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Bibliometric analysis of biotechnology

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Although *Derwent Biotechnology Abstracts* has been used in a variety of bibliometric studies, it has never undergone a systematic examination of its reliability and validity. The objective of this paper is to assess its quality for bibliometric studies attempting to analyse the evolution of biotechnology research, to map leading organizations, and to study the interaction between science and technology. The first part reviews the tools used in bibliometric studies of biotechnology and describes the *Derwent Biotechnology Abstracts* database. The second part is a case study of plant genetic research, with special emphasis on Canada.

Introduction

Following the elucidation of the DNA molecule by Watson and Crick in 1953, molecular biology emerged as a fast growing discipline (*Kenney*, 1986). Putting emphasis on the potential impact of genetics research on disease detection and treatment, its scientific community benefited from massive public funds through US health research programs, culminating in the international Human Genome Projects of the 90's (*Hilgartner*, 1995; *Davies*, 2001). The discoveries of the recombinant DNA technique by Boyer and Cohen in 1973 and of monoclonal antibodies by Milstein and Kohler in 1975 were a turning point, ushering the commercial exploitation of pure research, with new firms, many of them founded by university researchers, being created (*Kenney*, 1986). Biotechnology thus emerges as one of the areas where interaction between science and technology appears closest with industry rapidly exploiting new knowledge developed by academia (*Powell* et al., 1996; *Swann* et al., 1998; *Zucker* et al., 1998; *Mowery* et al., 2001). It has attracted considerable attention from sociology and economics in an effort to understand this dynamic. In this context, bibliometric offers tools to study these interactions.

Bibliometric studies of biotechnology exploit two distinct types of databases. The first one consists of classical bibliometric databases, such as ISI products for scientific publications (for example, the *Science Citation Index*) or national patent databases (for example, the American patent database USPTO). They have been extensively exploited

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and their strength and weaknesses are now well known (*Okubo*, 1997; *Griliches*, 1990). As we will see below, in regards to biotechnology they however offer limited indexing information as to research content and, because they cover all fields, they leave bibliometricians with the task of having to draw boundaries between biotechnology and other areas on the basis of very limited descriptive data. The second type of tools includes more specialized databases. Various public and commercial organizations offer a large variety of indexing products covering scientific publications and patents, as well as other research output such as genes sequences. The most widely quoted source is the *Derwent Biotechnology Abstracts*, which includes both publications and patents. Although it has been used in a variety of bibliometric studies, it has never undergone a systematic examination of its reliability and validity.*

The objective of this paper is to assess *Derwent Biotechnology Abstracts'* quality for bibliometric studies attempting to analyse the evolution of biotechnology research, to map leading organizations, and to study the interaction between science and technology. The first part reviews the tools used in bibliometric studies of biotechnology and describes the *Derwent Biotechnology Abstracts* database. The second part is a case study of plant genetic research, with special emphasis on Canada.

Bibliometric analysis of biotechnology

Biotechnology databases

ISI databases are still the main tool for bibliometric studies and the only ones offering citations and complete affiliations of all authors. They encompass a relatively small selection of journals among the huge number of papers published worldwide. Taking into account the governance of scientific research and the peer-review system, the assumption is that researchers have an incentive to rapidly publish their findings in leading and most widely diffused journals. On one hand, these journals offer researchers the highest visibility in his or her community, and on the other hand, they should also be the most discriminating in manuscripts' evaluation. In this respect, ISI, despite its small number of journals, probably accounts for a large share of most significant scientific breakthroughs.** The selection of journals is largely based on the number of citations

* A paper in this journal questioned its reliability and validity (*Ramani* and *De Looze*, 2000).
** This is an application of the Bradford law to demonstrate the concentration of "significant" publications (*Garfield*, 1972).

obtained and the latter are used to evaluate researchers' or organizations' performance through direct citation count or impact factor.

These databases have often been criticized for their potential selection bias in favor of American and English language journals, meaning that research output from other countries and in languages other than English would be underestimated (*Carpenter* and *Narin*, 1981). Related to that, and probably more relevant in the case of biotechnology, is that certain research objects have limited geographical application and such results would appear only in national journals, imperfectly covered by ISI. The other limitation is that they offer very sparse information on research matter. Since keywords or classification codes are not included, data indexing has to be based either on the title, the abstract (now available in some ISI products), citations, or more frequently on the journal title since ISI and CHI have developed classification schemes based entirely on the journals themselves, based on very broad categories. The *Biotechnology Citation Index* introduced in 1996 selects publications in biotechnology related journals, and includes abstracts, citations and a few keywords. When the objective is to study the structure of the field or the evolution of given specialties, ISI databases on their own provide only limited assistance.

Patents, as an output of technology-related activities, are analysed using the same bibliometric methods as scientific publications. Patents however describe inventions, rather than innovation, and more importantly they fail to provide information on the commercial success of these inventions (*Griliches*, 1990). Furthermore, propensity to patent depends on decisions made by individuals and on firms' strategies based on expectations of costs and benefits to be derived from invention protection, as well as on the rules and laws within each national jurisdiction, facilitating, or hindering, patenting. Propensity to patent will fluctuate from one industry to another, and from one country to the other.

In biotechnology, this propensity is expected to be rather high. Studies suggest that recent increases in the overall number of patent applications are partly due to new opportunities derived from commercial biotechnology (*Mowery* et al., 2001; *Kortum* and *Lerner*, 1999). In public research organizations, clear intellectual property rights are required to commercialize new knowledge in order for instance to licence or to get access to venture capital (*Banerjee* et al., 2000). The same holds for dedicated biotechnology firms, which establish contractual arrangements with various partners, including universities, pharmaceutical firms or venture capitalists. The literature however suggests strong national variations in the commercialisation of biotechnology,

with a pattern of direct involvement by public research organisations and venture capital characterizing North-America (*Senker* and *Van Vliet*, 1998; *Giesecke*, 2000; *Swann* et al., 1998). In other countries, patenting appears less frequent.

During the 90's, *Narin* and his colleagues developed a new tool called patent bibliometrics (*Narin*, 1994) or linkage bibliometrics (*Meyer*, 2000), which measures patent citations to scientific literature or other patents. Citations to scientific literature in patents is used to analyse the link between science and technology, in as much as they serve as an indicator of the diffusion of scientific research within industry (*Narin* et al., 1997). From a bibliometrics standpoint, concerns are raised about the validity of such indicators which depends on whether the citation originates with applicants or patents examiners, and also about the meaning of references appearing in patents (*Vinkler*, 1994). *Meyer* (2000) and *Tijssen* (2001) have concluded that the relation between science and technology revealed by patent citations to scientific literature is neither direct, nor unilateral or science-dependent. In this context, data have to be interpreted as describing the complex web of interactions between science and technology taking place in biotechnology.

Table 1 indicates which databases were selected in a sample of bibliometric studies dealing with biotechnology. The *Science Citation Index* is used for research dealing with the scientific dynamic of biotechnology research. The tool includes for instance journal-to-journal citations to determine specialties (*McCain*, 1995b). Other broad disciplinary databases, such as *BIOSIS* (biology and agriculture), *MEDLINE* (medicine), *Chemical Abstracts* (chemistry), *Agricola* or *Pascal* are seldom, if ever, used (*DeLooze* and *Lemarié*, 1997). More specialized publication databases are retained when the objective is to analyse a research subfield or a specific application. For instance, *Hinze* and *Grupp* (1996) analysing the structure of research in food sciences selected the *Food Science and Technology Abstracts* for publications, and *Derwent Biotechnology Abstracts* for patents. *DeLooze* (1994) studying plant biotechnologies selected the specialized database *Commonwealth Agricultural Bureau*. A few studies, dealing with the cognitive structure of the field or devoted to the development of new bibliometric tools, have elaborated a journal set integrating a small number of journals characterizing specific subfields (*Rip* and *Courtial*, 1984; *Nordstrom*, 1987). Finally, some researchers have built their own databases, for instance, a study designed to evaluate funding programs, required biotechnology researchers to supply their resume (*Lewison*, 1994).

Table 1. Bibliometric studies of biotechnology

Study	Objective of the study	Databases
Rip and *Courtial,* 1984	To analyse the structure of the field through co-word analysis	The journal : *Biotechnology and Bioengineering*
Nordstrom, 1987	To differentiate pure and applied research	Two journals : *Canadian Journal of Botany* and *Canadian Journal of Plant Science*
Nederhof, 1988	To compare the evolution of research and production in six countries	*Chemical Abstracts*
Thomas, 1992	To evaluate research performance of groups outside USA and EC; and to evaluate ISI coverage for such countries	SCI and publications list obtained from researchers
Singh and *Saxena,* 1992	To analyse the evolution of research and of leading organizations	*Derwent Biotechnology Abstracts*
Martens and *Saretzki,* 1994	To analyse scientific communication	Scientific conferences listings
DeLooze, 1994	To analyse the structure of the field through co-word analysis	*Commonwealth Agricultural Bureau*
Zucker et al., 1994	To analyse interaction between public research organizations researchers and industry	GenBank, SCI
Lewison, 1994	To analyse transnationality of EC funded projects	SCI and publications list obtained from researchers
McCain, 1995a	To analyse the structure of the field through co-classification	*Derwent Biotechnology Abstracts*
McCain, 1995b	To analyse the structure of the field and specialties through co-classification	SCI and *Derwent Biotechnology Abstracts*
Hinze and *Grupp,* 1996	To analyse the structure of the field and science and technology interactions	*Food Science and Technology Abstracts* and *World Patent Index Latest* (from Derwent)
DeLooze and *Lemarié,* 1997	To compare different databases for co-word analysis	*Food Science and Technology Abstracts*, *Agricola*, *Pascal*, *SCI*, *Derwent Biotechnology Abstract*
Wolf, 1998	To evaluate European Research	SCI and *World Patent Index* (from Derwent)
Leydesdorff and *Heimeriks,* 1998	To analyse the structure of the field in Europe, USA and Japan	SCI (journal-to-journal citations) and five journals
Joly and *DeLooze,* 1999	To analyse relations between research organisations	*Derwent Biotechnology Abstracts*
DeLooze and *Ramani, 1999*	To compare patenting in France, Germany and the UK	*Derwent Biotechnology Abstracts*
Banerjee et al., 2000	To analyse the evolution of the field	*Derwent Biotechnology Abstracts*
McMillan et al., 2000	To analyse interactions between science and technology	CHI database
DeLooze et al., 2001	To analyse scientific publications and applications for patents	*SCI* and *Derwent Biotechnology Abstracts*

Among these specialized databases, the most frequently used is *Derwent Biotechnology Abstracts*. *McCain* (1995a) in a study of biotechnology research specialties selected it for its wide coverage of patents and scientific publications. Adding a co-classification analysis, this database offers classification codes. In a related study mapping the cognitive structure of the field, *McCain* (1995b) exploited the *Science Citation Index* for a journal-to-journal citation analysis, and the Derwent database to access descriptive information, such as the classification codes characterizing each journal. *DeLooze* and her colleagues also retained *Derwent Biotechnology Abstracts* in several studies to trace patents and publications by firms (*Joly* and *DeLooze*, 1999). The same database is also selected in a study on specific applications related to public health (*Singh* and *Saxena*, 1992). For patents, various other Derwent products are exploited (*Hinze* and *Grupp*, 1996).

Special attention should be devoted here to several studies by economists utilizing bibliometric methods to analyse the interaction between science and technology in biotechnology. *Zucker* and her colleagues established a list of star scientists in genetics using the genetic sequence database *GenBank* (*Zucker* et al., 1994 and 1998).* They later referred to the *Science Citation Index* to trace citations to these publications and to establish a list of their collaborations through coauthorship. *DeCarolis* and *Deeds* (1999), as well as *Audrestch* and *Stephan* (1996), retained different sources, such as stock market prospectuses of new dedicated biotechnology firms, patents, citations to publications and strategic alliances. Narin's patent bibliometric's method also found applications in biotechnology (*McMillan* et al., 2000).

In these bibliometric studies, the choice of the database is, most of the time, not fully explained. *McCain* (1995a) justified the use of *Derwent Biotechnology Abstracts* by a survey of the secondary literature from library sciences, but generally speaking researchers' needs seem to be the implicit factor. ISI products are used when citations are required, while *Derwent Biotechnology Abstracts* provides more descriptive information. For specific applications, more specialized databases pinpoint the relevant set of publications. One of the rare biotechnology databases comparison confirms this trend (*DeLooze* and *Lemarié*, 1997). Each of the five databases retained in this study covered different journals and literature, and each provided different information, such as keywords or classification codes requiring therefore a specific bibliometric treatment. It emphasizes the fact that each database offers a specific profile of research, and that its content should be studied carefully.

* The most extensive presentation of their method can be find in *Zucker* et al. (1994).

Derwent Biotechnology Abstracts

Derwent Biotechnology Abstracts emerges as the most frequently used database for patents analysis. First, such bibliometric studies extensively exploit patents because, as mentioned previously, they probably have greater validity for biotechnology. Second, because of its indexing information, this database offers more relevant data than for instance USPTO. For publications, bibliometricians retain a diversity of sources, ranging from large databases such as the *Science Citation Index*, to specific ones according to their needs, and *Derwent Biotechnology Abstracts* is one of the most frequently selected.

The specificity of this database relies on two features.* The first is its extensive coverage of patents, indexing those issued by 40 different authorities. Most scientific publication databases do not cover patents, while individual national patent databases reveal only part of the profile. Concerning the latter, national American or European research organizations are over represented in their own national patent databases, which implies a bias in international comparison. Furthermore, a selection has to be done to retain only biotechnology patents, which is difficult in view of the lack of proper indexing information in national databases.

The second feature, as frequently stated, is its indexing information. For patents and publications, its classification codes account for twelve groups, each with a breakdown into one to seven subgroups (Appendix 1). These groups refer to biotechnology areas of applications, from pharmaceutical (group D), agriculture (group E), food (group F), or environment (group M). Each patent or publication is indexed in one or up to six classification codes, allowing to pinpoint more precisely specific technologies and, through co-classification analysis, to map its structure. Classification codes were modified in 1992 to provide a more accurate description of new developments in biotechnology.

In order to assess reliability and validity, four main issues should be addressed.

The definition of biotechnology. The first two issues, related to the coverage of *Derwent Biotechnology Abstracts*, will provide a clear picture of its content, in order to understand what they have to offer. There is no standard definition of what is included in biotechnology research. Since its emergence, American and European visions diverge (*Rip* and *Nederhof*, 1986). The former put emphasis on new techniques, such as the recombinant DNA or monoclonal antibodies, on the basis of genetic engineering. The latter adds more traditional techniques and is more concerned by their applications. A further problem is that the definition can be derived from different levels of analysis

* For a complete description of the database, see *Derwent* (2000).

(*Stokes*, 1996). From a scientific point of view, biotechnology is highly multi-disciplinary and evolves rapidly, from a technical standpoint, it frequently refers to the application of specific new techniques, although it sometimes includes much older processes, so that the borders are blurred. These techniques have broad applications in a large number of industries. Institutions also play a role since Government is an important actor, and definitions vary from country to country.

Derwent Biotechnology Abstracts defines biotechnology as "the development and application of biological organisms and molecules in technical and industrial processes (i.e., the application of microorganisms, animal or plant tissue cultures, enzymes, or any other cellular or subcellular biological system) which impact industries such as pharmaceutical, agriculture, food, environmental control and many other commercial operations" (*Derwent*, 2000: 7). Its list of classification codes indicates the applications covered (Appendix 1). It is important to stress that Derwent offers other products on related areas, such as *Derwent Geneseq*, covering patents including genetic sequences.

Coverage of the database. Since 1982, the database retrieves patents from 40 authorities (35% of records), publications from about 1200 scientific journals (48%), and abstracts of conferences (17%) (*Derwent*, 2000). To provide an illustration of its coverage and to compare with other databases, we have examined the case of scientific journals. Table 2 lists those accountable for the largest number of records between 1996 and 1999.

Journals with the largest number of records for the period selected in *Derwent Biotechnology Abstracts* are *Applied Microbiology and Biotechnology, Applied and Environmental Microbiology, Applied Biochemistry and Microbiology, Biotechnology and Bioengineering,* and *Biotechnology Letters*. These journals are largely devoted to industrial applications of biotechnology. Their coverage widely refers to a European definition of biotechnology, where research related for instance to molecular biology and genetics is generally excluded. For example, 282 papers from *Nature Biotechnology* are indexed in *Derwent Biotechnology Abstracts* from 1996 to 1999, but only 18 from *Nature Genetics*. There is only one paper from the *American Journal of Human Genetics* and eleven from *Human Molecular Genetics.*

The *Derwent Biotechnology Abstracts* list of journals is fairly similar to those associated with the subfield called "biotechnology and applied microbiology" by ISI, covering "journals that focus on the use of organisms, especially microbes, in the production of foods and drugs, the bioconversion of toxic and unsanitary wastes, and the use of recombinant DNA to produce improved plants and animals and diagnostic products" (*ISI*, 2001). On the basis of this definition, *Nature Genetics*, the *American Journal of Human Genetics* and *Human Molecular Genetics*, for instance, are not

included in this subfield, but in "genetics and heredity". The ISI database *Biotechnology Citation Index* covers a larger research area, including the subfield of "biotechnology and applied microbiology" as well as that of "genetics and heredity", and journals in many other subfields related to microbiology or agricultural research. This database thus offers a vision of biotechnology more attuned to the North-American definition of the field, than that of the Europe based *Derwent Biotechnology Abstracts* with its application-centered definition of biotechnology.* It partly excludes scientific research devoted to molecular biology. This has to be taken into account in the analysis of statistics derived from *Derwent Biotechnology Abstracts* because it provides only limited information about related subfields.

Table 2. Journals accountable for the largest number of records in *Derwent Biotechnology Abstract* (1996–1999)

Journal	1996-1997	1998-1999	Total
Biotechnology and Bioengineering[a,b]	503	576	1079
Applied Microbiology and Biotechnology[a,b]	515	420	935
Applied and Environmental Microbiology[a,b]	407	499	906
Biotechnology Letters[a,b]	504	400	904
Journal of Fermentation Bioengineering (now *Journal of Bioscience and Bioengineering*)[a,b]	333	362	695
In-Vitro Cellular & Development Biology[a]	543	93	636
Journal of Biotechnology[a,b]	313	295	608
Enzyme and Microbial Technology[a,b]	251	347	598
Plant Cell Reports[a]	264	318	582
Biotechnology Techniques[a,b]	297	278	575
Applied Biochemistry and Biotechnology[a,b]	383	137	520
Bioscience Biotechnology and Biochemistry[a,b]	277	230	507
Bioprocess Engineering[a,b]	192	280	472
Journal of Antibiotics[a,b]	272	194	466
BioTechniques[a]	321	112	433

[a]: journal indexed by ISI in 1999
[b]: journal classified by ISI in "biotechnology and applied microbiology"
Source: *Derwent Biotechnology Abstracts*.

One could expect that, for the subfields it retains, *Derwent Biotechnology Abstracts*, would cover more sources than ISI databases (*McCain*, 1995a). First, as mentioned previously, conferences abstracts make up 17% of its records. Second, as a European database, it is expected to cover more broadly national and European journals (*McCain*, 1995a). For Canada, the coverage of national journals was however very limited. For a

* For the origin of Derwent, see *Oppenhem* (1982).

group of Canadian journals, such as *Genome*, the *Canadian Journal of Botany* and the *Canadian Journal of Chemical Engineering*, no records were found after 1997, and only one for *Biochemistry and Cell Biology*. These four journals are still mentioned by *Derwent Biotechnology Abstracts* in their list of "journals most frequently cited" (*Derwent*, 2000). Only the *Canadian Journal of Microbiology* is still indexed. The coverage of Canadian journals therefore strongly declined during the period studied. The *Canadian Journal of Microbiology* and *Genome* appear in the ISI journal listing in the subfield of "biotechnology and applied microbiology", while only *Genome* is in the short-list of journals indexed by the *Biotechnology Citation Index*.

If the coverage of *Derwent Biotechnology Abstracts* was expected to be larger for publications than comparable databases, it does not seem to be true in more recent years. The annual number of records from scientific literature decreased from around 10000 up to the mid 90's to around 6000 from 1998. National journals, from Canada as for other countries, seem to have suffered from this operation.* As indicated in Table 2, journals with the largest number of records are all indexed by ISI. Following the fast increase in patenting and especially in biotechnology, *Derwent Biotechnology Abstracts* increased its patent records from 5586 in 1996 to 8035 in 1999.** It seems that it has been done at the expense of publications.

Authors and affiliations. ISI databases include all affiliations of authors, allowing for the analysis of collaborations between countries and organizations. Starting in 1995, *Derwent Biotechnology Abstracts* presents more information on this issue within two fields (CA: corporate affiliate or patentee; LO: location of work). For patents, organizations are listed in the first field, while cities and countries are in the second. For publications, the first one lists all organizations involved, while the second includes the full address of the corresponding author. *Derwent Biotechnology Abstracts* lists the name of all organizations involved in publications or as assignee for patents. However, the information is dispersed in two fields, and for publications only the complete address, city and country, of one organization is presented. Collaboration in research is more difficult to trace than with ISI databases.

Comparison. The last issue addresses the question of time-series and international comparison. The reliability of time-series depends partly on the impact of changes to the database itself. Three changes have to be considered. As mentioned, the coverage of scientific publications decreased in 1998, which implies that the two periods are

* For instance, the *Indian Journal of Microbiology* has only half the records it had in the mid 90's and the Russian journal *Genetika* was not indexed after 1998.

** USPTO offers a rather similar pattern, evaluating the increasing in patents granted in biotechnology from about 5000 in 1996 to 9000 in 1998 and in 1999 (*Biotechnology Industry Organization,* 2001).

difficult to compare. For publications and patents, all organizations are listed only since 1995, and they cannot be traced prior to that period. Classification codes for both were adjusted in 1992 in order to describe more accurately the evolution of biotechnology research.

For patents, two limitations should be stressed. The fact that *Derwent Biotechnology Abstracts* covers 40 different national authorities is certainly helpful, but comparison, must be done carefully. First, rules about what can be patented vary from one country to another. Second, delays between application and delivery are also different from one authority to the other.

Plant genetics

Research dynamic in plant genetic

Crop research is largely devoted to increasing yields by reducing losses caused by insects, viruses and other destructive disorders (*NRC*, 2000). Two broad methods are available. The first implies the use of herbicides, pesticides and other chemical products to stop the proliferation of undesirable organisms. For farmers, this means higher production costs, and environmentalists are strongly critical of the impact on human health. Furthermore, pests tend to develop resistance and chemical products have to be continually modified. The second method is the selection of desirable traits through hybridization or biotechnological techniques. Since different varieties of plants react differently to local conditions and various threats, selection of specific traits increases yields. Biotechnology techniques, such as recombinant DNA by adding specific genes, make it possible to modify plants more rapidly and accurately.

In May 1994, Pioneer Hi-Bred obtained first regulatory approval of a transgenic plant in Canada for *Imidazolinone Resistant Maize*, to date 49 crops have been approved. They are generally associated with first generation plant genetic research, most are herbicide-tolerant or offer resistance to particular pests (*Kalaitzandonakes*, 2000). The objective is to increase yields and reduce production costs, for instance, by reducing pesticide use. Since 1995, diffusion of transgenic crops in North America was fastest for cotton, soybeans, corn and canola (*James*, 2000). In 2000, it was estimated that 44.2 million hectares worldwide were cultivated using such transgenic crops.

Large agbiotech firms, such as Monsanto or Pioneer Hi-Bred, witnessing the success of health biotechnology in the 80's, increased their investments in the early 90's and developed these transgenic crops (*El Feki*, 2000). Following first regulatory approvals in the mid 90's and fast diffusion in North America, the industry expanded rapidly.

Soon new players emerged. Biotechnology firms, such as Aventis, invested in transgenic plants to exploit their expertise, were followed by frequent fusions and mergers designed to create major players, to harness all the knowledge needed to succeed, and to secure property rights on different technologies (*Kalaitzandonakes* and *Hayenga*, 2000). For instance, Monsanto acquired an array of smaller players for 8.5 billions US$, such as the biotechnology firm Calgene and the seed producer DeKalb Genetics (*Shoemaker,* 2001).

Consumer response in Europe was however disastrous. In 1998, concerns were raised about the impact of transgenic plants on the environment and human health. In recent years, diffusion of transgenic crops slowed down. Four countries, USA, Canada, Argentina and China, account for 99% of transgenic crop area in 2000 (*James*, 2000). In North America, increase in area was lower in 2000 than during previous years. Explanations suggested are related to bans in export markets and mixed results achieved by farmers, such as the lack of significant impact on herbicide use (*Fernandez-Cornejo* and *McBride*, 2000). Only three European Unions countries, Spain, Germany and France, reported very small areas planted with transgenic crops in 2000. Early reports on European consumers preferences suggested that their fears would not vanish rapidly (*Deutsche Bank*, 1999). In 2000, their concerns were fed by US newspaper reports of taco shells partly made from a genetically-modified maze not approved for human consumption and the import in the UK of the seed of an oilseed rape contaminated by a transgenic plant (*Genewatch*, 2001). Both cases were exploited by opponents as demonstrating regulatory failures. It should be added that international prices of corn, wheat and soybean are at historic lows, and most countries are facing surpluses, so that the timing for the diffusion of transgenic plants is rather poor. Since 1999, agbiotech firms have reduced their R&D effort, although public research even in countries enforcing bans on transgenic crops is maintained (*Kalaitzandonakes*, 2000; *Shoemaker,* 2001).

Research on the second generation of transgenic crops is still ongoing. Its objective is to enhance quality traits, such as taste, color, or nutrinational value. Such research seems to be much more complex and costly than the first generation (*McElroy*, 1999). Furthermore, it targets directly the consumer. Inputs in the plant industry follow a segmented supply chain from the agbiotech industry, to the farmer, to wholesales and retailers, to finally reach the consumer (*Kesan*, 2000). In this context, the agbiotech industry has no direct interaction with the final customer. This explains largely why first generation transgenic plants offer properties of direct value to the farmer. Taking into account actual concerns in Europe, the diffusion of transgenic plants of the second generation may pose a challenge.

Research on plant genetic

Research on plant genetics in *Derwent Biotechnology Abstracts* corresponds to the classification code E2, *Plant Genetic Engineering*.* Since classification codes were adjusted in 1992 and especially for this code on plant genetic, reliable time-series can be generated only for the period starting in 1992 for patents and publications. By the same token, the addition in 1995 of the field completing affiliation information for authors (publications) or assignees (patents), makes it possible to compare country and organization only for the post-1995 period. The period here corresponds to index years. For patents, it should be taken into consideration that they were delivered by different national authorities. Table 3 presents the distribution by priority country for the 1571 patents in plant genetic indexed between 1996 and 1999. American patents account for more than half of our database, followed by Japan (13%), Great-Britain (9%) and Germany (5%). The number of Canadian patents is very small (< 1%).

Table 3. Priority country of plant genetic patents – 1996-1999

Country	Patents
USA	890
Japan	201
Great Britain	139
Germany	74
European Patent	71
France	45
Australia	40
World Patent	30
Canada	14
Others	67
Total	1571

Source: *Derwent Biotechnology Abstracts*.

Patents in plant genetic more than doubled between 1992-1995 and 1996-1999, the point where it showed among the highest growths in *Derwent Biotechnology Abstracts* (Table 4). In fact, classes related to applications of genetics, to human health and plants are characterized by the fastest rise during this period.

* "Includes crop improvement via genetic manipulation techniques, including cell/tissue culture or plant transformation using Agrobacterium, microprojectile/biolistic particle bombardment etc. Transgenic plant construction for improved virus disease-resistance, insect resistance, herbicide/pesticide resistance, altered flower color, etc., and production of recombinant proteins/antibodies " (*Derwent*, 2000: 29).

Table 4. Patents and publications in biotechnology

Classification code	Patents			Publications		
	1992-1995	1996-1999	%	1992-1995	1996-1999	%
A Genetic Engineering and Fermentation	13287	20872	57	23739	18022	-24
A1 Nucleic Acid Technology	10512	18224	73	17810	12938	-27
A2 Fermentation	3129	3119	0	6727	6258	-7
B Engineering - Biochemical Engineering	1005	804	-20	3552	2674	-2
C Analysis - Sensors and Analysis	468	441	-6	1682	877	-48
D Pharmaceuticals	9710	15628	61	10235	7991	-22
D1 Antibiotics	678	569	-16	1374	935	-32
D2 Hormones	313	292	-7	448	239	-47
D3 Peptides and Proteins	2413	6674	176	1200	1085	-10
D4 Vaccines	1244	1885	52	1116	799	-28
D5 Other Pharmaceuticals	3152	2401	-24	2797	1609	-42
D6 Antibodies	1384	1918	39	944	684	-28
D7 Clinical Genetic Techniques	1946	7152	268	2977	3099	4
E Agriculture	2083	2959	42	6269	4581	-27
E1 Biological Control Agents	321	295	-8	511	295	-42
E2 Plant Genetic Engineering	661	1571	138	1668	1579	-5
E3 Pesticides	398	432	9	561	695	24
E4 In-Vitro Propagation	589	498	-15	3320	1996	-40
E5 Agriculture, Other	306	443	45	533	300	-44
F Food - Food and Food Additives	1616	1608	-1	2510	2019	-20
G Fuels, Mining and Metal Recovery	564	494	-12	2094	1443	-31
G1Biofuels and Solvents	406	298	-27	1611	877	-46
G2 Mining and Metal Recovery	162	197	22	489	569	16
H Other Chemicals	1722	1598	-7	3070	2805	-9
H1 Polymers	523	511	-2	823	767	-7
H2 Chiral Compounds	541	530	-2	1244	1167	-6
H3 Miscellaneous Compounds	429	570	33	680	890	31
J Cell Culture	3683	3626	-2	5501	2803	-49
J1 Animal Cell Cellule	3445	3472	1	4610	2119	-54
J2 Plant Cell Culture	269	198	-26	921	689	-26
K Biocatalysis	5325	4268	-20	12252	9102	-26
K1 Isolation and Characterization	2032	1653	-19	5567	3869	-31
K2 Application	3656	3095	-15	7276	5886	-19
L Purification – Downstream Processing	930	505	-46	1737	859	-51
M Waste Disposal and the Environnement	1507	1868	24	5767	5520	-4
M1 Industrial Waste Disposal	1177	1250	6	3212	2094	-35
M2 Environmental Biotechnology	371	763	106	2720	3689	36
TOTAL	20558	26375	28	41133	29906	-27

Source: *Derwent Biotechnology Abstracts*.

This suggests that scientific research previously generated new knowledge for which industrial applications were developed and that research organizations were trying to secure property rights for future commercialization.

American organizations account for half of these patents (Table 5). Other major countries are Japan (13%), United-Kingdom (7%), Germany (6%) and Australia (5%). The activity index established in comparison to the whole *Derwent Biotechnology Abstracts* database indicates that the countries specialized in plant genetic are Australia (4.52), Switzerland (2.03), and the United-Kingdom (1.61), and at the other end of the spectrum is Japan (0.56). Canadian organizations generate 3% of the patents, corresponding to an activity index of 1.37. This data imply that organizations from North-America, Australia and several European countries were very active in developing industrial applications from plant genetic in the mid 90's. In most European countries, market for such products is very limited, United-Kingdom for instance faces a ban on transgenic plants. It is not yet possible to indicate if the number of patent applications has recently decreased, and if a specifically European pattern will emerge.

Table 5. Leading countries for patents related to plant genetics – 1996-1999

Country	Patents	Activity Index
USA	798	1.11
Japan	209	0.56
UK	116	1.61
Germany	100	1.00
Australia	80	4.52
France	55	1.17
Canada	52	1.37
Switerland	44	2.02
The Netherlands	42	1.43
TOTAL	1571	----

Source: *Derwent Biotechnology Abstracts*.

Table 6 lists leading organizations, headed by private American firms, such as Pioneer, Monsanto, DuPont, Calgene, Mycogen, and DeKalb, and a small group of European firms, such as Zeneca, Novartis, and Mogen. Other participating organizations are university research centers and public laboratories. For the United States, they include the Department of Agriculture and universities with large agricultural research units, such as UC (Davis and Berkeley), Cornell, and Purdue. For Canada, public organizations, such as the Department of Agriculture, the Plant Biotechnology Institute at the NRC, and a few universities get the largest number of patents, while private firms

account only for a minute number. Figure 1, based on correspondence analysis, maps the specialities of leading Canadian organizations.*

Concerning private firms, this data reveals the profile of patents prior to the strong wave of mergers and acquisitions of the late 90's. For instance, DuPont merged with Pioneer, and Zeneca with Mogen. Monsanto bought other important players such as Calgene and DeKalb. It reveals the importance of intellectual property in the industry, and the fact that a few firms now control a very large number of patents.

Table 6. Leading organizations for patents related to plant genetics – 1996-1999

Organizations	Patents
Pioneer Hi-Bred International, USA	101
University of California, USA	49
Monsanto, USA	46
DuPont, USA	42
Zeneca, UK	40
Calgene, USA	36
CSIRO, Australia	31
Cornell Research Foundation, USA	30
Mycogen, USA	29
Novartis, Switzerland, Austria,USA,Denmark	28
USDA, USA	22
Dekalb Genetics Corporation, USA	20
Washington State University Research Foundation, USA	19
Purdue Research Foundation, USA	18
Danisco, Denmark	17
State University of New Jersey, USA	17
Japan Tobacco, Japan	16
Sumitomo Chemical, Japan	16
Max Planck Society, Germany	16
Mogen, The Netherlands	16
Agriculture and Agri-Food Canada, Canada	15
Other Canadian Organizations	
National Research Council	8
Queen's University	6
McGill University	4
Performance Plants	3
Guelph University	3

Source: *Derwent Biotechnology Abstracts*.

* Data analyzed are the classification codes describing their patents.

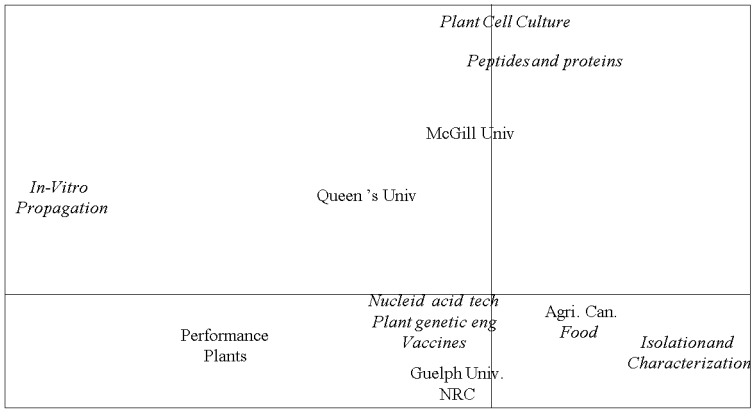


Figure 1. Canadian organizations specialties through correspondence analysis. Patents: 1996-1999

Such mix of public and private organizations was expected from the literature. In the United States, in particular, public organizations are responsible for a large number of patents. The interaction between public and private sectors can be measured by the fact that 10% of the patents have multiple assignees. For instance, Pioneer appears with the University of Missouri, Agrow Seeds with Cornell, and Lucky Biotech with UC. The complete picture might add licences awarded by public assignees to private firms.

In *Derwent Biotechnology Abstracts*, 1579 publications were indexed in plant genetic from 1996 to 1999 (Table 4). As indicated previously, Derwent decreased the number of publications indexed during the period, thereby reducing the reliability of its data. In this class, the number of publications indexed decreased by 5% from 1996-1999, compared to a total decline of 27% for the whole database.

Organizations based in the United States represent 38% of these plant genetic publications from 1996 to 1999 (Table 7). According to the activity index, countries most highly specialized in plants genetics are the United-Kingdom (1.44), the Netherlands (1.26), and the United States (1.28). Canada's share of publications in this class almost equals its weight in the whole database. Organizations involved in plant genetic appear in Table 8. Public national agriculture organizations, such as USDA in the United States or INRA in France, are the leaders, followed by university research centers, for instance Cornell, UC or the University of Georgia.

Table 7. Leading countries in publications related to plant genetics – 1996-1999

Country	Publications	Activity Index
USA	603	1.28
UK	137	1.44
Japan	97	0.50
Germany	85	0.87
India	72	1.02
France	67	1.00
Canada	57	0.98
The Netherlands	47	1.26
TOTAL	1579	---

Source: *Derwent Biotechnology Abstracts*.

Table 8. Leading organizations for publications related to plant genetics – 1996-1999

Organizations	Publications
USDA-ARS, USA	87
Cornell University, USA	47
INRA, France	44
University of California, USA	41
University of Georgia, USA	37
John Innes Centre, UK	35
Monsanto,USA	30
Texas A+M University, USA	27
Centre for Genetics Engineering and Biotechnology Havana, Cuba	26
University of Florida, USA	25
CNRS, France	24
Swiss Federal Institute of Technology, Swiss	23
DLO-Cent., The Netherlands	21
North Carolina State University, USA	20
University of Ghent, Belgium	19
University of Wisconsin-Madison, USA	19
Scripps Research Institute, USA	18
Chinese Academy of Sciences, China	17
State University of New Jersey, USA	17
Michigan State University, USA	17
Canadian Organizations	
Agriculture and Agri-Food Canada	14
University of Guelph	8
University of Calgary	8
Laval University	7
National Research Council, Plant Biotechnology Institute	4
Petawawa National Forest Institute	4
University of Saskatchewan	4

Source: Derwent Biotechnology Abstracts.

This list includes also public organizations from less developed countries, such as China and Cuba, which have developed transgenic plants (*Singer* and *Daar*, 2001). Monsanto is the only private firm whose researchers are responsible for a large number of publications. One-third of the 1579 publications are attributed to authors from two or more organizations indicating the large number of interactions. For instance, researchers from Monsanto are co-authors with researchers from 10 public research organizations, among them Texas A&M and the University of Florida. The same indicator reveals links between the University of Georgia and Mycogen.

Although Monsanto is the only private firm to appear in the list of organizations having the largest number of publications, researchers from several other firms also publish. All the firms which are assignees of a large number of patents (Table 5) were found in the publication database. It indicates that their researchers have a scientific production, and that they can have interactions with counterparts in public organizations.

It is interesting to note that some public organizations having a large publication output are also assignees of a large number of patents. For instance, Cornell and UC are important players in both fields. For others, there are some discrepancies between the two activities. Further research is needed to determine whether this behavior is explained by the specialty, which does not lend itself to patents, or by commercialization strategies.

Canadian research, as revealed by its publications, is also headed by its public laboratories and universities. Their specialties are mapped in Figure 2.

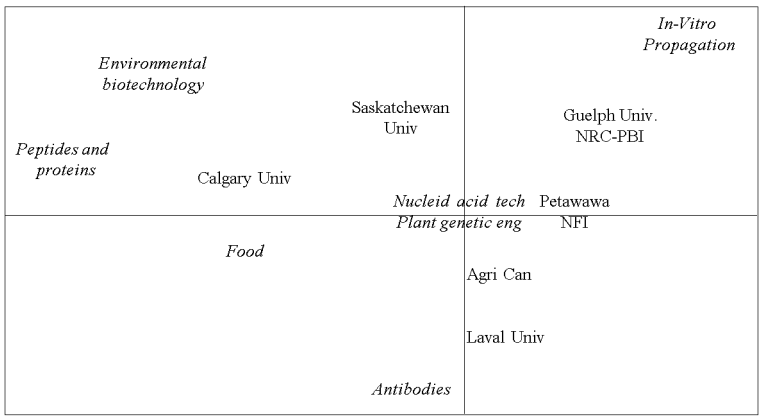


Figure 2. Canadian organizations specialties through correspondence analysis. Publications: 1996-1999

Conclusion

The profile of research on plant genetic is convergent with studies using other methods. It offers reliable information on some important issues. The international comparison of patents shows the lead of American firms, followed by their European competitors. It is however too early to determine whether the strategy of the latter has changed in recent years following European consumer concerns over modified food. Data also show the extensive involvement of American public research organizations in the commercialization of knowledge at a time when some of the leading universities routinely patent their findings. The profile for scientific activity, although less reliable, is largely dominated by national public agricultural bodies and universities, with a limited direct involvement of firms. Actors from less developed countries, such as Cuba, India and China, are also active in research on plant genetic.

Derwent Biotechnology Abstracts is the most frequently used database for the bibliometric analysis of biotechnology. This paper dealt with its reliability and validity whenever the objective is to trace the evolution of research, and pinpoint leading organizations and their interactions. As a European organization, Derwent was inspired by a European definition of biotechnology, putting emphasis on applications in a variety of areas. Conversely, its coverage of human genetic is limited.

Compared with other patents and publications databases, it offers much more substantial indexing information. The study of plant genetic was easier because classification codes allowed for the selection of records corresponding to this subfield. However, its classification codes were modified in 1992, so that time-series cannot be produced for most research areas. Most emerging fields of research obviously suffer from the same problem when information services have to regularly adjust their indexing schemes.

Derwent Biotechnology Abstracts extensively indexes patents. At least in the United-States, patents are required to enforce intellectual property in order to reap benefits from future commercialization. Interactions can be mapped through organizations whose researchers co-author publications or when patents have multiple assignees. In our database, 10% of patents delivered between 1996 and 1999 had multiple assignees. Derwent coverage of scientific publications seems to be less reliable. During the period studied, the number of such records decreased from 10,000 to 6000 per year. National journals have suffered most. Analysis of scientific publications in *Derwent Biotechnology Abstracts* should take this pattern into consideration.

To obtain a broader and more reliable profile of research on biotechnology, new tools are now available and should be tested in the case of scientific research, for instance, new databases list genetic sequences. National regulatory bodies register new products having reached the stage of clinical test or, for transgenic plants, field tests. More information is certainly needed on intellectual property and licensing. Since large networks of public and private organizations drive commercialization in biotechnology, assignees designate only the first actor. The late 90's wave of fusions and mergers of firms changed the pattern. Public organizations are assignees of a large number of patents, which they hope to license to firms.

*

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Appendix 1
Classification Codes in Derwent Biotechnology Abstracts ( ): post-1992

A Microbiology (Genetic Engineering and Fermentation)
- A1 Genetics (Nucleic Acid Technology)
- A2 Fermentation

B Engineering
- B1 Biochemical Engineering

C Chemistry (Analysis)
- C1 Analysis and Structure (Sensors and Analysis)

D Pharmaceuticals
- D1 Antibiotics
- D2 Hormones
- D3 Interferon (Peptides and Proteins)
- D4 Vaccines
- D5 Other Pharmaceuticals
- (D6) (Antibodies)
- (D7) (Clinical Genetic Techniques)

E Agriculture
- E1 Biological Control Agents
- E2 Nitrogen Fixation (Plant Genetic Engineering)
- E3 Pesticides
- E4 Cultivation in-vitro (In-Vitro Propagation)
- E5 Agriculture, Other

F Food Additives and SCP (Food)
- F1 Additives and SCP (Food and Food Additives)

G Energy (Fuels, Mining and Metal Recovery)
- G1 Fuels (Biofuels and Solvents)
- (G2) (Mining and Metal Recovery)

H Other Chemicals
- H1 Polymers
- H2 Polyunsaturates (Chiral Compounda)
- H3 Solvents (Miscellaneous Compounds)
- H4 Miscellaneous Compounds (no H4 post-1992)

J Cell Culture
- J1 Animal Cell Culture
- J2 Plant Cell Culture

K Biocatalysis
- K1 Isolation and Characterization
- K2 Application

L Purification
- L1 Downstream Processing

M Waste Disposal (Waste Disposal and the Environment)
- M1 Industrial Waste Disposal
- (M2) (Environmental Biotechnology)

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