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The Value of a New Biotechnology Considering R&D Investment and Regulatory Issues

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The Canadian canola sector has transformed over the last 40 decades due to emerging biotechnologies, evolving intellectual property rights, and a changing role for the government. This article examines the overall impact of biotechnology in this sector over time, including the potential producer benefits of several new biotechnologies and the changing role of government, especially the appropriateness of public research and development in Canada. Producers benefit significantly from growing new privately developed canola varieties (in 2012 the value was $726 million). There has been a general increase in the area seeded to canola, the number of varieties available, and the yields of those varieties. Additionally, the new canola varieties offer environmental benefits (e.g., weed control and reduced tillage) and health benefits (or healthcare savings). Canadian governments were initially involved in the direct provision of the applied and basic research that first developed canola. Today they have generally withdrawn from commercial variety development, while facilitating private-sector research and often generating restricted access to basic research results (i.e., exclusive licensing). As such, although federal funding has fallen, Canada's public sector continues to play an important but shifting role in today's canola industry, indeed it was jointly responsible for one of the key HT technologies (LibertyLink).

Key words: biotechnology, intellectual property rights, IPR, privatization, canola, returns to research, producers' benefits, policies, regulations, government role, research and development, R&D.

Introduction

The prevalence of the products of biotechnology in Canada's canola industry is vast. More than 95% of Canada's seeded area is in herbicide-tolerant (HT) varieties, which are products of biotechnology. Overall, the industry has experienced significant growth; for instance, the area seeded to canola varieties has increased from less than one million hectares (ha) in the 1960s to over 8 million today (Statistics Canada, n.d.). Later in the article we show that the number of commercial varieties available and the index of yields for those varieties have increased sharply since the 1980s (Brewin & Malla, 2012; Phillips, 2001). Agricultural biotechnology could facilitate further productivity growth in crops such as canola. However, the policies and regulations that are in place might need to further evolve to insure continuing growth in the sector. Furthermore, assessing the benefits to Canadian producers by adopting HT and hybrid varieties over time would improve our understanding of the sector and the gains that are possible under comparable regulations for similar sectors. A significant portion of these benefits were facilitated by changing the institutions in Canada to provide incentives to private investment.

Biotechnology and improved intellectual property rights (IPRs) have completely transformed the Canadian canola industry, which in turn has changed the role of governments and public involvement in canola research and development (R&D; e.g., Malla & Gray, 2003, 2005). In the 1970s, most of the research effort was publicly funded in Canada (almost all varieties were bred by the federal government) and the products of research (e.g., new varieties, best practices, even new crops) were in the public domain and were deemed to be a public good. They were made available to producers without payment to the breeders. As well, all canola varieties were open pollinated and there was no patent protection related to technologies used in public breeding. Currently, some 13 private firms dominate canola research investment and they control most of the research output both in terms of new varieties and proprietary technologies embedded in these varieties or used to create them (Brewin & Malla, 2012).[1]

Today almost all canola varieties grown are protected by some form of IPRs, coupled with technology use agreements (TUAs) or license agreements that enable firms to charge farmers an annual fee for growing their varieties. The development of patentable genetic traits helped foster the exclusion of use by others as did the nature of the emerging seed market (e.g., hybrid varieties that require the purchase of the seeds every year in order to keep the desirable hybrid vigor). The changes in law and technologies have created enforceable IPRs, which in turn increased incentives for private firms to invest in canola R&D, as private research firms could capture most of the value from the products of their research. The combined effect of all these changes was that canola became a major Canadian crop in terms of area grown and revenue generated,[2] and the private sector has taken the lead role in the Canadian canola research sector.

In the current Canadian canola industry, the public sector is increasingly more focused on basic research, while it withdraws from various applied research areas (i.e., commercial variety development) and indirectly facilitates private research (e.g., public-private collaboration on projects, private research subsidization, provision of infrastructure to facilitate private research). Overall, governments continue to make large but diminishing public investments mainly in basic research, which contributes to the research platforms used by private firms for applied agricultural research (see Gray & Malla, 2011; Gray, Malla, & Tran, 2006). The public sector has also worked to protect and commercialize IPRs. The common practice of public institutions now is to charge a fee above marginal cost to access basis research or to grant exclusive licenses (e.g., Gray & Malla, 2011; Smyth & Gray, 2011).

The canola sector privatization brought a much needed increase in R&D investment. However, it also brought a series of complex problems regarding the future of the canola sector and the appropriate public role in researching canola for Canada today. Concerns have been raised about private-sector issues such as industry concentration, the pricing of seed, fees for using new technologies or patented gene traits, the obstacles to commercialize new varieties or second-generation HT crops, and the recent practice of the gene trait cross-licensing agreements between private firms. Concerns have also been raised regarding the appropriateness of the public provision of applied research, basic research, research infrastructure to facilitate private research, private-public collaboration on projects, and even government subsidization of private research.

Government research policies have changed as the structure of the canola research industry changed. Research priorities and available technologies have also evolved. Hence, an examination of the most recent estimates of the returns to research and the distribution of benefits will help us understand the canola sector. In the past, high rates of returns to agricultural research investment supported government involvement in R&D. However, there are questions about whether the returns to canola-related agricultural research remain high, and whether producers benefit from the new technologies (e.g., HT). It is also important to examine the results of Canada's past regulatory choices for the canola sector to see what other sectors and jurisdictions might learn.

Consequently, the objectives of this article are:

- to examine the broad impacts of biotechnology in the canola sector;
- to evaluate and update the potential benefits of new biotechnologies, namely herbicide tolerance and hybridization over time;
- to examine the evolution of government involvement in Canadian canola R&D over time, its appropriateness, and potential further needs for public intervention; and
- to draw some lessons from the Canadian canola experience that could be used by other crops and/or countries.

The article will explore important trends in Canada's canola sector over time, including area planted, yield, varieties, and health traits. It will assess previous esti-

1. *Phillips (2001) showed that the number of firms and institutions involved in breeding Brassica napus went from 3 in 1984 (with 4 commercial varieties) to 17 in 1998 (with 86 varieties). Brewin and Malla (2012) showed that the seeded area of the varieties in 2008 from 11 private firms comprised more than 99% of the total seeded area. However, the registration of new varieties was made less onerous by 1998. In 1984 only varietal candidates that exceeded the performance of the checks could be supported for registration, while by 1998 any candidate that just equaled the checks could be supported for registration (R.K. Downey, personal communication, March 22, 2015).*
2. *Wheat was the dominant crop in terms of seeded area for most of the last century. The current Agriculture and Agri-Food Canada (AAFC) forecast for 2014/2015 estimates 22.7 million metric tons of spring wheat production at $215/ton ($4.9 billion in revenues) on 7.36 million ha. Canola production is estimated at 14.5 million tons at $480/ton ($7.0 billion in revenues) grown on 7.83 million ha. Canola revenues were higher than spring wheat in all of the last three crop years. Area seeded to spring wheat was higher than canola in 2013/2014 (AAFC, 2014).*

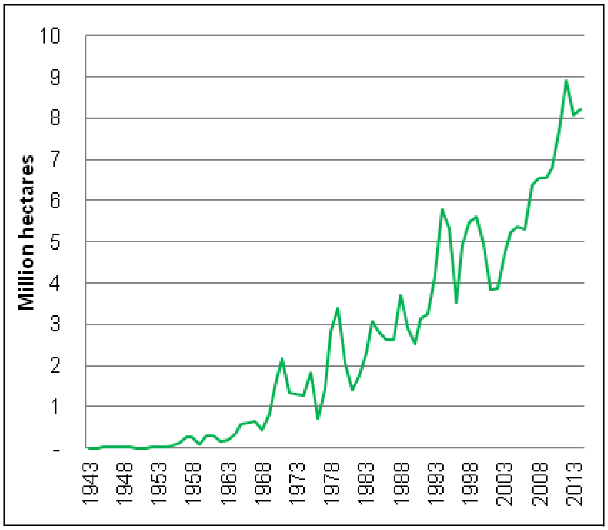

Figure 1. The area of land seeded to canola in Canada (in ha).
Source: Statistics Canada (n.d.)

mates of the rate of returns to agricultural R&D investment and the share of returns to producers. Externalities created by biotech adoption, including but not limited to environmental impacts (weed resistance, greenhouse gas emissions, etc.) and potential health benefits (due to new canola varieties with health traits) will also be examined. As well, the indirect effects of biotech adoption on incentives to research, and IPR-related issues will be discussed. Using a unique data set, we will estimate the direct returns to western Canadian farmers facilitated by private-sector incentives. Specifically, the benefits of HT variety adoption and hybrid adoption as compared to open-pollinated, non-HT systems over time will be calculated from 1996 (when canola seed trait patent royalties became common) to 2012.

Finally, policy implications/recommendations will be discussed. The appropriate government role, if any, in today's biotech industry will also be addressed. Potential policies and regulations, especially associated with the development of new technologies and varieties, will also be explored. Whenever it is applicable, attempts will be made to discuss potential implications that the Canadian canola experience could have for other crops or even countries.

Features of the Canola Industry: Area, Varieties, Yields, Health Traits

The introduction of biotechnology had a profound impact on the yields of new varieties of canola, as well as the seeded area, the number of varieties, and the traits of these new varieties (Brewin & Malla, 2012). Through patents and the facilitation of hybridization, biotechnology also helped generate returns to private researchers for new varieties and their embedded technologies.

Figure 1 shows the area of rapeseed/canola from 1943 to 2013 (Statistics Canada, n.d.).Three significant increases in area have occurred over time: one took place around 1970 with the introduction of 'canola'[3] varieties; another spike happens around 1994 when private breeders entered the market with HT varieties and hybrids; and the last shift started around 2004 and continued up to 2011 due to the introduction of very high-yielding hybrid varieties, especially Invigor 5020 in 2003 and then Invigor 5440 in 2007.

Along with increased area, two other metrics of the changes in the canola caused by biotechnology include the ownership and numbers of varieties of canola being used by farmers. Table 1 lists the 50 leading varieties in terms of total area seeded between 1970 and 2012. Area seeded is a clear measure of the value of the seed to producers and, as the seed sector became dominated by the private sector, of seed revenues. The leading varieties were listed in the table by release date. Prior to 1989, the dominant varieties were bred by public researchers. The varieties with the overall highest total seeded area were Westar and Tobin. Both of these varieties were used to seed more than 9 million ha in aggregate over their commercial life-time. Westar was planted on at least 20,000 ha for 11 years; Tobin area per year exceeded that mark for 15 years. Beginning in 1989, the private sector—especially Svalöf Weibull—started offering better varieties in terms of yield index. Changes in yield were another key shifter over time (Table 1). Svalöf's variety Garrison, with an index of 148, marked a significant jump in measured yields, but was poorly suited to Canadian growing conditions. Initial HT varieties like

3. *Dr. Baldur Stefansson bred the first 'double low' canola variety. He also collaborated with Dr. R. Keith Downey on zero eruic acid (Stefansson, Hougen, & Downey, 1961). However, Dr. Downey developed the first low erucic acid B. napus and B. rapa varieties. The half-seed technique was used to test for oil composition not gluconsinate as we stated in our earlier paper. Dr. Downey discovered the low-glucosinate trait in 1968, which he shared with Dr. Stefansson. Dr. Downey went on to breed Candle and Tobin, varieties that were vital to the success of canola. For a more detailed history, see Kramer, Sauer, and Pigden (1983) or National Research Council (1992). For an assessment of the economic impact of the creation of canola, see Nagy and Furtan (1978). This important contribution by Dr. Downey was overlooked in our earlier paper.*

Table 1. Dominant canola varieties from 1970 to 2012.*

Rank in area	Variety name*	Yield index	Type of HT	Hybrid	Breeder	1st year seeded	Polish	Area in ha 1970 to 2012
18	Span	100	Conventional		Agriculture Canada	1971	Pol.	2,255,389
50	Zephyr	100	Conventional		Agriculture Canada	1972		755,219
22	Midas	127	Conventional		Agriculture Canada	1973		2,067,624
5	Torch	100	Conventional		Agriculture Canada	1973	Pol.	4,657,145
9	Tower	109	Conventional		University of Manitoba	1974		3,044,723
6	Candle	94	Conventional		Agriculture Canada	1977	Pol.	3,511,164
11	Regent	102	Conventional		University of Manitoba	1978		2,933,710
30	Altex	105	Conventional		University of Alberta	1979		1,549,198
2	Tobin	103	Conventional		Agriculture Canada	1983	Pol.	9,408,145
1	Westar	122	Conventional		Agriculture Canada	1984		10,433,682
12	Legend	123	Conventional		Svalöf Weibull AB	1989		2,725,085
49	AC Parkland	103	Conventional		Agriculture Canada	1990	Pol.	767,038
38	Horizon	105	Conventional		Svalöf Weibull AB	1990	Pol.	1,031,567
10	AC Excel	119	Conventional		Agriculture Canada	1991		2,951,079
32	Profit	111	Conventional		Agriculture Canada	1991		1,344,435
31	Vanguard	118	Conventional		Svalöf Weibull AB	1991		1,522,612
7	Hyola 401	122	Conventional	HYB	Advanta Canada Inc.	1992		3,257,502
26	Reward	106	Conventional		University of Manitoba	1992	Pol.	1,729,657
41	Garrison	148	Conventional		Svalöf Weibull AB	1993		989,377
36	Legacy	129	Conventional		Svalöf Weibull AB	1993		1,062,039
20	Quantum	148	Conventional		University of Alberta	1994		2,140,152
15	45A71	128	Clearfield		Pioneer Hi-Bred Production Ltd.	1995		2,536,230
43	Ebony	123	Conventional		Monsanto Canada Seeds	1995		893,461
37	Innovator	116	Liberty Link		AgrEvo (Aventis)/ Ag. Canada	1995		1,042,689
25	46A65	134	Conventional		Pioneer Hi-Bred Production Ltd.	1996		1,738,195
17	Quest	126	Roundup Ready		Agricore Cooperative Ltd.	1996		2,324,224
42	45A51	130	Roundup Ready		Pioneer Hi-Bred Production Ltd.	1998		969,123
39	InVigor 2153	138	Liberty Link	HYB	Aventis CropScience Canada Co.	1998		1,012,486
48	DKL3235	121	Roundup Ready		Monsanto Canada	1999		802,094
40	InVigor 2273	143	Liberty Link	HYB	Aventis CropScience Canada Co.	1999		999,353
14	46A76	132	Clearfield		Pioneer Hi-Bred Production Ltd.	2000		2,575,559
46	Conquest	126	Roundup Ready		University of Alberta	2000		837,981
23	DKL34-55	131	Roundup Ready		Monsanto Canada	2000		1,976,250
28	InVigor 2573	155	Liberty Link	HYB	Aventis CropScience Canada Co.	2000		1,652,741
29	InVigor 2663	159	Liberty Link	HYB	Aventis CropScience Canada Co.	2001		1,620,551
34	InVigor 2733	155	Liberty Link	HYB	Aventis CropScience Canada Co.	2001		1,140,204
19	45H21	159	Roundup Ready	HYB	Pioneer Hi-Bred Production Ltd.	2002		2,168,118
4	InVigor 5020	165	Liberty Link	HYB	Bayer Crop Science	2004		5,487,043
8	InVigor 5030	175	Liberty Link	HYB	Bayer Crop Science	2004		3,104,999
13	InVigor 5070	174	Liberty Link	HYB	Bayer Crop Science	2004		2,582,199
21	DKL71-45 RR	156	Roundup Ready	HYB	Monsanto Canada	2006		2,118,698
33	Invigor 9590	171	Liberty Link	HYB	Bayer Crop Science	2007		1,233,684
3	**Invigor 5440**	179	Liberty Link	HYB	Bayer Crop Science	2008		6,577,964
27	Invigor 8440	171	Liberty Link	HYB	Bayer Crop Science	2008		1,682,522
47	DkL72-65 rr	163	Roundup Ready	HYB	Monsanto Canada	2009		808,031
44	**45H29**	177	Clearfield	HYB	Pioneer Hi-Bred Production Ltd.	2010		881,002
45	Invigor 5770	184	Liberty Link	HYB	Bayer Crop Science	2010		849,544
35	**DKL73-45 RR**	166	Roundup Ready	HYB	Monsanto Canada	2011		1,085,919
24	**Invigor L130**	173	Liberty Link	HYB	Bayer Crop Science	2011		1,940,361
16	**Invigor L150**	177	Liberty Link	HYB	Bayer Crop Science	2011		2,525,350
…								
141	45P70*	159	Conventional		Pioneer Hi-Bred Production Ltd.	2006		165,878

Sources: Seed Manitoba *(various years); Manitoba Agricultural Services Corporation (n.d.);* SaskSeed Guide *(2013); Agriculture Financial Services Corporation (various years);* Alberta Seed Guide *(various years); Statistics Canada (n.d.); Gray et al. (2006); Brewin and Malla (2012); and authors' calculations.*

** Bolded varieties were still seeded on 20,000 ha in 2012. 45P70 had the highest area of any conventional variety in 2008-2012. The yield indexes posted in Table 1 are updates of the calculations of Brewin and Malla (2012), who used the variety Torch as the starting base of 100. The beginning indexes were based on seed trial publications in the three prairie provinces but later indexes were adjusted by available yield trials posted with seed guides and supplemented with farm survey based data available, often Crop Insurance Surveys. Tobin's yield index seems low because Polish varieties tended to have lower yield. However, good oil and growing properties (fewer growing days) made Tobin very popular. We would like to thank Dr. R.K. Downey for pointing out errors related to some breeder information and the yield index of some Polish varieties in the earlier version(s) of this article.*

glysophate-tolerant Ebony and glufosinate-tolerant Innovator were a step backwards for yield, but still saw steady demand in terms of seeded area.

Herbicide resistance became a key characteristic of the dominant varieties after the late 1990s. From 1996 to 2007, HT varieties went from 10% to 96% of total area seeded (Canola Council of Canada [CCC], 2013). The TUAs used by the early patent holders of the HT traits, along with a rise in hybrid canola seed, facilitated the returns to breeders. The flexibility of these new traits in weed management came to be viewed as a very valuable feature by Canadian producers who were normally willing to pay private breeders for this technology. By 2012, privately-bred, hybrid, HT canola varieties dominated Canadian acreage. No publicly owned variety has seen any significant area in Canada since 2001. The most popular open-pollinated, non-HT variety in the last four years—45P70—was bred by a private breeder (Pioneer Hi-Bred) and was seeded on less than 1,400 ha in 2012.

The biotechnology that created HT also helped some firms develop hybrid varieties, because it facilitated crosses with HT and non-HT parents. The rise of very high-yielding hybrids seems to be behind the last big jump in area that began in 2004. By then, HT was also a major factor in seed choice. Higher-yielding hybrid varieties, especially the Liberty Link (LL) varieties, saw a significant increase in market share from 2003 to 2012. By 2004, most of the area was going to varieties that were both HT and hybrid—especially InVigor 5020. By 2010, 90% of the total seeded area (around 7 million ha) was seeded to HT varieties (CCC, 2013). Our data shows that 85% of these are also hybrid.

Although new varieties have taken over since 2004, the clear winners in terms of area and yield remain in the InVigor line except for the recent rise of DEKALB/Monsanto's DKL73-45 RR, which is a Roundup Ready (RR) Hybrid. InVigor 5440 and 5020 are now among the most dominant canola varieties—in terms of area seeded—ever developed. Only Westar and Tobin, which are conventional public varieties, were seed on more hectares. InVigors 5440, L150, and L130 are the only varieties to exceed Westar's yearly average of just under 1 million ha per year. However, in Westar's heyday (1984-1996), the total seeded area of canola was normally under 4 million ha.

Productivity was not the only focus of the canola breeders through this period. Higher quality oils were also a goal in breeding over the last three decades. High-erucic-acid rapeseed varieties used as industrial lubricants were seeded on several hundred thousand hectares by the mid-1990s; the University of Manitoba developed all of them. In the 1970s, the breeding program was mainly focused in reducing erucic acid that was shown to be a threat to human health and reducing glucosinolates in meal, which were shown to be less efficient animal feed. In other words, the research priority was the switch from rapeseed to canola quality (low glucosinolate and low erucic acid). The name 'canola' was initially registered in 1978 to designate "double-low" rapeseed varieties. In 2000, Dow Agrosciences released several high-omega-9 and low-linolenic oils under the brand name Nexera, representing the newer canola varieties with health traits. From 2000 to 2008, just over 1 million ha were seeded to Nexera varieties. Cargill introduced competing varieties with the same basic characteristics as Nexera in 2001. They have been seeded on just over 800,000 ha from 2001-2008. Lastly, innovation has also moved into the area of medicine. For example, SemBioSys Genetics has developed a technology to use canola to produce the anti-coagulant hirudin (Phillips, 2001).

Canola Industry Assessment: Returns to Research, Productivity, Environmental, and Health Benefits

Overview

Historically, agricultural research investment has resulted in high rates of returns. The results of a meta-analysis that included 294 post-war studies (1,858 estimates) of returns to R&D investment established high rates of return to agricultural research. Specifically,

> "in the 95 percent data set, the overall average rate of return across all 1,144 observations was 58.6 percent per annum, with a standard deviation of 51.7 …. In the second data set the overall average rate of return across all 1,181 observations was 63.4 percent per annum with a standard deviation of 66.7" (Alston, Marra, Pardey, & Wyatt, 1998, p. 27).

A similar meta-analysis of Canadian studies on rate of returns to agricultural research during the period of 1978 to 2001 also revealed high returns on investment.

> "The benefit-cost ratio was 27.5:1 for the aggregate total of Ontario agricultural research undertaken between 1950 and 1972. … Research studies in western Canada also show high returns, with benefit-cost ratios ranging from

> 12.1:1 to 34.1:1 for barley, wheat, and rapeseed, and 37.1:1 for beef" (Brinkman, 2004, p. 132).

A more recent meta-analysis that examined the rate of return in Canadian agricultural research also found high returns to agricultural R&D investment:

> "our review of rate of return studies found a significant amount of compelling evidence that the rate of return from investment in agricultural research has historically been very high and generally remained so…. The one exception to the general finding of high rates of return to applied research is in the canola sector, where significant private investment has occurred. Not surprisingly, this is also the crop sector that makes widespread use of patented technology and more recently hybridization, both of which virtually eliminate downstream spillovers. Given the ability to capture full value from their research, large private investment has driven the rate of return down closer to general market rates of return" (Gray & Malla, 2007, pp. 1-2).

A number of studies have examined the returns to canola research over time, evolving from simple cases of assessing the returns to yield increasing technical change due to public research investment, to more complex cases of evaluating the implications of private research involvement in canola research, as well assessing environmental and healthcare externalities as a result of research-induced technical progress. Additionally, producers' heterogeneity was introduced to the analysis of returns to canola research and canola-crop productivity was also assessed in the literature. All these different but related standpoints in the literature provide us with useful insights regarding canola-crop research and potential lessons that could be used by other crops or countries.

Returns to Research

The older studies of returns to public canola (or rapeseed) research investment from higher-yielding varieties (improved yield research) have shown high rates of returns. For example, Nagy and Furtan (1978) have estimated an internal rate of return (IRR) equal to 101% and the benefit-to-cost ratio (B/C) equal to 17.64 for the period 1960 to 1974 due to improvement in the yielding of canola varieties. Regarding the distribution of the benefits, it was estimated that the producers' share was 47% of the total gains. Ulrich, Furtan, and Downey (1984) calculated that the IRR from improved yield was equal to 51% (68% producers' share; 1951-1982). Lastly, Ulrich and Furtan (1985) estimated the IRR due to technical change that improved the yield of the canola varieties while incorporating trade effects equal to 50% (65% producers' share).

In a more recent study on returns to canola research, the implications of private research involvement in canola R&D was evaluated and suggested that research benefits have declined over time. Specifically, Malla, Gray, and Phillips (2004) examined the rates of returns to canola research investment for the period 1960 to 1999, reflecting the period of increased private investment, IPR establishment, and government research subsidies to private firms. It would have been expected—with the establishment of IPRs and the private sector increasingly involved in canola research—that the research benefits would have increased over time. However, it has been shown that since the 1980s the rates of returns to canola research investment (public and private) has started to decline, and by the mid-1990s approached market rates. Specially, the average IRR for canola research investment has steadily declined, approaching the level of market returns over time (1970-1999) even though it initially exceeded 25% per year; a similar trend was observed for the marginal IRR (for the marginal/extra dollars invested), but it changed more dramatically over time than the average IRR, even reaching below market rates. Hence, there has been a decline in the total returns to canola research, which indicates the net marginal returns to research were negative. The authors raised concerns that IPRs have provided incentives to private firms to undertake R&D on canola varieties because with IPRs they could retain ownership over the new varieties and technologies. The research outcomes became excludable, which in turn increased private research investment. At the same time, research subsidies that reduced the private sector research costs led to research over-investment (the private optimal amount of research was exceeding the social optimal level of research), leading to a reduction in research benefits.

It has also been argued that the producers' share of advances made by private breeding companies has dropped considerably when compared to the public advances made in the past. Additionally, it was not just the high rate of return that attracted private industry to canola; they saw that hybrids were a very real possibility and they know that with hybrids, they control the seed market (R.K. Downey, personal communication, March 22, 2015).

A different point was raised in the literature regarding producers' heterogeneity and significant research benefits to some producers. Specifically, Fulton and Keyowski (1999) estimated the producer benefits of adapting the new herbicide-resistant (HR) canola varieties (new technology) while allowing for producers' heterogeneity. A number of different canola product lines (Roundup Ready, Smart Open Pollinated, Liberty Hybrids, and Conventional Open Pollinated) were considered in order to assess the gains of HR canola. The authors claimed that

> "…the pricing and adoption of HR canola in Canada cannot be understood if producers are seen as being homogeneous. We develop a conceptual model of producer heterogeneity that represents the distribution of benefits among producers. In this context, some farmers benefit from the new technology leading to adoption, while others do not" (Fulton & Keyowski, 1999, p. 85).

They estimated that the gross returns ($/acre) of Roundup Ready canola was on average equal to $225.30 in 1999, Smart Open Pollinated was $213.75, Liberty Hybrids was $238.10, and open pollinated was $242.13. Hence, at the average the benefits of growing HT canola were not higher than that of the conventional canola varieties; in other words, the new technology was not superior in terms of total average farmer returns as compared to traditional technology. However, the agronomic, management, and technological factors facing farmers are very important determinant of producers' benefits; some producers benefit greatly from HR technology, while for others the benefits did not outweigh the costs.

Returns to Research and Environmental Benefits

A number of studies have examined producers' benefits from adopting new canola varieties while also accounting for potential agronomic- or environmental-related economic benefits (i.e., environmental related externalities); these studies have revealed significant environmental benefits and high rates of returns to producers. Specifically, the CCC (2001) and Phillips (2003) estimated the agronomic and economic benefits associated with the adoption of the new HT canola varieties and revealed significant rates of returns. According to CCC (2001, p. 51),

> "clearly, the majority of growers surveyed believed that there are significant advantages to transgenic canola. Participants in the survey and in the case studies stated that their primary reason for adopting transgenic canola were not economic, but agronomic. The transgenic [HT] system is simple, the weed control is early and effective, and the system fits well into a reduced or no-till operation."

Hence, the agronomic benefits associated with HT canola were a primary deciding factor in a farmer's choice to adopt this new technology, and a significant contributor to the overall farmer returns.

According to CCC (2001), HT technology allowed for improved yield, slightly increased fertilizer usage, increased seed costs, decreased tillage use, improved soil moisture conservation, decreased summer fallow, improved rotation flexibility, lower dockage, and decreased herbicide inputs. Regarding total benefits (direct and indirect), it was concluded based on the net gain in gross margin of transgenic over the acreage harvested under the conventional production system as well as producers' survey, that

> "the direct impacts based on the detailed model calculation is estimated at $249.0 million in 2000 dollars. The farmers net income based estimate of direct impact is $144.0 million. The indirect impact in 2000 dollars is estimated to range between $58.0 and $215.0 million, using the lower and upper multiplier, respectively,…the total economic impact of transgenic canola production systems has been estimated to be up to $464.0 million over the period 1997 to 2000, inclusive of direct and indirect impacts" (CCC, 2001, p. 53).

Lastly, the direct producers' benefits of transgenic canola were estimated at $66 million in 2000 (or $10.62 per acre).

Additionally, Phillips (2003) calculated the producers' net benefits associated with the adoption of the new HT technology equal to $70 million in 2000. The study examined the direct and indirect effects of HT canola adoption on producers (e.g., higher seed costs, lower herbicide costs, fewer herbicide applications, lower dockage, earlier seeding) and the general economic implication on the global industry/economy. Lastly, CCC assessed the management of volunteer HT canola (volunteer canola as a weed) and concluded that "differences in, and costs of, volunteer control management between systems are subtle, and practices are not significantly different for HT versus conventional systems" (CCC, 2005, p. iii).

Recent studies by Smyth, Gusta, Belcher, Phillips, and Castle (2010) and Gusta, Smyth, Belcher, Phillips, and Castle (2011) emphasized the importance of incorporating some substantial indirect benefits and costs in the estimation of the economic benefits of HT canola for producers (e.g., potential spillovers, cost from controlling volunteer canola) for which those earlier studies did not fully account and revealed high returns to producers. The data for the project was based on a producer survey (2007) that was comprised of six areas of focus, including weed control, volunteer canola control, canola production history, specific weed-control measures on canola fields and subsequent crops, crop and liability insurance, and general demographics, as well as three major impacts: 'spillover' (multi-year benefits due to fewer weeds or easier weed control on field from one year to the next), 'reduced tillage' (cost of weed control), and 'cost of volunteer control' (when HT becomes an in-crop weed or volunteer). It was estimated that the average direct benefits (direct economic impact) of HT canola (2005-2007) was equal to $150 million, while the average total indirect economic benefits/costs associated with the new technology was equal to $235-$278 (2005-2007). Specifically, the spillover benefit ranged from $67 million to $110 million, the value/benefits of reduced tillage was equal to $153 million, and the cost for controlling volunteer canola was $15 million for the period 2005-2007. Finally, the authors claimed that the new technology generated net total benefits (direct and indirect benefits) between $1.063 and $1.192 billion for producers for the period 2005 to 2007, mainly due to lower input costs and better weed control. Hence, substantial economic benefits are recognized at the producer level with the adoption of HT technology.

Lastly, Smyth et al. (2011a, 2011b) examined environmental issues associated with HR canola adoption and concluded that the environmental impacts with HR varieties are indeed very important; additionally, the changes in herbicide use after adoption of "herbicide-resistant"[4] varieties was also significant. According to Smyth et al. (2011a, p. 492):

> "the commercialization and widespread adoption of herbicide-resistant (HR) canola has changed weed management practices in western Canada. Before the introduction of HR canola, weeds were controlled by herbicides and tillage as the leading herbicides at that time required tillage to allow for soil incorporation of the herbicide. Much of the tillage associated with HR canola production has been eliminated as 64% of producers are now using zero or minimum tillage as their preferred form of crop and soil management. Additionally, there have been significant changes regarding the use and application of herbicides for weed control in canola…. The cumulative environmental impact was reduced almost 50% with the use of HR herbicides."

Furthermore, Smyth et al. (2011b, p. 403) pointed out that

> "a reduction in the total number of chemical applications over the 3-year period was reported, resulting in a decrease of herbicide active ingredient being applied to farmland in western Canada of nearly 1.3 million kg annually. Fewer tillage passes over the survey period were reported, improving moisture conservation, decreasing soil erosion and contributing to carbon sequestration in annual cropland. An estimated 1 million tonnes of carbon is either sequestered or no longer released under land management facilitated by HT canola production, as compared to 1995. The value of this carbon off-set is estimated to be CAD$5 million."

Returns to Research and Health Benefits

The economic benefits associated with quality-improving technical change in canola research as well as health-related benefits (healthcare externalities) were also evaluated in the literature. Specifically, Malla (1996) and Gray and Malla (2001) examined the economic implications of the switch from rapeseed to canola quality (low glucosinolate and low erucic acid), as well as the health implications in terms of healthcare

4. *There is no significant difference between herbicide resistance and herbicide tolerance in most usage.*

savings due to increased consumption of canola oil (monounsaturated fatty acids). It showed significant healthcare savings as a result of increased consumption of canola oil, which was mainly due to health information in the mid-1980s that monounsaturated fatty acids—like canola oil—lowers LDL (harmful) cholesterol levels but does not lower HDL (beneficial) cholesterol levels compared to polyunsaturated fatty acids (e.g., soybean oil and corn oil). This in turn reduces the risk of coronary heart disease. Additionally, the studies show a reduction of the genetic potential for yield due to quality impositions like reducing erucic acid (shown to be a threat to human health) and reducing glucosinolates in meal (shown to be a threat to animal nutrition). This was the focus of the public breeding program in 1970s. Regarding research benefits, it was estimated that the industry as a whole (producers, processors, consumers) has gained from health/nutrition research, but producers were the largest beneficiaries of health information.

Specifically, according to Gray and Malla (2001, pp. 234-235),

> "in making the switch to canola some genetic yield potential was given up. … [In] the post adoption period yields remain 9.1 percent below the trend established by rapeseed…. In the late 1980s, nutritional research created positive health information about canola that increased demand and raised the price of canola oil relative to soybean oil by an estimated $32 per metric ton… Given a $1.67 per kilogram externality, such a demand shift would reduce health costs by an estimated $25 million per year in Canada."

Hence, the increase in demand that was associated with a reduction in yield could be attributed to the switch to canola, indicating that the focus on the quality characteristics of canola products came at the expense of potential yield. Furthermore, the increased consumption of canola oil also provided substantial benefits to taxpayers through reduced incidence and, in turn, the cost of coronary heart disease. It was concluded that the healthcare costs savings associated with nutrition could be an important—however, neglected—aspect of the economics of agricultural and research policy.

The potential health benefits of trans-fat-free canola oil using the example of Natreon canola oil (Nexera, produced by Dow Agroscience, Inc) was assessed in the literature, revealing very significant external or social benefits related to canola oil with health traits, in terms of reduction in healthcare costs or healthcare savings in Canada. Given the increased public attention on the correlation between high cholesterol levels and consumption of trans-fatty acids (TFA), a lot of research effort was devoted to new seed canola varieties with high oleic content that could produce stable oil without the hydrogenation process that creates trans-fats. The new canola variety called Nexera was an example of such seeds that created Natreon, a branded oil grown from Nexera, which was considered as a functional lipid food due to its modification of fatty acid composition ("low-linolenic" and "high-oleic" fatty acid profile), which in turn reduces the risk of cardiovascular diseases. Malla et al. (2007) estimated that annual healthcare savings from reduction in daily TFA intake (TFA-free oil; Nexera/Natreon) ranging from $1.818 billion to $639 million (equal to $1.094 billion for the base scenario), which results in a nontrivial healthcare cost savings, and in turn could significantly increase economic welfare.

Productivity

Agriculture production and productivity of the major crops growing in Canada including canola has been assessed in the literature over time, and some studies indicate a slowdown of productivity growth in crop production since 1990. The productivity in canola crop in terms of partial productivity such as crop yields (land productivity) over time was estimated by calculating the acreage-weighted experimental yield index and average realized yields (actual farm canola crop yields or yields per seeded acre). Veeman and Gray (2009, 2010) showed that canola farm yield, like other major field crops growing in Canada, exhibit constant absolute growth but declining proportional growth rate; such as yields increased by roughly 60% from 1960 to 2007, which indicated the presence of a linear trend. Hence, they concluded that the productivity growth slowed down in crop production including canola.[5] Research

5. *Average canola-farm yield was impacted by several major factors. 1. The availability of cheap glyphosate that moved canola from a summer fallow crop to one grown in stubble. 2. Production could now be done on poorer land (weeds could be controlled). 3. The major shift from a 40:60 ratio of B. rapa –B. napus to a 15:85 ratio. 4. The large jump in acres sown to canola resulting in new growers and less suitable land being put in canola. 5. Canola production extended southward into dryer production areas (lower potential yield; R.K. Downey, personal communication, March 22, 2015). As well, some of the yield plateaus were the result of having to incorporate quality or resistance genes from agronomical non-adapted germplasm.*

trial yield indexes grew rapidly until 1972, then declined from 1975 to 1983 as rapeseed was replaced by canola (low glucosinolate and low erucic acid); from 1986 to 1994, canola yields increased significantly, while in the late 1990s yield dropped due to the adoption of HT varieties (with agronomic benefits regarding weed control in expense of yield levels). Lastly, since 1998—with the introduction of hybrid varieties—canola yield have grown rapidly (Veeman & Gray, 2009, 2010). Hence, research efforts over time that have focused on quality improvement or agronomic benefits of canola varieties have come at the expense of yields.

Stewart, Veeman, and Unterschultz (2009) analyzed the total factor productivity (TFP) growth in the crops (including canola crop) and livestock sector in the prairie region of western Canada and concluded an economically significant slowdown in agricultural productivity growth in Canada. Contrary, a study by Darku, Malla, and Tran (2012) that examined productivity growth rate using TFP in crops (including canola crop) and livestock in Canada found no evidence that agricultural productivity growth has recently slowed down. Hence, there is mixed and competing evidence regarding agricultural productivity growth in Canada, with predominant results that agricultural productivity growth has slowed.

Insights from the Assessment: A Summary

In summary, the rate of return to canola research has been high in general, and producers enjoy a significant share of the benefits (Table 2). However, the establishment of IPRs combined with research subsidies could reduce the potential research benefits, leading to research over-investment. The above brief review also emphasizes the importance of health and environmental benefits associated with new canola varieties (new technologies) and canola varieties with health traits. Another point raised above involved whether there is a productivity growth slowdown. Some concerns have been raised regarding growth rate in canola farm yield.

There are a number of lessons that could be drawn, including (1) investment in crop R&D results in high returns; (2) overall, farmers benefit from adopting new technologies; (3) government subsidies could be more appropriate for crops with imperfect property rights, or small and new crops; (4) the establishment of enforceable IPRs is important, as they provide incentives to private firms to undertake research; (5) quality-improving technical change is important, as it could increase social wellbeing; (6) technical change that results in agronomic improvement is important, as it provides significant direct and indirect benefits (positive externality) to all the parties involved in the sector; and (7) in general, government policies and regulations could significantly affect firms' R&D incentives and outcomes.

Government policies and programs are important, as they could significantly affect firms' incentives to undertake research, the amount and type of research effort, and so on, which in turn affect the total benefits generated from the R&D investment and the distribution of research benefits. Government research policies have changed over time, as has the structure of the canola research industry, the research priorities/focus, the available technologies, and so on, of the canola research industry. Hence, a close look at today's returns to research, the current research policies, and the research direction of the today's canola research industry is crucial to comprehend the canola sector, assess the effectiveness of the current policies, and potentially make policy recommendations.

Direct Returns to Western Canadian Farmers over Time

The previous section reveals significant producer benefits associated with the new canola varieties. For example, the recent study by Gusta et al. (2011) estimated average (direct and indirect) annual benefits from HT canola ranging from $354-$397 million, with the direct producer benefits of $150 million (average 2005-2007). Gusta et al. (2011) considered the economic and ecological impacts of the introduction of HT canola on western Canadian farmers. Using surveys, they assessed the impact of reduced tillage and chemical costs while accounting for the costs of dealing with volunteer HT canola control. However, Gusta et al. (2011) relied on Phillips (2003) to estimate direct producer impacts of roughly $11 per acre using data from 2000. Phillips (2003) and Gusta et al. (2011) had calculated some yield gains due to seeding timing, but no significant yield changes linked to improving varieties were part of their estimates. Brewin and Malla (2012) showed that the biotechnology-driven explosion in research and varietal development in Canada had led to greatly improved yields in canola. By 2012, yields for hybrid HT canola were significantly better than any conventional[6] variety.

The gains in yield from HT and hybridization should be included in the producers' benefits when estimating the impacts of evolving biotechnology on the canola industry. In 2000, the yield differences between the best conventional varieties and any HT system were minor.

Table 2. Summary of returns to canola research studies.

Study	Returns to research
Meta-analysis	
Alston et al. (1998): 294 studies	IRR: 58.6 - 63.4%
Brinkman (2004): Canadian studies	B/C: 12.1 - 34.1 (barley, wheat, rapeseed)
Gray and Malla (2007): Canadian studies	IRR: large number of studies; 30-50% or greater
Canola	
Nagy and Furtan (1978): Rapeseed/canola	B/C: 17.64; IRR: 101; Producer benefits (direct): 47%
Ulrich, Furtan, and Downey (1984): Rapeseed/canola	IRR: 51; Producer benefits (direct): 68%
Ulrich and Furtan (1985): Rapeseed/canola	IRR: 50 ; Producer benefits (direct): 65%
Furtan and Ulrich (1987): Rapeseed/canola	B/C: 34.1
Fulton and Keyowski (1999): Canola	Producer benefits (direct): $213.75 - $242.13/acre (gross returns)
Gray and Malla (2001)	Switch from rapeseed to canola and health information: $32 per metric ton increase in demand; 9% permanent reduction in yield; $1.67/kg externality, or $25 million per year health costs savings in Canada; industry gained and producers benefited
CCC (2001): Transgenic canola	Producer benefits (direct): $66 million in 2000 (or $10.62 per acre) Total indirect impact: $58.0 - $215.0 million (1997-2000)
Phillips (2003): HT canola	Producer benefits (direct): $70 million (in 2000)
Malla et al. (2004): Rapeseed/canola	IRR: Initially exceeded 25%; declined to market returns (40%→7%)
CCC (2005): Volunteer HT canola	Environmental benefits: HT and conventional systems; not significantly different (w.r.t volunteer control management)
Malla, Hobbs, and Perger (2007): Nexara canola	Healthcare savings: CDN$1.818 billion - $639 million annually (from reduction in daily TFA intake)
Veeman and Gray (2009, 2010): Major Canadian crops including canola	Crop yields: constant absolute growth and declining proportional growth rate in yield; a slowdown of productivity growth in crop production since 1990
Smyth et al. (2010) and Gusta et al. (2011): HT canola	Producer benefits (direct): $150 million (average 2005-2007) Producer benefits (indirect & environmental benefits): $235 - $278 million (average 2005-2007)
Smyth et al. (2011a): HR canola	Producer benefits (indirect & environmental benefits): 64% of producers are now using zero or minimum tillage; 50% reduction in the use of HR herbicides
Smyth et al. (2011b): HT canola	Environmental benefits: 1 million metric tons of carbon is either sequestered or no longer released (HT canola); Environmental benefits CDN$5 million

Source: Authors

By 2012 the yield index for the canola variety with the highest area in western Canada—Invigor L150—was 184.4, compared with an index of 137.2 for the only open-pollinated non-HT variety with any significant area, 45P70.

The rapid increase in area seeded to canola also affects the impact of biotechnology on canola as benefits are accumulated over each hectare planted. Figure 1 in the previous section shows the rapid increase in area that has occurred since Phillips' calculations in 2000. Specifically, the area of land seeded to canola has roughly doubled between 2000 and 2012.

Consequently, the benefits by HT systems measured by Fulton and Keyowski (1999) for 1999 and by Brewin and Malla (2012) for 2011 could be updated to reflect current prices and higher yields relative to conventional yields for each of the major HT systems. The costs and benefits associated with different canola product lines (Roundup Ready, Liberty Link, Clearfield, and conventional) in 2012 are shown in Table 3.

Specifically, Table 3 shows the gross return to each major HT system being used. The gain in gross returns can be directly attributed to the improved varieties using these HT systems. Revenues change because of prices

6. *Given that 85% of all seeded canola area is seeded to hybrids and 99% are GMO, the term conventional is not appropriate for open-pollinated canola that has not been genetically modified. However, that is the convention in the literature related to HT assessment.*

Table 3. Canola product lines: A system comparison of costs and benefits in 2012.

Farmer system costs[1]	Roundup Ready	Liberty Link	Clearfield	Conventional
Seed cost ($/ha)	$97.74	$91.76	$91.64	$33.84
Herbicide cost ($/ha)	$12.35	$28.55	$33.76	$74.10
TUA ($/ha)	$37.05	$25.56	$30.21	$0.00
System cost ($/ha)	$147.14	$145.88	$155.61	$107.94
Gross returns				
Yield (tonne/ha)[2]	1.85	1.95	1.89	1.70
Commodity price ($/ton)[3]	$530	$530	$530	$530
Expected gross ($/ha)	$983	$1,034	$1,004	$900
Less system costs ($/ha)	($147)	($146)	($156)	($108)
Net farm returns ($/ha)	$836	$888	$848	$792

[1] Sources: 2011 costs estimated from Manitoba Agriculture, Food and Rural Initiatives (2011); and Saskatchewan Ministry of Agriculture (2011).

[2] Yields estimated by authors using average annual yield and indexes from same sources as in Table 1.

[3] These estimate are based on 2011 costs but 2012 yield indexes and forecasted price.

and yield gains attributed to hybridization, and costs are adjusted due to the prices and the improved methods of weed control from HT. Hence, producers benefit significantly from growing new canola varieties instead of conventional canola varieties. This finding is in accordance with Brewin and Malla (2012) but contradicts the Fulton and Keyowski (1999) conclusion that the average benefits of growing HT canola were not higher than that of conventional canola varieties.

Table 3 reflects 2012 based on a representative budget and indexed yields as calculated above. Table 4 calculates these benefits for every year from 1996-2012 to estimate the total benefit of these changes over time. The first set of columns shows the evolving yield improvement from 1996 to 2012, including yield advances in open-pollinated non-HT canola. Conventional yields were sampled in the data as discussed above. Statistics Canada (n.d.) sources were used to collect average yearly canola prices (shown for each year) and the total seeded area. Seeding costs and herbicide costs were adjusted using representative prices supplied by the CCC.

In Table 4 the benefits of each HT system are compared to a conventional base case and both conventional and HT system yields adjust over time based on a weighted average of each variety by area. Seeded areas, herbicide costs and canola prices also adjust. The table lists a weighted yield index based on the area seeded to each variety assessed for Table 1 above by the appropriate HT system: Liberty Link (LL), Clearfield (Clear), and Roundup Ready (RR) as well as the conventional (Conv) alternatives. The total gain above conventional gross incomes show the gain in returns (including revenue gains from yield, cost increases from seed, and TUAs and herbicide reductions) for each HT system above the conventional options for that year.

A total value (TV) as of 2012 was calculated for 1996 to 2012 using the formula

$$TV = \Sigma_{n=t}^{N} b_n \, (1 + r)^{N-n}, \qquad (1)$$

where N is the end date (2012), b_n is the gain above to farmers who adopt the HT systems in the n^{th} year, r is the interest rate (5%), and t is the starting year of 1996.

The TV is reported at the bottom of Table 4. Over time, yield gains and herbicide cost savings led to high gains to farmers from the adoption of LL, Clearfield, and RR canola seeding systems. In total, the benefit of hybrid HT canola varieties from 1996 to 2012 (in 2012 dollars) was estimated at $30 billion. The gains jumped in 2004 because of yield gains and in 2008 because of canola prices. The gains should not be considered gains from private-sector investments alone; indeed, the high gains linked to LL systems were at least partially supported by the breeding lines of AAFC researcher Dr. Gerhard Rakow (R.K. Downey, personal communication, March 22, 2015). It could also be argued that the farmers' benefits have been reduced slightly as producer check-offs were collected to cover some of the research activity. However that research could be used for disease prevention and agronomy that benefit all of the system choices.

Note that this benefit estimation has ignored other crops. While the area seeded to canola increased over the study period, the area of other crops like wheat and barley fell (Statistics Canada, n.d.). Wheat revenues have been drifting behind canola revenues for some years (AAFC, 2014), and we are not attempting a complete accounting of TFP. This estimation is just the gain that HT hybrids have made above open-pollinated conventional canola varieties.

The benefit estimation also ignored possible market impacts of significant productivity increases. We are essentially assuming that actual prices used in the estimation reflected all price impacts of growing yield

Table 4. Direct returns to farmers from 1996 to 2012.

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Estimated yields (t/ha)																	
Conv	1.42	1.42	1.47	1.44	1.37	1.36	1.28	1.26	1.18	1.36	1.25	1.48	1.62	1.71	1.73	1.72	1.7
LL	1.29	1.35	1.42	1.48	1.55	1.66	1.69	1.73	1.78	1.87	1.89	1.91	1.9	1.93	1.94	1.96	1.95
Clear	1.42	1.42	1.42	1.43	1.45	1.46	1.54	1.46	1.43	1.48	1.48	1.52	1.76	1.82	1.8	1.91	1.89
RR	1.41	1.39	1.39	1.4	1.41	1.41	1.47	1.54	1.52	1.53	1.57	1.55	1.61	1.7	1.71	1.75	1.85
Canola prices	$381	$385	$378	$295	$221	$276	$346	$350	$349	$262	$279	$369	$505	$422	$410	$534	$575
Seeded area (million ha)																	
Conv	3.07	3.11	2.28	1.65	1.49	0.68	0.64	0.62	0.46	0.13	0.14	0.12	0.09	0.07	0.12	0.08	0.04
LL	0.13	1.00	1.08	1.13	0.71	0.65	0.99	1.22	1.58	2.54	2.38	2.97	3.42	3.69	3.96	4.67	5.08
Clear	0.26	0.55	0.65	0.65	0.91	0.80	0.68	0.72	0.71	0.56	0.57	0.51	0.59	0.18	0.23	0.56	0.73
RR	0.02	0.19	1.39	2.08	1.76	1.66	1.53	2.10	2.40	2.07	2.15	2.73	2.44	2.74	2.80	2.37	3.07
Revenue ($/ha)																	
Conv	541.08	548.67	554.96	423.38	302.46	374.93	443.31	440.47	410.06	357.91	347.44	545.96	816.52	722.26	710.02	921.18	976.96
LL	491.19	519.39	536.76	437.78	341.94	458.81	584.14	605.10	621.00	490.12	526.18	704.36	957.64	812.76	795.69	1,049.48	1,121.88
Clear	541.02	545.72	535.07	421.59	321.42	403.68	532.75	512.37	499.74	388.96	412.77	560.69	886.46	767.21	738.46	1,021.87	1,089.74
RR	535.33	536.23	526.73	413.50	311.07	390.49	509.23	539.27	529.89	400.92	437.75	573.13	811.32	716.12	699.06	937.13	1,066.90
Gross revenue less costs ($/ha)																	
Conv	405	412	419	287	166	239	307	304	266	218	203	402	655	557	556	815	869
LL	379	408	425	326	230	347	472	493	508	374	411	589	832	677	651	899	971
Clear	374	378	368	254	154	236	365	345	343	222	249	398	699	543	579	883	939
RR	426	426	417	304	201	281	399	429	415	282	325	463	690	593	564	798	920
Gain in gross over conv ($/ha)																	
LL	-25.39	-4.77	6.30	38.90	63.98	108.38	165.33	189.13	242.68	156.11	208.40	186.21	176.73	119.98	95.06	83.36	102.34
Clear	-31.19	-34.07	-51.02	-32.91	-12.17	-2.37	58.32	40.77	77.57	4.59	46.08	-4.17	44.44	-13.89	22.97	68.29	69.76
RR	20.79	14.10	-1.69	16.66	35.15	42.10	92.46	125.34	149.94	64.41	122.73	60.23	35.07	36.40	8.43	-17.30	50.74
Total gain over conv (million $)																	
LL	-3.42	-4.75	6.79	44.12	45.27	70.20	162.90	231.37	384.03	396.24	496.31	552.18	604.57	443.14	376.59	389.41	519.70
Clear	-8.08	-18.60	-33.20	-21.42	-11.13	-1.90	39.38	29.54	54.79	2.59	26.33	-2.13	26.25	-2.56	5.38	38.38	50.87
RR	0.52	2.71	-2.35	34.72	61.97	69.87	141.55	263.56	360.58	133.23	263.70	164.37	85.70	99.78	23.60	-41.04	155.58
Total value of gains in 2012 (5%)							LL:	$19,812		Clear:	$460			RR:	$9,802		

potential. If open-pollinated public varieties had lowered canola output, the prices may have been slightly higher; but, canola prices are dominated by the world oilseed complex, and Canada's production does not have a significant impact on prices. As the total supply of canola increased, domestic crushing did expand significantly. In 2014/15, crushing is expected to use half of the total production (AAFC, 2014).

The Evolution of Policies and Regulations in the Canadian Canola Industry

Overview

The federal and provincial governments of Canada have historically played a large role in canola research, much like most other crops in Canada (Malla & Gray, 2003, 2005). During most of the 20th century, research funds primarily came from governments (especially the federal government), and agricultural research was carried out mostly in public institutions such as federal government experimental stations or publicly funded universities. In turn, the output from the research—whether it was a new variety, new technology, or even a new crop—was deemed to be a public good and was given freely to industry. Given the inability of researchers under this system to capture significant value from their research, private research investment was very limited. New varieties, products, ideas, and technologies generated from public research could be reproduced, used, and shared without remuneration to the researcher (a non-excludable research outcome). The economic rationale for government involvement in agricultural R&D was based on the private sector underinvestment in agricultural R&D (see above) from a social point of view, based also on the evidence of the high rates of returns to agricultural research investment.

With the introduction of biotechnology and the IPRs that followed, the canola sector has dramatically changed over time, which in turn has changed the role of government and the public involvement in canola R&D. From 1970 to 1989 the leading canola varieties were open pollinated and there was no method of using patent protection. In the 1990s, plant breeders' rights (PBR) were established in Canada. The U.S. Patent and Trademark Office started to recognize and protect biotech processes, and the industry started using license agreements (TUAs) for products like transgenic crops that enabled firms to charge farmers an annual fee for growing their varieties.

The new technologies and patent protection came with improved PBRs that allowed the exclusion of reuse without compensation. Some new varieties became excludable due to patentable genetic traits, such as HT varieties that were linked to a particular herbicide and designer varieties that were meant for new processes or markets. As well, technology had improved the process for hybrid production, which increased vigor (and yield) but required the purchase of new seeds every year to keep the desirable vigor. The combined effect of all the changes that took place during the 1990s was a remarkable shift in canola research outcomes (e.g., new varieties, some traits and technologies) from non-excludable to excludable, which in turn created private R&D incentives. The inventor could retain ownership over some products of canola research investment and capture much of the value of the investment.

Governments have continued to make large public investment in research, particularly in basic research, which creates a positive spillover to private firms (see Gray et al., 2006; Gray & Malla, 2011). Public investment has contributed to the knowledge and research platforms used by private firms for applied agricultural research, and public research made private research firms more productive. Moreover, Agriculture and Agri-Food Canada indicated that it was withdrawing from commercial variety development, thus increasing the market share for private breeders. In recent policy initiatives like Growing Forward II (AAFC, 2012), universities and other public institutions were also given the mandate to co-operate with private institutions (e.g., collaboration on projects, provision of infrastructure to facilitate private research) in order to avoid competition with private companies while fostering spillovers.

The changes that have taken place in the canola sector (the registration of new canola varieties, the ownership of IPRs and patents, the revenue generated from crop R&D investment, etc.) are evidence of the transformation. Canola research has shifted from a modest public investment to a large private investment. In 1970, 83% of the total spending on canola research ($18 million) was public. In 1980, the public share was 69% of the total annual research expenditure ($30 million). By 2000, the total $150 million expenditures in canola research investment was 70% private (Gray, Malla, & Phillips, 2001; Malla & Gray, 2005). Currently, the private share of seed sales is over 95%.

The funding shift is also confirmed by the ownership of new canola varieties. Prior to 1985, all of the varieties introduced were developed by public institutions. From 1990 to 1999, 86% of the 162 new varieties registered were developed by private institutions. Today, virtual all of the leading canola varieties are private.

The distribution and magnitude of crop research revenue also has been altered over time. Although the private firms were beginning to capture some revenue from the sales of their products by 1990s, by 2001 private firms were capturing over $250 million in revenue and had nearly completely crowded out public-sector sales. The ownership of canola patents has also become dominated by private firms (Brewin & Malla, 2012; Canadian Food Inspection Agency, n.d.; Smyth & Gray, 2011). Currently, private firms hold most of the oilseed HT patents as well as the majority of canola-related patents in Canada. However, the public sector also holds some patents and some institutions actively protect and commercialize IPRs (Gray & Malla, 2011).

Issues Related to Canola Privatization and Government Challenges

The introduction of biotechnology, improved IPRs, and the canola sector privatization brought a much needed increase in R&D investment. It also, however, triggered a series of issues threatening the future of the canola sector and challenging the current role of the government role in today's biotech canola industry. For example, there have been concerns about industry concentration, the pricing of the varieties, the rules for using new technologies/varieties with specific gene traits, the amount and type of R&D effort, and the obstacles to commercializing new traits and varieties.

The non-rival nature of research outcomes has contributed to the concentration of research activity in a few private firms in the canola industry. The product of R&D (e.g., new technology, new knowledge, new variety) is a non-rival good, meaning that anyone can use the technology created from R&D repeatedly without exhaustion. This non-rival nature of agricultural research output tends to create a concentrated industry because firms move to capture economies of scale and scope (Fulton & Giannakas, 2001). Integration has advanced even further due to strategies such as vertical integration, mergers, acquisitions, and joint-venture arrangements to preserve freedom to operate (Falcon & Fowler, 2002; Kalaitzandonakes & Bjornson, 1997; Lesser, 1998; Lindner, 1999). The concentrated nature of the canola research industry, with the exclusive IPRs, provides research firms some degree of market power, which allows them to charge higher prices for their new varieties/technologies. This affects technology adoption and the distribution of the gains from research, which in turn affects the public and downstream political support for funding (Fulton & Keyowski, 1999; Lindner, 1993; Malla & Gray, 2003; Moschini & Lapan, 1997).

Despite the concentration, research fragmentation in IPR ownership has resulted in concerns over commercialization of new varieties or products of research and related to the tragedy of anti-commons (the underuse of resources and less innovation). Although recent gene trait cross licensing agreements (licensing of mutually beneficial technology) improve freedom to operate, they lead to even more industry concentration. In the case where IPRs are well established, the negotiation of the rights to use IPRs could be very difficult and the transaction cost of negotiating freedom to operate could be quite high, especially when a research product embodies many pieces of IPRs (Falcon & Fowler, 2002). This high transaction cost could shut out breeding firms and deter entry by other firms, as well as create an economic barrier for the commercialization of second-generation GM crops.

Generally, freedom-to-operate issues have adversely affected the structure of the canola research sector. Low freedom to operate can also create the tragedy of anti-commons because competing patent rights could actually prevent research activities to be undertaken or hamper firms in getting research products to the market place (Buchanan & Yoon, 2000; Falcon & Fowler, 2002; Galushko & Oikonomou, 2007; Graff, Cullen, Bradford, Zilberman, & Bennett, 2003; Heller & Eisenberg, 1998; Smyth & Gray, 2011; Wright, 1998). Hence, too many IPRs could lead to less innovation.

The sharing of knowledge in both the private and public sectors has been reduced, which has increased research costs, and this could slow down progress in the Canadian plant-breeding industry in the long run (Galushko, Gray, & Oikonomou, 2012; Galushko & Oikonomou, 2007).

Gene trait cross-licensing agreements were a recent strategy used by private canola-breeding firms in order to facilitate IPR sharing (e.g., Galushko, Gray, & Smyth, 2010; Smyth & Gray, 2011; Stiegert, Shi, & Chavas, 2010) while the sector has moved away from mergers and acquisitions. For example, a cross-licensing of HT traits agreement was made recently between Monsanto and Bayer Crop Science. Given that Monsanto's and Bayer Crop Science's canola varieties account for 85% of the total Canadian canola seed market (Brewin & Malla, 2012), gene trait cross-licensing agreements raise additional concerns over market concentration.

Issues Regarding the Role of Government

Concerns have also been raised regarding the appropriateness of the public provision of applied research (e.g., new varieties); basic research (e.g., new technology/knowledge, genes, germplasm, research platforms); research infrastructure to facilitate private research (e.g., Innovation Place in Saskatoon, SK), private-public collaboration; or even government subsidization of private research (e.g., Agriculture and Agri-Food Canada Matching Investment Initiative, which matched private research investment with public research resources).

In Canada, the federal government has been historically involved in the direct provision of applied research in addition to funding basic research. However, with the introduction of modern biotechnology, private investment took on some of the applied research. Although funding has been falling, the federal government has increasingly focused on funding basic research while withdrawing from applied research. It has also indirectly facilitated private research.

Consequently, the question that arises is whether today's government involvement in canola R&D is appropriate or sufficient, and whether it results in an optimal mix and amount of R&D effort and outcomes. There is concern that the growth in the canola sector could be sustained and even increased over time. It has been shown in the literature that in a case of almost complete IPRs coupled with the subsidization of research, the amount of private research could exceed the social optimal amount. This leads to reduced returns to research over time (Malla, Gray, & Phillips, 2004). It has also been shown that private firms invest less in R&D than the socially optimal level even with enforceable IPRs (or, fully appropriable IPRs) because they cannot appropriate all the research benefits generated from their investment (some benefits may be going to the buyers of their products like farmers through the increase in surplus; Malla & Gray, 2003).

Research underinvestment is augmented when the amount of basic research available is not sufficient (or, underprovided). This could be the case at present in Canada as research budgets have been falling.

Moreover, a public undertaking of applied research or expanding applied public research could reduce even further the private R&D incentives (crowd out private applied research) as the public and private sector compete for the same market. However, in the situation where basic research is underprovided, public provision of basic research could increase incentives for private firms to undertake more research. In addition, the appropriate amount of government subsidy on the cost of R&D could increase the amount of applied research to the social optimum. While a government subsidy on research output has the same effect on R&D as the subsidy on R&D cost, it also increases farmers' welfare and may be a desirable policy from a distributional prospective (Malla & Gray, 2003). This adds support to the public provision of basic research as well as targeted government subsidies as appropriate government policies in the today's biotech industry.

Moreover, it has been shown that restricted access to basic research results (i.e., exclusive licensing) could improve welfare as compared to an unpriced public release of the IP in the case of canola. Specifically, research regarding management of public basic-research intellectual property suggests that "in mature industries where interfirm lump-sum research spillovers are likely to be small … excess entry is likely to exist … restricting access to basic research through either pricing or restrictive licensing is likely to be welfare improving" (Gray & Malla, 2011, pp. 486-487).

Lastly, varieties with health traits or varieties that provide significant environmental benefits could come at the expense of a variety's yield potential and even result in a firm's inability to capture the full value of an investment. This could justify some forms of regulation or government involvement. Hence, the government might play an important role in R&D focused on health or the environment, as the private sector might have inadequate incentives to invest in these technologies. As well, farmers might be unwilling to adapt these technologies (e.g., varieties) without price compensation if the impacts (e.g., yield loss) reduce their overall returns.

In summary, public provision of basic research, targeted government subsidies (e.g., subsidies on the cost of R&D or research output), charging fees above marginal cost to access basic research, or granting exclusive licenses have merit as appropriate government policies that could improve social welfare. Government's role could also be important in R&D regarding varieties with health traits or environmental benefits.

In general, the public should directly invest in areas where industry may not invest (e.g., agronomic research, open-pollinated non-HT varieties) and/or areas where property rights are not defined or well defined; alternatively, the government could provide research resources to match private research expenditures in areas the private sector may not invest in otherwise. The public sector should also play an important role in the provision of basic research.

In closing, the above overview of the Canadian canola sector policies and regulations provides us with insights and lessons that could be used by other crops or countries. However, it was also noted that there is no "one-size-fits-all" economic policy.

Summary and Concluding Comments

The Canadian canola sector has transformed over time due to emerging biotechnology, IPRs, technologies, and a changing role for the government. Prior to 1989, most canola research was a result of public investment and the products of research were public goods. Currently, private firms dominate in research investment and therefore control most of the research output both in terms of new varieties and patented technology. Canadian federal and provincial governments have historically been involved in the direct provision of applied research (such as new varieties) while undertaking basic research. Today the public sector has withdrawn from commercial variety development. Concurrently, the public sector has been facilitating private sector research with means such as private-public collaborations, the subsidization of private R&D, and the provision of infrastructure to facilitate private research.

The introduction of biotechnology and improved IPRs brought a much needed increase in R&D investment into the canola sector; however, it also brought a number of complex issues (such as market concentration, high variety pricing, difficulty in new variety commercialization, mergers, acquisitions, and gene trait cross-licensing agreements) as well as concerns regarding the future of the canola sector and the appropriate role of the government, if any, in today's privatized biotech Canadian canola research sector.

Given all the changes in the canola sector, another issue is whether producers benefit from the new technologies. In this article, we specifically assessed the impact of biotechnology that led to several new HT and hybrid canola systems. We calculated the cumulative benefit of this adoption at $30 billion from 1996 to 2012, and it has been on an upward trend for most of that period. For the 2012 crop year, we estimated the net benefits at $726 million. In this study we also assessed the overall impact of biotechnology in the canola sector; evaluated the potential benefits of new biotechnologies, especially HT and hybridization over time; and examined the evolution of government involvement in Canadian canola R&D over time and the appropriate role of government in today's biotech industry. Some lessons from the Canadian canola experience were also drawn.

There have been significant benefits associated with the new canola varieties. The area seeded to canola varieties, the number of varieties available, and canola yields have increased over time. There are also significant health benefits (or healthcare savings) related to canola oils with health traits. Additionally, there are important environmental benefits associated with new canola varieties and new technologies (e.g., better weed control, better volunteer canola management, reduced tillage). Furthermore, producers benefit significantly from growing new canola varieties. Over time, yield gains and herbicide cost savings led to high gains to farmers from the adoption of HT canola seeding systems.

The evidence suggests that public provision of basic research, as well as subsidies on the cost of R&D and the research output, appear to be appropriate government policies in Canada's canola industry. The common practice of public institutions charging a fee above marginal cost to access basis research or granting exclusive licenses could be welfare improving, as compared to unpriced public release of the IP in the case of canola. Varieties with health traits or varieties that provide significant environmental benefits could come at the expense of yield potential and could result in an inability to capture the full value of firm R&D investments. Government will likely play an important role in this type of R&D. In general, the public sector should directly invest in areas that the private sector industry may not invest (e.g., agronomic research, open-pollinated non-HT varieties) but show high returns to investment somewhere in the supply chain.

Government still has an important role to plays in today's privatized biotech industry but not in the direct provision of applied research, such as IPR varieties and commercialization. The patent system in this sector has generated adequate incentives to trigger major private investment in biotechnology related to canola. Appropriate government policies and programs could contribute to the growth and the competitiveness of the Canadian canola sector, as well as improve the well-being of all parties involved in the sector and in general increase social well-being.

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