capital, although this is concentrated in the pharmaceutical sector. The need for more skilled labour, in particular, could act as an impediment to the diffusion of these technologies, particularly to firms in the wood, pulp and paper sector and in mining. Both have below average percentages of employees with a post-secondary education combined with an above average percentage of firms that believe that biotechnology use increases the demand for skilled labour.

10. Internal and External Information Sources

Firms can obtain information on the use of biotechnology from both internal sources, such as their research or production engineering departments, or from sources outside of the firm, such as federal research programmes or universities. The survey asks respondents to indicate which of seven internal and thirteen external information sources are 'principal sources of information for the adoption of biotechnologies or biotechnology equipment'. An 'other' category is also provided for both questions and an option of 'no significant external input' is provided for external information sources.

The most interesting question about the use of internal information sources concerns technological complexity and the stage of development of the technology. Less expertise should be required to adopt well-understood, developed technologies than to adopt complex technologies that are under intense development. Operating staff or production engineers should rank among the principal information sources for developed biotechnologies while the research and experimental development staff should be more important to the adoption of complex biotechnologies. The types of internal sources that are of importance will therefore suggest how far biotechnology has progressed to an 'off the shelf' technology that can be readily integrated into the firm's existing production, products or pollution control systems.

External information sources are more likely to be influenced by government policy and are therefore are of interest from a policy perspective. For example, the value of universities as an information source can be directly influenced by government funding of biotechnology research or programmes to encourage the transfer of knowledge from the public to the private sector.

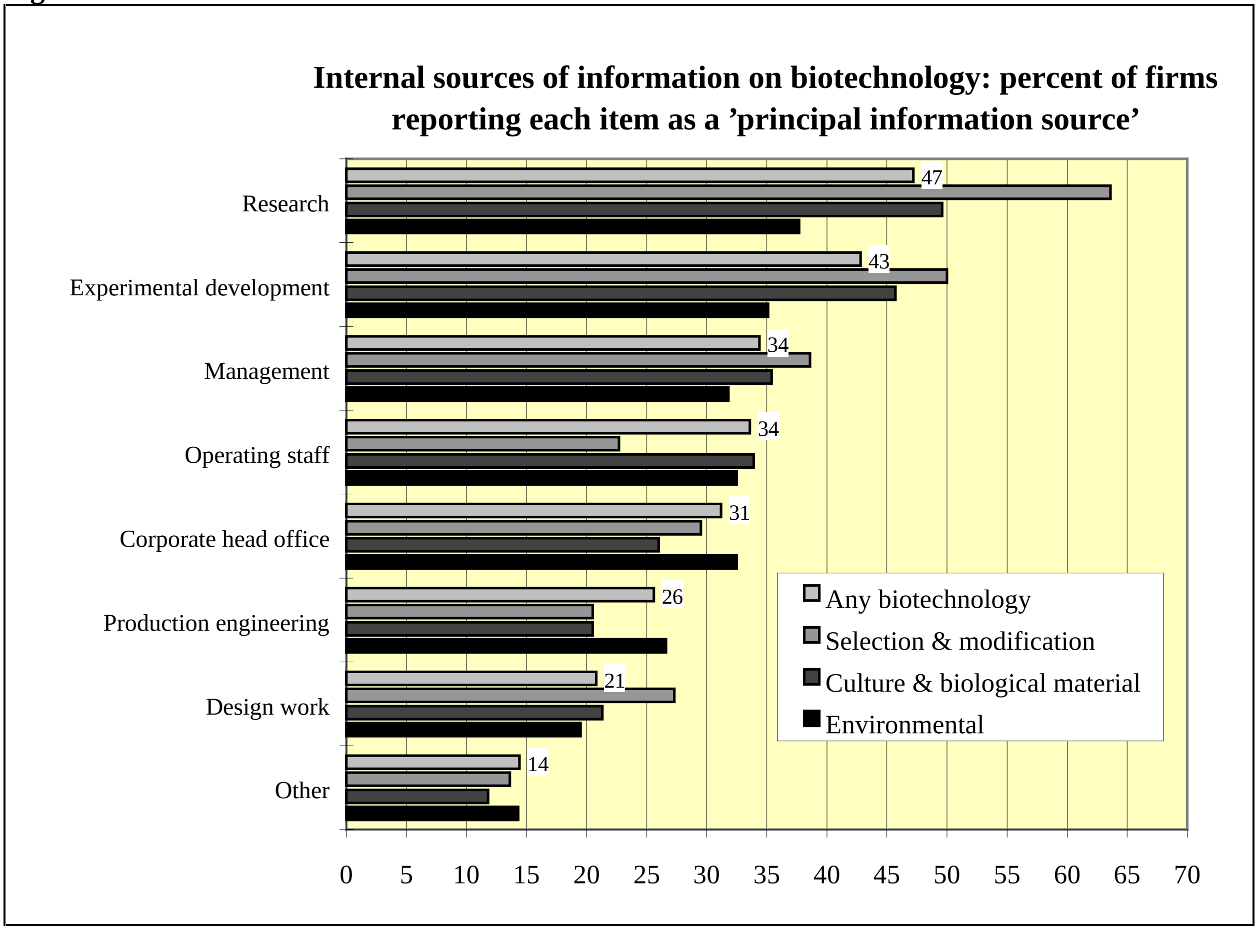
10.1. Internal Information Sources

Figure 10.1 gives the percentage of firms in each technology class that report that an internal source is a 'principal information source' for the adoption of biotechnologies or biotechnology equipment[46]. The first group, 'any' biotechnology, is equal to a 'yes' response if the firm used the source for any of the three biotechnology classes. The results for 'any biotechnology' show that the most frequently used sources concern the two parts of the firm that are most active in the development of a technology: research and experimental development. In contrast, operating staff and production engineering, both of which should be more involved in the implementation of developed technologies, are less frequently cited.

The results for specific technology classes vary from this general pattern. The adoption of the technologically-advanced selection & modification technologies is the most dependent on research and experimental development. These two sources are cited, respectively, by 64% and 50% of the firms active in this technology. In contrast, only 20% of these firms cite production engineering and 23% cite their operating staff. The results for the culture and biological material technology class are similar, but fewer firms that are active in environmental biotechnologies cite research and experimental development (38% and 35%, respectively), although both of these sources are cited more frequently than any other. The difference in the percentage of environ-

[46] See Table A-19, Appendix A, for the full results. 21 firms did not answer any of the 24 questions in this question group and are therefore excluded from all of the analyses. The results in this chapter are limited to the firm level, rather than using employee-weighting, because the influence of external information sources on technology adoption takes place at the firm level. The effect of firm size is examined directly, since it could influence the use of both internal and external sources.

Figure 10.1



mental biotechnology users that cite these two sources versus production engineering or operating staff is also considerably smaller than for the other two technology classes.

Additional analyses explored the effect of four factors on the use of each internal information source: firm size, sector of activity, R&D status (whether or not the firm performed R&D), and the proportion of the labour force with a college or university education[47]. None of these factors had any effect on the probability that a firm cites the 'other' category. For this reason, this category is not discussed below[48].

The single most important influence on the use of internal sources is whether or not the firm performs R&D. A considerably higher percentage of R&D performers than non-R&D performers find research (59% versus 19%) and experimental development staff (54% versus 17%) to be a

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47 These analyses use both simple comparisons and logistic regression to simultaneously control for the effect of several variables. All of the results reported here are significant in a logistic regression for the any biotechnology group. The regressions include variables for the log of the number of employees, R&D status, the percentage of employees with a college or university education, and dummy variables for seven of the eight sectors, with the pharmaceutical sector as the reference group. All logistic regression models fit the data with the exception of the model for 'other internal sources'.

48 The 'other' category appears to be cited randomly, with no discernible pattern in its use in a wide range of descriptive analyses and logistic regressions.

principal internal information source[49]. This is expected, since R&D performers are much more likely to have staff active in these areas. However, R&D performers are also more likely to cite design, production engineering, and the corporate head office as important internal information sources. The percentage of staff with a college or university education increases the likelihood that the firm finds research, design, and production engineering to be a principal source of information, probably because these activities require skilled staff. The results for both R&D and labour skills indicates that a high level of internal expertise is required to adopt biotechnology.

Firm size, as measured by the number of employees, has a significant influence on a range of firm strategies, as shown in the preceding chapters of this report. However, the size of the firm has very little impact on the use of internal information sources. It has no effect on the likelihood that the firm cites research, experimental development, design, production engineering, or operating staff as an internal information source. The probability that the corporate head office is a principal information source increases with the number of employees, which is expected since larger firms are more likely to have a separate head office, but the value of management decreases with the number of employees. The latter result could be due to the central role of management in the technological development of small, high technology firms.

The firm's sector of activity has no independent influence on any of the internal sources of information. Instead, sectoral differences are explained by the factors noted above. For example, a higher percentage of pharmaceutical firms cite research, but this is entirely due to the fact that a very high percentage of pharmaceutical firms conduct R&D.

The central role of the firm's R&D status is illustrated through the average number of internal sources that are cited by R&D performing and non-R&D performing firms, as shown in Figure 10.2. For all technology classes, R&D performing firms cite significantly more internal sources than non R&D performing firms.

10.2. Utilization stage for biotechnology

The principal internal information sources could vary by the stage of biotechnology use reached by the firm. For example, firms that are still in the research stage could be more dependent upon research and experimental development than firms that apply biotechnology to their production, products, or pollution control systems. The latter group of firms, in particular, should be more likely to depend on operating and production engineering staff if these technologies have become standardised. However, the stage of biotechnology use had no effect on any of the internal information sources[50], with one exception. Firms that have reached the application stage are less likely to use research staff as an internal information source than firms that are still in the research stage for at least one biotechnology.

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49 Results for the any biotechnology group. The differences are statistically significant ($p < 0.001$).

50 This conclusion is based on a series of logistic regression analyses. The first series includes a dummy variable for 198 firms that are in the application stage for biotechnology use compared to 52 firms that are in the research stage for at least one biotechnology. The second series compares 96 firms that are only in the pollution control stage against 154 firms that are either in the research stage or use biotechnology for a different application. These variables are based on the results to the B1 questions on the utilization stage. Other variables included in the regressions are firm size, the number of biotechnologies in use, R&D status, the percentage of employees with a university or college education, and the firm's sector of activity.

These results suggest that biotechnology has not progressed to an ‘off-the-shelf’ technology that can be readily implemented by firms. This conclusion also applies to environmental biotechnologies, although firms that use environmental biotechnologies are less dependent on research and experimental staff than firms active in selection and modification technologies.

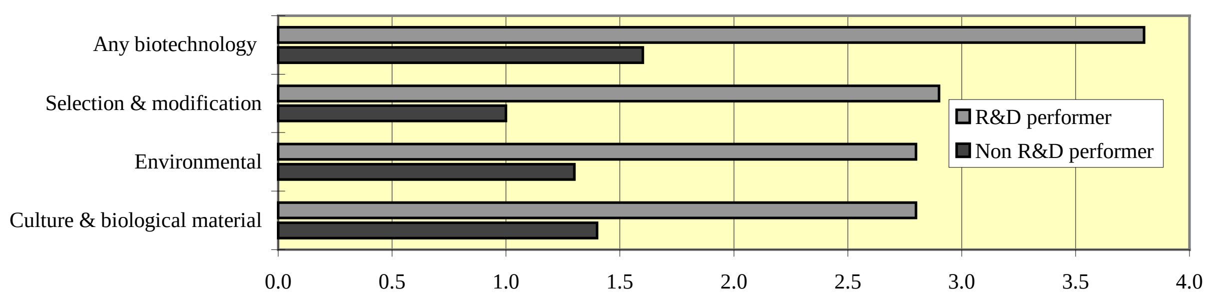
10.3. External Information Sources

There are two main questions of interest concerning external information sources. The first is similar to the question for internal sources and concerns the technical complexity of biotechnology. In particular, is there any evidence to suggest that environmental biotechnologies are simpler to adopt than the more advanced selection & modification or culture & biological material biotechnologies? The second question is: do firms find publicly-funded sources of information of value?

Figure 10.3 gives the percentage of firms in each technology class that cite an external source as a ‘principal information source’ for the adoption of biotechnologies or biotechnology equipment[51]. The most frequently cited source is publications, followed by consultants and service firms, supplier firms, trade fairs & conferences, and universities. These five sources also encompass the three most frequently cited external sources for each of the three technology classes.

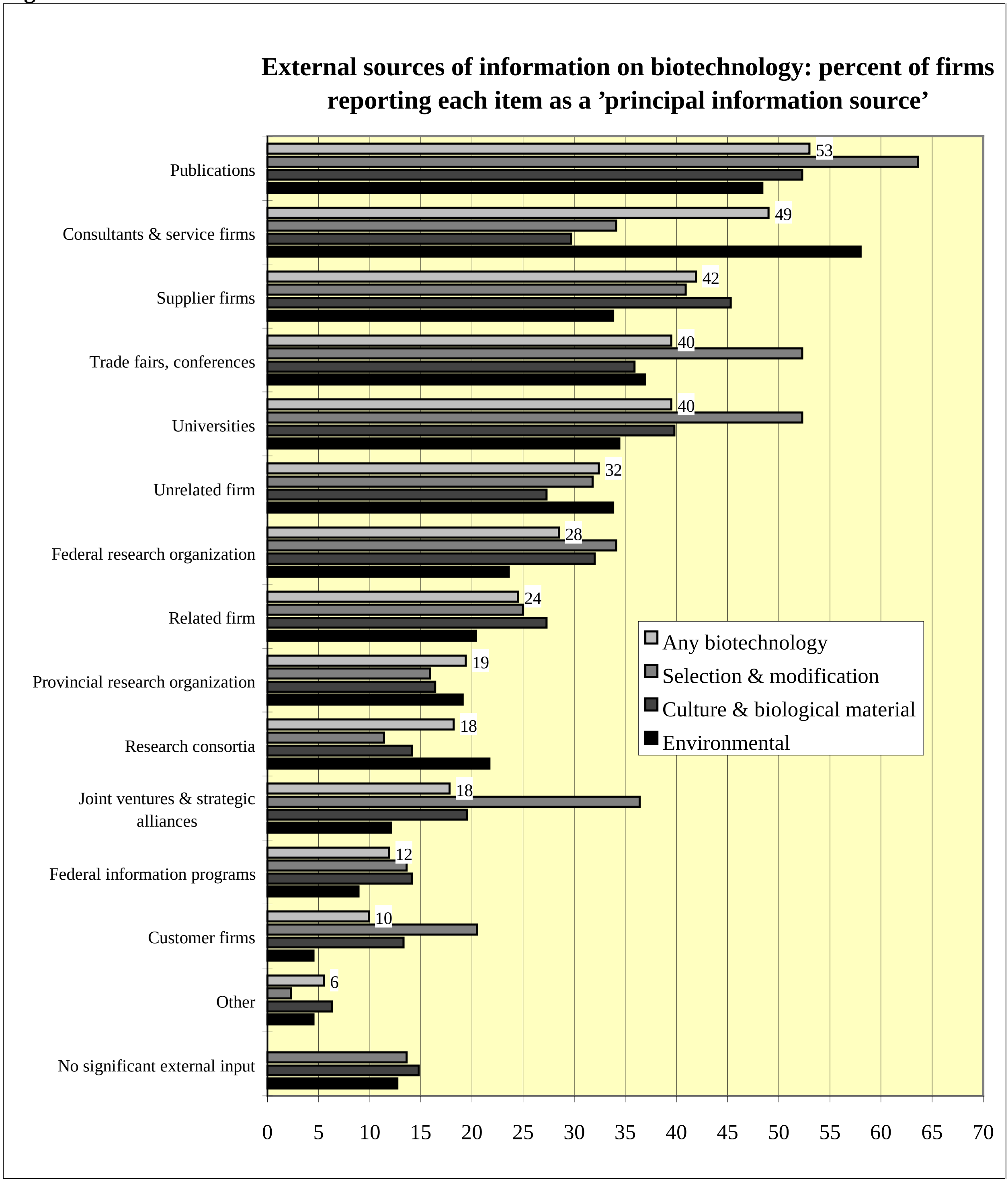
Figure 10.2

Average number of internal information sources cited by R&D performing firms and non R&D performing firms



[51] See Table A-20, Appendix A, for the full results. 18 firms did not answer any of the 45 questions in this question group and are therefore excluded from all of the results.

Figure 10.3



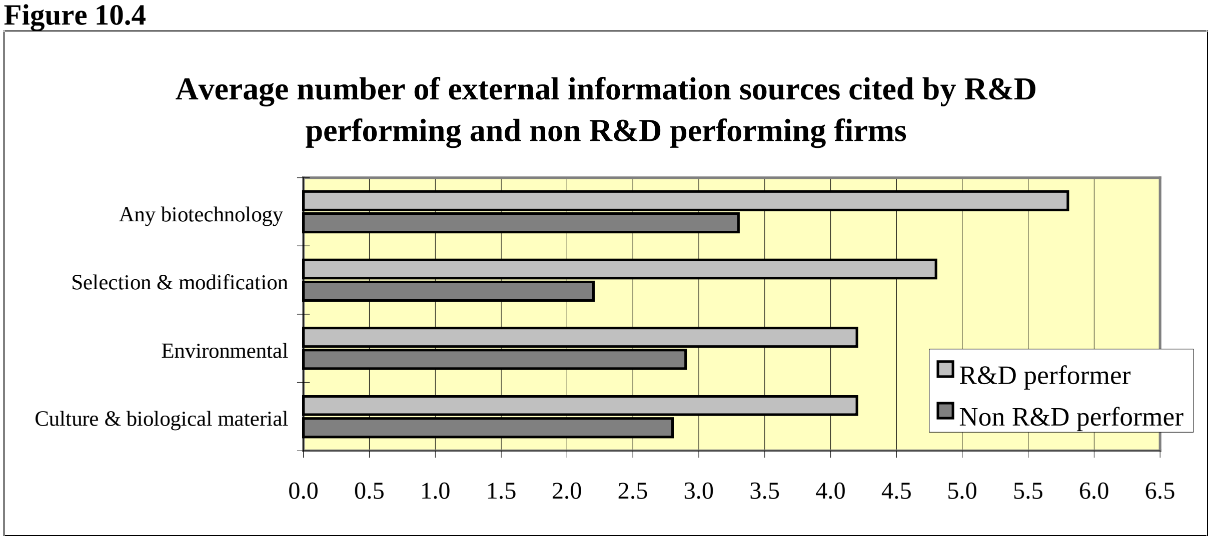
External sources of information on biotechnology: percent of firms reporting each item as a 'principal information source'
Publications
Consultants & service firms
Supplier firms
Trade fairs, conferences
Universities
Unrelated firm
Federal research organization
Related firm
Provincial research organization
Research consortia
Joint ventures & strategic alliances
Federal information programs
Customer firms
Other
No significant external input
53
49
42
40
40
32
28
24
19
18
18
12
10
6
Any biotechnology
Selection & modification
Culture & biological material
Environmental
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70

The distribution of the results for the selection & modification technologies and the culture & biological material technologies are closely correlated, with an R2 value of 0.85. This shows that the firms active in these two technologies use similar external information sources[52]. Firms active in environmental biotechnologies are more likely to use a different set of external sources, as shown by lower R2 values of 0.53 between the environmental and selection & modification results and of 0.62 between the environmental and culture & biological material technologies. The largest difference is for the use of consultant and service firms, which are cited by 58% of firms that use environmental biotechnology versus less than 34% of firms using the other two technology classes. Trade fairs and conferences, universities, and joint ventures are also cited less often by users of environmental biotechnology than by users of the other two technology classes.

10.4. Number of principal external information sources

The average number of cited external sources was determined for each technology class. There were no significant differences in the average by sector, with the exception of a significantly higher number of sources cited by pharmaceutical firms. Firm size had no effect except for users of environmental biotechnologies, where the number of cited sources increases with firm size. As with internal information sources, the most important factor that influences the number of cited external sources is the firm's R&D status. R&D performing firms cited a significantly higher percentage of external sources than firms that do not perform R&D, as shown in Figure 10.4.

Figure 10.4



[52] The R^2 result is only suggestive since the two groups of firms are not independent of each other. Many firms are active in both technologies.

10.5. Differences by sector

There are only a few differences by sector in the types of external information sources that are cited. Research consortia and consultants are used more frequently by firms in the resource sector than by manufacturing firms: 28% of resource firms use research consortia versus 11% of manufacturing firms, and 69% of resource firms use consultants versus 36% of manufacturing firms. These results indicate that resource firms require external sources of practical technical assistance to implement biotechnology. Customers are cited more frequently by manufacturing firms: 15% versus 2%. This reflects the greater opportunity in the manufacturing sector to develop customised products, whereas the resource sector usually produces standard commodities. Similar results by sector are found in analyses at the eight sector level. The only additional result of note based on a comparison of all eight sectors is that 50% of pharmaceutical firms cite joint ventures, compared to an average for all other sectors of 14%.

10.6. Logistic regressions

A series of logistic regression analyses are used to investigate the effect of five firm characteristics on the use of external information sources. These five characteristics are the firm's sector, its size (the log of the number of employees), the firm's R&D status, the percentage of the firm's employees with a college or university education, and the diversity of the firm's use of biotechnology. The latter is equal to the total number of the 22 biotechnologies that the firm reports using.

Table 10.1 summarizes the main results for four characteristics. The results for firm sector are not given because this rarely influenced the use of external information sources, as noted above[53]. The results for three series of regressions are provided. The selection & modification technologies are combined with the culture & biological material technologies because the use of external sources are very similar for these two classes. Regression results are also given for the use of environmental biotechnology and for any biotechnology.

The results are divided into three groups: publicly-funded information sources such as universities and federal research organizations, links with other firms, and other publicly available information, such as publications. The publicly-funded group also includes a summary source that is positive when the firm uses one or more of four public information sources: universities, federal research organizations, provincial research organizations, and federal information programs. Six external sources are not included in Table 10.1 because none of the variables influenced the use of the source: related firms, provincial research organizations, federal information programs, customer firms, 'no significant external input', and the 'other' category.

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[53] The number of sectors included in the regressions varies because of very small numbers of firms for some sectors. For example, there are very few manufacturing firms that use environmental technologies. For this reason, the sector of activity is covered by one variable that differentiates between manufacturing and resource firms. In contrast, seven sector dummies (plus the reference category) are included in the regressions for 'any' biotechnology.

Table 10.1 Summary of significant logistic regression results for external information sources[1] (* = p < 0.10, ** = p < 0.05)

Source	Selection, modification, culture, & biological material Biotechnology[2]				Environmental Biotechnology[3]				Any Biotechnology[4]			
	Firm size	Perform R&D	Biotech Diversity	% skilled labour	Firm size	Perform R&D	Biotech Diversity	% skilled Labour	Firm size	Perform R&D	Biotech Diversity	% skilled Labour
Publicly funded organizations												
Any Public source[5]		1.31**	0.23**			0.75*				1.20**	0.37**	
Universities		0.98*	0.33**		0.49*	1.03**	0.20*			1.37**	0.47**	
Fed research org		1.05*	0.33**							0.95**	0.42**	
Links with other firms												
Other firm			0.31**			1.04**		- 2.93**		0.95**	0.30**	
Supplier firms											0.19*	
Research consortia	-1.08**	1.53*	0.25*		0.93**			2.40**				
Consultants					0.84**				0.35*		0.21**	0.31**
Joint ventures		1.72**	0.30**							1.11**	0.32*	
Publicly available information												
Publications	-0.65**		0.32**								0.38*	1.56*
Trade fairs/confs	-0.69**	0.87*	0.18*								0.25**	

1: Results are only given if the regression meets three criteria: the regression makes a significant improvement ($p < 0.05$) to the $\chi 2$ value of the model, the combined percentage of correctly classified responses exceeds 60%, and the percentage of correctly classified 'no' and 'yes' responses each exceed 20%. The results for six external sources did not meet these requirements and are therefore not included in the Table: related firms, provincial research organizations, federal information programs, customer firms, 'no significant external input', and 'other'.

2: Limited to firms that use one or more of the 17 selection, modification, or culture and/or use of biological material technologies. Includes dummy variables for four sector groups (sector results not shown).

3: Limited to firms that use at least one of the 5 environmental biotechnologies. Includes a dummy variable for resource versus manufacturing sectors.

4: Includes all firms that use one or more of the 22 biotechnologies. Includes dummy variables for seven sectors plus a reference sector.

5: The firm cites one or more of four publicly funded information sources as a principal external source of information: Federal research organizations, universities, provincial research organizations, or federal information programs.

Firm size: measured as the log of the number of employees. **Performs R&D**: Firms performs R&D on a regular basis. **Biotech diversity**: Number of different biotechnologies used by the firm. **% Skilled labour**: Percent of all employees that have a college or university education.

Only a few simple rules are necessary to understand the results given in Table 10.1. A positive coefficient indicates that firms with the given characteristic are more likely than firms without the characteristic to use the information source. For example, the first coefficient of 1.31 in the upper left-hand corner means that firms that perform R&D are more likely than firms that do not perform R&D to use a publicly-funded information source. Conversely, the negative coefficient of 1.08 for firm size for the use of research consortia indicates that larger firms are less likely than smaller firms to use research consortia.

The size of each coefficient within a column can also be compared, but it is not possible to compare coefficients across the rows. The largest coefficient in the first column for 'Perform R&D' is 1.72 for joint ventures, while the smallest coefficient is for trade fairs/conferences. This shows that the difference in the percentage of R&D performing firms and non-performers that use joint ventures is greater than the difference for the use of trade fairs/conferences.

The main results that can be drawn from Table 10.1 are given below.

R&D performance and the diversity of biotechnologies in use: The two most important influences on the use of external information sources are whether or not the firm performs R&D and the number of biotechnologies that it uses. Both of these characteristics are indicators of the complexity of the biotechnologies in use. The diversity indicator is also significant for a larger number of sources than R&D status. This is probably because different information sources are required for different biotechnologies.

Publicly funded organizations: Two publicly funded sources, provincial research organizations and federal information programmes, are not included in Table 10.1 because none of the firm characteristics influenced the use of these programs, once all other variables were also taken into consideration. This indicates that these two programs provide information to a wide range of firms. This could be a desirable characteristic, or it could indicate that these programmes are inadequately focused on specific needs. The latter could be a more plausible explanation, given the fact that both programs are not widely cited. Only 19% of firms cite the use of provincial research organizations and 12% cite the use of federal information programs.

The major users of universities and federal research organizations are R&D performing firms that are active in a number of different biotechnologies. The size of the firm has no effect on the use of public information sources, except for environmental biotechnologies, where large firms are more likely than small firms to obtain information from universities.

Environmental biotechnology users: Firm size and labour skills have a considerably more important influence on the use of external information sources by firms that use environmental biotechnology than for firms active in the two other biotechnology classes. Large firms in this technology class are more likely than small firms to cite universities, research consortia, and consultants. R&D performing firms with a low proportion of skilled labour are more likely to cite other firms, while firms with a high percentage of skilled labour are more likely to cite research consortia. The results for other firms indicate that a low level of internal expertise forces these firms to turn to other firms for assistance. In contrast, a considerable level of internal expertise is required to participate in research consortia.

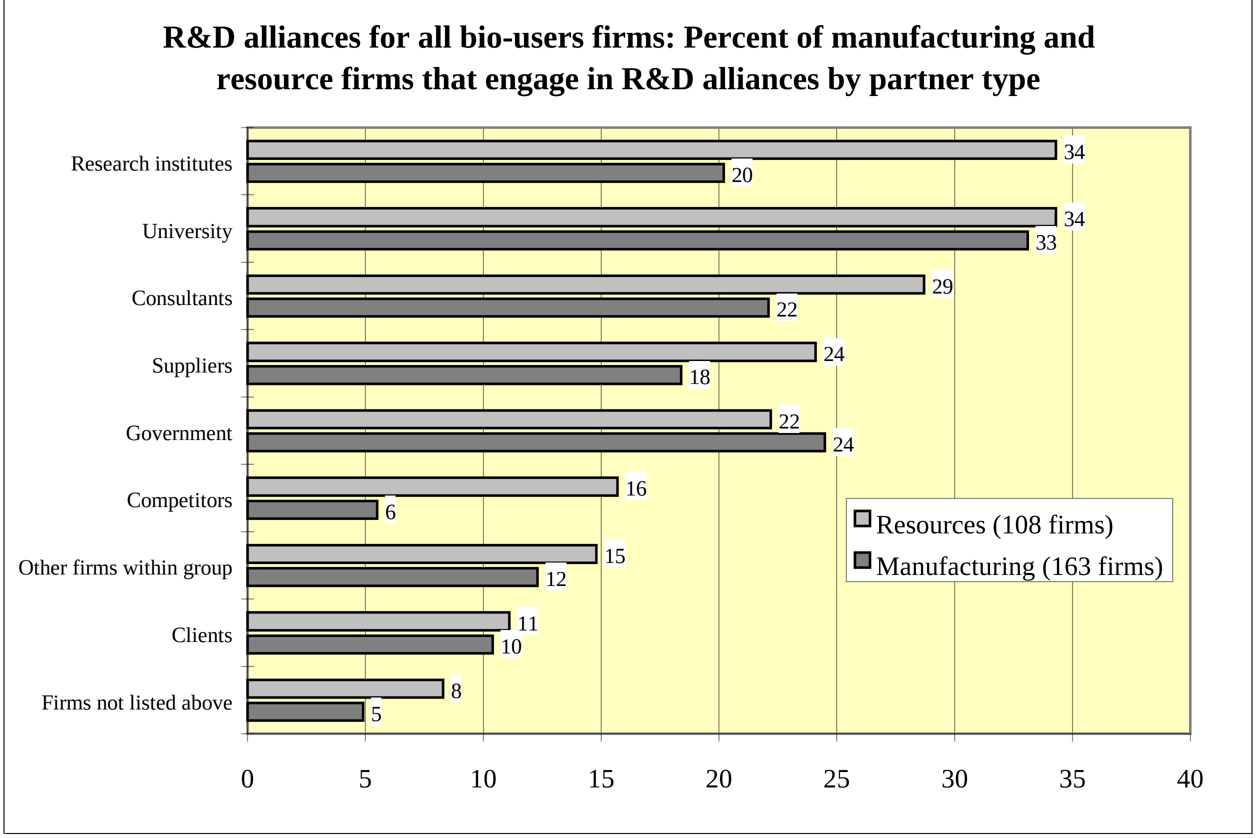
In general, there are some clues here to indicate that the needs of smaller firms for environmental biotechnology are not being met. Universities, a source of advanced biotechnology, are mostly used by large, R&D performing firms. Furthermore, large firms are much more likely than small firms to cite consultants, which includes service firms. This is particularly notable because consultants and service firms are the most widely used information source for users of environmental biotechnology, cited by 58% of these firms.

10.7. R&D Alliances

Alliances for R&D can provide a valuable source of information on new technologies. Unfortunately, the survey question does not specify the purpose of these alliances. Therefore, the results are a better indicator of the technological expertise of the firm than of its use of alliances as a means of obtaining information on biotechnology. As shown earlier in Table 3.3, most alliances occur with Canadian partners. Alliances with universities are the most frequent.

The prevalence of alliances among bio-user resource and manufacturing firms is given in Figure 10.5. The results are averaged over all firms in the sector, with firms that do not perform R&D assumed to have zero R&D alliances. The only significant difference in the R&D alliance rate is for alliances with research institutes and competitors, both of which are used more frequently by firms in the resource sectors[54].

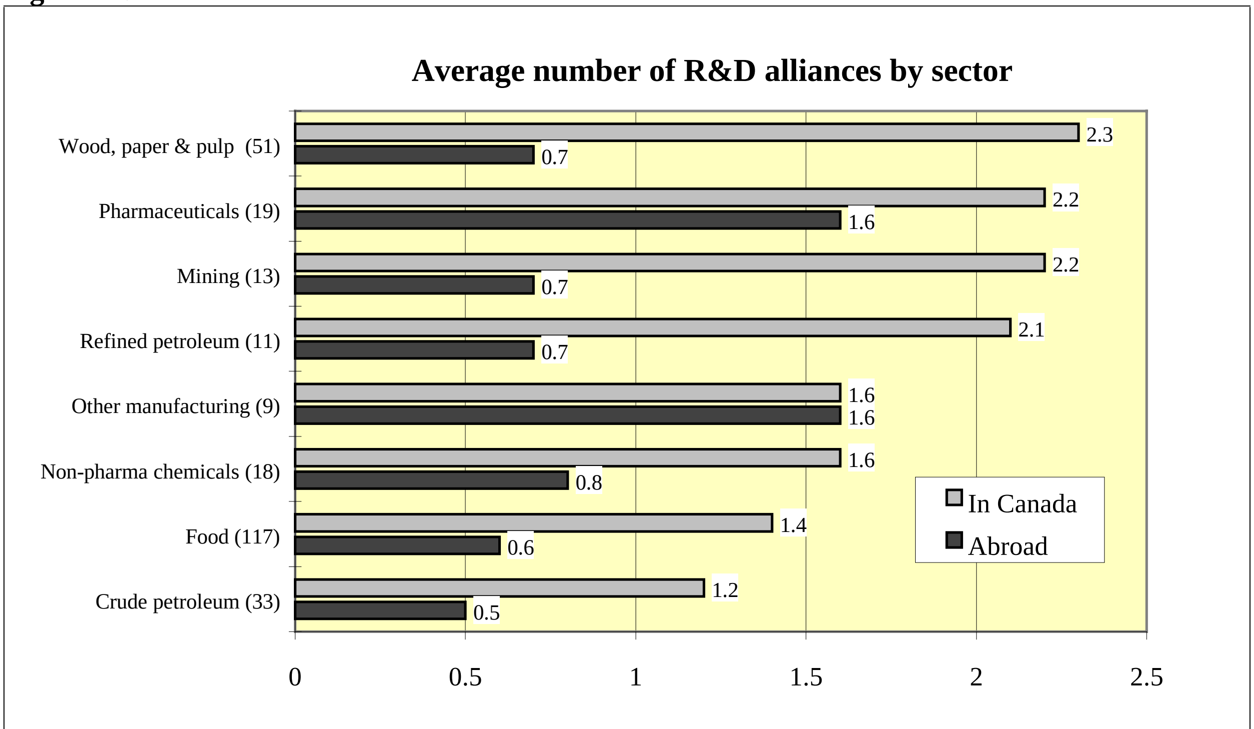
Figure 10.5



[54] Analyses at the eight sector level also only showed a statistically significant difference in alliance rates by sector for research institutions and competitors. The only other result of note at the eight sector level is that 63% of all pharmaceutical firms are engaged in a partnership with Canadian universities compared to an average of 31% for all other sectors.

Figure 10.6 gives the average number of R&D alliances in Canada and abroad for each of eight sectors, again assuming that firms that do not perform R&D have no R&D alliances. The results clearly show the importance of alliances in Canada compared to abroad. Surprisingly, the pharmaceutical sector does not have a larger number of alliances in Canada than most of the resource sectors, although pharmaceutical firms have an above average number of alliances with partners outside of Canada.

Figure 10.6



10.8. Conclusions

The analyses of internal and external information sources show that the adoption of biotechnology requires both considerable internal expertise within the firm and access to advanced sources of knowledge, such as universities, outside of the firm. Biotechnology is definitely not an 'off the shelf' technology than can be readily implemented into the firm's production, products, or pollution control systems. There is some evidence to suggest that environmental biotechnologies are closer to standardization than the other biotechnologies, but even here firms must draw on both internal and external expertise. This is shown most strongly by the high percentage of environmental firms that use external consulting services and sources. Firms in the resource sectors are also very active in R&D alliances with Canadian partners. Furthermore, less than 15% of firms in each technology class state that they required 'no significant external input'.

Universities are the favoured partner for R&D alliances and the most frequently cited information source out of the four publicly-funded research organizations. The latter is true for all three technology classes, for all eight sectors. On average, 49% of firms cite at least one of the four public organizations, which places publicly-funded sources in second place after publications (cited by

53% of the firms). Both universities and federal research organizations are most likely to be used by R&D performing firms that are active in a number of biotechnologies. Provincial research organizations and federal information programs are used by considerably fewer firms, although all types of firms make use of them. The most notable difference here is the high percentage of resource firms in the Prairies that use provincial research organizations.

Firm size has no effect on the use of public information sources, except for users of environmental technologies, where larger firms are more likely to use these sources. Otherwise, smaller firms do not appear to be at a disadvantage in their ability to access publicly-funded sources.

These results show that publicly-funded organizations are a valuable information source for the adoption of biotechnology, particularly by firms with enough internal expertise to make use of them. There are no publicly-funded sources that are used more frequently by firms that lack internal expertise, which could suggest a gap in the provision of information. On the other hand, basic information or technical services could be of little use to firms until biotechnology reaches a greater level of standardization.

11. Conclusions

The most technologically advanced biotechnologies are used by very few firms outside of the pharmaceutical sector. Even here, less than 15% of firms, after employee weighting, use a genetic engineering technology. The greatest rate of diffusion has occurred for environmental biotechnologies in the resource sectors, where a minimum of 25% of employee-weighted firms use bioremediation to break down or degrade hazardous substances.

The most optimistic estimate for future adoption combines firms that plan to adopt within two years with firms that state that biotechnology is 'not cost effective'. This results in an estimated 0.7% increase in the number of firms that will use genetic engineering, a 2% increase in the use of culture & biological material technologies, and a 3% increase in the use of environmental technologies. After employee-weighting, these rates increase to 0.3%, 5%, and 11% respectively. Over half of these increases, however, come from firms that currently use at least one biotechnology.

These relatively low adoption rates in the order of a few percent per year indicate that biotechnology use in Canada is in its early stages. This raises the question: what factors are preventing a more rapid increase in the adoption of biotechnology?

The results of many of the analyses in the preceding chapters, both of non-user and bio-user firms, point to a few major causes of the slow diffusion of biotechnology. But first, it is important to emphasize what is *not* responsible.

Government regulation, with the exception of the resource sectors, is not a major factor. Its role in the resource sectors is also suspect because this is precisely where biotechnology has diffused the furthest. Regulation is rarely mentioned by firms active in the food sector as an impediment to the adoption of biotechnology, even though this is a heavily regulated sector for public safety reasons. Small pharmaceutical firms mention regulation as a problem, but large pharmaceutical firms do not.

Nor is the high cost of biotechnology a drag on its diffusion to new users, although it is of concern to firms that currently use biotechnology. Cost is a relative notion - it is not so much the absolute cost of a technology that is a problem but costs relative to the benefits or the cost of a new technology relative to existing alternatives. Outside of the health sector, biotechnology is primarily a process technology that can replace existing technologies. This means that the relative cost of biotechnology compared to existing alternatives is of crucial importance, rather than the absolute costs.

Firm size plays a complex role. The rate of adoption increases with firm size, but this is partly attributable to the high percentage of large firms in the resource sectors, where biotechnology is the most widely used. Among bio-users, firm size only occasionally plays a role in the firm's relationship to biotechnology. In many cases, such as the ability to access external information sources, large size does not appear to provide any advantages. Therefore, firm size appears to act as a threshold barrier to the adoption of biotechnology, but once crossed it has little impact on the ability to use biotechnology.

The results of this study suggest that three factors explain the slow diffusion of biotechnology, both among non-users and among current users. These are the need for technical and scientific expertise, a lack of information, and a lack of commercially viable biotechnologies.

Expertise: A comparatively high level of internal technical expertise is required to use biotechnology. In general, firms that use biotechnology are more likely than non-users to perform R&D, to engage in R&D alliances, and to have a higher percentage of employees with a university education. The results for bio-users confirm the importance of expertise, especially to be able to use the selection & modification biotechnologies. For example, five times as many bio-users report that the use of biotechnology increases the need for skilled labour than those that report that it reduces this need. For comparison, only twice as many bio-user firms report an increase in the need for capital as report a decrease. The importance of scientific and technical expertise is also shown by the high percentage of firms that cite their own research and experimental development staff as a principal information source for the adoption of biotechnology. This is also true for all biotechnology classes, including environmental biotechnology. Users of environmental biotechnology have less internal expertise and are therefore more likely to obtain it from external consultants, but a higher percentage of university educated staff increases the likelihood that users of environmental technology can access external information sources.

These results stress that biotechnology, including environmental applications, are a long way from obtaining the status of an 'off the shelf' solution that can be readily implemented. Firms need a considerable level of internal expertise, and the ability to access external sources of expertise, to be able to use biotechnology.

Lack of information: Over 90% of non-users give a response of 'not applicable' to the questions on impediments to biotechnology adoption, strongly suggesting that non-users lack an adequate level of knowledge about biotechnologies to be able to make an informed judgement about why they have not acquired biotechnology. Non-users that did reply to these questions stressed factors that are linked to a lack of information, or a lack of commercially suitable applications. The results for bio-users show that experience with biotechnology, which would substantially increase the amount of information on biotechnology held by a firm, reduces the obstacles to adoption. For example, bio-users are less likely than non-users to find most of the impediments to the acquisition of biotechnology to be a problem. Furthermore, a much higher percentage of bio-users plan to adopt a new biotechnology than non-users, indicating that experience is helpful, although most of the planned adoption is occurring within the same area of expertise. A lack of information from external sources also forms a barrier to the implementation of environmental biotechnologies by large firms. There is an important role for external advice and information to encourage firms to adopt environmental biotechnology.

Lack of commercially viable biotechnology: A fundamental cause of the limited diffusion of biotechnology is a lack of commercially viable applications. Biotechnology, outside of the pharmaceutical sector, is basically a process innovation. It replaces an existing production method or intermediary product. Firms will not replace their existing production processes or product lines with versions based on biotechnology unless biotechnology provides proven advantages in terms of cost or product quality.

Generally, there is no self-reported difference in the state of advancement of the production technology used by non-users and bio-users. This suggests both that the improvement in production technology offered by biotechnology is minor *and* that competitive alternatives are available. In addition, the results of the questions on impediments to the acquisition of biotechnology, by the limited number of non-users that answered these questions, strongly points to a lack of commercially applicable biotechnologies. These problems are also mentioned by firms that use biotechnology. Users of environmental biotechnology frequently cite 'high maintenance costs' and other factors that relate to a lack of cost-effective biotechnologies.

11.1. Role of Government

Much of the discussion of the role of government policy in respect to biotechnology, both in Canada and abroad, focuses on the negative consequences of regulation or a lack of regulation. This argument is probably driven by the highly visible role of pharmaceutical firms in this debate, where regulation does play a pivotal role. However, the results of the diffusion survey indicate that regulation is a minor problem, partly because most potential uses of biotechnology do not involve the pharmaceutical sector. Clearly, further work is needed to determine why users of environmental technologies cite regulations as a barrier to the use of biotechnology, but in general the current fixation on regulation is not warranted. Instead, policy makers need to give greater attention to two other issues where government intervention could have beneficial results. These are programs to support the development of commercially viable applications and programs to improve the information available to non-users.

The survey results show that biotechnology is still a young technology, with a lack of commercially viable applications. Many of the potential applications, as identified in the sector reports of the *Canadian Biotechnology Strategy Taskforce*, are specific to unique conditions in Canada in the resource sectors. This limits the option to wait until a viable technology is developed somewhere else. Furthermore, the results on R&D alliances and the use of external sources show that expertise is needed in Canada, with a high percentage of respondents making use of publicly-funded research organizations within Canada or entering into R&D alliances with universities in Canada. It is important to stress that about five times as many bio-user firms that are engaged in R&D alliances have formed alliances with Canadian compared to foreign universities: 62% versus 13%. The only exception is the pharmaceutical sector, where firms have no difficulty in engaging in R&D alliances with universities or other groups outside of Canada.

Information programs can also play a role in overcoming a lack of knowledge of the advantages of biotechnology, particularly for non-users of biotechnology. For example, the diffusion of biotechnologies could be encouraged by publicising the fact that the adoption of environmental biotechnologies to control pollution does not always increase costs: 45% of firms that report a reduction in pollution from environmental biotechnologies also report cost savings. Of course, there is a need for more research to increase this to 100%.

Finally, some of the survey results identify areas where targeting research funds could be appropriate. Many of the benefits of biotechnology, in terms of improved product quality, productivity and lower rejection rates, are captured by very small and very large firms. The needs of mid-sized firms are not being met.

Glossary of Terms

Agricultural biotechnologies Use of one or more of five biotechnologies with mainly agricultural applications: tissue culture, somatic embryogenesis, bio-pesticides, classical/traditional breeding, and microbio-inoculants.

Antibodies/antigens Proteins produced in the body in response to the introduction of foreign molecules called antigens.

Bio sensing Use of a biological molecule, eg enzyme or antibodies in conjunction with a transducer for low level detection of substances such as sugars and proteins in body fluids, pollutants in water, etc.

Bio-bleaching Use of micro-organisms to bleach pulp.

Bio-leaching Use of micro-organisms to leach metals from ore.

Bio-pesticide Biological pest control through the use of naturally occurring microbes or bacteria.

Bio-reactors Enclosed containers in which micro-organisms are maintained under controlled conditions for the purpose of creating or destroying specific compounds.

Bio-user A firm that uses one or more of the 22 biotechnologies listed in the questionnaire.

Bioaugmentation The process of increasing the efficiency of the naturally occurring microbial population to concentrate or accumulate specific compounds. This is usually achieved by adding nutrients, oxygen or water.

Biological gas cleaning Use of micro-organisms to break down or degrade hazardous substances in a gas stream into less hazardous or non-toxic substances.

Bioprocessing Production stages that include fermentation, recovery and purification.

Bioremediation The use of naturally occurring or genetically modified micro-organisms to breakdown or degrade hazardous substances into less hazardous or non-toxic substances.

Classical/traditional breeding Genetic improvement of animals or plants by breeding selected individuals.

Culture and/or use of biological material The group of nine biotechnologies with a range of applications in agriculture and industrial processing: tissue culture, somatic embryo-genesis, bio-pesticides, classical/traditional breeding, bioprocessing, bio sensing, bio-bleaching, bio-leaching, and microbio-inoculants.

Environmental biotechnologies The group of five biotechnologies used for pollution control: bioaugmentation, bioremediation, bio-reactors, phytoremediation, and biological gas cleaning.

Gene probe A section of DNA of known structure or function which is marked with a radioactive isotope, dye, or enzyme so that it can be used to detect the presence of specific sequences of bases in another DNA molecule.

Gene therapy Replacement of a defective gene in an organism suffering from a genetic disease.

Genetic engineering Use of one or more of five biotechnologies that are required for or frequently used with recombinant DNA work: Recombinant DNA, peptide synthesis, gene probes, gene therapy, and DNA amplification.

Manufacturing sector Main industry falls in one of four sectors: food, pharmaceuticals, non-pharmaceutical chemicals, or other manufacturing.

Microbio-inoculants Naturally occurring bacterial inoculants used to promote plant growth.

Monoclonal antibodies A highly specific antibody which is derived from one line of cells and which recognizes only one specific complimentary antigen.

Non-user A firm that uses none of the 22 biotechnologies listed in the questionnaire.

Peptide synthesis Procedure to link two or more amino acids joined by a linkage called a peptide bond.

Process biotechnology Use of one or more of two biotechnologies that are frequently used in industrial processes: bioprocessing and bio sensing.

Rational drug design Analysis of the structures of active sites of enzymes and receptors in order to design pharmacologically active synthetic molecules that will fit these analysed structures.

Recombinant DNA Procedure used to join together DNA segments outside a cell.

Resource sector Main industry falls in one of four sectors: mining, crude petroleum extraction, petroleum refining, or wood, pulp and paper.

Selection and modification The group of eight biotechnologies based on genetic engineering or with pharmaceutical applications: recombinant DNA, antibodies/antigens, peptide synthesis, rational drug design, monoclonal antibodies, gene probes, gene therapy, and DNA amplification.

Somatic embryo-genesis Propagation of genetically desirable plant and tree lineages by tissue culture methods.

Technology class Area of biotechnology activity in which the firm is active. There are three: selection and modification, environmental, and culture and use of biological material. Several of the questions ask the respondents to reply for each of these three technology classes.

Tissue culture Propagation or growth of cells which are isolated from organisms in a nutrient medium in a laboratory environment.

Utilization stage The most advanced stage in the use of biotechnology. There are four options: research, as part of the production process, as part of the product sold, and as part of pollution control. Respondents can only choose one option that best represents their use of the technology.

Appendix A: Supplementary Tables

Note: The symbol ‘x’ is used when the results cannot be reported due to the requirements of the Statistics Canada Act.

Table A-1 The use of biotechnology, R&D performance, and exports by firm size

			Percent of firms that perform R&D[1]		Percent of sales from exports[2]	
Number of employees	**N**	**Percent of firms that use biotechnology**	**Non bio-users**	**Bio-users**	**Non bio-users**	**Bio-users**
0 – 50	600	8	35	67	45	47
50 – 99	488	9	45	60	41	52
100 – 249	468	10	53	58	43	58
250 – 499	213	17	63	72	46	63
500 – 999	108	38	69	77	41	57
> 1000	133	44	85	90	36	44
All	*2010*	*14*	*52*	*72*	*43*	*52*

1: Based on 1838 firms (excludes 172 firms that did not answer the question on R&D status).

2: Based on 720 firms (excludes 1,290 firms that did not answer the question on exports).

Table A-2 Percentage of firms and employees at the two-digit SIC level that use one or more bio-technologies

Sector	SIC	N	N	% of firms in sector that use biotechnology	% of employees in user firms
Fishing	3	4	x	-	20
Forestry services	5	6	x	-	39
Mining	6	49	13	26	30
Crude petroleum & gas	7	124	33	27	39
Food	10	678	92	14	23
Beverages	11	56	23	41	79
Tobacco	12	8	-	-	-
Leather products	17	10	-	-	-
Primary textiles	18	67	x	-	11
Textile products	19	63	x	-	5
Wood products	25	47	x	-	20
Paper & allied products	27	148	48	32	75
Printing & publishing	28	208	x	-	4
Fabricated metal products	30	18	x	-	8
Refined petroleum and coal	36	36	11	31	71
Pharmaceuticals	374	61	19	31	14
All other chemicals	37	234	18	8	--
Other (including instruments)	39	193	4	2	38
Total		*2010*	*271*		

Table A-3 Average number of employees by sector for bio-users and non-users

Sector	Non-user N	Non-user Average employees	Biotechnology user N	Biotechnology user Average employees
Mining	36	975	13	1185
Crude petroleum	91	239	33	458
Petroleum refining	25	249	11	2129
Wood and paper	150	214	51	1455
Food, beverages & tobacco	629	266	117	1444
Pharmaceuticals	42	380	19	513
Other chemicals	216	207	18	560
Other	550	193	9	506
All	*1739*	*247*	*271*	*1186*

Note: The difference in firm size for bio-user and non-user firms is statistically significant ($p < 0.05$) for all sectors except mining, crude petroleum, and pharmaceuticals.

Table A-4 Percentage of employees by firm size that are university or college graduates

Employee class	N	University graduates Non-users	University graduates Bio-users	College graduates Non-users	College graduates Bio-users	Both combined Non-users	Both combined Bio-users
> 50	600	17	26	13	13	30	39
50 – 99	488	11	17	10	8	21	26
100 – 249	468	10	15	9	13	19	28
250 – 499	213	11	14	8	10	19	24
500 – 1000	108	14	18	10	11	23	29
> 1000	133	12	14	10	10	22	24

Table A-5 Firm-level results for the percentage of employees by sector that are university or college graduates

Sector	University graduates Non users	University graduates Bio users	College graduates Non users	College graduates Bio users	Both combined Non users	Both combined Bio users
Mining	20	16	9	8	30	23
Crude petroleum	33	34	14	15	46	49
Refined petroleum	15	13	18	12	33	26
Wood & paper	8	8	8	10	17	18
Food	8	10	**8**	**10**	**16**	**20**
Chemicals	17	22	12	15	29	37
Pharmaceuticals	**33**	**48**	15	12	48	60
Other	13	32	13	11	**25**	**43**
All	***13***	***17***	*10*	*11*	***23***	***28***

Notes: results in **bold** when the difference is statistically significant ($p < .05$)

Table A-6 Employee-weighted results for the percentage of employees by sector that are university or college graduates

Sector	University graduates Non users	University graduates Bio users	College graduates Non users	College graduates Bio users	Both combined Non users	Both combined Bio users
Mining	7	17	4	8	11	25
Crude petroleum	25	33	13	17	38	50
Refined petroleum		16		12		28
Wood & paper	10	8	8	9	18	17
Food	6	10	7	9	13	19
Chemicals		16		12		29
Pharmaceuticals						
Other	37	37	15	12	52	49
All	*11*	*13*	*9*	*10*	*20*	*23*

Table A-7 Use of 22 biotechnologies: Percentage of all respondent firms by sector that use each biotechnology

Biotechnology	Resource-based sectors				Manufacturing sectors			
	Mining	Crude petroleum	Petroleum refining	Wood, pulp and paper	Food beverages & tobacco	Pharma	Non pharma chemicals	Other
Recombinant DNA	-	-	-	x	1	11.5	<	<
Antibodies/antigens	-	-	-	-	2	23.0	<	<
Peptide synthesis	-	-	-	-	x	6.6	<	0
Rational drug design	-	-	-	-	x	<	<	<
Monoclonal antibodies	-	-	-	-	1	18.0	<	<
Gene probe	-	-	-	-	1	<	<	<
Gene therapy	-	-	-	-	-	0	<	0
DNA amplification	-x	-	-	-	1	6.6	<	<
Bioaugmentation	x	10	x	11	2	<	<	0
Bioremediation	18	25	17	15	3	0	4.7	<
Bio-reactors	10	x	19	15	3	<	1.7	<
Phytoremediation	10	9	x	2	x	0	<	0
Biological gas cleaning	-	x	x	-	x	0	<	0
Tissue culture	-	-	-	x	2	19.7	<	0.7
Somatic embryo genesis	-	-	-	0	x	<	<	0
Bio-pesticide	-	-	-	x	1	<	<	0
Classical/traditional breeding	x	-	-	x	2	<	<	0
Bioprocessing	-	-	x	x	8	19.7	<	<
Bio sensing	x	-	x	x	2	9.8	<	<
Bio-bleaching	-	-	x	x	x	0	0	0
Bio-leaching	8	-	x	-	-	0	0	<
Microbio-inoculants	-	x	x	x	1	<	<	0

x : Confidential to meet secrecy requirements of the Statistics Act.

Table A-8 Use stage for 22 biotechnologies

	Firms	Percent of firms that use the biotechnology in: Research Stage	Production process	Product sold	Pollution control
Selection and modification technologies					
Recombinant DNA	17	53	18	29	-
Antibodies/antigens	31	30	33	37	-
Peptide synthesis	7	71	14	14	-
Rational drug design	7	100	-	-	-
Monoclonal antibodies	21	29	33	38	-
Gene probe	11	78	22	-	-
Gene therapy	x	100	-	-	-
DNA amplification	12	82	18	-	-
Environmental biotechnology					
Bioaugmentation	61	12	20	7	62
Bioremediation	110	9	6	3	82
Bio-reactors	71	8	19	1	71
Phytoremediation	26	20	12	4	64
Bio gas cleaning	9	12	12	12	62
Culture and use of biological material					
Tissue culture	31	36	58	3	3
Somatic embryo genesis	4	75	-	25	-
Bio-pesticides	12	33	25	42	-
Classical breeding	22	38	48	14	-
Bio-processing	80	10	70	15	4
Bio-sensing	28	36	46	4	14
Bio-bleaching	3	-	100	-	-
Bio-leaching	5	60	40	-	-
Microbial inoculants	10	33	11	33	22

x: Confidential to meet secrecy requirements of the Statistics Act.

Table A-9 Future plans to adopt biotechnology

	Within 2 years		All future potential users[1]	
Biotechnology class	Current users[2]	Non-users	All firms[3]	Employee weighted
Selection and modification				
Recombinant DNA	-	x	5	-
Antibodies/antigens	x	x	4	--
Peptide synthesis	x	x	4	-
Rational drug design	x	x	3	-
Monoclonal antibodies	3	x	7	--
Gene probe	x	-	7	--
Gene therapy	x	-	5	--
DNA amplification	3	x	8	--
Environmental				
Bioaugmentation	4	x	13	1
Bioremediation	9	10	27	4
Bio-reactors	8	6	32	4
Phytoremediation	4	x	14	4
Bio gas cleaning	x	x	19	2
Culture and use of biological material				
Tissue culture	3	x	9	--
Somatic embryo genesis	4	x	9	1
Bio-pesticides	x	4	13	1
Classical breeding	x	x	4	--
Bio-processing	3	5	14	1
Bio-sensing	3	9	16	1
Bio-bleaching	x	x	11	2
Bio-leaching	x	x	7	1
Microbial inoculants	4	x	8	--

1: Firms that plan to adopt within two years plus firms that state that the technology is too expensive.

2: A current user is a firm that uses any of the 22 biotechnologies.

3: Percent of potential adopters out of the 2,010 responding firms.

Table A-10. Importance of impediments to adopting biotechnology for non-user firms: Distribution of responses as a percentage of the total (N). Rows sum to 100%.

Impediment	N[1]	Not important	Moderately important	Very important
Cost-related problems				
High equipment costs	96	38	21	42
Lack of equity capital to implement new equipment	82	37	13	50
Lack of financial justification	86	23	10	66
Cost of training	80	39	22	39
Increased maintenance expenses	76	36	28	37
Insufficient market for product	72	28	15	57
Government regulations/standards	74	35	20	45
Availability of inputs				
Lack of equity capital for investment	72	36	17	47
Lack of outside capital for investment	71	32	24	44
Shortage of skills	73	36	18	47
Training difficulties	75	44	19	37
Organizational problems				
Difficulties in introducing organizational changes	78	49	31	20
Internal resistance to biotechnologies	71	59	21	20
Worker resistance	69	68	20	12
Other problems				
Lack of scientific and technical information	103	34	20	46
Lack of technical services (consulting, testing)	95	34	22	44
Lack of technical support from vendors	84	46	16	38
Biotechnologies not sufficiently developed	93	23	22	56
Lack of information about potential markets	89	21	20	58

[1]: Number of responses from non-user firms that answered something other than 'not applicable'.

Table A-11 Employee-weighted percentage of bio-user firms by sector that find each impediment of importance[1] (number of firms per sector in parentheses)

	M	CP	PR	WPP	F	P	NPC	O
Cost-related problems								
High equipment costs	31	38	90	54	46	4	13.5	42
Lack of equity capital to impl equip	22	16	32	46	14	3	1.0	42
Lack of financial justification	53	22	90	62	34	2	22.4	40
Cost of training	2	8	-	31	4	3	8.3	10
Increased maintenance expenses	24	33	19	51	10	3	0.6	10
Insufficient market for product	-	16	-	9	23	1	16.9	1
Government regulations/standards	54	68	90	46	41	13	30.9	3
Availability of inputs								
Lack of equity capital for investment	-	16	-	30	13	3	1.0	42
Lack of outside capital for investment	21	14	-	14	5.	2	7.6	42
Shortage of skills	45	19	1	28	5	3	13.2	46
Training difficulties	39	15	40	27	5	3	12.2	8
Organizational problems								
Difficulties in organizational changes	-	15	40	14	8	3	22.3	38
Internal resistance to biotechnologies	-	10	40	13	34	1	22.3	46
Worker resistance	-	1	-	26	2	1	-	-
Other problems								
Lack of scientific & tech information	54	21	32	28	17	2	14.3	7
Lack of technical services	39	13	-	36	16	2	11.9	--
Lack of tech support from vendors	23	11	32	30	18	64	0.1	--
Biotechnologies not developed	58	38	90	36	34	2	32.1	--
Lack of info about potential markets	2	20	-	16	15	41	6.5	9

[1]: Includes firms that responded 'not applicable'. Importance is defined as a moderately important, very important, or crucial response. Excludes 12 firms with 10 or more establishments. M: mining, CP: crude petroleum, PR: petroleum refining, WPP: wood, paper, and pulp, F: food, beverages and tobacco, P: pharmaceuticals, NPC: non-pharmaceutical chemicals, O: other manufacturing.

Table A-12 Percent of firms by technology class that report a difficulty from the implementation of a biotechnology process

	Any biotechnology		Selection & modification		Culture & biological material		Environmental	
	Firms	Employee weighted	Firms	Employee weighted	Firms	Employee weighted	Firms	Employee weighted
Number of firms	*252*		*45*		*127*		*156*	
Training	27	25	31	16	27	2	22	27
Skill availability	27	4	36	--	25	7	24	3
Adaptability to other tech	14	35	9	31	10	21	15	32
Adaptability to standards	21	43	11	21	16	18	22	46
Need for advice & info	27	45	16	36	20	25	30	43
Higher maintenance cost	22	35	9	1	13	25	28	40
Insufficient product market	5	49	7	18	7	34	3	42
Lack tech support of vendor	12	39	9	47	7	3	13	41
Regulatory constraints	29	17	33	1	20	6	31	19
Other	13	21	x	38	8	6	15	24
No barriers	44	54	36	36	42	57	35	41

Table A-13 Percent of firms by sector that report each barrier to the implementation of biotechnology processes for any of the three biotechnology classes

	M	CP	PR	WPP	F	P	NPC	O	p[1]
Number of firms	*11*	*30*	*10*	*50*	*108*	*18*	*18*	*7*	
Training	46	13	x	32	25	44	33	x	--
Skill availability	46	x	x	28	25	56	39	x	--
Adaptability to other tech	36	17	x	12	14	x	17	x	1
Adaptability to standards	27	20	30	30	18	x	22	x	1
Need for advice & information	55	27	x	34	25	17	28	x	--
Higher maintenance cost	x	13	x	32	24	17	17	-	--
Insufficient product market	x	-	-	-	6	x	11	x	--
Lack tech support of vendor	x	x	-	12	16	x	22	x	--
Regulatory constraints	36	50	40	30	20	33	28	x	--
Other	36	13	x	20	9	-	17	-	7
No barriers (at least one class)	36	40	60	44	48	33	33	x	1
No barriers (all three classes)	x	30	40	34	37	33	22	x	1

1: p value for an analysis of variance for differences by sector.

M: mining, CP: crude petroleum, PR: petroleum refining, WPP: wood, paper, and pulp, F: food, beverages and tobacco, P: pharmaceuticals, NPC: non-pharmaceutical chemicals, O: other manufacturing.

Table A-14 Employee-weighted average investment in biotechnology in 1996: by size and technology class (in Canadian dollars)

Employee class	All bio-users	Users of selection & modification biotechnology	Users of culture & biological material biotechnology	Users of environmental biotechnology
0 – 49	19257	27778	15612	4010
50 – 99	4746	1269	4927	2136
100 – 249	5089	835	3221	5633
250 – 499	3599	433	832	5210
500 – 999	2546	3232	2912	1581
> 1000	308	142	123	268

Table A-15 Percentage of firms that indicate that each factor has a positive influence on their decision to use a biotechnology by biotechnology class

	Any Biotechnology	Selection & modification	Culture and biological material	Environmental
Faster delivery time	11	21	14	5
Extend product range	22	45	33	8
Increase production flexibility	22	34	24	18
Lower maintenance cost	28	15	18	34
Improve market position	32	53	38	19
Other	33	23	23	35
Familiar with technology	34	47	32	27
Dev new products & processes	35	51	47	18
Lower production cost	40	45	37	36

Table A-16 Results of the use of biotechnology: percentage of firms by technology class that report each effect from the use of biotechnology

	Any biotechnology	Selection & modification	Culture & biological material	Environmental
Number of firms	*244*	*41*	*234*	*152*
Lower inventory	4	x	6	x
Reduced skill needs	5	x	5	4
Other	11	10	11	8
Reduced capital needs	12	x	7	13
Higher equip use rate	13	17	14	10
Better work conditions	14	17	15	11
Lower labour needs	14	22	9	13
Lower energy use	17	10	11	18
* No improvements	17	14	20	8
Lower reject rate	20	29	25	9
Better product flexibility	20	37	26	10
Lower material use	21	20	19	19
* More capital needs	23	24	20	22
* More skill needs	27	39	25	22
Improved productivity	28	32	34	18
Improved prod quality	39	44	50	12
Less enviro damage	50	17	15	72

*Not an improvement.

Table A-17 Secondary benefits from the adoption of environmental biotechnology

		Lower Costs[1]		Improved productivityr or quality[2]		Both combined	
	N	Firms	Employee weighted	Firms	Employee weighted	Firms	Employee weighted
Mining	7	57	86	x	1	43	72
Crude petroleum	20	65	72	20	40	65	58
Petroleum refining	4	x	80	x	42	x	78
Wood, paper & pulp	42	12	12	26	35	40	80
Food	25	24	67	36	49	75	68
Chemicals	10	40	68	x	6	71	36
All[3]	109	32	45	25	36	44	87

[1]: A positive response to one of: lower labour requirements, lower material consumption, lower energy consumption, lower product rejection rate.

[2]: A positive response to one of: improvement in productivity, improvement in product quality, increased equipment utilization rate.

[3]: Includes one firm from 'other manufacturing'.

Table A-18 Percent of firms in each sector that report each outcome from the use of any biotechnology

	M	CP	PR	WPP	F	P	NPC	O	p[1]
Number of firms	*11*	*29*	*10*	*47*	*105*	*18*	*17*	*7*	
Improved productivity	X	28	x	11	37	39	18	x	--
Lower labour needs	27	31	x	x	12	17	x	x	--
Lower material use	36	24	40	11	23	17	24	x	--
Lower energy use	27	34	x	x	16	x	29	-	--
Lower reject rate	X	x	30	x	34	x	x	x	--
Improved prod quality	X	x	x	15	54	39	18	43	--
Better product flexibility	-	-	x	15	27	39	18	43	--
Better work conditions	X	-	x	13	15	28	18	x	--
Less enviro damage	64	69	40	92	33	x	65	x	--
Reduced skill needs	-	14	x	x	5	-	x	-	--
Reduced capital needs	X	34	x	x	8	-	24	x	--
* More skill needs	27	x	x	38	24	56	18	x	--
* More capital needs	X	-	x	43	19	50	x	43	--
Higher equip use rate	-	x	-	17	13	28	x	x	--
Lower inventory	-	x	-	x	7	-	-	x	--
Other	X	x	10	x	9	x	24	x	--
* No improvements	X	10	x	x	26	22	x	x	--

[1]: p value for an analysis of variance for differences by sector.

M: mining, CP: crude petroleum, PR: petroleum refining, WPP: wood, paper, and pulp, F: food, beverages and tobacco, P: pharmaceuticals, NPC: non-pharmaceutical chemicals, O: other manufacturing.

Table A-19 Internal information sources: Percent of firms that report each source to be a principal information source for the adoption of biotechnology or biotechnology equipment

	Any biotechnology	Selection & modification	Culture & biological material	Environmental
Number of firms	*250*	*44*	*127*	*154*
Research	47	64	50	38
Experimental development	43	50	46	35
Design work	21	27	21	20
Production engineering	26	20	20	27
Operating staff	34	23	34	33
Management	34	39	35	32
Corporate head office	31	30	26	32
Other	14	14	12	14

Table A-20 External information sources: Percent of firms that report each source to be a principal information source for the adoption of biotechnology or biotechnology equipment

	Any biotechnology[1]	Selection & modification	Culture & biologic material	Environmental
Number of firms	*253*	*44*	*128*	*157*
Related firm	24	25	27	20
Unrelated firm	32	32	27	34
Federal research organization	28	34	32	24
Universities	40	52	40	34
Provincial research organization	19	16	16	19
Federal information programs	12	14	14	9
Research consortia	18	11	14	22
Consultants & service firms		34	30	58
Joint ventures & strategic alliances	18	36	20	12
Publications	53	64	52	48
Trade fairs, conferences	40	52	36	37
Customer firms	10	20	13	4
Supplier firms	42	41	45	34
No significant external input	-1	14	15	13
Other	6	x	6	4

[1]: Not relevant over the three technology classes.

Appendix B: Questionnaire Design

Question on the number of employees working with biotechnology

The results for this question are not useable because of errors in the responses:

- Firms that do not use any biotechnology (3% of non-user firms) report that they have biotechnology employees.
- Firms that use biotechnology (41% of bio-user firms) report that they have no employees working with biotechnology.

There are three possible causes of these errors:

- The respondents had a different definition of biotechnology in mind compared to the 22 options listed in Question B1. This error could occur because the respondents were asked to give the number of employees working with biotechnology before they saw the list of 22 biotechnologies. The results for bio-users suggest that firms that are most likely to use biotechnology for environmental reasons were less likely to state that they had employees working with biotechnology. For example, only 26% of bio-user pharmaceutical firms reported no biotechnology employees compared to 69% of mining firms.
- The respondents did not know the answer. It could be very difficult to estimate the percentage of employees 'working with' biotechnology, particularly in firms where biotechnologies are used in many different areas.
- Some firms can use biotechnology without any employees working with it. This appears to be an unlikely explanation.

Question C4 on Barriers

The factor 'No impediments (C4.21)' is not logical in the framework of the importance scale. This could explain the dismal response to this question.

Use of Three Biotechnology Classes

Six questions require the respondent to answer for each of three biotechnology classes: selection and modification of biological material, culture and/or use of biological material, and environmental biotechnologies. This division increases the response burden and makes the analyses considerably more complicated. I suggest that such a division is not used in future questionnaires. It is also unnecessary for two reasons. First, over 70% of firms are only active in one technology class. Second, the use of each technology class is dominated by firms in a few clearly defined industries, with little overlap. For example, almost all of the users of selection & modification and culture & biological material technologies are in the food and pharmaceutical sectors, while almost all of the users of environmental biotechnologies are in the resource sectors. This means that similar results can be obtained by using the firm's sector of activity.

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