AgBioForum, 15(3): 257-275. ©2012 AgBioForum.

The Consequences of Biotechnology: A Broad View of the Changes in the Canadian Canola Sector, 1969 to 2012

Derek G. Brewin
University of Manitoba

Stavroula Malla
University of Lethbridge

This article is a broad assessment of the effect of biotechnology on canola in Canada. We examine the effects of biotechnology on the canola industry in terms of area, varieties, and yields, as well as the returns to research and firm-level benefits. Evidence of the privatization of the canola industry is seen in the dominance of the private sector in the registration of new canola varieties. The latest development in the sector is the dominance of a few private firms, which raises new concerns.

However, the literature and our calculations indicate considerable benefits from canola research and recent technological advances. The area seeded to canola varieties, the number of varieties available, and canola crop yields have been on an upward trend for 50 years. Current producer benefits were estimated to be more than $1 billion and breeding firm returns were more than $700 million.

Key words: biotechnology, canola, mergers, plant breeding, returns to research, technical use agreements.

Introduction[1]

In the discussion of the consequences, opportunities, and challenges of modern biotechnology, few crops have seen a more significant impact than that of canola in Canada. The introduction of biotechnology and intellectual property rights (IPRs) has completely transformed the canola sector in Canada. Prior to 1970, almost all agricultural research in Canada was performed in public institutions, and research results were shared freely. All varieties were open-pollinated and non-transgenic, and there were no effective plant breeder rights (PBRs). In the mid 1980s, PBRs were established in several countries, and some private breeders started to be active in Canada. As technology advanced, patent offices started to recognize biotech processes including herbicide-tolerant (HT) canola. The new patents led the creators of HT canola to use license agreements, which were used to compel farmers to continue to pay for the technology at each planting rather than retaining seed from previous crops. Emerging canola hybrids also facilitated seed replacement, as they require the purchase of seeds every year in order to keep desirable traits. In 2012, a few private firms dominate canola research investment and they control most of the research output both in terms of new varieties and proprietary biotechnology.

The changes in canola seed led to an area increase from less than a half million hectares (ha) in 1968 to more than 8 million ha forecasted for 2012; from less than 5% of crop land in Canada to over 30%. Canola revenues are forecasted to be over $8 billion in 2012 (Agriculture and Agri-Food Canada [AAFC], 2012). Although initial public-sector research was a vital first step, the role of biotechnology was pivotal in creating HT varieties; this in turn facilitated the mass production of hybrid varieties. Together, patentable HT technology and hybrid seeds sales fostered a boom in private canola variety development and farm-level production. While previous studies have shown very high rates of return to canola research, more recent studies have revealed lower (market) rates of returns (Malla, Gray, & Phillips, 2004).

While the introduction of biotechnology and the enforcement of IPRs have created incentives to undertake canola research, it also created a number of complex issues. For instance, concerns have been raised with respect to market concentration as firms merge in the canola seed and herbicide market. More recently, firms have also started using gene trait cross-licensing agreements to facilitate technology sharing (e.g., Galushko, Gray, & Smyth, 2010; Smyth & Gray, 2011; Stiegert, Shi, & Chavas, 2010). Gene trait cross-licensing agreements have led to worries about the close relationships these agreements require between the few

1. *Although it contains a significantly different analysis, parts of this article began as a chapter for the upcoming book, Handbook on Agriculture, Biotechnology, and Development, by Smyth, Castle, and Phillips.*

dominant firms left in the sector. Furthermore, there have been concerns over the 'freedom to operate' problem that exists in agricultural biotechnology when rival firms create economic barriers for the commercialization of second-generation GM crops. There have also been concerns about the pricing of new canola varieties in a concentrated sector, the rules of using new technology, and the appropriate government role in today's biotech canola industry. This has coincided with a change in the nature of technology and the property rights for these research products. Thus, while the enforcement of IPRs creates incentives to undertake research, it also creates a number of complex impediments to future progress and a potential need for new policies to effectively address today's challenges in the canola industry.

The goal of this article is to assess the effect of advancing biotechnology on the canola industry in Canada. The next sections provide an overview of the canola industry in Canada and then present some IPR issues. The adoption of the biotechnology in the canola industry in terms of area, varieties, and yield are discussed and assessed next. Then, we examine the economic impact of adopting biotechnology in the canola industry in terms of returns to research and firm-level benefits, followed by our conclusion and implications.

A Crop Called 'Canola'

The name 'canola' was first used in 1978 when a modified rapeseed was developed by Canadian breeders Baldur Stefansson and Keith Downey[2] using traditional breeding techniques with modern testing procedures. The word canola can only be applied to rapeseed varieties that are "less than 2% erucic acid and…less than 30 μmol of glucosinolates per gram of air-dried, oil-free meal" (Casséus, 2008, p. 2). Like most of the agricultural research done in Canada before 1985, Stefansson's and Downey's research was publicly funded. Total public investments in rapeseed in the early 1970s were around $18 million (Malla et al., 2004). The rise of breeder's rights did lead to some private-sector breeding

2. *There is a small controversy over who the "Father of Canola" was: Manitoba claims it was Stefansson, who developed low-erucic acid varieties in 1968, and Saskatchewan claims it was Downey, who improved the sorting techniques used by several breeders as they chased the low glucosinolates in 1970. Scientific papers clearly show they were working together along with other researchers at the AAFC Research Station in Saskatoon (Downey & Harvey, 1963) and the University of Manitoba (Stefansson, Hougen, & Downey, 1961).*

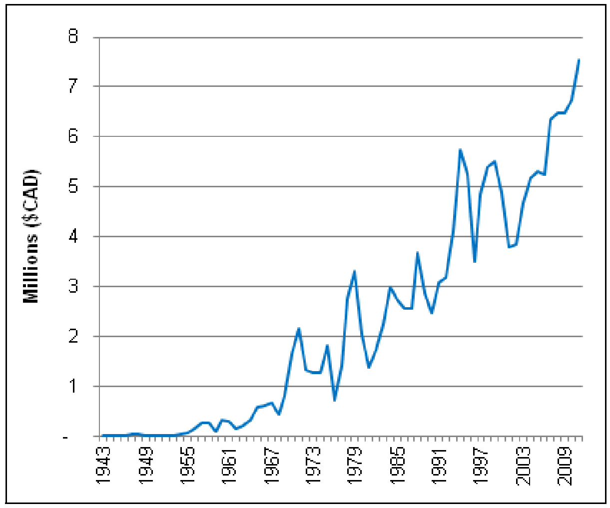

Figure 1. Area in hectares of rapeseed and canola, 1943 to 2011.
Source: Statistics Canada (2011)

investments in the mid 1980s, but the most dramatic shift in canola seed development began with the invention of HT varieties and soon thereafter the release of hybrid varieties in the mid 1990s. The first HT canola was introduced in 1996. HT canola has become very popular; it is now a trait in most of Canada's canola crop.

The area planted to canola has grown as varieties with improved yields and herbicide resistance made it a favorite crop in Western Canada. The area planted has been growing steadily since 1971 to well over 7 million hectares in 2011 (see Figure 1).

The popularity of canola with farmers and the possibility of huge revenues from seed sales have led to significant private investments in canola breeding (Gray, Malla, & Phillips, 2001; Malla & Gray, 2005). Currently, the vast majority of canola research is managed by the private sector (see Figure 2). Despite the considerable growth in the canola industry, even the private sector's most stringent supporters argue for continued support from the public purse. Note the references to public research and government support in the following quote:

> "Canola owes its success to innovation, from seed development through production practices to new uses and benefits…. Research, both private and public, is critical to innovation…. The Canola Council is coordinating focused research in partnership with AAFC. The program is driven by producers, industry, and researchers, who collectively determine the priorities and

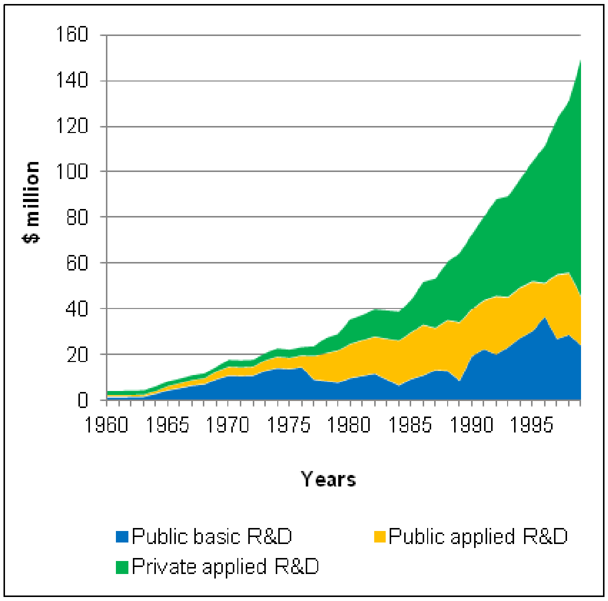

Figure 2. Research expenditure in the canola industry (1960-1999).
Source: Gray et al. (2001)

> then implement the research plan. While canola is a big crop in Canada, it is dwarfed by other competitive commodities in the international marketplace, like soybeans and palm. These industries are investing in innovation. We need to ensure a continued partnership between industry and government in Canada on research in order to stay competitive. Research needs to be industry-driven, supported by government, and we must make the most efficient use of resources" (Evidence from the Hon. JoAnne Buth[3] [then President, Canola Council of Canada] at the Canadian House of Commons, Standing Committee on Agriculture and Agri-Food, October 6, 2011).

This quote demonstrates the political push for a continued role for government policy and financial support even in the privately dominated canola seed market. Private researchers still benefit from base research and financial research incentives, and as the sector evolves, policy might need to focus on the problem arising from concentration among the firms and relaxing the freedom to operate. However, there is no doubt that the implementation of PBRs and the implementation of IPRs through technical agreements helped transform this industry. The next section will discuss some of the theory and practice of IPRs in Canada's canola industry.

Intellectual Property Theory and Practice in Canadian Canola

As canola changed from a predominantly open-pollinated, conventional crop to a hybrid HT crop, the role of the private sector expanded. This was facilitated by improving PBRs and testing the patents for biotechnology in court. In 1970, 83% of the total $18 million spent on canola research was from public sources, and 17% was from private sources (Gray et al., 2001; Malla & Gray, 2005). In 1980, research investments were 69% public and 31% private. By 2000, the private sector's share of canola research had grown to 70% of the total $149 million invested. Today, private research firms dominate the canola industry (see Figure 2).

HT has been deemed by many developed countries, including Canada, to be a patentable process and this patent protection has been used to compel farmers to sign technical use agreements (TUAs) when they buy HT seed. The TUA normally forbids the famers from saving some of their production for seed next year and forces new seed purchases every year in order to use HT technology. The patent protection was tested and upheld in the landmark case of *Monsanto v. Schmeiser*, which was eventually considered by the Supreme Court of Canada in 2004 (Lexum, 2004).

HT was also a valuable tool in solving the challenging problem of creating hybrid canola varieties. HT systems facilitate crossing because herbicides can be used to sterilize one half of a population of plants in the field (P. McVetty, personal communication, 2011). Hybrid technology does two things. First, it eventually fueled increases in yield because of the hybrid vigor that comes from crossing different parent lines: current hybrid varieties are normally at least 20% higher yielding than open pollinated options.[4] Second, the move to hybrid varieties further supported private incentives to develop new canola varieties because hybrid seeds are sold after the last crossing. Subsequent use of this seed will not

3. *The Honorable JoAnne Buth was named to Canada's Senate in January 2012.*

4. *The highest-yielding popular recent hybrid is Invigor 5070; indexed at 178.0, it is 20% higher yielding than the most recently bred, widely planted, open-pollinated, non-HT variety Quantum, which has an index of 147.9. Some open pollinated HT varieties are indexed closer to the hybrid yields, but these have not been widely used since 2000. Since 2000, total hybrid yields on seeded land have been roughly 24% higher than open-pollinated yields.*

Table 1. New varieties developed by institution and by period.

	1950-1959	1960-1969	1970-1979	1980-1984	1985-1989	1990-1994	1995-1998
				B. napus			
Total varieties by public institutions	1	4	5	4	8	8	10
Total varieties by private institutions	0	0	0	0	12	39	76
Total varieties	1	4	5	4	20	47	86
Number of active institutions	1	2	2	3	11	17	17
				B. rapa			
Total varieties by public institutions	1	2	5	1	1	4	2
Total varieties by private institutions	0	0	0	0	3	7	16
Total varieties	1	2	5	1	4	11	18
Number of active institutions	1	2	1	1	3	7	4

Source: Phillips and Khachatourians (2001)

Table 2. Adoption rate for HT canola varieties (million acres).

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Total canola acres	12.0	13.2	13.6	11.9	9.3	8.9	11.4	11.9	12.6	12.9	15.5
Roundup Ready	0.5	2.8	4.9	4.3	4.0	4.0	5.5	5.7	6.1	5.7	7.0
Liberty Link	1.0	1.6	2.5	1.8	1.5	1.5	2.4	3.7	4.2	5.2	6.2
Clearfield	1.7	2.2	2.5	3.0	1.9	1.4	2.6	2.2	1.8	1.4	1.7
Total HT	3.2	6.6	9.9	9.1	7.4	6.9	10.5	11.6	12.1	12.3	14.9
% HT	26.3%	50.0%	72.8%	76.5%	79.6%	77.5%	92.1%	97.5%	96.0%	95.3%	96.0%

Source: Total canola acres: Canola Council of Canada (2008)

lead to the same hybrid vigor yields. Farmers using hybrid varieties require new seed each year, so seed sales are significant. Hybrids now make up 85% of all canola seeded area in Canada.

Together with the patent-supported TUAs, hybrid seed sales have led to significant returns to the private sector. Revenues from seed sales in the canola market are now normally in the neighborhood of $100/hectare in most of Western Canada (Manitoba Agriculture, Food, and Rural Initiatives [MAFRI], 2011; Saskatchewan Ministry of Agriculture [SMA], 2011).

Various authors have argued that the economic benefits for producers by growing HT canola are significant (e.g., Gusta, Smyth, Belcher, Phillips, & Castle, 2011; Phillips, 2003; Serecon Management Consulting, Inc., 2001, 2005). These benefits come from the agronomic benefits of new HT varieties as well as the gain in productivity from improved breeding and hybridization (Veeman & Gray, 2010).

The introduction of biotechnology and IPRs has completely transformed the range of varieties in the Canadian canola industry. Prior to 1995, the dominant varieties in terms of area were all developed by public institutions. Single varieties dominated the area for several years at a time. Then PBRs were introduced. From 1995 to 1998, 88% of the 104 varieties registered were private. Today, almost all of the canola varieties available are private and more than 96% of the total varieties are HT (see Tables 1 and 2). In 2001, private firms earned more than $250 million in seed sales revenue and had effectively crowded out all public-sector varieties (Gray et al., 2001; see also Figure 3). In 2012, seed sales will be closer to $800 million. Moreover, most canola patents are held by private companies. The public sector also has moved to protect and actively commercialize IPRs (see Tables 3 and 4).[5]

Prior to effective PBRs and IPRs, most research was a result of public investment, and the products of research (or research output) were also in the public

5. *In 2005, 75% of Canadian university IPR license agreements with private firms were exclusive in nature, which is also common practice among US institutions (Gray & Malla, 2011).*

Table 3. Ownership of oilseed herbicide-tolerance patents in Canada: 2006.

		Public		Private					
Patent date	Individual	CAN	US	US MNE*	US small	EU MNE	EU small	CAN small	Total
Pre Oct. 1, 1989	1	2	0	2	2	2	1	0	10
Post Oct. 1, 1989	0	0	3	16	2	5	0	2	28
Total	1	2	3	18	4	7	1	2	38

** = Multi-national enterprise; Source: Smyth and Gray (2011)*

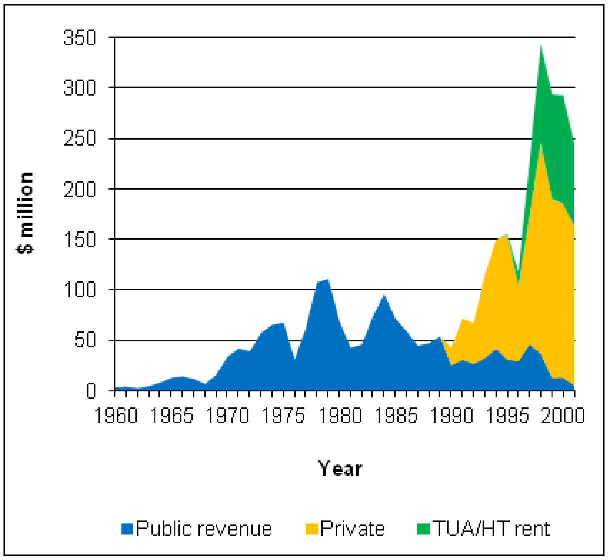

Figure 3. Crop research revenues in the canola industry.
Source: Gray et al. (2001)

domain as public goods (e.g., Malla & Gray, 2003, 2005). Government intervention was justified primarily on the basis that research outcomes were non-excludable (meaning that the inventor did not have the ability to exclude others from using, reproducing, or selling the new technology or products created from R&D), thus creating limited private R&D incentives. The government intervened to correct the market failure.

The introduction of biotechnology, IPRs, TUAs, and hybrid varieties has allowed the creation of excludable goods in the canola sector. This in turn created incentives for private investment because the inventor could extract most of the economic rents from research investments by retaining ownership over the new technology (Malla & Gray, 2003, 2005). Despite the considerable growth in private investment, the government continues to make large public investment in research—especially in basic research. This may create a positive spillover to private firms, as many successful industries are based on breakthrough innovations created in the public sector, and in turn could result in excess firm entry into the industry (Gray & Malla, 2011).

Table 4. Ownership of canola patents in Canada: 2011.

Year	Private	Public
1869-1989	7	3
1990-2006	20	12
2006-2011 (July 28th)	14	13

Source: Canadian Intellectual Properly Office (CIPO) database; Authors' estimates

At the same time, the non-rival (meaning that anyone can use the technology created from R&D over and over again) nature of research output has tended to create a concentrated research industry as firms move to capture economies of scale and scope, and technologies are marketed at a price that exceeds marginal cost. A further push towards concentration occurs when firms adopt strategies to preserve their own freedom to operate through vertical integration, mergers, acquisitions, and joint-venture arrangements. The concentrated nature of the research industry and the exclusive ownership of key pieces of IPRs give research firms some degree of market power; through higher prices, this reduces the incentive for product innovation and adoption downstream (Malla & Gray, 2003; Moschini & Lapan, 1997). Galushko et al. (2010) also showed that the move to protect IPRs in the canola industry has reduced the sharing of knowledge in both the public and private sector, increasing significantly the cost of conducting canola breeding research. Hence, the structure of the canola and broad agricultural research industry has been fundamentally altered.

The canola sector has seen mergers.[6] Some 25 firms have released successful seed varieties, but mergers and acquisitions have reduced the major firms to 14 (not including three universities). Table 5 lists the private firms—some of which have been amalgamated—by their share of seed revenues in 2008. The four largest firms currently involved in canola seed sales are: Bayer Crop Science, Dow Agrosciences, Monsanto, and Pio-

6. *Svalöf Weibull AB, a subsidiary of the Swedish Farmers Supply and Crop Marketing Association, created a new company with BASF (Phillips, 2001).*

Table 5. Share of seed revenues for 2008, by firm or public institution.

Canadian firms/institutions	Share of seed revenues
Public	
Advanta Canada Inc.	0.31%
Bayer Crop Science	55.14%
Brett-Young Seeds	1.01%
Canterra Seeds Ltd.	1.77%
Cargill Specialty Oils	6.55%
Maribo / Danisco Seed	0.00%
DLF-Trifolium	0.08%
Dow Agrosciences Canada Inc.	8.79%
Monsanto Canada Seeds Inc. / Calgenne / Limmagrain	10.48%
Norddeutsche Pflanzenzucht Hans-Georg	0.18%
Pioneer Hi-Bred Production Limited	10.63%
Svalöf Weibull AB	0.00%
Viterra / Sask Wheat Pool / Agricore / Proven Seeds	4.49%
Public	
Agriculture Canada	0.09%
University of Alberta	0.04%
University of Guelph	0.00%
University of Manitoba	0.43%

Sources: Alberta Seed Guide (ASG; n.d.); Gray, Malla, and Tran (2006); Manitoba Agricultural Services Corporation (MASC, 2011); Prairie Pools, Inc. (n.d.); Saskatchewan Seed Growers (SSG, 2011); Seed Manitoba (n.d.); Statistics Canada (2011); and authors' calculations.

neer Hi-Bred. Together they control 85% of all seed sales. Bayer has more than 55% of all seed revenues due to the success of their Liberty Link system.[7] The 10.48% shown for Monsanto underestimates their success of their Roundup Ready glysophate technology, which is used by all of their competitors except Bayer—and even Bayer will likely start to use it with recent cross-licensing agreements.

It has also been argued that concentrated breeding firms would try to capture much of the benefit farmers received from new traits through seed costs or TUAs. For example, the Fulton and Keyowski (1999) calculations suggested that the 'average' farmer was no better off using various seed/herbicide systems. This pricing of TUAs and now the pricing of hybrid seed is a great concern to primary producers who feel captive to a few large firms (Keystone Agricultural Producers [KAP], 2011). However, we show that in 2011, competition and prices have been strong enough that most farmers see a significant gain from new technologies over open-pollinated, non-HT canola varieties.

Additionally, when IPRs are well established, the negotiation of the rights to use innovations can become difficult and expensive, especially when a research product embodies many pieces of IPRs. Specifically, the introduction of a single genetic trait into a product of biotechnology can require the use of many separate pieces of IPR. Before the innovator can have 'freedom to operate' the innovator must reach an agreement with each of the other patent owners. If the ownership of the IPR is dispersed, negotiating 'freedom-to-operate' agreements to share the proceeds from the innovation is an expensive, time-consuming process and can be subject to delay by any of the parties involved (Falcon & Fowler, 2002). The high transaction costs associated with the exchange of IPR have also adversely affected the structure of the private and public research industries and have created an economic barrier for the commercialization of second generation GM crops.

The resulting problems in freedom to operate could create a tragedy of the anticommons that results in the underuse of resources and less innovation (e.g., Buchanan & Yoon, 2000; Falcon & Fowler, 2002; Graff, Cullen, Bradford, Zilberman, & Bennett, 2003; Heller & Eisenberg, 1998; Wright, 1998). "The anticommons arise whenever individuals have the ability to exclude others from using a resource but cannot use the resource themselves" (Smyth & Gray, 2011, p. 184). A tragedy of the anticommons can occur when there are economies of scale in germplasm development, but issues with property rights (freedom to operate) lead to less innovatory activity as competing inventors block activity with patent protection (Galushko & Oikonomou, 2007). Hence, too many property rights could lead to less innovation, as competing patent rights could actually prevent research activities to be undertaken or products from reaching the marketplace.

More recently, Canadian canola firms have moved away from mergers and acquisitions towards gene trait cross-licensing agreements to facilitate technology sharing (Galushko et al., 2010; Smyth & Gray, 2011; Stiegert et al., 2010). For example, an important gene trait cross-licensing agreement was made between the largest life science firms in the canola sector—Monsanto and Bayer Crop Science—in order to fight against the tragedy of anticommons (Smyth & Gray, 2011). Canola varieties with traits owned by these two firms account

7. *A single variety, InVigor 5020, raises revenues roughly equal to the total revenue for the three next-largest firms.*

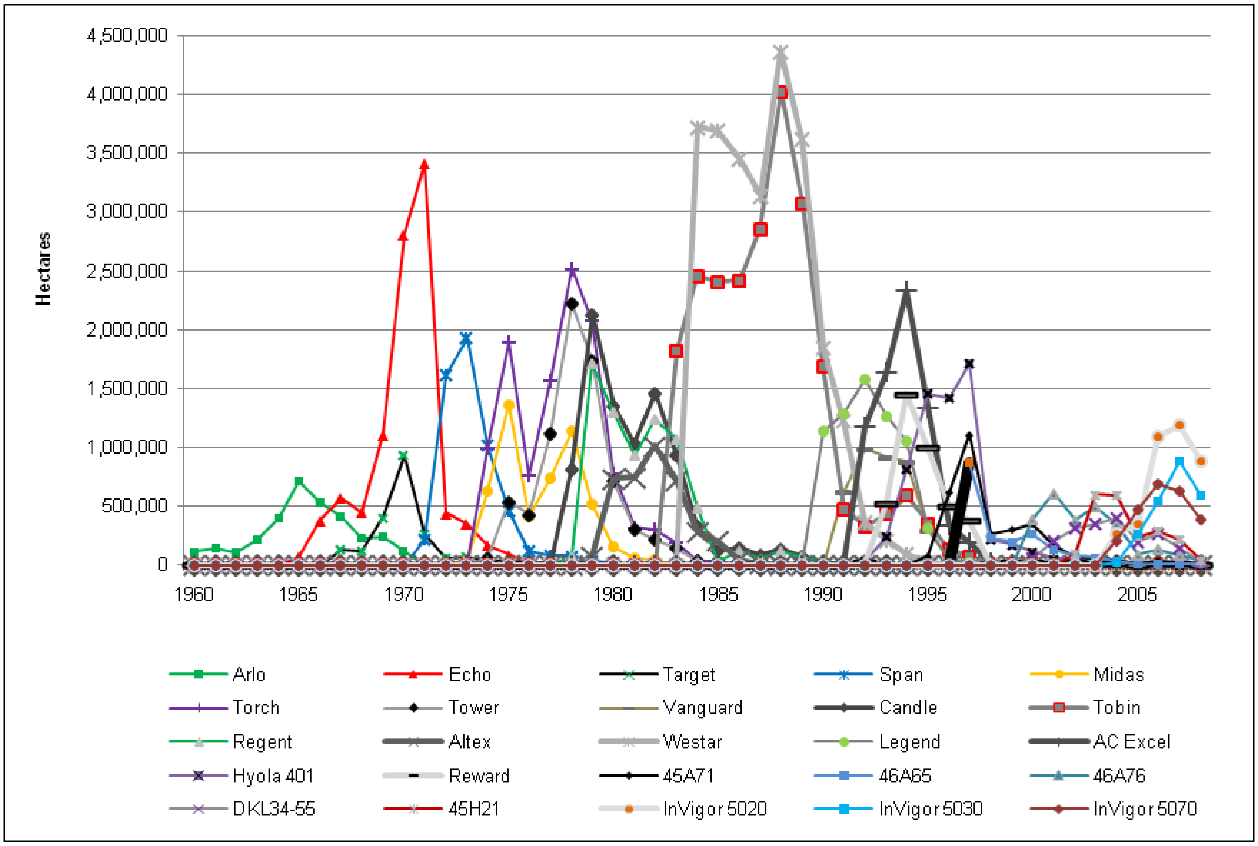

Figure 4. Top canola varieties by area and dominant breeders over time, 1960 to 2008.

Sources: ASG (n.d.); Gray et al. (2006); MASC (2011); Prairie Pools, Inc. (n.d.); Seed Manitoba (n.d.); SSG (2011); Statistics Canada (2011); and authors' calculations.

for more than 85% of the market. Smyth and Gray (2011, p. 187) provided four possible reasons for the recent switch to gene trait cross-license agreements:

> "first, anti-trust concerns…. Second, fostering and maintaining SME [small or medium size enterprises] innovation…. Third, there is recognition of 'sectoral' benefits to share IPRs. Finally, in perusing cross-license agreements, firms will inevitably have some clauses that outline at least the principles of how embodied traits will be commercialized, and how the potential revenue will be shared…to reassure their shareholders of benefits of the agreement."

However, these agreements raise additional concerns regarding market concentration, which can lead to higher costs for any new technology and lower economic benefits to producers.

Details of the Success of Canola: Area, Varieties, and Yield

Area

The first metric of the success of canola is the area of land that farmers were willing to commit to it. As rapeseed turned into canola and open-pollinated public varieties gave way to privately controlled HT and hybrid varieties, the area of land seeded to canola in Canada has exploded over time. Figure 1 shows the growth in area of rapeseed/canola from 1943 to 2011 (Statistics Canada, 2011). There are three marked increases in area: one increase occurred around 1970—with the low-erucic-acid 'canola' varieties; another jump occurs around 1995, when private breeders and HT varieties entered the market; and the third growth in area began about the time that very-high-yielding Liberty Link hybrids were developed (2004), and the growth continues at present.

The AAFC estimates the area planted to canola in 2012 will be just over 8 million hectares (AAFC, 2012). This would be the first time it has ever been seeded on more hectares than spring wheat in Canada. Production was estimated to be 14 million metric tonnes in 2011. The industry had a target of 15 million metric tonnes by 2015 (Canola Council of Canada [CCC], 2008). This target could be met in 2012 if AAFC forecasts are correct. The flexibility of herbicide tolerance and the higher-yielding hybrids—along with good prices—have made canola a vitally important crop on the Canadian prairies in terms of revenue.

Varieties

A second key metric of the major shifts in the canola sector is the ownership and number of varieties of canola entering the market place. Table 6 lists the 50 leading varieties in terms of area seeded between 1960 and 2008.[8] Figure 4 shows the area of dominant varieties over time and the breeders who were releasing them. As discussed above, the dominant varieties from 1965 to 1989 were bred by public researchers. Just two of these varieties where used to seed over 9 million hectares in aggregate, at a time when the total area of canola seeded in Canada was normally less than 3 million hectares per year.

The private-sector seed returns discussed in the sections above had a direct effect on variety development and seeded area. These rights were being established in the late 1980s and early 1990s. Full PBRs were enacted in Canada in 1990 (Phillips, 2001). In the late 1980s, a private cooperative from Sweden—Svalöf Weibull AB—began breeding in Canada. They were encouraged to invest in Canada by improved rules in seed registration and the higher returns from seed sales that resulted. By 1994, the dominant seeded varieties in terms of area in Western Canada were from Svalöf. They had bred several high-yielding varieties and were starting to be a market leader. Svalöf varieties and AAFC's AC Excel made up 60% of seeded area in 1994. Svalöf's Legend went on to be seeded on more than 200,000 hectares for six years. Between 1989 and 2008, Svalöf released some 75 canola varieties, 10 of which were in the top 50 in terms of total area.

The first commercially successful canola hybrid was released in 1992 by Advanta. It was seeded on around 6% of the seeded area in 1994. In 1996 Monsanto introduced several glysophate-tolerant varieties. Competing private firms introduced imazethapyr/imazamox(imaz) and glufosinate-tolerant varieties in 1996 and 1997. A glufosinate-tolerant variety was introduced in 1996 by Aventis (which became part of Bayer) and an imaz-tolerant variety was introduced in 1997 by Pioneer (Harker, Blackshaw, Kirkland, Derksen, & Wall, 2000). Herbicide resistance became a key characteristic in the late 1990s. As Fulton and Keyowski (1999) argued, HT canola may have been priced initially at nearly its full benefit to farmers. This may have dampened the initial HT impact on area, but HT was clearly a production tool that farmers valued and it became a standard in the industry. From 1996 to 2007, HT varieties went from 10% to 96% of total area seeded (CCC, 2010). By 2012, privately bred, hybrid, HT canola varieties dominate Canadian acreage. No publicly-owned, open-pollinated variety has seen any significant area since 2001.

The biotechnology that created HT was also helping some firms (especially Bayer/Aventis) to 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, herbicide resistance was also a major factor in seed choice. Higher-yielding hybrid varieties, especially the Liberty Link varieties, saw a significant increase in market share from 2003 to 2008.

Another part of the development of canola seed breeding was the rise of higher-quality oils. High-erucic-acid rapeseed varieties used as industrial lubricants were seeded on several hundred thousand hectares in the mid-1990s. Most of them were developed at the University of Manitoba. Dow Agrosciences released several high-omega-9 and low-linolenic oils under the brand name Nexera in 2000. Just over 1 million hectares were seeded to Nexera varieties from 2000 to 2008. Cargill introduced competing varieties with similar characteristics to Nexera in 2001. Cargill's Victory varieties were seeded on just over 800,000 hectares from 2001 to 2008.

Yield

Crop yield has been widely used as a partial productivity measure in the crop sector. However, measuring crop productivity in terms of crop yields is a very difficult task. For example, the impact of changes in yield;

8. *The area for these varieties was based on Prairie Pools Inc. until 1997; after that, it was based on producer surveys by Western Canadian crop-insurance providers (ASG, 2011; MASC, 2011; SSG, 2011). Some varieties could have been missed—especially after 1997—due to poor survey results in some years.*

Table 6. Top 50 Canadian canola varieties by area 1965 to 2008 (listed according to release).[a]

Variety	Released	HT System	Breeder	Arg./pol.	Pub./ priv.	Yield index	OP, HYB	Total area (ha)
Echo	1965	Conventional	Agriculture Canada	Polish	Public	109.1	OP	3,999,714
Target	1967	Conventional	Agriculture Canada (U of MB)	Argentine	Public	102.0	OP	836,294
Oro	1968	Conventional	Agriculture Canada	Argentine	Public	99.0	OP	753,332
Span	1971	Conventional	Agriculture Canada	Polish	Public	100.1	OP	2,255,389
Zephyr	1972	Conventional	Agriculture Canada	Argentine	Public	100.0	OP	755,219
Torch	1973	Conventional	Agriculture Canada	Polish	Public	100.1	OP	4,657,145
Midas	1973	Conventional	Agriculture Canada	Argentine	Public	127.0	OP	2,067,624
Tower	1974	Conventional	Agriculture Canada	Argentine	Public	109.0	OP	3,044,723
Tobin	1977	Conventional	Agriculture Canada	Polish	Public	90.1	OP	9,395,614
Candle	1977	Conventional	Agriculture Canada	Polish	Public	87.0	OP	3,511,164
Regent	1978	Conventional	Agriculture Canada	Argentine	Public	102.0	OP	2,933,710
Altex	1979	Conventional	Agriculture Canada	Argentine	Public	105.0	OP	1,549,198
Westar	1984	Conventional	Agriculture Canada	Argentine	Public	122.0	OP	10,433,193
Legend	1989	Conventional	Svalöf Weibull AB	Argentine	Private	123.0	OP	2,724,336
Horizon	1990	Conventional	Svalöf Weibull AB	Polish	Private	91.9	OP	1,018,277
Colt	1990	Conventional	Svalöf Weibull AB	Polish	Private	89.2	OP	719,485
Delta	1990	Conventional	Svalöf Weibull AB	Argentine	Private	132.4	OP	628,745
AC Parkland	1990	Conventional	Agriculture Canada	Polish	Public	90.1	OP	765,509
Vanguard	1991	Conventional	Svalöf Weibull AB	Argentine	Private	118.1	OP	1,522,612
Bounty	1991	Conventional	Svalöf Weibull AB	Argentine	Private	132.4	OP	744,856
AC Excel	1991	Conventional	Agriculture Canada	Argentine	Public	119.3	OP	2,910,293
Profit	1991	Conventional	Agriculture Canada	Argentine	Public	110.7	OP	1,344,435
Reward	1992	Conventional	University of Manitoba	Polish	Public	92.8	OP	1,655,547
Goldrush	1992	Conventional	Svalöf Weibull AB	Polish	Private	92.8	OP	740,873
Hyola 401	1992	Conventional	Advanta Canada Inc.	Argentine	Private	121.7	HYB	2,869,540
Garrison	1993	Conventional	Svalöf Weibull AB	Argentine	Private	147.9	OP	977,510
Crusher	1993	Conventional	Svalöf Weibull AB	Argentine	Private	133.6	OP	726,142
Cyclone	1993	Conventional	DLF-Trifolium	Argentine	Private	137.2	OP	618,065
Legacy	1994	Conventional	Svalöf Weibull AB	Argentine	Private	128.9	OP	1,060,984
Quantum	1996	Conventional	University of Alberta	Argentine	Public	147.9	OP	1,843,006
45A71	1996	Clearfield	Pioneer Hi-Bred Production Limited	Argentine	Private	127.7	OP	1,784,873
Ebony	1996	Conventional	Monsanto Canada Seeds	Argentine	Private	122.9	OP	705,345
Innovator	1996	Liberty Link	Aventis CropScience Canada Co.	Argentine	Private	115.7	OP	900,976
46A65	1997	Conventional	Pioneer Hi-Bred Production Limited	Argentine	Private	133.6	OP	1,179,306
Quest	1997	Roundup Ready	Agricore Cooperative Ltd.	Argentine	Private	126.5	OP	1,469,523

Table 6. Top 50 Canadian canola varieties by area 1965 to 2008 (listed according to release).[a]

45A51	1998	Roundup Ready	Pioneer Hi-Bred Production Limited	Argentine	Private	130.0	OP	578,132
DKL3235	1999	Roundup Ready	Monsanto Canada	Argentine	Private	120.5	OP	478,773
46A76	2000	Clearfield	Pioneer Hi-Bred Production Limited	Argentine	Private	152.7	OP	1,494,188
DKL34-55	2000	Roundup Ready	Monsanto Canada	Argentine	Private	128.9	OP	1,162,577
InVigor 2663	2000	Liberty Link	Aventis CropScience Canada Co.	Argentine	Private	162.3	HYB	964,443
InVigor 2153	2000	Liberty Link	Aventis CropScience Canada Co.	Argentine	Private	138.4	HYB	603,405
InVigor 2273	2000	Liberty Link	Aventis CropScience Canada Co.	Argentine	Private	143.2	HYB	596,550
Conquest	2001	Roundup Ready	University of Alberta	Argentine	Public	126.5	OP	499,702
InVigor 2573	2001	Liberty Link	Aventis CropScience Canada Co.	Argentine	Private	158.7	HYB	983,774
InVigor 2733	2001	Liberty Link	Aventis CropScience Canada Co.	Argentine	Private	155.1	HYB	678,581
45H21	2002	Roundup Ready	Pioneer Hi-Bred Production Limited	Argentine	Private	160.4	HYB	1,247,232
InVigor 5020	2003	Liberty Link	Bayer Crop Science	Argentine	Private	169.7	HYB	2,228,406
InVigor 5070	2003	Liberty Link	Bayer Crop Science	Argentine	Private	178.0	HYB	1,509,571
InVigor 5030	2003	Liberty Link	Bayer Crop Science	Argentine	Private	172.4	HYB	1,390,503
DKL71-45 RR	2005	Roundup Ready	Monsanto Canada	Argentine	Private	160.4	HYB	639,132

Sources: ASG (n.d.); Gray et al. (2006); MASC (2011); Prairie Pools, Inc. (n.d.); Seed Manitoba (n.d.); SSG (2011); Statistics Canada (2011); and authors' calculations.

[a] *Table 6 is built on data and methods first described in Gray et al. (2006). The data on the percentage of acreage sown to each canola variety were obtained from: Nagy and Furtan (1978), which covered the period 1960 to 1976; 1977 to 1992 was based on various issues of Prairie Pools Inc.'s* Prairies Grain Variety Survey *(n.d.); 1992 to 2008 was based on MASC (2011), Saskatchewan Crop Insurance Corporation (2009), and Alberta Agriculture, Food, and Rural Development's* Crop Variety Performance Comparisons (n.d.)*.*

The relative yield of different canola varieties and the classifications of each canola variety were based on: Alberta Agriculture, Food, and Rural Development's Crop Variety Performance Comparisons *(n.d.); SSG (2011); Canadian Food Inspection Agency's (CFIA)* Plant Varieties Journal *(n.d.); CFIA's* List of Varieties which are Registered in Canada *(n.d.), Canola Council of Canada's* Prairie Canola Variety Trials *(n.d.); Seed Manitoba (n.d.); and Wright (2011). The Minnesota Canola Production Centre (2004) was used to help in the classification of varieties in terms of public or private. The area seeded to canola was obtained fromStatistics Canada's* Field Crop Reporting Series *(Statistics Canada, 2011).*

changing land uses, such as reduced summer fallow; more cropping diversity; and changes in cropping technology, such as reduced tillage on productivity cannot be easily separated from one another (Veeman & Gray, 2010). Furthermore, important quality changes are not captured in the yield estimates even though they increase the value of the crop. For example in the case of canola, quality changes such as the canola transformation from rapeseed (in the early 1970s), the introduction of HT and hybrid canola varieties (in the middle 1990s), as well as the introduction of canola varieties high in oleic acid (in the early 2000s) are not accounted for in the yield estimates (Veeman & Gray, 2010).

It has been shown in the literature that the average (actual farm) canola crop yields have increased moderately over time, while acreage-weighted research trial yield indexes (yields in experimental trials) grew unevenly but quite rapidly. Specifically, it has been shown that yield trends of the average farm yields for the major crops grown in Canada (wheat, barley, canola, corn, soybean, peas) exhibit constant absolute growth but a declining proportional growth rate (see Figure 5;

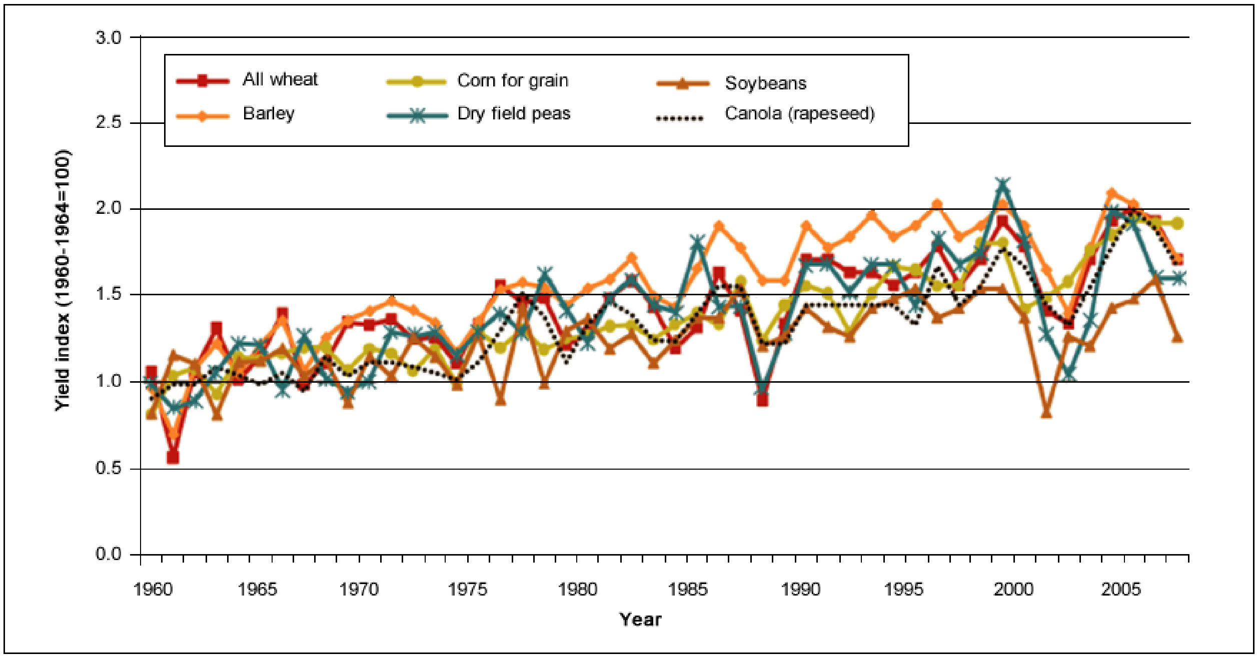

Figure 5. Canadian crop yields, 1960-2007 (base 1960-1964=100).
Source: Veeman and Gray (2010), [CANSIM Database]

Veeman & Gray, 2010). From the 1960s to 2007, the yields of canola—like the other major crops—increased by about 60%, and a linear trend was supported from the data in this period; this implies a constant absolute growth and declining proportional growth rates in yield. Regarding research trials or experimental yield indices for canola, it was also concluded that

> "canola yields in experimental trials grew rapidly until 1972, but this growth was reversed from 1975 to 1983 as canola, with low glucosinolate and low eurcic acid replaced rapeseed, with the accompanying yield drag of any major crop transformation. Canola trial yields then increased significantly from 1986 to 1994, only to retreat in the late 1990s as herbicide-tolerant varieties were adopted, with major agronomic benefits to growers in terms of weed control but again with the accompanying yield limitations of a major change in the available varieties. Since 1998, canola yields have again grown rapidly, as hybrid varieties have been developed and widely adopted" (Veeman & Gray, 2010, p. 131; see also Figure 6).

The yield indexes presented in Table 6 use reported experimental trials from government and farmer cooperative sources to show the same basic pattern as Veeman and Gray suggested above.[9] Using some of the pre 'canola' varieties as the starting index (100), drastic yield jumps have occurred due to single varieties like Westar in 1984 (122), Delta in 1990 (132.4), Garrison in 1993 (147.9), and InVigor 2663 in 2000 (162.3). There were dominant varieties with lower yields in the late 1970s and mid-1990s as the breeders worked around the drags suggested by Veeman and Gray that were caused by the conversion of rapeseed to canola and the introduction of HT. The current dominance of hybrids is also shown in Table 6. Since the introduction of hybrid HT InVigor 2663, only one variety that saw any significant area was not a hybrid; it offered a yield disadvantage of nearly 30% over the top-yielding hybrid.

The overwhelming evidence from the review of a growing seeded area and changing varieties, in terms of ownership and yield potential, is that canola has been readily adopted by farmers as a viable and adaptable crop. Public canola breeding has largely been replaced by an emerging and evolving private sector, and that sector has developed drastically improved seeds.

9. *Table 6 uses methods that were mentioned in Gray, Malla, and Tran (2006) to index variety yields.*

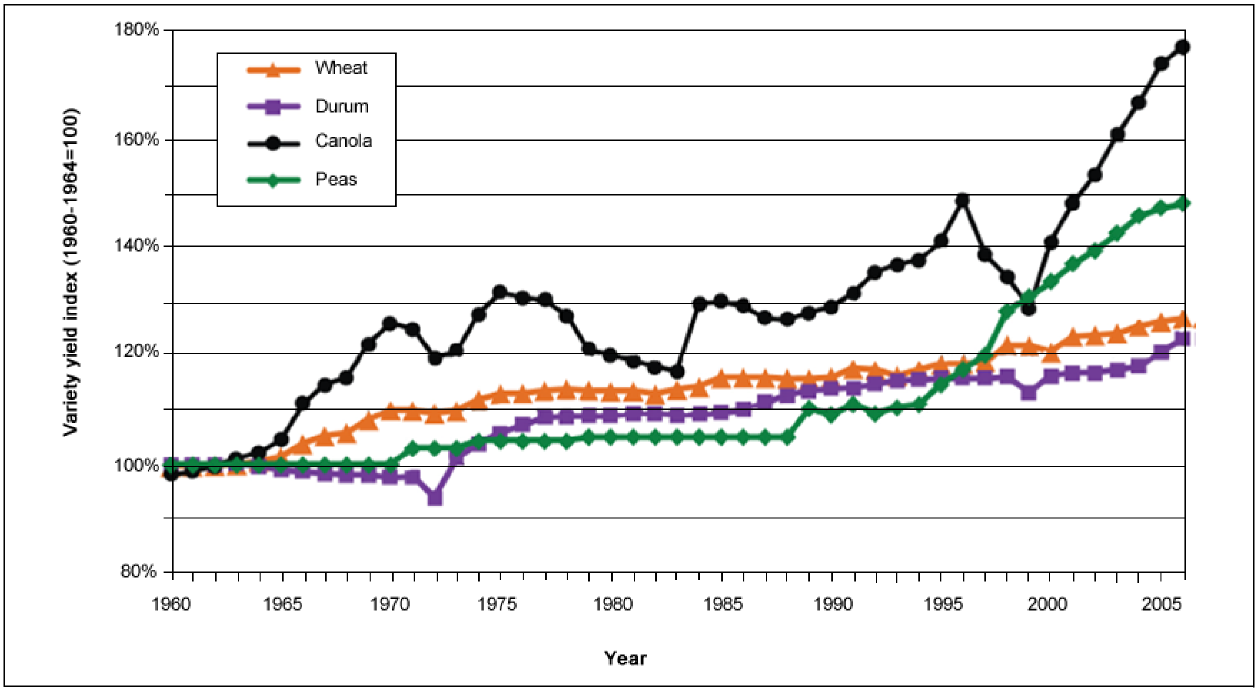

Figure 6. Research trial yield indexes for selected Canadian crops, 1960-2006 (1960-1964=100).
Source: Veeman and Gray (2010), based on research trial data and seeded area.

Economic Impacts: Returns to Research and Farmer Benefits

Agricultural research typically generates very high returns on investment. It was estimated based on 294 post-war studies from around the world of returns to agricultural R&D investment (1,858 estimates) that the annual internal rate of return (IRR) averaged 64.2% per year for research only, 46.3% per year for research and extension combined, and 75.6% per year for extension only (Alston, Marra, Pardey, & Wyatt, 1998). It was concluded that "there is no evidence to support the view that the rate of return has declined over time" (Alston et al., 1998, p. 27). Furthermore, a summary of the Canadian studies on returns to agricultural research (1978-2001) revealed that

> "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…. Overall, it appears that public agricultural research is one of the highest payback uses of public funds" (Brinkman, 2004, p. 132).

In the case of canola, older studies have shown there are very high rates of return to research investment, while more recent studies show returns at market rates. Nagy and Furtan (1978) calculated the IRR from improved yield research to be 101% and the benefit to cost ratio equal to 17.64 (1960-1974). Ulrich, Furtan, and Downey (1984) estimated that the IRR from improved yield research was equal to 51% (1951-1982). Ulrich and Furtan (1985) found that the estimated Canadian IRR from higher-yielding varieties was equal to 50% when trade effects were incorporated. Regarding the distribution of benefits, Nagy and Furtan (1978) calculated that 47% of the total gain accrued to producers, while Ulrich et al. (1984) and Ulrich and Furtan (1985) concluded that producers could lay claim to 68% and 65% of the gains, respectively.

In a more recent study that examined the gains to canola research in the presence of intellectual property rights and research subsidies (1960-1999), it was shown that the rate of return to canola research has diminished since the early 1980s and approached market rates by the mid-1990s (Malla et al., 2004; see also Figure 7, Model 1 & 2). Specifically, the average IRR initially exceeded 25% per year but steadily declined from 1970 to 1999; it eventually approached the level of market returns. Furthermore, the IRR for the marginal dollars invested each year showed a much more dramatic decline and was below a market rate for IRR during the 1990s. Consequently, it was concluded that

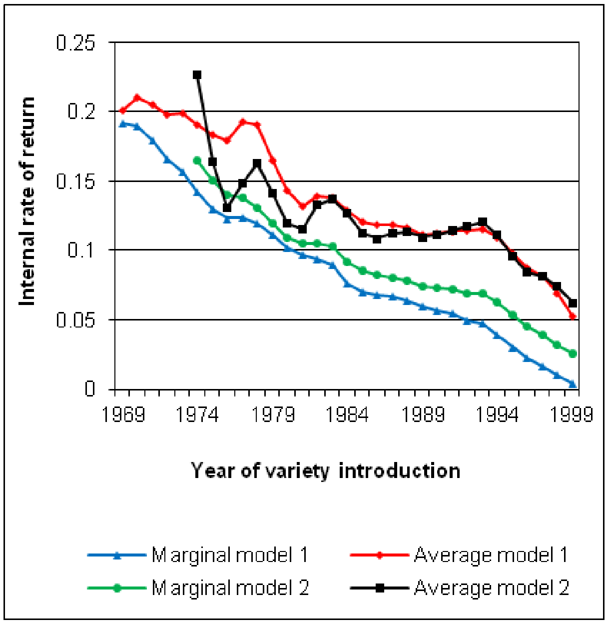

Figure 7. The marginal and average IRR for canola research 1968-1999.

Source: Malla, Gray, and Phillips (2004)

> "the influx of private investment into crop research, which has accompanied the establishment of intellectual property rights (IPRs) and the introduction of biotechnology, suggests high rates of return. However, the empirical analysis of the canola research sector shows a decline in the total net return to research during a period of increased investment, indicating that net marginal returns to research have been negative…. The combined effect of IPRs and public incentives has driven the quantity of research beyond the socially optimal" (Malla et al., 2004, p. 63).

Finally, it was suggested that when nearly complete IPRs exist, government incentives for research (e.g., research subsidies) could reduce social welfare (Malla et al., 2004). This poses a clear problem when compared to the request for public funds mentioned by the president of the Canola Council above.

Additionally, a number of studies have examined the economic benefits of genetically-modified, herbicide-tolerant canola (GMHT) for producers and revealed significant gains. Specifically, it was estimated that the producers' benefits from GMHT range from $60 to $70 million in 2000 (Serecon Management Consulting, Inc., 2001; Phillips, 2003, respectively). According to the report by Serecon Management Consulting, Inc. (2001), the main determinants of the producers' benefits were 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. Phillips (2003) estimated the broad economic impacts on the global economy with the adoption of the new technology, as well as the direct and indirect effects on producers; these included higher seed costs, lower herbicide costs, fewer herbicide applications, lower dockage, and earlier seeding. Finally, the study by Serecon Management Consulting, Inc. (2005) for the CCC examined the management of volunteer GMHT canola and assessed that there were net benefits to growing GMHT canola instead of open-pollinated, non-HT varieties.

Recently, Gusta et al. (2011) also examined the producers' benefits from GMHT based on an 80-question producer survey from 2007. The survey was focused on three major impacts: reduced tillage (cost of weed control), cost of volunteer control (when GMHT canola becomes an in-crop weed or volunteer), and spillover (multi-year benefits due to fewer weeds or easier weed control on fields next year). They concluded that "the new technology generated between $1.063 billion CAD and $1.192 billion annual net direct and indirect benefits for producers from 2005-2007; this is partly attributed to lower input costs and partly attributed to better weed control" (Gusta et al., 2011, p. 1; also see Table 7). The Serecon Management Consulting, Inc. (2001) and Phillips (2003) studies did not take into account the impact of any spillovers or any increased costs from controlling volunteer canola like the study of Gusta et al. (2011).

In addressing returns to heterogeneous farm populations, Fulton and Keyowski (1999) estimated and compared the producer benefits of different canola product lines (Roundup Ready, Liberty Hybrids, and open pollinated) for 1999 values. They argued that

> "the pricing and adoption of HR [herbicide-resistant] 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, p. 85).

Hence, they argued that the differing agronomic, management, and technological factors facing each farm are very important determinants of the benefits of HR. Their

Table 7. Economic benefit of GMHT canola (2005-07; all figures in million $CAD).

			Spillover			Cost of	Total benefits	
Year	Acres	Direct	Low	High	Reduced tillage	volunteer control	Low	High
2005	12.6M	$141	$63	$103	$153	$14	$343	$383
2006	12.8M	$143	$64	$105	$153	$14	$346	$387
2007	14.8M	$165	$73	$121	$153	$17	$374	$422
Average	13.4M	$150	$67	$110	$153	$15	$354	$397

Source: Gusta et al. (2011)

Table 8. Canola product lines: A system comparison of costs and benefits.

Farmer system costs[1]	Roundup Ready	Liberty Link	Clearfield	Open pollinated	Total
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	$107.94	
Gross returns					
Yield (tne/ha)[2]	1.90	1.91	1.72	1.57	
Commodity price ($/tn)[3]	$530	$530	$530	$530	
Expected gross ($/ha)	$1,005	$1,013	$911	$833	
Less system costs ($/ha)	($147)	($146)	($156)	($108)	
Net farm returns ($/ha)	$858	$867	$756	$725	
Total benefits[3]					
Share of seeded area (ha)	3,680,000	3,760,000	480,000	80,000	8,000,000
Farmer gains over OP	$488,107,707	$533,302,020	$14,707,653	$0	**$1,036,117,379**
Seed revenues	$496,019,472	$441,142,000	$58,485,648	$2,707,120	$998,354,240
Research costs[4]	$59,800,000	$61,100,000	$7,800,000	$1,300,000	$130,000,000
Seed production[5]	$63,480,000	$64,860,000	$8,280,000	$1,380,000	$138,000,000
Net return to breeders	$372,739,472	$315,182,000	$42,405,648	$27,120	**$730,354,240**

Sources: [1] 2011 costs estimated from MAFRI (2011) and SMA (2011).
[2] Yields estimated by authors using Manitoba average annual yield and indexes from same sources as in Table 6.
[3] These estimate are based on 2011 costs but 2012 forecasted area of 8 million Ha and forecasted price.
[4] Research costs inflated by 1.3 based on Gray et al. (2001).
[5] Seed production costs: see footnote 11.

analysis for an average farmer showed no gains from the new technologies above the conventional 1999 open pollinated systems.

However, when we update Fulton and Keyowski's estimates of benefits to farmers under different production systems using current 2011 values, farmers (and breeders) appear to gain significantly by using the new technologies versus open-pollinated canola (see Table 8). Specifically, using 2011 costs and AAFC price forecasts (AAFC, 2012), the average benefits for producers using Roundup Ready and Liberty Link appear to be over $850/ha and are much higher than an open-pollinated system. These gains remain significant even under a wide range of canola prices (see Appendix Tables A1 and A2). Using yield tests for the dominant varieties (the same sources as used for Table 6), we calculate a much lower yield for an open-pollinated system relative to the other systems.[10] At current prices, these higher yields for new technologies create a significant benefit, even with higher costs to use the new technologies. The gains from better seeds far outweigh the costs for the seed, TUA, and herbicide. Farmer benefits from Bayer's

Liberty Link system and the dominant Roundup Ready systems are estimated around $133 per hectare more than the returns to open-pollinated systems. These two systems account for 94% of the area seeded to canola in Canada (CCC, 2010). Looking at system-wide benefits, we use AAFC's 2012 estimate for seeded area for canola of 8 million hectares. It appears that average farmer benefits (an aggregate of Roundup Ready, Liberty Link, and Clearfield systems) would be over $1 billion for 2012. This large figure does not include the farmer benefits due to heterogeneity, as the differences between farmers can further augment these average benefits—as was shown by Fulton and Keyowski (1999).

Additionally, breeding firms also significantly benefit from the new technologies even over a range of prices (see Table 8 and Appendix Tables A1 and A2). Currently, the average seed and TUA costs to producers total just under $125/ha for canola across Western Canada (MAFRI, 2011; SMA, 2011); combined with the 2012 AAFC areas estimates, these result in approximately $1 billion in revenues to the seed industry. Furthermore, Gray et al. (2001) estimated private research investments at roughly $100 million in 2001 (or around $130 million in 2012 dollars). So, breeders face some research costs and they must also produce the seed itself. The seed production costs are lower for canola because of the low seeding rates (6.2 kg/ha of seed can yield 1,800 kg/ha) relative to other crops used in Canada, such as wheat. Even if seed production costs are $5,000 per hectare for seed growers, total seed production costs would be less than $140 million.[11] Consequently, given seed revenue, research cost and seed production, the net benefit or return to breeders could approach $750 million in 2012. This does not include any return from herbicide sales.

Like farmers, the distribution of benefits to canola research firms likely varies widely. Note that currently a single firm (Bayer) receives around 55% of total seed revenues. Monsanto is also getting significant revenues from their own seed sales and in royalties from their competitors who are using Roundup Ready technology (on nearly half of the area). However, as Figure 4 showed, the area of winning varieties is falling over time and the length of time a variety dominates the market is decreasing as well; this affects the risks of canola seed production, especially for smaller firms. The chances of developing a variety with the area and lasting power of Westar or Tobin are getting very low. This reduces expected returns and has likely led to lower research investments for smaller firms. For the dominant firms, current seed revenues offer a substantial capital advantage over their smaller competitors and the ownership of patents on market-tested technology can earn them extra benefits in royalties for several decades. The large firms are booming and the small firms face reduced opportunity, thus the sector is expected to contract further.

Conclusion and Implications

The introduction of biotechnology and the development of IPR protection in plant breeding provided new incentives for massive private investment into canola research, but it also resulted in research fragmentation and patent/IPR ownership; a series of mergers and acquisitions; and, more recently, a need for gene trait cross-licensing agreements. All of these changes could affect the incentives for product innovation, variety adoption downstream, knowledge sharing, and could increase the cost of conducting research. Other issues—such as freedom to operate, economic barriers for the commercialization of new varieties, the underuse of resources, and less innovation (tragedy of the anti-commons)—could affect the returns to research and the distribution of benefits. Some research suggests the returns to research have begun to drop off toward market rates (Malla et al., 2004). Current budgets presented above, however, suggest significant gains to producers and returns to breeders in the current seed market.

The overall assessment of the effect of advancing biotechnology on the canola industry in Canada is very important, especially given that few crops have seen a more significant role than that of canola in Canada in terms of the consequences, opportunities, and challenges of advancing biotechnology.

To address the assessment of biotechnology on canola, we draw on related literature and attempted our own estimates. We examined the effects of biotechnology on the canola industry in terms of area, varieties, and yields, as well as the returns to research and firm-level benefits. The success of canola as a major crop in Canada is linked to the modification of the seed, initially

10. *Fulton and Keyowski (1999) might have had a different data source, but the dominant open-pollinated variety for 1999 was Pioneer Hi-Bred's 46A65, which had a tested yield of about 82% of Bayer's Invigor 2273. Pioneer's 46A65 is still the open-pollinated variety in 2011.*
11. *Each of the eight million seeded ha will need 6.2 kg of seed or a total of 49,600 metric tonnes of seed. About 27,600 ha of production would be needed to supply that seed. This would cost around $138 million at $5,000/ha.*

by public researchers and more recently by private researchers mainly through biotechnology. Evidence of the privatization of the canola industry is seen in the dominance of the private sector in the registration of new canola varieties which has coincided with a change in the nature of the technology and the property rights for these research products. The dominance of a few firms is the latest development in the sector. As of 2008, a single firm—Bayer—controlled 55% of seed sales, and four firms control roughly 85% of seed sales. The recent need for cross-licensing agreements has linked the two most dominant firms in the sector—Bayer and Monsanto—in a joint venture. This level of concentration could lead to inflated prices. This suggests regulations concerning anti-competitive behavior may be key to advancing the sector in the future.

However, the literature and our calculations indicate that there are, overall, considerable benefits from canola research and recent technological advances. The area seeded to canola varieties, the number of varieties available, and canola crop yields have been on an upward trend for 50 years. Producer behavior—as measured by seeded area and chosen varieties—suggests farmers are happy to adopt innovations in seed/herbicide systems. Private breeding firms appear to be benefiting as well, although recent estimates of returns to research are lower and approaching market rates. At currently high seeded areas and high prices, producer benefits were estimated to be more than $1 billion and breeding firm returns were more than $700 million. Various authors have also argued that the economic benefits for producers by growing HT canola are significant (e.g., Gusta et al., 2011; Phillips, 2003; Serecon Management Consulting, Inc., 2001, 2005). These benefits come from the agronomic benefits of new HT varieties as well as the gain in productivity from improved breeding and hybridization (Veeman & Gray, 2010).

To summarize, the canola industry has benefited enormously from biotechnology but not without some cost. While the problems noted in this article regarding concentration might create some regulatory challenges, the current gains to producers from biotechnology and returns to research firms in the Canadian canola industry are beneficial.

References

Agriculture and Agri-Food Canada (AAFC). (2012, April 12). *Canada: Grains and oilseeds outlook*. Ottawa, ON: Author. Available on the World Wide Web: http://www.agr.gc.ca/pol/mad-dam/pubs/go-co/pdf/go-co_2012-04-12_eng.pdf.

Alberta Agriculture, Food, and Rural Development. (n.d.). *Crop variety performance comparisons: Various soil zones*. Edmonton, AB: Author.

Alberta Seed Guide (ASG). (n.d.). *Seed.ab.ca: Alberta's seed guide* [various years]. Lacombe, AB: Author. Available on the World Wide Web: http://www.seed.ab.ca/index.html.

Alston, J.M., Marra, M.C., Pardey, P.G., & Wyatt, T.J. (1998, November). *Research returns redux: A meta-analysis of the returns to agricultural R&D* (EPTD Discussion Paper No. 38). Washington, DC: International Food Policy Research Institute (IFPRI), Environment and Production Technology Division (EPTD).

Brinkman, G.L. (2004). Strategic policy issues for agricultural research in Canada. *Current Agriculture, Food & Resource Issues*, *5*, 131-147.

Buchanan, J.M., & Yoon, Y.J. (2000). Symmetric tragedies: Commons and anticommons. *The Journal of Law and Economics*, *43*(1), 1-14.

Buth, J. (2011). Evidence at Standing Committee on Agriculture and Agri-Food, Canada's House of Commons. Oct.6, 2011. Accessed 15 May 2012 from http://www.parl.gc.ca/HousePublications/Publication.aspx?Mode=1&Parl=41&Ses=1&Language=E&DocId=5165512&File=0.

Canadian Food Inspection Agency (CFIA), Plant Breeders' Rights Office. (n.d.). *Plant Varieties Journal* [various issues]. Ottawa, ON: Author.

CFIA. (n.d.). *List of varieties which are registered in Canada*. Ottawa: Author.

Canola Council of Canada (CCC). (2008). *Canola: Growing great 2015—In brief*. Winnipeg, MB: Author. Available on the World Wide Web: http://www.canolacouncil.org/media/502091/growing_great_ pdf.pdf.

CCC. (2010, December). *Estimated percentage of HT and conventional canola* [online database]. Winnipeg, MB: Author. Available on the World Wide Web: http://www.canolacouncil.org/markets-stats/statistics/estimated-acreage-and-percentage/.

CCC. (n.d.). *Prairie canola variety trials*. Winnipeg, MB: Author.

Casséus, L. (2009, April). Canola: A Canadian success story (Statistics Canada Catalogue No. 96-325-x). In *Canadian agriculture at a glance*. Ottawa, ON: Statistics Canada. Available on the World Wide Web: http://www.statcan.gc.ca/pub/96-325-x/2007000/article/10778-eng.htm.

Downey, R.K., & Harvey, B.L. (1963). Methods of breeding for oil quality in rape. *Canadian Journal of Plant Science*, *43*(3), 271-275.

Falcon, W.P., & Fowler, C. (2002). Carving up the commons—Emergence of a new international regime for germplasm development and transfer. *Food Policy*, *27*, 197-222.

Fulton, M., & Keyowski, L. (1999). The producer benefits of herbicide-resistant canola. *AgBioForum*, *2*(2), 85-93. Available on the World Wide Web: http://www.agbioforum.org.

Galushko, V., Gray, R., & Smyth, S. (2010). Resolving FTO barriers in GM canola. *AgBioForum*, *13*(4), 360-369. Available on the World Wide Web: http://www.agbioforum.org.

Galushko, V., & Oikonomou, E. (2007, August). *IP protection in Canadian agriculture: A shift to "tragedy of anticommons"?* (CAIRN Policy Brief No. 4). Saskatoon, SK: Canadian Agricultural Innovation Research Network (CAIRN).

Graff, G.D., Cullen, S.E., Bradford, K.J., Zilberman, D., & Bennett, A.B. (2003). The public-private structure of intellectual property ownership in agricultural biotechnology. *Nature Biotechnology*, *21*(9), 989-995.

Gray, R., & Malla, S. (2011). Managing public IP with downstream interfirm research spillovers. *Canadian Journal of Agricultural Economics*, *59*, 475-491.

Gray, R., Malla, S., & Phillips, P.W.B. (2001). Industrial development and collective action. In P.W.B. Phillips & G.G. Khachatourians (Eds.), *The biotechnology revolution in global agriculture: Innovation, invention and investment in the canola industry.* Wallingford, UK: CABI Publishing.

Gray, R., Malla, S., & Tran, K.C. (2006). Spillovers and crowding effects in a mixed biotech industry: The case of canola. *AgBioForum*, *9*(1), 31-41. Available on the World Wide Web: http://www.agbioforum.org.

Gusta, M., Smyth, S.J., Belcher, K., Phillips, P.W.B., & Castle, D. (2011). Economic benefits of genetically-modified herbicide-tolerant canola for producers. *AgBioForum*, *14*(1), 1-13. Available on the World Wide Web: http://www.agbioforum.org.

Harker, K.N., Blackshaw, R.E., Kirkland, K.J., Derksen, D.A., & Wall, D. (2000). Herbicide-tolerant canola: Weed control and yield comparisons in western Canada. *Canadian Journal of Plant Science*, *80*, 647-654.

Heller, M.A., & Eisenberg, R.S. (1998). Can patents deter innovation? The anticommons in biomedical research. *Science*, *280*(5364), 698-701.

Keystone Agricultural Producers (KAP). (2011). *Policy synopsis 2011*. Winnipeg, MB: Author. Available on the World Wide Web: http://www.kap.mb.ca/Policy%20Synopsis%20for%20Web%202011.pdf.

Lexum. (2004). Judgments of the Supreme Court of Canada: Monsanto Canada Inc. v. Schmeiser, [2004] 1 S.C.R. 902, 2004 SCC 34. Montreal: Author. Available on the World Wide Web: http://scc.lexum.org/en/2004/2004scc34/2004scc34.html.

Malla, S., Gray, R., & Phillips, P.W.B. (2004). Gains to research in the presence of intellectual property rights and research subsidies. *Review of Agricultural Economics*, *26*(1), 63-81.

Malla, S., & Gray, R. (2003). Public research policy for today's agricultural biotech research industry. *Canadian Journal of Agricultural Economics*, *51*, 347-369.

Malla, S., & Gray, R. (2005). The crowding effects of basic and applied research: A theoretical and empirical analysis of an agricultural biotech industry. *American Journal of Agricultural Economics*, *87*(2), 423-438.

Manitoba Agriculture, Food, and Rural Initiatives (MAFRI). (2011, January). *Guidelines for estimating crop production costs—2011*. Manitoba, Canada: Manitoba Government. Available on the World Wide Web: http://www.gov.mb.ca/agriculture/financial/farm/pdf/copcropproductioncosts2011_westernmb.pdf.

Manitoba Agricultural Services Corporation (MASC). (2011). *Manitoba management plus program: MMPP variety yield data browser* [online database]. Manitoba, Canada: Author. Available on the World Wide Web: http://www.mmpp.com/mmpp.nsf/mmpp_browser_variety.html.

Minnesota Canola Production Centre (2004). *Annual report*. St. Paul, MN: Author. Available on the World Wide Web: http://www.mncanola.org/pdf/2004%20CPC%20Final%20Report.pdf.

Moschini, G., & Lapan, H. (1997). Intellectual property rights and the welfare effects of agricultural R&D. *American Journal of Agricultural Economics*, *79*, 1229-1242.

Nagy, J.G., & Furtan, W.F. (1978). Economic costs and returns from crop development research: The case of rapeseed breeding in Canada. *Canadian Journal of Agricultural Economics*, *26*, 1-14.

Phillips, P.W.B., & Khachatourians, G.G. (2001). *The biotechnology revolution in global agriculture: Invention, innovation and investment in the canola sector.* Wallingford, UK: CABI Publishing.

Phillips, P.W.B. (2003). The economic impact of herbicide tolerant canola in Canada. In N. Kalaitzandonakes (Ed.), *The economic and environmental impacts of agbiotech: A global perspective* (pp. 119-140). New York: Kluwer Academic Publishers.

Phillips, P.W.B. (2001). Regulating discovery. In P.W.B. Phillips & G.G. Khachatourians (Eds.), *The biotechnology revolution in global agriculture: Innovation, invention and investment in the canola industry.* Wallingford, UK: CABI Publishing.

Prairie Pools, Inc. (n.d.). *Prairie grain variety survey 1977-1992*. Regina, SK: Author.

Saskatchewan Crop Insurance Corporation. (2009). Saskatchewan Management Plus: Canola variety data; by crop district [online database]. Melville, SK: Author.

Saskatchewan Ministry of Agriculture (SMA). (2011). *Crop planning guide, 2011: Dark brown soil zone*. Regina, SK: Author. Available on the World Wide Web: http://www.agriculture.gov.sk.ca/Default.aspx?DN= 1a1101e3-f7bb-4c4d-ba4c-a4faadff5e80.

Saskatchewan Seed Growers Association (SSG). (2011). Sask-Seed [online]. Yorktown, SK: Author. Available on the World Wide Web: http://www.saskseed.ca/guides.html.

Serecon Management Consulting, Inc. (2001, January). *An agronomic and economic assessment of transgenic canola*. Winnipeg, MB: Canola Council of Canada.

Serecon Management Consulting, Inc. (2005, April). *Herbicide tolerant volunteer canola management in subsequent crops*. Winnipeg, MB: Canola Council of Canada. Available on the World Wide Web: http://www.jcci.unimelb.edu.au/GMCanola 2007/HT_canola_final.pdf.

Seed Manitoba. (n.d.). [Website]. Winnipeg, MB: Manitoba Crop Variety Evaluation Team. Available on the World Wide Web: http://www.seedmb.ca/.

Smyth, S.J., & Gray, R. (2011). Intellectual property sharing agreements in gene technology: Implications for research and commercialization. *International Journal of Intellectual Property Management*, *4*(3), 179-190.

Statistics Canada. (2011). *Estimated areas, yield, production and average farm price of principal field crops, in metric units, annual* (Field Crop Reporting Series CANSIM Table 001-0010). Ottawa, ON: Statistics Canada. Accessed 24 August 2011 from: http://www5.statcan.gc.ca/cansim/a26?lang=eng &id=0010010&p2=17.

Stefansson, B.R., Hougen, F.W., & Downey, R.K. (1961). Note on the isolation of rape plants with seed oil free from erucic acid. *Canadian Journal of Plant Science*, *41*, 218-219.

Stiegert, K.W., Shi, G., & Chavas, J.P. (2010). Innovation, integration, and the biotechnology revolution in U.S. seed markets. *Choices*, *25*(2).

Ulrich, A., & Furtan, W.H. (1985). *An investigation in the rates of returns from the Canadian crop breeding program* (Unpublished report). Saskatoon, Saskatchewan: University of Saskatchewan, Department of Agricultural Economics.

Ulrich, A., Furtan, W.H., & Downey, K. (1984). *Biotechnology and rapeseed breeding: Some economic considerations.* Ottawa, ON: Science Council of Canada.

Veeman, T.S., & Gray, R. (2010). The shifting patterns of agricultural production and productivity in Canada. In J.M. Alston, B.A. Babcock, & P.G. Pardey (Eds.), *The shifting patterns of agricultural production and productivity worldwide*. Ames, IA: The Midwest Agribusiness Trade Research and Information Center, Iowa State University.

Wright, B.D. (1998). Public germplasm development at a crossroads: Biotechnology and intellectual property. *California Agriculture*, *52*(6), 8-13.

Wright, J. (2011). *List of varieties registered for production in Alberta*. Lacombe, AB: Agriculture Financial Services Corporation. Available on the World Wide Web: http://www.afsc.ca/doc.aspx?id=21.

Acknowledgments

The authors wish to thank Cecil Nagy at the Department of Bioresource Policy, Business, and Economics at the University of Saskatchewan for his insights and assistance with the canola varieties data.

Appendix

See next page for Tables A1 and A2.

Table A1. Canola product lines: A system comparison of costs and benefits. Low price ($300/tn).

Farmer system cost [1]	Roundup Ready	Liberty Link	Clearfield	Open pollinated	Total
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	$107.94	
Gross returns					
Yield (tne/ha)[2]	1.90	1.91	1.72	1.57	
Commodity price ($/tn)[3]	$300	$300	$300	$300	
Expected gross ($/ha)	$569	$573	$516	$472	
Less system costs ($/ha)	($147)	($146)	($156)	($108)	
Net farm returns ($/ha)	$422	$427	$360	$364	
Total benefits[3]					
Share of seeded area (ha)	3,680,000	3,760,000	480,000	80,000	8,000,000
Farmer gains over OP	$213,687,477	$239,963,747	-$1,604,873	$0	**$452,046,351**
Seed revenues	$496,019,472	$441,142,000	$58,485,648	$2,707,120	$998,354,240
Research costs[4]	$59,800,000	$61,100,000	$7,800,000	$1,300,000	$130,000,000
Seed production[5]	$63,480,000	$64,860,000	$8,280,000	$1,380,000	$138,000,000
Net return to breeders	$372,739,472	$315,182,000	$42,405,648	$27,120	**$730,354,240**

Sources: [1] 2011 costs estimated from MAFRI (2011) and SMA (2011).
[2] Yields estimated by authors using Manitoba average annual yield and indexes from same sources as in Table 6.
[3] These estimate are based on 2011 costs but 2012 forecasted area of 8 million Ha and forecasted price.
[4] Research costs inflated by 1.3 based on Gray et al. (2001).
[5] Seed production costs: see footnote 11.

Table A2. Canola product lines: A system comparison of costs and benefits. High price ($700/tn).

Farmer system costs[1]	Roundup Ready	Liberty Link	Clearfield	Open pollinated	Total
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	$107.94	
Gross returns					
Yield (tne/ha)[2]	1.90	1.91	1.72	1.57	
Commodity price ($/tn)[3]	$700	$700	$700	$700	
Expected gross ($/ha)	$1,327	$1,338	$1,204	$1,100	
Less system costs ($/ha)	($147)	($146)	($156)	($108)	
Net farm returns ($/ha)	$1,180	$1,192	$1,048	$992	
Total benefits[3]					
Share of seeded area (ha)	3,680,000	3,760,000	480,000	80,000	8,000,000
Farmer gains over OP	$690,940,050	$750,117,265	$26,764,737	$0	**$1,467,822,052**
Seed revenues	$496,019,472	$441,142,000	$58,485,648	$2,707,120	$998,354,240
Research costs[4]	$59,800,000	$61,100,000	$7,800,000	$1,300,000	$130,000,000
Seed production[5]	$63,480,000	$64,860,000	$8,280,000	$1,380,000	$138,000,000
Net return to breeders	$372,739,472	$315,182,000	$42,405,648	$27,120	**$730,354,240**

See Table A1 for footnotes and sources.