

Socio-Economic Assessment of Biotech R&D Investment in Canadian Rapeseed/Canola

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Research investment has been a major driver of economic growth. Economic impact analysis of R&D investment should account for all direct and indirect related benefits and costs. This study examines the direct financial and indirect economic impacts of environmental and human health improvements from R&D investment in the Canadian biotech canola sector. It was found that investment in biotech canola R&D has yielded high rates of financial return and significant indirect environmental and human health benefits. The implications of these results for research policy are discussed, and several policy recommendations are made that could contribute to the biotech rapeseed/canola sector's growth, improvement in individual wellbeing, and increased overall social welfare. The paper sheds light on the important but neglected issue of accounting for environmental and health-related externalities when assessing R&D investment.

Keywords: *R&D Investment, Returns to Research, Environmental and Health Externalities, Biotechnology, Canola*

Introduction

Investment in agricultural research has been shown to be a key determinant of economic growth (Solow, 1957; Romer, 1990) with a high rate of returns (Griliches, 1988). During the 20th century, most agricultural crop production research was undertaken by public institutions, and the products of that research were held in the public domain (Huffman and Evenson, 1993). The introduction of modern biotechnology and improved Intellectual Property Rights (IPRs) has conferred monopolistic rights to the inventor, leading to increased private investment in agricultural research, which in turn has resulted in a concentrated privatized industry (Brewin and Malla, 2012; Malla and Brewin, 2019). These changes are particularly apparent in the Canadian rapeseed/canola sector, which has been transformed from a minor to a major crop over the last four decades with significant growth in area planted to rapeseed/canola cultivars, the number of cultivars available, and yields that have been on an upward trend for 50 years.

The agricultural industry around the world faces some major challenges regarding food security, sustainably balancing future supply and demand at a time of constrained research budgets, increasing pressures from population growth, changing consumption patterns and dietary preferences, post-harvest losses, climate change, loss in ecosystem biodiversity, and demands for the use of biomass to provide renewable energy (EASAC, 2013; United Nations, 2017; FAO, 2022). While global population is expected to grow significantly in the next few decades,

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it has been shown that agricultural productivity growth has slowed, especially in the world's richest countries (U.S. Bureau of Labor Statistics, 2021; USDA, 2021; OECD, 2023). Alston and Pardey (2010a; 2010b) attribute the slowdown in global productivity to underinvestment in certain types of productivity enhancing agricultural R&D. There is compelling evidence that investment in agricultural research, biotech rapeseed/canola in particular, also contributes to sustainable development and reduces environmental footprints, with benefits to breeders, farmers, consumers, and the overall economy.

Additionally, there is an important link between agricultural research and human health (Gray and Malla, 2001; Malla, Hobbs, and Perger, 2007; Hobbs, et al., 2014; Hobbs, et al., 2021). The incidence and severity of many major diseases (e.g., diabetes, coronary heart disease, cancer) are affected by diet. Research into improved food products and nutrition has the potential to improve health and reduce costs associated with disease. While first generation biotech crops focused on improving agronomic traits to benefit farmers, second-generation agricultural biotechnology research has focused more on improving the 'functional' attributes or nutritional quality of crops that help to address public health issues related to nutritional deficiencies and rising health care costs (Glass and Fanzo, 2017; Malla and Brewin, 2019; Matovu, 2021). In 2022, total health expenditure in Canada reached \$331 billion, or \$8,563 per person, which represented 12.2 % of Canada's gross domestic product (GDP) (CIHI, 2024). The economic benefits associated with 'quality improving' technical changes and/or health-related benefits (healthcare externalities) are very important, as they could increase social well-being.

The use of new genetically modified (GM) cultivars of rapeseed/canola in Canada have provided positive indirect benefits (externalities) associated with rapeseed/canola production as well as consumption. Positive production externalities, primarily resulting in environmental benefits, occur from a reduction in herbicide applications associated with reduced fuel consumption from fewer hectares being sprayed, as well as lower greenhouse gas emissions (Barfoot and Brookes, 2014; Brookes and Barfoot, 2020; Brookes, 2022; Bacon et al., 2023). Associated with the reduction in herbicide application has been an increase in carbon sequestration in the soil, resulting from less soil disruption (Sutherland et al. 2021; Brookes, 2022), as well as reduced soil and water contamination, which positively benefits the environment (Barfoot and Brookes, 2014; Bacon et al., 2023). Additionally, with the adoption of GM rapeseed/canola cultivars, there has been a shift in management practices through the adoption of zero tillage practices that have improved the carbon sequestration in the soil (Sutherland et al., 2021; Brookes, 2022).

Positive consumption externalities have been identified in healthcare savings from consumption of GM rapeseed/canola food products with improved oil profiles that contain no trans-fat or low saturated fatty acids (Malla and Brewin, 2015; Amiri et al., 2020). Increased levels of monounsaturated and polyunsaturated fatty acids have associated health benefits from reduction in cholesterol and reduced risk of cardiovascular diseases (Schwingshackl and Hoffmann, 2012; Jain et al., 2015; Malla and Brewin, 2015; Amiri et al., 2020; MacIntosh et al., 2021; Saini et al., 2021; Government of Canada, 2021; Qin et al., 2023).

The overall goal of this study is to gain a better understanding of the economic, environmental, and human health impacts of agricultural research in the Canadian rapeseed/canola sector. The appropriate government's role in canola research is also discussed.

Assessing Direct and Indirect Benefits of Biotech R&D Investment – Rapeseed/Canola in Canada

General Methods of Assessing Returns to Investments in Agricultural Research

Measuring returns to investments in agricultural research is important but very difficult. The net economic benefits of an investment typically are measured in one of three ways: the net present value (NPV), the benefit-cost ratio (B/C), and the internal rate of return (IRR).¹

The NPV, which measures the absolute net present value of the gain of the project, is defined as: $NPV = \sum_{t=1}^{\infty} \frac{B_t - C_t}{(1+r)^t}$ where: B_t is the sum of benefits that result from the project in year t ; C_t is the sum of the costs associated with the project in year t ; and, r is the rate of discount.

The benefit cost ratio (B/C ratio) can compare the benefits of investment on a per-dollar cost basis.

The B/C ratio is defined as: $B/C = \frac{\sum_{t=1}^{\infty} \frac{B_t}{(1+r)^t}}{\sum_{t=1}^{\infty} \frac{C_t}{(1+r)^t}}$. If B/C is greater than 1.0, then for every \$1 cost of the project, the gain is more than \$1 so the project may be undertaken. If there are a lot of projects and a limited source of funding, the ones with the higher B-C ratio should be given preference. Hence, the B-C ratio can be used to rank the agriculture research projects or programs.

The IRR is the estimated discount rate that results in a NPV equal to zero. IRR is defined as: $0 = \sum_{t=1}^{\infty} \frac{B_t - C_t}{(1+IRR)^t}$. If IRR is greater than the selected discount rate or

¹For more information see: Government of Canada (2023). Canada's Cost-Benefit Analysis Guide for Regulatory Proposals. <https://www.canada.ca/en/government/system/laws/developing-improving-federal-regulations/requirements-developing-managing-reviewing-regulations/guidelines-tools/cost-benefit-analysis-guide-regulatory-proposals.html>; OECD (Organization for Economic Co-operation and Development) (2018). Cost-Benefit Analysis and the Environment. Further Developments and Policy. Use. <https://www.oecd.org/publications/cost-benefit-analysis-and-the-environment-9789264085169-en.htm>; OECD (Organization for Economic Co-operation and Development) (2006). Cost-Benefit Analysis and the Environment. Recent Developments. https://www.oecd-ilibrary.org/environment/cost-benefit-analysis-and-the-environment_9789264010055-en; CRRDC (Council of Rural Research and Development Corporations) (2014). Impact Assessment Guidelines, <https://www.ruralrdc.com.au/wp-content/uploads/2018/08/CRRDC-Impact-Assessment-Guidelines-V.1-070514.pdf>; Alston, J.M., Norton, G.W., and Pardey, P.G. (1997). *Science Under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting*. Ithaca and London: Cornell University Press.

the opportunity cost of funds/capital, then the agricultural research project or program is profitable.

Direct Economic Benefits - Returns to Research on Improving Productivity of Rapeseed/Canola

Nagy and Furtan (1978) studied investment in rapeseed breeding research in Canada to estimate the rate of return and the net benefits to consumers and producers. The study measured the internal rate of return (IRR) and the net benefits for producers and consumers for the period 1960-1974 due to improvement in the yield of rapeseed/canola cultivars. They found that producers had a net benefit of 47% and consumers had a net benefit of 53%. Additionally, they estimated an IRR value of 101%, indicating a severe underinvestment in yield increasing research. In an updated study that included several additional years of data, Ulrich, et al. (1984) calculated the IRR from improved yield research in Canadian rapeseed/canola production to be 51% (68% producers' share, 32% consumers' share) for the period of 1951 to 1982.

Fulton and Keyowski (1999) assessed the producer benefits of adopting the new herbicide-resistant (HR) canola cultivars, such as Roundup Ready, Smart Open Pollinated, Liberty Hybrids, and Conventional Open Pollinated rapeseed/canola cultivars. They estimated that the gross returns (\$/acre) of Roundup Ready canola were \$225.30 on average, Smart Open Pollinated were \$213.75, Liberty Hybrids were \$238.10, and open-pollinated were \$242.13 in 1999. They concluded that the agronomic, management and technological factors facing farmers were very important determinants of producers' benefits and while some producers benefited greatly from new HR technology, others did not.

Malla et al. (2004) evaluated the net economic benefits received from investing in research and development in the Canadian rapeseed/canola sector from 1960 to 1999. Their study additionally examined changes within the rapeseed/canola sector with the introduction of intellectual property rights (IPRs) and biotechnology that created incentives for private firm investment. From 1960 to 1999 the Canadian rapeseed/canola sector underwent many changes including the shift from public to private research as new technologies, IPRs, government support and subsidies created incentives for private firms to invest in rapeseed/canola research. Using data from a variety of different sources they estimated "the average IRR initially exceeded 25% per year and steadily declined during 1970-1999, ultimately approaching the level of market returns. The IRR for the marginal dollars invested each year shows a much more dramatic decline and during the 1990s, was well below the market rates of return" (Malla et al. 2004). Additionally, they found that the NPV declined with increases in investment in research and their models showed "greater research expenditures increased net present value from \$61 million in 1973 when the PV costs were \$15.8 million to a peak of \$131 million in 1993 when the PV of costs were \$74.1 million. Subsequently, the NPV declined as the increase in expenditure exceeded the growth in benefits. By 1999, the net present value of yield increases had declined to \$94 million when the PV of costs was \$116 million" (Malla et al. 2004). The authors suggested that "The results of this study challenge current

government policy in canola research. The canola research industry is subsidized and property rights for canola seed are well established. Given that property rights allow private firms to capture the full social benefit of investment, this will attract capital and drive the rate of return toward normal levels. If government subsidizes the costs of private research, it is certainly possible to create overinvestment in an industry.” (Malla et al. 2004). Their study concluded that “If the canola research sector is to receive future public support, these expenditures should be directed toward areas of research where IPRs are poorly defined...the decreasing IRR suggests that the role of government in applied research should be focused on those sectors and technologies where IPRs do not exist” (Malla et al. 2004).

Malla and Brewin (2012) assessed the effects that advancements in biotechnology had on the Canadian rapeseed/canola sector, the adoption of biotechnology in the rapeseed/canola sector and the economic impacts from adoption of biotechnology at the firm level. Their study evaluated the Canadian rapeseed/canola sector from 1969 to 2012 with data compiled from a variety of sources to assess the area seeded, yield and different varieties of rapeseed/canola. Several different canola product lines were considered such as Roundup Ready, Liberty Link, Clearfield, and Open Pollinated. They compared the costs and benefits of the adoption of different canola cultivars to generate estimates of producers' benefits and the net return to breeders. The net returns to breeders were based on the difference between seed revenue and costs of research and seed production, while the farmers' net returns were calculated as the difference between the farmers' system cost and their gross returns. The study found that the rapeseed/canola sector had been positively impacted by biotechnology when considering the area seeded to rapeseed/canola, the number of cultivars available; additionally, rapeseed/canola yields had been on an upward trend for 50 years. It was estimated that the farmer gains (over open pollinated varieties) of Roundup Ready canola were \$488 million (\$858/ha), Liberty Link were \$533 million (\$867/ha), Clearfield were \$14 million (765/ha) (open pollinated: \$725/ha) in 2011. Further, it was estimated that “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” (Malla and Brewin, 2012). Compared to Fulton and Keyowski (1999) and Malla et al. (2004) it was concluded that “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...Some research suggests the returns to research have begun to drop off toward market rates (Malla, et al. 2004). Current budgets ... suggest significant gains to producers and returns to breeders in the current seed market.” (Malla and Brewin, 2012). It was also stated that “Various authors have also argued that the economic benefits for producers by growing HT canola are significant (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)”. (Malla and Brewin, 2012). Therefore, it was clear that the adoption of biotechnology into the rapeseed/canola sector had been very beneficial, especially to producers and plant breeders.

Biotechnology has played an important role in the Canadian rapeseed/canola sector and contributed to the creation of modified rapeseed/canola cultivars, such as herbicide tolerant (HT) canola. Malla and Brewin (2015) estimated the cumulative benefit of herbicide tolerant canola adoption to be \$30 billion from 1996 to 2012 and it was on an upward trend for most of that period. They calculated the net benefits for the 2012 crop year to be \$726 million. Other trends mentioned in the study about the rapeseed/canola sector include significant benefits associated with new rapeseed/canola herbicide tolerant varieties that have increased yield, area seeded, and the number of cultivars available. They also examined the role of government and identified “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.” (Malla and Brewin, 2015).

Indirect Benefits – Environmental Improvements

A study conducted by the Canola Council of Canada assessed the “agronomic and economic impacts associated with transgenic canola to better understand the impact it has had on agriculture in western Canada” (Canola Council of Canada 2001). The direct and indirect impacts were assessed with the direct impacts defined as “the net impact on the economic returns due to the combined impacts on revenues and on operating costs from changes in key agronomic practices relating to pesticide use, fertilization, tillage, and other practices” (Canola Council of Canada, 2001). The indirect and induced impacts were defined as “the impacts on the rural communities, on the impact supply industries serving the industry, on canola prices, and on other crop production in western Canada” (Canola Council of Canada, 2001). Additionally, the indirect impacts included an environmental assessment of herbicides, fertilizers, and energy between conventional and transgenic canola production. The study surveyed 650 producers, with 325 growing conventional canola and 325 growing transgenic canola in the year 2000. It was concluded that the producer herbicide costs were lower in transgenic canola production (\$16.22 per acre) compared to conventional canola (\$21.72 per acre). Participants in the study stated that their primary reason for adopting transgenic canola were not economic, but agronomic. Among the agronomic benefits were early and effective weed control, decreased tillage use, improved soil moisture conservation, improved rotation flexibility, lower dockage, and decreased herbicide inputs.

The aggregate economic impact of the adoption of transgenic canola production was measured by the net gain in gross margin of transgenic cultivars over non-transgenic cultivars for the acreage harvested in each system. The number of transgenic acres increased from approximately 1.5 million acres in 1997 to 6.1 million acres in 2000. Expressing this annual impact in 2000 dollars resulted in \$28.8 million in 1997, up to \$72.9 and \$81.2 million in 1998 and 1999 respectively, and then down to \$66.0 million in 2000. The cumulative net impact of this adoption was estimated at \$249.0 million over the four-year period (Canola Council of Canada, 2001). The

cumulative economic impact “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 ... (and) 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” (Canola Council of Canada, 2001).

Similarly, Phillips (2003) investigated the benefits and costs of herbicide tolerant (HT) canola on farmers, innovators, and markets, while also discussing “some of the unintended indirect impacts of the HT technology on producer, markets, and the environment” (Phillips, 2003). The study estimated that the net benefit producers gained in 2000 was \$70 million with producers capturing approximately 29% of the gross benefits of the new technology. He noted that producers who planted herbicide tolerant (HT) rapeseed/canola cultivars obtained a variety of direct and indirect benefits, including lower herbicide costs, less herbicide application, higher seed costs, earlier seeding, and lower dockage. In addition to a gross increase in the net operating return to innovators of “C\$140 million gross annual return to the innovators in 1999-2000” (Phillips, 2003) he acknowledged that HT rapeseed/ canola cultivars had a positive environmental impact with less toxic herbicides being used and a reduction in the amount of herbicide ingredients being applied.

Smyth et al. (2010) and Gusta et al. (2011) assessed the economic and ecological impacts of genetically modified herbicide tolerant (HT) rapeseed/canola in western Canada based on the results of an 80-question survey given to Canadian producers in Alberta, Saskatchewan, and Manitoba in 2007. The producer survey comprised six focus areas: 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. The survey also accounted for three major impacts: ‘spillover’ i.e., multi-year benefits due to fewer weeds or easier weed control on a field from one year to the next; ‘reduced tillage’ i.e., cost of weed control; and ‘cost of volunteer control’ when HT became an in-crop weed or volunteer. Results from their studies indicated that the average direct benefits associated with the new technology were \$150 million for the period 2005-2007. They estimated that the spillover benefits ranged from \$67 million to \$110 million, reduced tillage decreased costs by \$153 million, while an additional cost for controlling volunteer canola was \$15 million (2005-2007). Consequently, the average total indirect economic benefits of genetically modified HT rapeseed/canola were \$235-\$278 (2005-2007). The authors claimed that “The survey revealed 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). The authors concluded that “This report refutes the claims and accusations made by critics of agricultural biotechnology that genetically modified crops do not benefit farmers and are harmful to the environment...the benefits are numerous and substantial.” (Smyth et al. 2010).

Smyth et al. (2011a) compared the environmental impact of the herbicides applied in 2006 to HR cultivars relative to the environmental impacts of the herbicides

that were applied to rapeseed/canola in 1995 before the introduction of HR rapeseed/canola in Western Canada. They developed an Environmental Index (EI) to compare the relative toxicity of the herbicides on farm workers and found that "... substantial environmental benefits, associated with changes in herbicide use patterns, from the widespread adoption of HR canola... The cumulative EI effect from herbicides dropped by 53% between the two periods. When the subcomponent values of the EI are compared, there is a reduction of over 40% in each of the subcomponents. The farmworker and ecology subcomponents decline by 56% and 54%, respectively, whereas the consumer subcomponent declines by 42%...The total volume of herbicide active ingredient applied to canola fields dropped by 1.3 million kg, representing a 38% reduction in quantity between the 2 years" (Smyth et al. 2011a). The overall canola production in 1995 and 2006 was very similar and the decline in the environmental index can be linked to the adoption of HR canola. The authors concluded that "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." (Smyth et al., 2011a).

Similarly, Smyth et al. (2011b), assessed the environmental impacts from herbicide tolerant (HT) canola production in the three-prairie provinces of Alberta, Saskatchewan, and Manitoba. The study was "comprised of six major areas of focus: weed control; volunteer canola control; canola production history; specific weed control measures on canola fields and subsequent crops; crops and liability insurance; and general demographics" (Smyth et al., 2011b). They found that producers were applying one less herbicide application after the uptake of HT canola. This demonstrated significant environmental benefits with HT canola production with around 1.3 million kg reduction in herbicide/pesticide application and the adoption of zero-tillage practices that had greater carbon sequestration, increased moisture composition, and reduced soil disturbance. Summarizing their results, they wrote "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 are 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 C\$5 million." (Smyth et al. 2011b).

Malla and Brewin (2015) found that, in addition to the economic benefits from biotech research in the Canadian rapeseed/canola sector (detailed in the previous section), several positive externalities resulted in the form of reduced environmental impacts (e.g., better weed control, better volunteer canola management, reduced tillage).

Indirect Benefits - Human Health Improvements

A study by Gray and Malla (2001), investigated the economic impact of switching from rapeseed to canola cultivars that have lower yields but improved quality with health benefits such as a reduction in coronary heart disease. They focused on the development of canola cultivars that contain lower levels of erucic acid (shown to be a threat to human health) and glucosinolates in meal (shown to be a threat to animal nutrition). Additionally, the rapeseed/canola cultivars are associated with positive health benefits by containing a low level of saturated fat and a high level of monounsaturated fat. Gray and Malla (2001) indicated the significance of the type of fatty acid found in oil because “The strong linkage between blood cholesterol and coronary heart disease has led to much research on how consumption of different types of fats affects serum cholesterol levels... research showed that the consumption of saturated fatty acids increases blood cholesterol levels ..it was shown that consumption of monounsaturated fatty acids also lowered cholesterol and that these fatty acids were in fact preferable to polyunsaturated fatty acids because the monounsaturated fatty acids lowered LDL (harmful) cholesterol levels but not HDL (beneficial) cholesterol levels” (Gray and Malla, 2001). A decrease in cholesterol from monounsaturated fatty acids can lead to a reduction in coronary heart disease providing a positive health benefit for consumers and taxpayers. Additionally, the overall effect received from the consumption of these quality improved canola varieties is less heart disease in individuals and reduction in public health care costs.

It was estimated that the sector (producers, processors, consumers) had gained from quality-improving technical change (health/nutrition research) even though it came at the expense of potential yield, but producers were the largest beneficiaries of health information. According to Gray and Malla (2001), “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.” The study concluded that “Preliminary research suggests that canola has also provided substantial benefits to taxpayers through reduced incidence and cost of coronary heart disease. These external cost savings are as large as the market value of the crop. This suggests that the health care costs associated with nutrition may be an important but largely neglected aspect of the economics of agricultural and research policy.” (Gray and Malla, 2001)

Malla et al. (2007) explored the potential magnitude of the health benefits, and the social benefits associated with the development of a trans fat-free canola oil using the example of Natreon canola oil (Nexera, produced by Dow Agroscience, Inc). Recently, mounting scientific evidence has linked the consumption of trans fatty acids (TFA) and elevated cholesterol levels, and in turn, a higher incidence of coronary heart disease has garnered much public attention. Cardiovascular disease is the largest contributor to health-care costs and the leading cause of death in Canada. It has been shown that the main source of TFA is hydrogenated vegetable

oils. Responding to consumer interest in trans fat-free products, much research was devoted to new seed canola cultivars with high oleic content (monounsaturated fatty acid) that could produce stable oil without the hydrogenation process that creates trans-fats. The new canola cultivar called ‘Nexera’ was an example of such seeds that created ‘Natreon’, a branded oil grown from Nexera. This new canola oil was considered as a functional lipid food due to its modification of fatty acid composition. Functional food is defined as a food product that has physiological benefits and/or reduces the risk of a chronic disease beyond a basic nutrition function. It has higher levels of oleic acid (monounsaturated fatty acid) and lower levels of linolenic acid (polyunsaturated omega-3 fatty acid) than conventional canola oil while has the lowest saturated fat content of all vegetable oils, which in turn reduces the risk of cardiovascular diseases.

The authors estimated the potential savings in health care or illness costs if new nonhydrogenated vegetable oils replace the trans-fat-rich hydrogenated oils in the Canadian market ranging from \$1.818 billion to \$639 million the found that the health benefits from reduced daily TFA intake and the development of healthier foods, in this case trans fat-free vegetable oil, were nontrivial and potentially increases economic welfare. The study revealed very significant external/indirect or social benefits related to canola oil with health traits, in terms of reduction in healthcare costs or healthcare savings in Canada.

Table 1. Summary of Economic Returns to Canadian Rapeseed/Canola Research Studies

Study	Methods>Returns to Research
Direct Economic Benefits	
Nagy and Furtan (1978): Rapeseed/Canola	IRR: 101%; Producer Benefits (direct): 47%; Consumer Benefits: 53%
Ulrich, Furtan, and Downey (1984): Rapeseed/Canola	IRR: 51%; Producer Benefits (direct): 68%; Consumer Benefits: 32
Fulton and Keyowski (1999): HR canola	Producer Benefits (direct): \$213.75-\$242.13/acre (gross returns, \$/acre, in 1999)
Malla, Gray, and Phillips (2004): Rapeseed/Canola	IRR: Initially exceeded 25%; declined to market returns; (40% down to 7%); NPV: \$61 million (in 1973), \$131 million (in 1993), \$94 million (in 1999)
Malla and Brewin (2012): HT canola	Net returns to breeders: more than \$700 million (high price, in 2011); Aggregate Producer Benefits: more than \$1 billion (high price, in 2011)
Malla and Brewin (2015): HT canola	Producer Benefits: \$30 billion (cumulative 1996-2012), upward trend; \$726 million (2012)
Indirect Benefits /Environmental Improvements	
Canola Council of Canada (2001): transgenic canola	Producer Benefits (direct): \$66 million in 2000 (or \$10.62 per acre); \$249.0 million (cumulative, 1997-2000);
	Total Indirect Impact: \$58.0 - \$215.0 million (cumulative 1997-2000);

	Total Economic Impact: \$464.0 million (cumulative, 1997-2000)
Phillips (2003): HT canola	Producer Benefits (direct): \$70 million (in 2000); acknowledge environmental benefits from the reduction in herbicide application
Smyth, Gusta, Belcher, Phillips, and Castle (2010) and Gusta, Smyth, Belcher, Phillips, and Castle (2011): GMHT canola	Producer Benefits (direct): \$150 million (average 2005-2007); Producer Benefits (indirect & environmental benefits): \$235-\$278 million (average 2005-2007)
Smyth, Gusta, Belcher, Phillips, and Castle (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, Gusta, Belcher, Phillips, and Castle (2011b): HT canola	Environmental Benefits: nearly 1.3 million kg annually decrease in herbicide/chemical applications; 1 million metric tons of carbon is either sequestered or no longer released, Environmental benefits CAD\$5 million (value of the carbon off-set) annually
Indirect Benefits/Human Health Improvements	
Gray and Malla (2001): Rapeseed/Canola	Switch from rapeseed to canola & 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 & producers benefited
Malla, Hobbs, and Perger (2007): Nexara Canola	Healthcare Savings: \$ 1,818 - \$ 639 million annually (from a reduction in daily TFA intake)

Source: Authors'

Conclusions and Policy Recommendations

Based on the results found by several economists, it can be inferred that research policy has been very successful in the Canadian canola crop with high economic rates of return on investment as well as significant positive externalities in the form of environmental and human health benefits. Specifically, as has been shown through a review of many comprehensive well-done studies, the Canadian rapeseed/canola sector has had high overall economic returns to investments in the research (Nagy and Furtan, 1978; Ulrich et al. 1984; Malla et al. 2004; Malla and Brewin, 2012), with direct benefits to producers (Nagy and Furtan, 1978; Ulrich et al. 1984; Fulton and Keyowski, 1999; Canola Council of Canada, 2001; Gray and Malla, 2001; Phillips, 2003; Smyth et al., 2010; Gusta et al., 2011; Smyth et al., 2011a; Malla and Brewin, 2012; Malla and Brewin, 2015). Additionally, there have been production-related environmental improvements (sometimes called positive externalities) through reductions in the amount of herbicides applied and greenhouse gas emissions, as well as increased carbon sequestration from advances in canola crop production as a result of agronomic and biotech research (Canola Council of Canada, 2001; Phillips, 2003; Smyth et al., 2010;

Gusta et al., 2011; Smyth et al., 2011a; Smyth et al., 2011b). Similarly, there have been human health improvements from consuming oils from biotech-produced rapeseed/canola (sometimes called positive consumption-related externalities) as a result of reduced cholesterol, lowering the risk of cardiovascular disease from improvement in trans fat, saturated fat, monounsaturated fatty acids, and polyunsaturated fatty acids in the canola oil providing a healthcare cost saving (Gray and Malla, 2001; Malla, Hobbs, and Perger, 2007).

While most studies on returns to biotech research on rapeseed/canola have focused on the economic returns that resulted from greater demand and/or lower costs of production, more attention should be paid to an assessment of the Canadian rapeseed/canola sector's production and consumption externalities. Positive externalities that resulted from planting of GM cultivars with specific traits and consumption of the resultant products have been important and significant in terms of reduced environmental impacts, actions on climate change, healthcare cost savings, growing populations, and food security. Accounting for all external benefits and costs associated with any innovation is essential as it allow us to provide a more accurate estimation of the total benefits from research investment.

The review of the rate of return studies to investments in biotech rapeseed/canola production and consumption in Canada also found compelling evidence that the economic return from investment in rapeseed/canola agricultural research has historically been very high and generally remained so. These high rates of return, which are consistent with many agricultural research studies for specific crops in Canada and internationally, suggest a persistent underinvestment in rapeseed/canola agricultural research by both the public and private sectors. Hence, the persistent high rates of return to rapeseed/canola research investment strongly suggest that additional research is desirable.

It has been shown that private firms invest less in R&D than the socially optimal amount even with fully appropriable IPRs (intellectual property rights) because they cannot fully appropriate all the research benefits or capture the full value generated from their investment (Malla and Gray, 2003; 2005). Economic theory suggests that the incentives for private investment in research are inadequate if some research spillover benefits go to others who do not pay for the research (e.g., improvements in environmental and human health benefits). Research firms are only concerned with their private benefits from an R&D investment and not the spillover effects that their action might have on others. This lack of private incentive creates underinvestment in research and correspondingly creates a high social rate of return for the limited dollars that are expended.

Overall, there is a role for public support of agricultural research even with the establishment of completely enforceable IPRs and biotechnologies. The public should invest in research into cultivars that will result in human health or environmental benefits and areas where IPRs are not well defined or where the private sector is not able to capture all the research benefits. In general, the public sector should invest in areas where industry does not have adequate incentives to invest (e.g., basic research, agronomic research, open-pollinated non-HT crops, cultivars with health or environmental benefits).

In summary, there is compelling evidence that investment in the Canadian biotech rapeseed/canola sector contributes to sustainable development and reduced environmental footprints, with benefits to breeders, farmers, consumers, and the overall economy. Economic impact assessment of rapeseed/canola R&D investment should account for all direct and indirect related benefits and costs. Although the rapeseed/canola sector has a high level of private investment, there is an important role for public support of agricultural research, especially in cultivars that have health or environmental benefits where industry might not have adequate incentives to invest.

References

- Alston JM, Beddow JM, Pardey PG (2010a) *Global Patterns of Crop Yields and Other Partial Productivity Measures and Prices*. In *The Shifting Patterns of Agricultural Production and Productivity Worldwide*. Ames, IA: Midwest Agribusiness Trade Research and Information Center (MATRIC), Iowa State University.
- Alston JM, James JS, Andersen MA, Pardey PG (2010b) *Research Funding and Performance*. In *Persistence Pays: U.S. Agricultural Productivity Growth and the Benefits from Public R&D Spending*, 137–185. Springer.
- Amiri M, Raeisi-Dehkordi H, Sarrafzadegan N, Forbes SC, Salehi-Abargouei A (2020) The effects of canola oil on cardiovascular risk factors: A systematic review and meta-analysis with dose–response analysis of controlled clinical trials. *Nutrition, Metabolism and Cardiovascular Diseases* 30(12): 2133–2145.
- Bacon M-H, Vandelac L, Gagnon M-A, Parent L (2023) Poisoning regulation, research, health, and the environment: The glyphosate-based herbicides case in Canada. *Toxics* 11(2): 121.
- Barfoot P, Brookes G (2014) Key global environmental impacts of genetically modified (GM) crop use 1996–2012. *GM Crops & Food* 5(2): 149–160.
- Berger MC, Blomquist GC, Kenkel D, Tolley GS (1987) Valuing changes in health risks: A comparison of alternative measures. *Southern Economic Journal* 53(4): 967–984.
- Brewin DG, Malla S (2012) The consequences of biotechnology: A broad view of the changes in the Canadian canola sector, 1969–2012. *AgBioForum* 15(3): 257–275.
- Brookes G (2022) Genetically modified (GM) crop use 1996–2020: Impacts on carbon emissions. *GM Crops & Food* 13(1): 242–261.
- Brookes G, Barfoot P (2020) GM crop technology use 1996–2018: Farm income and production impacts. *GM Crops & Food* 11(4): 242–261.
- Canadian Institute for Health Information (CIHI) (2024) *National Health Expenditure Trends, 2022 – Snapshot*. <https://www.cihi.ca/en/national-health-expenditure-trends-2022-snapshot#SnippetTab>
- Canola Council of Canada (2001) *An Agronomic and Economic Assessment of Transgenic Canola*. Serecon Management Consulting Inc. and Koch Paul Associates. https://www.canolacouncil.org/biotech/files/canola_report.pdf
- EASAC (European Academies Science Advisory Council) (2013) *Planting the Future: Opportunities and Challenges for Using Crop Genetic Improvement Technologies for Sustainable Agriculture*. Policy Report 21. <https://www.easac.eu/>
- FAO (Food and Agriculture Organization of the United Nations) (2022) *The State of Food Security and Nutrition in the World 2022*. <https://www.fao.org/3/cc0639en/online/sofi-2022/key-messages.html>
- FDA (Food and Drug Administration) (2003) Food labelling; Trans fatty acids in nutrition labelling; Final rule and proposed rule. *Federal Register* 68(133): Rules and Regulations.

- Fulton M, Keyowski L (1999) The producer benefits of herbicide-resistant canola. *AgBioForum* 2(2): 85–93.
- Glass S, Fanzo J (2017) Genetic modification technology for nutrition and improving diets: An ethical perspective. *Current Opinion in Biotechnology* 44: 46–51.
- Government of Canada (2021) *Novel Food Information: Highly Refined DHA-Enhanced Oil Derived from NS-B50027-4 Canola*. <https://www.canada.ca/en/health-canada/services/food-nutrition/genetically-modified-foods-other-novel-foods/approved-products/highly-refined-dha-enhanced-oil-derived-ns-b50027-4-canola/technical-summary.html>
- Gray R, Malla S (2001) The evaluation of the economic and external health benefits from canola research. In Alston JM, Pardey PG, Taylor MJ (eds) *Agricultural Science Policy: Changing Global Agendas*. Baltimore, MD: Johns Hopkins University Press.
- Griliches Z (1988) Productivity puzzles and R&D: Another nonexplanation. *Journal of Economic Perspectives* 2(4): 9–21.
- Gusta M, Smyth SJ, Belcher K, Phillips PWB, Castle D (2011) Economic benefits of genetically-modified herbicide-tolerant canola for producers. *AgBioForum* 14(1): 1–13.
- Gyrd-Hansen D (2003) Willingness to pay for a QALY. *Health Economics* 12(12): 1049–1060.
- Hobbs JE, Malla S, Yeung MT (2021) Regulating health claims: An international comparison. In Caporale C, Pavone IR, Ragionieri MP (eds) *International Food Law. How Food Law Can Balance Health, Environment and Animal Welfare*, Vol. 40, Chapter 10. The Netherlands: Kluwer Law International BV, 187–212.
- Hobbs JE, Malla S, Sogah EK, Yeung MT (2014) *Regulating Health Foods: Policy Challenges and Consumer Conundrums*. Cheltenham, UK: Edward Elgar Publishing.
- Huffman WE, Evenson RE (1993) *Science for Agriculture: A Long-Term Perspective*. Ames, IA: Iowa State University Press.
- Jain AP, Aggarwal KK, Zhang P-Y (2015) Omega-3 fatty acids and cardiovascular disease. *European Review for Medical and Pharmacological Sciences* 19: 441–445.
- MacIntosh SC, Shaw M, Connelly M, Yao ZJ (2021) Food and feed safety of NS-B50027-4 omega-3 canola (*Brassica napus*): A new source of long-chain omega-3 fatty acids. *Frontiers in Nutrition* 8. <https://doi.org/10.3389/fnut.2021.716659>
- Malla S, Brewin D (2019) Crop research, biotech canola, and innovation policy in Canada: Challenges, opportunities, and evolution. *Canadian Journal of Agricultural Economics* 67(2): 135–150.
- Malla S, Brewin D (2015) The value of a new biotechnology considering R&D investment and regulatory issues. *AgBioForum* 18: 6–25.
- Malla S, Gray R (2003) Public research policy for today’s agricultural biotech research industry. *Canadian Journal of Agricultural Economics* 51(2): 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.
- Malla S, Gray R, Phillips PWB (2004) Gains to research in the presence of intellectual property rights and research subsidies. *Review of Agricultural Economics* 26(1): 63–81.
- Malla S, Hobbs JE, Perger O (2007) Valuing the health benefits of a novel functional food. *Canadian Journal of Agricultural Economics* 55(1): 115–136.
- Matovu J (2021) Does the inclusion of second generation genetically modified plants in feeds have any effect on animal performance? *Turkish Journal of Agriculture – Food Science and Technology* 9(10): 1799–1807.
- Nagy JG, Furtan WH (1978) Economic costs and returns from crop development research: The case of rapeseed breeding in Canada. *Canadian Journal of Agricultural Economics* 26(1): 1–14.
- OECD (Organization for Economic Co-operation and Development) (2023) *Continued slowdown in productivity growth weighs down on living standards*. <https://www.oecd.org>

- org/sdd/productivity-stats/continued-slowdown-in-productivity-growth-weighs-down-on-living-standards.htm
- Phillips PWB (2003) *The economic impact of herbicide tolerant canola in Canada*. In Kalaitzandonakes N (ed) *The Economic and Environmental Impacts of Agbiotech: A Global Perspective*, 119–140. New York: Kluwer Academic Publishers.
- Phillips PWB, Khachatourians GG (2001) *The Biotechnology Revolution in Global Agriculture: Invention, Innovation and Investment in the Canola Sector*. Oxford: CABI.
- Qin J, Kurt E, LBassi T, Sa L, Xie D (2023) Biotechnological production of omega-3 fatty acids: Current status and future perspectives. *Frontiers in Microbiology* 14. <https://doi.org/10.3389/fmicb.2023.1280296>
- Romer P (1990) Endogenous technological change. *Journal of Political Economy* 98(2): S71–S102.
- Saini RK, Prasad P, Sreedhar RV, Naidu KA, Shang X, Keum YS (2021) Omega-3 polyunsaturated fatty acids (PUFAs): Emerging plant and microbial sources, oxidative stability, bioavailability, and health benefits—a review. *Antioxidants* 10(10): 1627.
- Schwingshackl L, Hoffmann G (2012) Monounsaturated fatty acids and risk of cardiovascular disease: Synopsis of the evidence available from systematic reviews and meta-analyses. *Nutrients* 4(12): 1989–2007.
- Serecon Management Consulting Inc. (2005) *Herbicide Tolerant Volunteer Canola Management in Subsequent Crops*. Winnipeg, MB: Canola Council of Canada. http://www.jcci.Unimelb.edu.au/GMCanola2007/HT_canola_final.pdf
- Serecon Management Consulting Inc. (2001) *An Agronomic and Economic Assessment of Transgenic Canola*. Winnipeg, MB: Canola Council of Canada.
- Smyth SJ, Gusta M, Belcher K, Phillips PWB, Castle D (2011a) Changes in herbicide use after adoption of HR canola in Western Canada. *Weed Technology* 25(3): 492–500.
- Smyth SJ, Gusta M, Belcher K, Phillips PWB, Castle D (2011b) Environmental impacts from herbicide-tolerant canola production in Western Canada. *Agricultural Systems* 104(5): 403–410.
- Solow RM (1957) Technical change and the aggregate production function. *Review of Economics and Statistics* 39(3): 312–320.
- Sutherland C, Gleim S, Smyth SJ (2021) Correlating genetically modified crops, glyphosate use and increased carbon sequestration. *Sustainability* 13(21): 11679.
- Ulrich A, Furtan WH, Downey K (1984) *Biotechnology and Rapeseed Breeding: Some Economic Considerations*. Ottawa, ON: Science Council of Canada.
- United Nations, Department of Economic and Social Affairs (2017) *World Population Prospects: The 2017 Revision*. https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/files/documents/2020/Jan/un_2017_world_population_prospects-2017_revision_databooklet.pdf
- US Bureau of Labor Statistics (2021) *The U.S. Productivity Slowdown: An Economy-Wide and Industry-Level Analysis*. <https://www.bls.gov/opub/mlr/2021/article/the-us-productivity-slowdown-the-economy-wide-and-industry-level-analysis.htm>
- USDA (US Department of Agriculture) Economic Research Service (2021) *Slowing Productivity Reduces Growth in Global Agricultural Output*. <https://www.ers.usda.gov/amber-waves/2021/december/slowing-productivity-reduces-growth-in-global-agricultural-output/>
- Veeman TS, Gray R (2010) *The shifting patterns of agricultural production and productivity in Canada*. In Alston JM, Babcock BA, Pardey PG (eds) *The Shifting Patterns of Agricultural Production and Productivity Worldwide*. Ames, IA: Midwest Agribusiness Trade Research and Information Center, Iowa State University.

