IPRs, canola and public research in Canada

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Abstract:

Canola was initially developed and managed by the public sector in order to generate benefits for consumers and farmers in Canada. The development recently of a more market directed innovation process and the introduction in the 1980s of new intellectual property rights for breeding processes, genetics and seeds spurred significant private investments. As a result, a significant share of the breeding methods, biotechnologies, germplasm and seed stock is now privately controlled. This paper argues that although the state may no longer have a clear rationale for developing technologies or varieties, it fulfils a critical role by creating know-why knowledge and by providing a platform of know-how and know-who knowledge for competitive private firms to use to develop new varieties and products. Equity and competitive goals, which historically were sought through public investment in research, may now be more effectively pursued through regulatory channels.

Introduction

Agriculture has been one sector where the state has historically contributed a significant share of research resources and undertaken a large share of the research effort. Except for those products with effective hybrids (e.g. maize corn), most of the effort has been undertaken by governments, publicly-funded universities or by private companies funded by public grants.

That relationship held true in the canola sector, in Canada and globally, until the early 1980s. Since then, however, new, proprietary technologies have been developed and most of the resulting crop innovations have been commercialised by private companies. The transformation from a largely public industry to an increasingly private one has been precipitated by new, more cost effective technologies, by significant industrial restructuring facilitated by large financial investments and by the introduction of legally-sanctioned intellectual property rights for biotechnological processes, genetic discoveries/constructs and commercial varieties.

As the germplasm, technologies, genes and seeds industry have been privatised, the public sector has been forced from its historical role as lead innovator and is seeking a new way to contribute to continued agri-food development. In the past the public sector financed, undertook and commercialised the innovations for canola; now public institutions are testing a variety of new roles, ranging from regulator to partner.

The optimal role for the public sector in coming years will be determined by the characteristics of innovation in the sector, the corresponding industrial structure and the effective intellectual property rights regime.

Background

To get a full appreciation for the extent of innovation since 1980, it is instructive to look at the endpoints in the process. As recently as 1982, there were only six canola cultivars actively grown in the world, all bred by public sector institutions in Canada: the Agriculture and Agri-food Canada (AAFC) research stations in Saskatoon, Alberta and Ottawa, the National Research Council in Ottawa and Saskatoon and the Universities of Manitoba, Alberta, Saskatchewan and Guelph. They used largely non-proprietary technologies developed by those institutions: the half-seed breeding technique and special applications of a gas liquid spectrometer (Kneen, 1992). All of the seeds produced and sold in Canada until then were in the public domain. The rate of development of new varieties was also relatively slow, with an average of one new variety every two years, and the average lifespan of a cultivar was about 10 years.

About 1985 there was a sharp acceleration of private sector research and investment in canola development. Four key factors led to the infusion of private money. First, health research and market development efforts throughout the 1980s opened the market for expanded production, which made further investment in seed varieties more commercially viable. In 1984, for the first time, it was shown in health studies that the consumption of mono-unsaturated fatty acids such as canola is preferable to poly-unsaturated fatty acids, because monounsaturated fatty acids lower LDL (harmful) cholesterol levels without affecting HDL (beneficial) cholesterol levels (Malla 1996, 16-7).Then, in 1985 the US affirmed low erucic acid rapeseed oil as a food substance "Generally Regarded as Safe" (GRAS) and in 1988 the use of the name "canola" on food labels in the US was approved. Second, breakthroughs in breeding methodologies improved the economics of private sector breeding. The general practice of shuttling seeds between northern and southern climates (e.g. between Canada and Chile) and the application of computers as aids in the laboratories shortened the traditional breeding period significantly. This was also the period when new biotechnology processes (i.e. cell fusion, genetic recombination, polymerase chain reaction and genome maps) shortened the development process, from an average of 12 years to as short as three years for in-fill varieties. Third, financial deregulation in the early 1980s in North America led to a large pool of capital seeking new investment opportunities, which coincided with the budget crunch in universities and public institutes and new pressures to commercialize new technologies for profit. As a result, the biotechnology industry became a focal point for private investment. The fourth and perhaps most crucial factor was the introduction of intellectual property rights for biological inventions. In 1980, a US Supreme Court decision (Chakrabarty v. Diamond) explicitly allowed patents for living organisms and in 1985 US plant patents were explicitly allowed (Lesser 1998). In 1990, after a 10-year domestic debate, Canada assigned intellectual property rights to private developers (via the Plant Breeders Protection Act).

Table 1: Canola varieties developed by institution and by year

Years	40-59	60-69	70-79	80-84	85-89	90-94	95	96
Number of argentine varieties developed								
Public institutions	2	4	5	5	10	9	2	2
Private companies	0	0	0	0	7	24	16	23
Total all institutions	2	4	5	5	17	33	18	25
Number of polish varieties developed								
Public institutions	2	2	3	1	0	3	0	2
Private companies	0	0	0	0	2	8	2	5
Total all institutions	2	2	3	1	2	11	2	7
Market share by institution*								
Public institutions	100%	100%	99.8%	99%	98%	49%	27%	26%
Private companies	0%	0%	0.2%	0.7%	0.4%	43%	57%	61%

Source: Canola Council of Canada, Canola Growers Manual (http://www.canola-council.org/manual/canolafr.htm); market share estimates by Nagy & Furtan (1940-78), Three Prairie Pools Varieties Survey (1978-91) and author (1991-96).
* market shares do not add to 100% because some acreage not being reported to specific varieties

These changes, combined more recently with successful development of hybrid technologies for canola, helped private firms to capture the profits of innovation, setting the stage for intensive innovative activity in the sector in the 1990s. Between 1982 and 1997, a number of new proprietary technologies replaced the publicly developed breeding methods and more than 125 new varieties were introduced (table 1). More than 75% of the new varieties were developed by private companies, so that by 1996 only about one quarter of the seed sold in Canada had been developed by public institutions (this may understate the role of the public sector somewhat because many of the privately registered varieties were either developed using AAFC germplasm or were developed in collaboration with AAFC or NRC). The average active lifespan of a cultivar declined to about three years by 1997.

The public research institutions—the universities and public labs—have been seeking a continuing role, now that the technologies and the marketplace have been effectively privatised. The optimal role for the public sector in coming years will be determined by the characteristics of innovation in the sector and the effective intellectual property rights regime.

The rationale for public investment in agri-food research

Public involvement in agri-food research has historically been justified based on a number of factors.

First, governments argued that private firms were not doing the optimal amount of research to develop new varieties for farmers. Numerous studies show that research in agriculture provides high returns; Nagy and Furtan (1978) estimated that public canola research up to 1979 yielded a 101% internal rate of return. This high rate of return can be explained by two factors. First, without any means for private investors to capture the gains from their research (e.g. IPRs), they under-invest, causing higher marginal returns to research. This has been borne out by studies that show that private returns average less than half of total benefits of research (Ulrich, Furtan & Schmitz 1986). Less often stated but perhaps as important, most studies show that farmers tended to bid away the gains from agronomic, yield-enhancing innovations, so that consumers ultimately gain (Akino & Hayami 1975, Hayami & Herdt 1975, Scobie and Posada 1978, Nagy & Furtan 1978, Mullen, Wohlgenant & Farris 1988 and Lemieux & Wohlgenant 1989). Hence, public investment was one means of supporting consumers.

Second, concerns about economic development and diversification have driven government efforts to develop new varieties. The Canadian government had from the beginning of its canola research effort a goal to establish a new crop and income option for Western Canadian farmers (NRC, 1992, 2). Canola has successfully provided a diversified option to traditional wheat, durum, barley and oats crops, now using on average 11 million acres annually and producing a crop worth on average more than C$2.5 billion annually, which at times vies for wheat as the most valuable crop in Western Canada.

Third, governments have always been concerned about equity issues, specifically how the gains to research are shared among producers, private companies and consumers. Recent economic research shows that imperfect competition in the input sectors—the four-company concentration ratio is 67% in the canola seed industry (Phillips 1998) and 65% in the chemicals industry (Just & Hueth, 1993)—and the monopsonistic nature of the food processing industry reduces the returns to farmers and possibly to consumers. The presence of a public sector seed developer that gives away its intellectual property effectively reduces the market power of oligopolies and potentially increases the returns to farmers and consumers.

Fourth, some governments have viewed public research, especially in the 1990s, as a factor in competitiveness. If knowledge spill-overs are limited to a specific location, then that creates the possibility that "comparative advantage is endogenously generated" because as "countries engage in technological competition, comparative advantage evolves over time" (Grossman & Helpman 1991, 338). Thus, if the final product is tradable but the innovation-based knowledge is a non-transferable intermediate factor of production, then the fact that innovation begins or is supported in one jurisdiction could indefinitely put that site on a higher trajectory of R&D and new product development (Grossman & Helpman 1991, 220-1). As a result, the high-technology share of GDP and of exports will be higher than otherwise, and farmers could realize higher incomes as they earned a premium for being early adopters.

The author's purpose in this paper is not to examine whether these reasons for public investment were appropriate in the past but to determine whether any of them hold now that IPRs exist and new biotechnologies have been developed.

The characteristics of innovation

Innovation yields knowledge that exhibits a number of different traits in terms of how it can be used, who can use it and how widely or narrowly it can be applied. An examination of the innovation process provides some insight into which types of knowledge the private sector may adequately provide while identifying those areas where public effort may be required.

The innovation process has historically been viewed as a linear process, starting with research and leading through development, production and marketing phases (Figure 1). Although this may have made some sense in earlier times when many innovations were simply the product of inventors' ingenuity, it is clear that a new model is needed that incorporates the non-linear nature of innovation and the increasingly important role for market knowledge in the process.

Klein & Rosenberg (1986) provide an approach that explicitly identifies the role of both market and research knowledge. Their "chain-link model of innovation" (Figure 2) involves a basically linear process moving from potential market to invention, design, adaptation and adoption, with feedback loops from each stage to previous stages. This model also provides the potential for the innovator to seek out existing knowledge or to undertake or commission research to solve problems in the innovation process. This dynamic model raises a number of questions about the types and roles of knowledge in the process.

Figure 1: The linear model of innovation

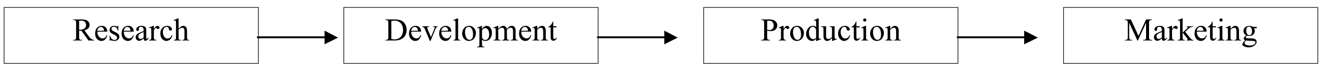
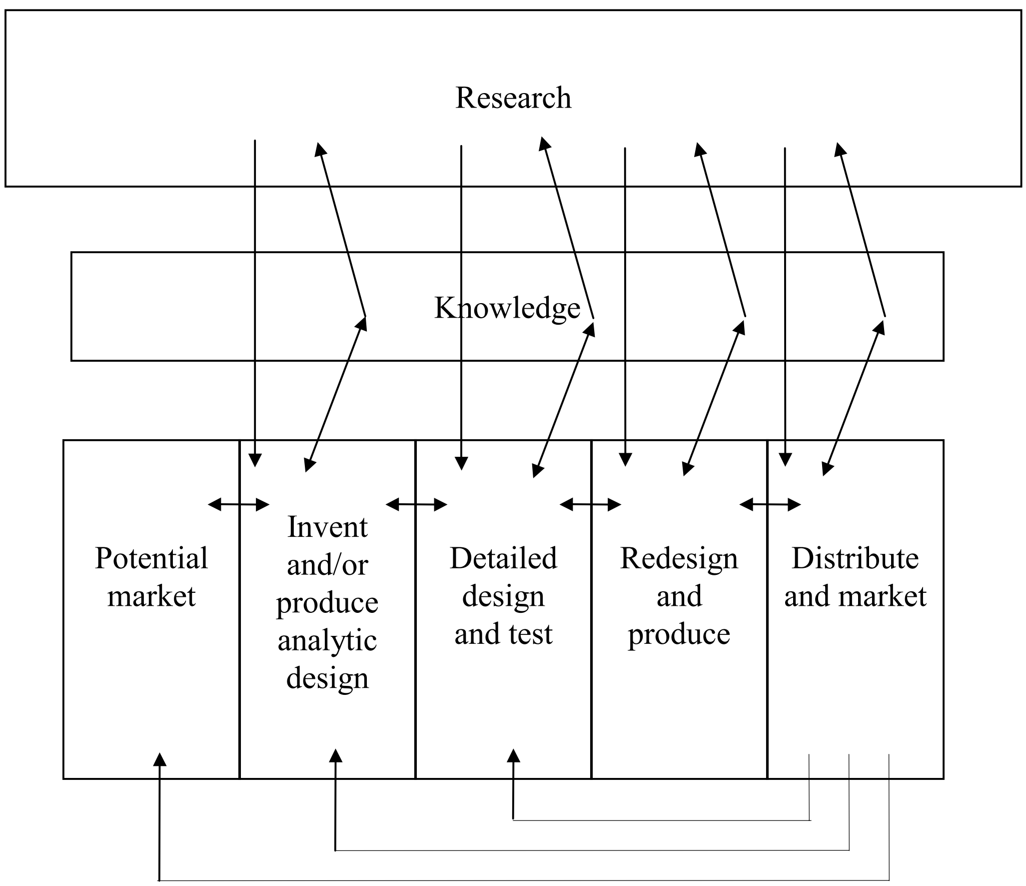


Figure 2: Chain-link model of innovation



Lundvall and Johnson (1994) and Malecki (1997) provide part of the answer, with their categorisation of four types of knowledge: know-why, know-what, know-how and know-who (table 2).

<table>
<tr><td colspan="4">Table 2: Types of knowledge based on who produces it, how codifiable it is and how accessible it is</td></tr>
<tr><td>degree of codification</td><td>produced by private sector</td><td>produced by public sector</td><td>extent of disclosure</td></tr>
<tr><td>completely codified</td><td>know-what protected by patents</td><td>know-why published in scientific papers</td><td>fully disclosed</td></tr>
<tr><td>completely tacit</td><td colspan="2">know-how and know-who produced within community</td><td>restricted access</td></tr>
<tr><td colspan="4">Source: Adapted by Author from Malecki, 1997, p. 58.</td></tr>
</table>

Each of the four types of knowledge has specific features.

- Know-why refers to scientific knowledge of the principles and laws of nature, which in the case of plant breeding relates to the science of plant physiology, plant molecular biology, theoretical and applied genetics, genomics and bio-chemistry. Most of this work is undertaken in publicly-funded universities and a few research institutes and is subsequently published in academic or professional journals. This knowledge would be in the knowledge block in the chain-link model, having been created almost exclusively in the research block.
- Know-what refers to knowledge about facts: in the case of plant breeding, this would include the specific steps involved in key transformation processes. This type of knowledge can often be codified and thereby acquire the properties of a commodity. In the case of canola, much of this knowledge is produced in private companies and public laboratories and is protected by patents. The stock of know-what would be in the knowledge block in the chain-link model, having been created in the research, invention, design and adoption blocks.
- Know-how refers to the skills or capacity to do something: in the canola case this involves the ability of scientists to combine the know-why and know-what to develop new varieties. This capacity is often learned by doing, which makes it more difficult to codify and to transfer to others. Know-how would be represented in the research block and also in the invention, design and adaptation stages.

- Know-who "involves information about who knows what and who knows how to do what" (OECD 1996, 12). It is becoming increasingly important in the biotechnology-based agri-food industry because, as the breadth of knowledge required to transform plants expands, it is necessary to collaborate to develop new products. Know-who knowledge is seldom codified but accumulates often within an organisation or, at times, in communities where there is a cluster of public and private entities, all engaged in the same type of research and development, and all which exchange technologies, germplasm and staff. This type of knowledge would be represented by the arrows in the chain-link model, as know-who is the basis for those flows.

The new growth theory (Romer 1990, Lucas 1988, and Grossman and Helpman 1991) adds a further element by distinguishing innovations by two additional characteristics: rivalry and excludability. Rivalry measures whether the innovation results in a good or service that can only be used by one person at one time (such as a product or personal service) or in an output (usually knowledge) that for little relative expense, or in some cases no cost, can be disseminated to and used by every producer in a country or the world, and one's use is not limited by another's use. Excludability measures whether the innovation is protected from widespread use by legal means (e.g. patent) or whether its adoption is limited by industrial organisation requirements or climate. If it is excludable, then the innovator can appropriate all the benefits from the innovation.

Table 3 identifies how rivalry and excludability influence growth. With rival innovation and excludability—e.g. hybrid corn varieties or, more recently, canola varieties protected by plant breeders rights—there should be little need for public investment as private investment is likely to be forthcoming. With rival innovations (e.g. new varieties) but no excludability—the traditional case presented for public investments in agricultural and canola research—there would be no basis for private innovation and hence there is a role for public investment. Increasingly, however, the research effort is targeted less on rival varieties (which simply could be encouraged through Plant Breeders Rights, hybrids or contracts) but more on new non-rival innovations—either blueprints or applied science—which have the potential to provide a competitive advantage to a firm, while at the same time exhibit increasing returns to scale which, if realised, have the potential to raise and sustain global growth rates. That is clearly of great interest to the public sector.

Table 3: Categories of innovation and their outcomes		
	Excludable	Not Excludable
Rival	good or product protected by patent or copyright; decreasing returns to scale; e.g. hybrid corn	good or product is fully transferable; perfectly competitive example; no basis for innovation; e.g. common case for public investment in agricultural research
Non-rival	knowledge/blueprints that are protected by patent or copyright or are non-transferable due to climate/industrial organization—if knowledge is perfectly excludable, the innovation would exhibit decreasing returns to scale because of declining average sales per process	know-why knowledge; within firms the innovation exhibits decreasing returns to scale but externalities due to full transfer of knowledge lead to increasing returns to scale in economy; e.g. endogenous growth case

If non-rival innovations are fully excludable, then they would exhibit decreasing returns. As Grossman and Helpman (1991, 53) observe, there is limited demand, so that as the number of innovations rises (e.g. different transformation technologies or different herbicide tolerant genes), the average sales per innovation will fall. Eventually profit per innovation will stabilise and innovation will converge to a stable path.

The key factor is the non-appropriability of some of the results of innovation, which theory suggests would lead to under-investment in this type of research. Although economists have modelled differently the effect of general or applied science innovations, the results converge on a common view—some parts of the non-rival knowledge accumulated (largely know-why and parts of know-how and know-who) are not excludable. With technological change—Romer (1990, s72) defines this as "improvement in the instructions for mixing together raw materials"—non-excludable knowledge spills over into the economy as a whole and raises the marginal value of new innovations. Hence, the positive externality associated with private investment leads to a sectoral or national production function with increasing returns to scale.

Intellectual property rights regimes

The key to private research activity, then, is the appropriability of the resulting gains. There are a wide range of means to ensure excludability of the results of the research, ranging from climatic or locational factors that restrict the transfer of technologies geographically, to measures that firms can undertake on their own—such as vertical integration between researchers and the unit doing the marketing, contracts and trade secrets—to legally sanctioned protection for intellectual property, as provided by patents and plant breeders rights (see table 4).

There are a number of non-legislative approaches to ensuring excludability and capture of the rents on canola research.

Selective choice of research priorities has helped to make the research results more excludable (Rosenberg, Landau & Movery 1992, 179). Given that know-who and know-how tend to be found within firms or larger geographic clusters of research, there is a strong tendency for research communities to produce competitive, like-types of innovation which relate to the specific climate, soil characteristics, microbiology and industrial structure. In the canola sector, for instance, some of the varieties can only produce in the Canadian climate (certain pests or microbes limit or curtail production in other areas) and many of the new genetically-altered varieties require a certain scale of production (e.g. total acreage or average field size) or complementary investments (e.g. mechanized seeding, spraying and harvest equipment). As a result, some of the Canadian innovation into canola cannot be transferred elsewhere, setting the base for excludability between jurisdictions.

Industrial restructuring has been at least partly driven by efforts to capture the returns to intellectual property. Perhaps most dramatic was the industrial restructuring that occurred in the chemical sector itself. As Just and Heuth (1993) point out, chemical firms had an incentive to invest in genetics to protect the value of their intellectual property rights in patented herbicides. As a result, all of the large chemical companies moved to partner their agrochemical divisions with genetics and seeds units. AgrEvo in 1996 purchased 75% of Plant Genetics Systems of Belgium, an early leader in transgenics in canola and the owner of the InVigor™ hybrid technology, DowElanco owns Mycogen (the owner of the Bt gene and a variety of transformation technologies), in 1996 Monsanto purchased Calgene (the owner of the patented agrobacterium transformation technology for canola) and has since acquired significant interests in DeKalb and Limagrain Canada, Zeneca bought Mogen while Dupont in 1997 invested $1.7 billion for a 20% stake in Pioneer Hi-Bred. As a result, the private genetics and seeds business has become almost fully vertically-integrated. This integration has allowed the major agrochemical companies to acquire or to develop proprietary technologies that support their core agrochemical businesses.

Table 4: IPR regimes for 96 canola varieties developed during 1990-96			
	# varieties	% varieties	% market share in 1997
production input contracts involving proprietary complementary technologies (e.g. HT varieties)	4	4%	35%
identity preserving production contracts for novel traits	10	10%	<5%
hybrids/synthetics	17	18%	15%
Plant Breeders Rights*	36	>37%*	70%
Source: CCC webpage and author's calculations * 186 applications had been received by CFIA as of March 1998, many which were pending (CFIA 1998).			

Production input contracts (Rosenberg, Landau & Movery 1992, 183) have been used by most of the companies that have developed herbicide-tolerant varieties of canola. AgrEvo's Liberty Link^{TM} system, for example, includes a package sold to farmers of a glufosinate-tolerant variety protected by Plant Breeders Rights and the patented Liberty glufosinate herbicide. Given that Liberty^{TM} is only licensed in Canada for use on AgrEvo's varieties, it is difficult for farmers to use bin-run seed for replanting in future years as they would be unable to purchase the herbicide. Monsanto, the producer of Round-up^{TM} herbicide, has significant competition in the herbicide market (given that its primary patent has expired) and so has adopted another approach to marketing its herbicide-tolerant varieties. It has developed and patented a Round-up^{TM} Ready (RR) gene, which it licenses to any other breeder (by 1998 to Alberta Wheat Pool, Pioneer Hi-Bred, AAFC, Svalof Weibull and Limagrain). In order to acquire these new seeds, farmers are required to attend a sign-up meeting, to agree to a Technology Use Agreement (which prohibits bin-run seeding and grants Monsanto rights to inspect fields for their seed), to pay a $15/acre technology fee and to buy a package of seed and Round-Up^{TM} herbicide. Monsanto is actively enforcing its production input contracts—it has hired field investigators in Western Canada and expended more than C$100K by 1998 to search for infractions.

Identify-preserved production contracts are used increasingly to capture some of the added value resulting from canolas with novel traits. Canola has already been modified to produce a wide variety of engineered fat chains, industrial oils (e.g. laurate) and proteins, including low-value, end-of-the-scale proteins for improved nutritional value of the seeds, intermediate-value, bulk proteins such as industrial and food enzymes, and high-value proteins, mainly of interest to the pharmaceutical industry. End-users, such as Procter & Gamble, Nabisco, Frito Lay, Lubrizoil, Mobil Oil, Shell Oil and Ciba Geigy, are showing significant interest. Between 1994 and 1997 in Canada there were 184 field trials of transgenic varieties of canola that were manipulated to modify the oil composition, change the nutritional balance of the seed or to produce nutra- or pharmaceutical products (CFIA, 1997). Each of these products is produced an IPP production contract in order to capture from the marketplace the value inherent in the new end-use attributes.

The development of effective **hybrid technologies** for canola has provided another technical mechanism for protecting intellectual property. It is uneconomic for farmers to replant seed from a hybrid or synthetic crop as they will lose half of the specific genetic traits with each successive planting and the resulting crops exhibit uneven growth. Firms that sell hybrid varieties are almost certainly assured that farmers will return each year to purchase new seed. The first canola hybrids were developed in the late 1980s and between 1990 and 1996 there were 17 hybrid/synthetic varieties developed and introduced, accounting for about 18% of all the new varieties over the period. Only a few firms are actively breeding hybrids—Zeneca has about half of the varieties while AgrEvo, with its purchase of PGS and its In-Vigor™ technology, is expanding its use of hybrids.

Companies also rely on **trade secrets** to protect their proprietary investments in oil modification technologies and germplasm. Historically, germplasm was public. Now, apart from the deposits of germplasm for PBR protected varieties, private breeders withhold access to all breeding lines and use them as bargaining chips in negotiating collaborations with other private companies.

No commercial firm relies exclusively on non-legal means to control the use of its intellectual property. All use one or more of the formal mechanisms, including patents, Plant Breeders Rights or trademarks. An examination of the canola breeding system shows the dominance of private companies in key stages of the process. Virtually every step of the research process is patented or otherwise protected, mostly by entrepreneurial start-ups which are now part of the larger agrochemical seed industry. The public sector, both in Canada and elsewhere have been largely absent from the key areas of the know-what knowledge required to transform canola.

Table 5: Canola related patents, by type and patent holder					
		Company		School/Government	
	Product	Process	Product	Process	Total
1981-89	14	12	0	9	35
1990-96	75	35	2	7	119
Total	89	47	2	16	154
Source: I.B.M. Internet U.S. Patent Database					

Both original **patents** (i.e. mechanical or electrical inventions) and the new extended patents (for genes or gene processes) have been actively used by the research community (Evenson 1998). Given that Canada was slower to introduce extended patents, most of the early patenting for canola was done in the US (only 19 patents for canola related work have been provided by the Canadian Intellectual Property Office between October 1989 and March 1998, compared with about 120 patents issued by the US Patent Office over the same period). Before 1982 all of the processes used to develop new canola varieties were in the public domain. Since then, there has been a rapid expansion of effort globally, with the result that most of the processes now are owned by others. The US patent database shows that of the 154 patents issued for canola inventions since 1981, about 40% were issued for process inventions and 60% for products (table5). As one might expect, the public sector (universities and governments) has done significantly less patenting (12% of total patents) and almost all of their patents have been for processes (CIPO data shows that 4 of the 19 or about 21% of canola-related patents applications in Canada between 1989 and 1998 were by the public sector). In contrast, the patent data for private companies suggests that about one third of their work is focused on processes and two-thirds on product development. The CIPO data, which goes up to 1997, shows an increase in transformation process patents that have not been filed in the US. Almost 60% (11 of 19) of the patents were for transformation processes (e.g. promoter genes, hybrid technologies).

Looking at the data by firm, we see that among those companies patenting more frequently, the bulk of the patents have been issued to end users of canola (e.g. the big food processors such as Nabisco and Procter and Gamble), with a little interest from industrial users (e.g. Shell Oil) and the rest produced by the plant breeding and chemical companies (e.g. Pioneer Hi-Bred, Calgene and Monsanto) (table 6). The Canadian data shows a much greater bias to the plant breeding ventures, with almost half of the canola patents since 1989 issued to breeding companies.

Table 6: Patents for canola processes or products, by firm						
	Nabisco	P&G	P.H.B.I.	Calgene	Shell Oil	Monsanto
1982-88	1	4	0	0	4	0
1989-95	25	18	8	10	1	3
Total	26	22	8	10	5	3
Source: IBM Internet U.S. Patent Database						

One interesting feature is that some of the technologies have been patented only in the US. For example, Calgene's two patents on agrobacterium transformation for canola are only in the US. Although that would suggest that those technologies are unprotected in Canada, the fact that resulting transformed canola may be exported to the US constrains Canadian breeders and effectively forces them to get licenses for the use of these technologies.

Trademarks have also been used by parts of the industry to distinguish "canola" grade rapeseed from other varieties. In 1978, the Rapeseed Association (now the Canola Council of Canada), trademarked the new low erucic acid, low glucosinolate rapeseed as "canola."[1] Since then there have been seven attempts by private firms (mostly breeders or food processors) to trademark either new varieties or to trademark specific canola oil food preparations (CIPO). In addition, all agricultural chemicals are trademarked and a number of the breeding companies have trademarked their industrial processes (e.g. PGS's In-Vigor™ hybrid process). In almost every case, adoption of trademarks has been designed to supplement other intellectual property protection and to differentiate for marketing purposes the specific products.

Plant breeder's rights, finally introduced in Canada in 1990 (in place in the US in the 1930s), provide somewhat weaker protection than patents for new varieties. Although the period of protection is almost as long as patents (18 years from the date of registration) and the holder of the plant breeder's right is required to deposit and make available for research purposes a propagating sample (usually deposited in the National Seed Collection in Saskatoon), farmers have the right to retain seed for their own use. Since PBRs were introduced in 1990, breeders have automatically applied for PBR on virtually all new open-pollinated varieties (186 applications by March 1998) but only 36 of the varieties were awarded a certificate by March

[1] This new type of rapeseed had 5% or less of erucic acid and less than 3 milligrams of glucosinolates per gram of air dried meal. The quality standards for canola were tightened in 1996 to allow only 2% erucic acid and less than 30 micromoles of glucosinolates per gram of meal.

1998. As noted above, some companies seek to go beyond the protection granted by PBRs, requiring farmers to sign away their farmer's exemption in order to gain access to the seed. An additional concern raised recently by breeders is that the interaction of PBRs and patents may diminish the research exemption provided under PBR legislation. US patent law does not readily allow breeders to use patented materials (e.g. varieties with patented genes) to develop new varieties. Thus, although PBRs allows breeders to access the germplasm, companies holding patents on elements embedded in the germplasm may effectively block commercialization of any varieties that use some of that germplasm, even if the element used is not explicitly patented (confidential discussion regarding International Seed Federation (FIS) report).

Academics, public research institutions and some private companies choose not to exercise their intellectual property right for immediate monetary gain and instead **publish the results of their research in academic journals**—mostly know-why knowledge that is vital to future research but often has little commercial application. This includes the Arabidopsis genome project which is being developed and so far has been put into the public domain through academic publication. The genomic information, however, has significant potential to be codified and thereby become a commodity that is rationed based on price.[2] Prior publication, except in limited cases within a year of patent application in Canada, effectively precludes future efforts to protect the resulting intellectual property through patent or Plant Breeders Rights. As such, publication effectively grants the author rights to citation by subsequent researchers (a key currency of academics) but allows the economic benefits of the innovation to become public property (i.e. non-rival, non-excluded knowledge).

Taken together, the informal mechanisms and legal rights have effectively protected the vast majority of the technologies being used and the products flowing from the canola research community. The public role has been thereby changed.

An evolving role for the public sector

The public sector no longer plans and invests as if it is the only actor in the canola development industry. The significant presence of the private sector in the research of know-what knowledge

[2] Other genome projects have been effectively privatized by firms that have taken and assembled the public information in a way to extract economic gain.

and in the product commercialization stages means that the public objectives may in many cases already be realized without public involvement beyond setting the environment for private efforts.

It is instructive to look at the role of the state in the four elements of knowledge development and more generally in the product development process, as characterized by the chain-link innovation model.

1. Product Development: All of the early work on canola was done by the private sector based primarily on a linear model of innovation (figure 1). Although researchers from Canada Packers were involved in and funded some the work in a search for a Canadian-sourced edible oil, the bulk of the product development effort was done by scientists in AAFC, the NRC and four Canadian universities. Until 1985, all of the varieties were developed and registered by one of those institutions. Since the mid 1980s, however, a rapid expansion of private investment in canola research has supplemented and almost overwhelmed the public effort.

This research effort conforms more to the chain-link model of innovation than the linear model. AgrEvo, for example, identified the market opportunity for herbicide tolerant canola, undertook much of the basic gene isolation work in Frankfurt and then partnered with AAFC to get access to a base of canola varieties and to tap into its know-how and know-who to ultimately develop its Liberty-link canola. It then partnered with the Wheat Pools in Western Canada to prove up the product and market it. Since 1985, more than 75% of the new varieties have been privately developed along these lines (often developed directly by public institutions using private funds) and the seeds market has shifted heavily towards private seed sales, accounting for an estimated 60% in 1996, up from only trace amounts in the mid 1980s (table 1).

Using the four public objectives as criteria, it is not clear that the state has any continuing justification for investing public funds in varietal development. Recent rates of investment indicate that instead of under-investing in variety development, private industry may in fact be over-investing in research and development for canola varieties. Industry participants suggest each new agronomic variety requires demand for seed for about 250,000 acres per year for three years to yield the targeted rate of return for biotechnology investments. Given an average of about 11 million acres planted in Canada, that would suggest only about 45 varieties could be sustained over the long-term. As of 1996, more than 100 varieties were registered for sale. Furthermore, with an average life of three years, the optimal annual replenishment rate of new varieties should be about 15, not the current 30 per year. The potential to capture new market share for farm chemicals (upstream value added) or in the specialty oils market (downstream value added) may justify this rate of investment from a firm perspective, but this accelerated "creative destruction" may be socially wasteful. Economic development and diversification also seem to be progressing apace, with new agronomic traits being bred into commercial varieties. The dispersion of canola into new growing areas has actually accelerated since 1985, at least partly due to the profit incentive of the seed merchants to develop and market new varieties for new growing areas. The total area seeded to canola in Western Canada rose to a record 14 million acres in 1994, equal to about 15% of Canada's total crops acreage. All indications are that more new private varieties suited to new areas are imminent. Between 1994 and 1997, there were 97 field trials for transgenic varieties that involved introducing stress, insect, viral and fungal resistance into canola (CFIA, 1997). Equity continues to be a key concern of the public sector. But recent economic research suggests that rapid innovation rates observed in the industry may effectively reduce the market power resulting from imperfect competition in the input sectors and the monopsonistic nature of the end-users. Extending Green's (1997) analysis, one could argue that the shorter breeding cycle and the resulting short lifespan of each new variety (approximately three years) may effectively limit the market power. Competitiveness in the research and seeds business is more a local than a global concern, but it has driven and is continuing to influence Canadian public research policy. Given the recent consolidations of the seeds industry (both horizontally and vertically), however, it is hard to see how public marketing of seeds helps Canada remain competitive in the industry. It is possible that public varieties instead reduce the potential market for private breeders, which reduces their incentive to locate locally.

Based on the above, the decision by AAFC in the late 1980s to reduce its efforts on direct varietal development and sale appears to have been wise. Rather than re-enter the business, the government may want to review its remaining support for breeding public commercial varieties. This is especially true as access to the seeds market is getting more difficult.

2. Know-why knowledge: After knowledge of the marketplace, basic scientific knowledge is the second most critical factor in developing and sustaining a knowledge-based industry or economy.

As one might expect, few private companies undertake know-why research. Clearly, without a financial incentive, there is little reason for this activity. A search of the ISI special database of canola-related research, published in academic or scientific journals between 1981 and 1996, shows that staff from about 130 private companies published at least one journal article in that period, in total accounting for about 6% of published articles (table 7). More than half of the companies had only one article credited to one of their staff. Only three companies—Allelix Crop Technologies (now merged with Pioneer Hi-Bred), Calgene and Unilever—published an average of more than one journal article per year. The vast majority of know-why work, as one might expect, is done by the public sector, 58% in universities and 36% in publicly-funded research agencies.

Table 7: Sources of canola related know-why knowledge

	number of entities	number of articles	citation rate
Private Companies	130	358	7.9
Universities	660	3616	6.0
Public institutes and agencies	670	2305	3.4
Total Institutions	1460	6279	5.9

Source: Author's calculations using ISI special tabulation of academic publications related to canola.

The private sector simply has not and, based on theory, likely will not do an adequate amount of research to add to the stock of know-why knowledge. This would appear to be a critical, long-term role for the public sector.

Two recent trends in the public sector, however, may jeopardize the development of new know-why knowledge. First, the recent efforts by public institutions—both universities and research institutes—to enter the know-what business by patenting their knowledge has directed much public academic and research effort toward patent counts and commercially valuable research. All of the universities, AAFC and the NRC have actively moved their organizations to protect and exploit their intellectual property, first by setting up IP offices and then by patenting and licensing their 'know-what' innovations. To support that drive, faculty and research scientists are now rewarded for their commercial innovations, both with a share of the financial returns and with patents providing credit toward merit increases and promotion. Second, the public institutions have begun to sell their services either on a straight fee-for-service basis or through "collaborations". Many of the faculty and research scientists at all of the universities working on canola have entered contractual or collaborative relationships with the private companies (Alberta with Alberta Wheat Pool, Calgary with DowAgrosciences, Manitoba with Rhône-Poulenc, UGG and Saskatchewan Wheat Pool and Saskatchewan with Saskatchewan Wheat Pool) while AAFC has undertaken extensive fee-for-service varietal development work. The NRC, in contrast, has engaged in less fee-for-service work and instead has favoured extensive collaborations on more basic research where both cash and intellectual capital are exchanged.

Table 8: Output of the top Canadian research centres relative to the canola research undertaken globally

% of total papers per period	1981-85	1986-90	1991-96
AAFC	9.9%	6.2%	7.8%
NRC/PBI	0.7%	0.7%	1.2%
University of Guelph	5.5%	6.4%	2.6%
University of Saskatchewan	5.0%	4.9%	3.2%
University of Alberta	3.6%	3.9%	2.3%
University of Manitoba	2.5%	5.1%	3.8%
University of Calgary	0.0%	1.0%	1.3%
Total 7 institutions	27.2%	29.5%	23.6%

Source: Author's calculations using ISI special tabulation of publications related to canola.

The evidence suggests that these shifts have diminished the output of know-why research from the public institutions. After engaging in commercial arrangements, AAFC, and the five Canadian universities lost market share while only the NRC gained market share (table 8). It is perhaps more disconcerting that the quality of the work being published publicly (based on the number of citations) in most Canadian institutions has dropped relative to the rest of the institutions doing research (table 9). The research being published by AAAFC and the four traditional canola research universities has a lower citation rate than the average in the period after they began to work in collaboration with industry.

Table 9: Relative citation rate for pure agricultural research papers produced by the top Canadian research centres for canola (Average for all canola papers in period = 1.0)

	1981-85	1986-90	1991-96
AAFC	0.84	1.23	1.00
NRC/PBI	1.80	1.94	2.30
University of Guelph	1.05	1.13	1.22

University of Saskatchewan	1.53	0.67	0.87
University of Alberta.	0.98	0.78	0.91
University of Manitoba	0.94	0.86	0.94
University of Calgary	--	3.19	1.67
Source: Author's calculations using ISI special tabulation of publications related to canola.			

The fact that the quantity and quality of the NRC output has risen both absolutely and relatively to the total while AAFC output has fallen relatively over the past five years suggests that the two institutions may be pursuing different strategies. The NRC since 1989 has done significant work with others, 90% of which has been via joint-venture collaborations with groups of private companies, that involve the pooling of money, staff and intellectual property. In contrast, AAFC has tended to do a significantly larger share of its work with single companies via "fee-for-service" work, which has not led to any other contribution than money. In the NRC case, the greater exchange of non-financial information appears to support the development of know-why knowledge. This difference of operation may help to explain why the NRC has seen a significant rise in its volume and quality of know-why work, while AAFC has seen a fall in both.

Some argue that information in patents becomes public so, even if effort is diverted to know-what research, the results become known. Practically, about 70 percent of the information contained in patents does not appear in any trade journal for at least five years after the patent has been granted and at least 50 percent of this information is never published in mainstream technical journals (Industry Canada 1988). Given that in North America the information included in a patent application is kept confidential until the patent is issued (up to two years), this diversion of output to the proprietary route slows the dissemination of information, and the cost and difficulty of accessing full patent information at times may make the results of the research inaccessible to many academics.

3. Know What knowledge: All participants in the Canadian canola research community—both public and private researchers—are focused on attempts to protect and capitalize on new innovations. Although most of the patents issued are to private companies, there has been an increase in recent years of public patenting as public labs and universities have sought either to justify their existence or to have sought new sources of funding for on-going research.

As indicated in table 10, private companies hold patents on most of the key technologies involved in the transformation of canola. Given the variety of technologies now available, it is unclear whether there is any shortage of supply. From a corporate perspective, the key issue is not how to get more resources for research but how to ensure international market access, because as noted above, the rate of innovation is a function of the market size. Hence biotechnology companies are extremely concerned about technical barriers to trade, such as differing sanitary and phytosanitary standards, incomplete intellectual property rights, and trade related investment measures, which impede international trade.

Public breeders (or scientists who recently moved from the public to private sector) appear to be the most concerned about the privatization of the technologies, partly because it is a radical change in the culture of the industry (which was open and collegial until recently) and partly because license fees and Materials Transfer Agreements place strains on already tight budgets. One response of the public breeders has been to seek to protect and exploit any intellectual property they develop in order to keep in the game and have "chips" for bargaining with the private companies (Lesser 1998). NRC and AAFC both stipulate in their collaboration agreements that any resulting innovations will be the intellectual property of the public institution, and that the private collaborator has a right of first refusal on commercializing the technology. Although the public labs (and at times universities) have thereby begun to develop a "portfolio" of intellectual property, so far all of the innovations have been useful but relatively minor and the revenues from the licensing of the technologies has not repaid the cost of patenting them and running their respective intellectual property offices.

Table 10: IPRs related to canola breeding processes

	Key technologies (and owner, if any)	IPR regime
genomic information	• Arabidopsis genome project • amplified fragment linkage polymorphing for gene mapping (patented) • molecular markers	data is in public domain but AFLP technology is patented
germplasm	• public gene banks in Canada, US, Germany, Russia, India, Pakistan, Australia, Japan and others • private gene collections	restricted access only for private collections
rDNA strands/genes	• HT genes (Monsanto, AgrEvo, American Cyanamid, and Rhone Poulenc) • antifungal proteins (Zeneca) • antishatter (Limagrain) • fatty acids (Calgene) • pharmaceutical compounds (Ciba Geigy or ?)	100% private patents
transformation	• agrobacterium (Mogen, PGS)	100% private patents

technologies (general)	• Whiskers (Zeneca) • biolistics (Dupont) • chemical mutagenesis (public domain)	except mutagenesis
transformation technologies (brassica specific)	• agrobacterium methods for brassica (Calgene has 2 patents that effectively control all transformation in the genus)	100% private patents
selectable markers	• large number of privately patented markers for selecting specific transformants (Monstanto, PGS, others	100% private patents
growth promoters (constitutive)	• constitutive promoters (e.g. for HT, disease, drought, salt resistance, to express genes in all cells in plants, including 35S (Monstanto)	100% private patents
growth promoters (tissue specific)	tissue specific promoters: • pod/shatter control (Limagrain) • floral morphology (AgrEvo and others; multiple) • oil traits (AAFC and others)	100% public and private patents
hybrid technologies	• In-Vigor™ (PGS) • CMS System (Zeneca) • Ogura CMS Systems (INRA) • Lemke (NPZ) • Kosena system (Mitsubishi) • Polima (China; public domain)	all patented except Polima, which is in the public domain
oil processing technologies	• oleosin partitioning technology for separating and purifying recombinant nutraceutical or pharmaceutical proteins (SemBioSys) • other oil processing technologies	100% patents or trade secrets
traditional breeding technologies	• double haploid process • backcrossing • gas liquid specrometre analysis	all in public domain
Source: Personal communications with canola researchers and patent searches		

Furthermore, some private companies which collaborate with NRC or AAFC to develop new technologies (which the public agencies patent) are concerned that public IPRs reduce their ability to use the technologies. They say that potential private sector partners want clear ownership lines before they will agree to use this new technology. Publicly-held patents do not appear to provide this certainty.

Instead of volume of research, the issue appears to be access to the supply of technologies, or in the jargon of the industry "freedom to operate". Most companies provide access to their proprietary technologies at least partly because few if any of the companies are fully self sufficient. Although a firm may control one or more patents, it usually will need to license or joint-venture with some other patent holder to get access to parts of the transformation process for which they do not have patents. This reciprocal dependence keeps at least some access. Nevertheless, there have been suggestions from within the industry that some firms have at times strategically withheld access to the best patented technologies in order to slow competitors while others appear to restrict access to technologies if the resulting product would compete with the patent holder's product line. At other times, the patents appear to be used by their holders to negotiate an equity stake in follow-on inventions. Most concern focuses on Calgene's two patents for the agrobacterium transformation of canola. The unusual feature is that Calgene has both a process patent and a patent that covers all brassica transgenic constructs, whether developed using the agrobacterium method or not. Many fear that this gives Calgene absolute control over all transgenic canola work.

Rather than have the public sector invest to duplicate private research to ensure open access to technologies, the state would be wiser to use the powers vested in its intellectual property rights regime or competition laws to encourage greater dissemination of non-rival, patented innovations to generate more access and hence greater spill-over effects. Canadian patent law and the Plant Breeders Protection Act both provide for compulsory licenses to remedy what is called "abuse" of patent rights. If firms use their patents to "hinder" trade and industry—i.e. not meeting demand in Canada, hindering trade or industry in Canada by refusal to grant a license (if such a license is in the public interest), attaching unreasonable conditions to such a license, using a process patent to prejudice unfairly production of a non-patented product or allow the patent on such a product to prejudice unfairly its manufacture, use or sale—another company or the state can challenge them after only three years of the patent grant (CIPO 1998). Meanwhile, the anti-combines provisions of the Competition Act allow the state to pursue anti-competitive behavior through investigation and prosecution. Neither provision has yet been used in Canada in the area of biotechnology.

As far as **competitiveness** is concerned, it would appear that knowledge of basic transformation processes (the know-what patentable recipes) can flow relatively freely across borders or continents, given a basic level of prior learning (or 'know why'). All the appropriate technologies are in use in Canada. Therefore, it is not clear that the transformation processes need to be developed within the local research community in order for the research centre to produce commercializable products that add greater value to the local economy. Rather, it may be adequate for the technologies to be available. Looking at the chain link model of innovation, the key to success is to take these new ideas and ultimately place them in the market to earn a return. The question for a region worried about competitiveness, then, is how to assemble the various pieces in a way that the local economy and society benefit from the effort; this points directly to the know-how and know-who elements of knowledge generation.

4. **Know-who and know-how knowledge**: Potentially the most important public policy role and arguably the key to regional competitiveness in a knowledge-based sector is the generation and transmission of the non-codified knowledge that holds things together—the know-how and know-who. Most economies operate under the assumption that the human elements of a firm or industry operate in some black box, governed by either the 'invisible hand' or a Walrasian auctioneer. In reality, there is something that holds an economy together that goes beyond economic transactions; people develop skills and have relationships which together convert bits of information into operable knowledge. This tacit type of knowledge is learned almost exclusively through experience. Researchers learn how to do things and who to work with through trial and error. Most of the innovation literature assumes that this know-how and, perhaps more importantly, this know-who evolves within corporations or institutions. That may hold true in an industry or within firms that are largely self-sufficient but, as noted above, there are few firms that have the internal capacity to undertake all the research and development necessary to create a marketable variety. Some companies may have that capacity within their global operations (e.g. Monsanto/Calgene, AgrEvo/PGS, Pioneer Hi-Bred) but in many cases working through the geographically-dispersed multiple layers of these multinational enterprises is more complex and less cost-effective than buying-in from a more accessible and timely local source. Hence, although Monsanto and AgrEvo both have giant research "universities" and labs at their headquarters in a the US and Germany, respectively, both have collaborated extensively in Saskatoon with both AAFC and the National Research Council. Furthermore, in knowledge-based industries training and upgrading are critical, making it essential for private researchers to interact with the broader research community. For all these reasons, most of the firms in the industry have developed an extensive "community" of networks with both collaborators and competitors, involving other private companies, universities, AAFC and the NRC.

As with most communities, proximity matters. Formal and informal face-to-face meetings and working side-by-side on laboratory benches and in the greenhouses are critical elements of both developing the know-who and transmitting the know-how. It is highly unlikely that the community would have developed if there were only competitive firms in Saskatoon; the non-competitive environment offered by AAFC and NRC create the platform for these relationships. Table 11 outlines the depth of these arrangements at NRC.

Table 11: Relationships between NRC and other institutions, 1995-96 (Total number of guest researchers in lab)		
	Location	NRC Guest Researchers
AAFC	Saskatoon	8
AgrEvo Canada Inc.	Saskatoon	17
CanAmera Foods Inc.	Saskatoon	2
Canola Council of Canada	Winnipeg	10
DowElanco Canada Inc.	Saskatoon	1
Limagrain Canada Inc.	Saskatoon	Alliance
MicrobioRizogen	Saskatoon	1
Monsanto Canada Inc.	Saskatoon	Collaborative Agreement
New Leaf Biotechnology Inc.	Saskatoon	1
Plant Genetic Systems Canada Inc.	Saskatoon	2
Prairie Plant Systems	Saskatoon	5
Saskatchewan Wheat Pool	Saskatoon	9
University of Calgary	Calgary	Collaborative Agreement
University of Manitoba	Winnipeg	1
University of Saskatchewan	Saskatoon	7
Zeneca Seeds	Winnipeg	2
Source: NRC 1997.		

Collaborations are the key to the public institutions. Both AAFC and NRC have extensive arrangements with each other, public universities and private companies. In 1995-96 alone, NRC had more than 31 arrangements—ranging from research agreements to collaborative work agreements and licenses—that brought more than 65 guest researchers from other institutions into the NRC labs (NRC 1997). The NRC set a goal in 1996 to expand that effort by at least 15% by 1998-99. The key feature of these arrangements would be that the core research team at NRC is able to learn from all of the collaborations, thereby adding further to the know-how knowledge and provide a visible, efficient point of entry for know-who knowledge.

The training and recruitment role played by the two key public institutions helps to solidify the sense of community. Both institutions have scale, with a significant number of full-time permanent scientists working within their operations and with a regular flow of young post-doctoral scientists who work in the public labs on the way to a permanent career. The NRC collaborations provide a handy recruitment and screening system for the companies. Once a collaboration is begun between the NRC and a private company, the NRC usually hires a recently graduated Ph.D. scientist, most frequently on a one- to three-year contract, to undertake the work. The permanent staff at the NRC collaborate with the private sector scientists to manage the work of the contract employee(s). At the end or, commonly, before the end of the collaboration, the contract research scientist may be offered a permanent appointment with the private sector collaborator. In essence, the collaboration provides a screening process for recruitment. If the contract scientist does not meet expectations, the private company is not obligated to hire the person. The process also has the benefit of being efficient—the NRC has at any one time on average 15-20 contract scientists on staff, which enables them to develop the special mentoring and assessment skills that both help the entering scientist and reduce the costs.

As far as competitiveness is concerned, one gets a sense of their importance in the system when one examines the list of NRC collaborators and their location (table 11). Even firms not resident in Saskatoon have developed extensive links to gain access to the knowledge in those two institutions, which suggests that spillover benefits from the know-how and know-who located in Saskatoon may be significant and may not move far from Saskatoon. So far, the pull of externalities has not been strong enough to concentrate the entire industry in Saskatoon, as theory would suggest. Interviews with firms that have collaborations in Saskatoon but are not resident in Saskatoon revealed that undepreciated investments elsewhere, economies of scale within corporate "discovery" labs and specific agronomic features (e.g. growing season) offset some of the pull.

Although one cannot state conclusively that an efficient knowledge of know-how and know-who would not be generated without public institutions, the evidence to date strongly supports the contention that public institutions have been and are critical to the creation of know-how and know-who knowledge that makes competitive canola development possible.

Conclusion

The combination of a transformation in the innovation process—away from a supply-driven linear model and towards a demand pull, chain-link system—and the introduction of a new intellectual property rights regime have both worked to shift the impetus in canola development towards private sector investment and away from public involvement. As a result, the public sector in Canada has been challenged to find a new role.

This analysis concludes that the public sector has little reason to undertake canola varietal development (and possibly strong reasons not to do so) or to undertake research to create new patentable processes. Instead, public funds would appear to be best used to undertake basic know-why research and to partner with the private sector through collaborations to develop a community platform for the creation and dissemination of tacit know-how and know-who knowledge. Public research efforts, however, are unlikely to be able to address satisfactorily concerns about equity and competition—those problems are more appropriately and likely more effectively dealt with through regulatory and competition policy.

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