COMPARING THE ADOPTION OF GENETICALLY MODIFIED CANOLA IN CANADA AND AUSTRALIA: THE ENVIRONMENTAL AND ECONOMIC OPPORTUNITY COSTS OF DELAY

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ABSTRACT

This thesis evaluates the opportunity costs of incorporating a socio-economic consideration (SEC) into national regulation on genetically modified (GM) crops. Australia approved the cultivation of GM canola through a science-based risk assessment in 2003, but allowed state moratoria to be instituted on an SEC-based on potential trade impacts over the period 2004 to 2008 and 2010 in the main canola growing states. This analysis constructs a counterfactual assessment, using the Canadian experience to create an S-curve of adoption, to measure the opportunity costs of the SEC-based moratoria through environmental and economic impacts between 2004 and 2014.

The impacts will be assessed through a per hectare analysis of canola, by variety, and subsequently aggregated into GM and non-GM variables in New South Wales, Victoria, and Western Australia, and Australia as a whole. These variables, and their respective number of canola hectares are used to create a cumulative impact of the delay from the SEC-based moratoria through comparison of the scenario under the S-curve and the one reflecting the actuality. The environmental impacts will be assessed through the amount of active ingredients applied during pest management, the Environmental Impact Quotient, and greenhouse gas emissions as a by-product of fuel use from the change in machinery passes from cultivation and spray applications. The economic impacts will be measured through the variable costs of the weed control programs, yield, and producer margins, comparing impacts between gross margins, comparative margins, and a calculated contribution margin. The objective of this work is to gain insight into the opportunity cost and impact of incorporating SECs into GM crop regulation.

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LIST OF ABBREVIATIONS

ABARES	Australian Bureau of Agricultural Resource Economics and Sciences
AI	Active Ingredient
ANZFA	Australia New Zealand Food Authority
AOF	Australian Oilseed Federation
AP	Adventitious Presence
Bt	Bacillus Thuringiensis
CFIA	Canadian Food Inspection Agency
CPB	Cartagena Protocol on Biodiversity
DAFWA	Department of Agriculture and Food of Western Australia
EIQ	Environmental Impact Quotient
EPR	End Point Royalty
EU	European Union
FSANZ	Food Safety Australia New Zealand
GHG	Greenhouse Gas
GM	Genetically Modified
GMO	Genetically Modified Organism
GRDC	Grains Research and Development Corporation
HC	Health Canada
HT	Herbicide Tolerant
IPM	Integrated Pest Management
IR	Insect Resistant
mt	Metric Tonne
NSW	New South Wales
OGTR	Office of the Gene Technology Regulator
PNT	Plant with Novel Traits
RAF	Risk Assessment Framework
RARMP	Risk Assessment and Risk Management Plan
RR	Roundup Ready®
R&D	Research and Development
SEC	Socio-Economic Consideration
SPS	Sanitary and Phytosanitary
TAF	Technology Access Fee
TUA	Technology Use Agreement
TT	Triazine Tolerant®
WA	Western Australia
WTO	World Trade Organization
ZTMT	Zero-Tillage Min-Tillage

Chapter 1. Introduction

1.1 Introduction

The technology and innovation associated with genetically modified organisms (GMOs) has gained a strong foothold in many agricultural producing areas around the world. In 2014, the adoption of genetically modified (GM) crops was taking place in 28 countries and was planted on 181.5 million hectares globally, up from six adopting countries and 1.7 million hectares in 1996 (James, 2014). The research and development (R&D) in GM crops through the 1980s and 1990s had a wide ranging array of plants identified with potential to be modified, but the number in commercial production has largely been limited to four main GM crops, canola, cotton, maize, and soybeans (Anderson, 2010).

The first generation of GM crops is generally regarded as those incorporating input traits (Smyth, Khachatourians, and Phillips, 2002). Input trait technologies involve an input reduction in the production of the crop, herbicide tolerance (HT) and insect resistance (IR) are the dominant traits commercialized within the four main crops (Brookes and Barfoot, 2014). Second generation GM crops are regarded as those involving output traits (Smyth and Gray, 2011). Output trait technologies involve some additional output from the GM crop, such as quality improvements in nutritional enrichment or for industrial purposes. While there has been the approval of a few second generation GM crops, the Arctic apple and bruise resistant potatoes for instance, the most talked about output trait crop has been Golden Rice. It experienced a long delay in the risk assessment on the safety of its biofortification with vitamin A- from the late 1990s until approval in the Philippines in 2013, although Golden Rice has still not yet been grown commercially (Newell-McGloughlin, 2014). Third generation GM crops involve the expression of advantageous enzymes, such as a pharmaceutical antibodies or industrial biodegradable plastics. These GM traits face a large hurdle in the complexity of regulatory policy and garner only a small portion of GMO R&D (Qaim, 2009). The effects and description of GMOs in this analysis will be limited to the first generation of input trait varieties.

There have been important advantages associated with the adoption of GM crops. Approved GM crops have resulted in yield increases of 21% across all varieties (Kluemper and Qaim, 2014). These yield impacts are distributed unevenly across crops and countries with developing countries seeing the largest proportional increases, where yields have increased by 37% in GM IR Bacillus Thuringiensis (Bt) cotton in India and 34% in GM Bt maize in the Philippines (Qaim, 2009). Similar to yield effects, GM crops have resulted in large reductions in insecticide and herbicide use, as well as large increases in gross margins and family incomes (Brookes and Barfoot, 2014; Qaim, 2010). In the nearly 20 years since GM crops have been commercially cultivated the technology continues to be welfare enhancing (Kathage and Qaim, 2012), with "no effects on human health… shown as a result of the consumption of such foods" (World Health Organization, 2014).

The strong benefits observed in GM crops has, however, been accompanied by controversy over worries about the potential impacts that biotechnology may still have on biodiversity and human health (Shiva, 2014). The anti-GM movement attempts to bring consumer desires and environmental worries to the forefront and to influence regulatory policy without scientific evidence. This influence on regulatory policy which ignores scientific evidence and raises other issues is one example of a socio-economic consideration (SEC) in policy making.

1.2 Research Problem Statement

SECs are a broadly defined set of social issues that attempt to protect certain interests of a society. A sampling of these interests include protection of the benefits to producers or society, consumer choice, the environment, ethical and equitable outcomes, food security and safety, impacts to biodiversity, and international trade concerns (Ludlow, Smyth and Falck-Zepeda, 2014). The nature of these concerns are naturally subjective in nature, as issues such as ethical outcomes are not universally defined and are a by-product of cultural heritage. The absence of definition does not make SECs any less strongly held by some members of civil society, but their inclusion in regulatory policy making does make for ambiguous interpretations. In a globalized world of international trade, the ambiguity of SECs may allow them to behave as trade barriers to protect vested interests (Phillips and Kerr, 2000).

The European Union's (EU) use of SECs encourages discrimination against GM foods, despite 20 years of evidence that show no harm and all major scientific bodies declaring no additional risks compared to conventional varieties (American Medical Association, 2012;

European Commission, 2010; National Academy of Sciences Engineering and Medicine, 2016; World Health Organization, 2014). The impact of SECs is not only felt domestically but can have direct consequences on other nations. While developed countries can provide evidence and are able to accept market fluidity consequences, developing nations are far more limited in their choices and may be starkly affected by another country's adoption of a SEC-based moratorium (Paarlberg, 2008).

The precautionary principle[1] has become an integral aspect of SECs and can be an asset to the safe and responsible adoption of new innovations and technologies. There is a limitation in the precautionary principle relevant to SECs in that it does not allow for a full evaluation of the benefits and costs. In the case of GM crops and the incorporation of an SEC-based moratoria, i.e. not based on scientific evidence, the principle illustrates the obvious benefit that by not adopting the GMO there is zero risk from the technology. However, it does not allow for an evaluation of the opportunity costs of such preventative measures and the externalities that are being foregone from the rejection of the GMO.

The adoption of new innovations requires careful assessment, as each new innovation carries with it a series of unknown benefits and costs, only the most preliminary of which are known at the development of the innovation. At the onset of the 20th century the automobile was just beginning to enter commercial production; and who could have ever predicted at that time how it would affect society. Yet if the precautionary principle was strongly enforced we would certainly not be as connected as we are now. Society is clearly able to accept some degree of risk in adoption of new technology, one of the costs of the automobile are the associated car accidents that occur, while the benefits include the mobility afforded, which seems to outweigh the costs as we still drive. Just as new technologies result in winners and losers in society, innovations need to be met with regulations that can evaluate the benefits against the risk and costs to maximize societal benefits.

Innovations in agricultural biotechnology are not a one size fits all solution for all countries, nor is GM the only agricultural innovation. This case study will attempt to quantify the impacts

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[1] The precautionary principle is when the assessment of risk on a new innovation is uncertain with the potential for harm, the resulting policy should exhibit precaution to avoid and diminish that potential harm. Another interpretation is that "if a course of action carries even a remote chance of irreparable damage, then one should not pursue it, no matter how great the benefits may be" (European Commission, 2010, p. 21).

of adopting SEC-based moratoria on GM crops to highlight the opportunity costs of delaying adoption, post-successful completion of a risk assessment. While the effects of consumer concerns and ethical issues cannot be measured in the evaluation of incorporating an SEC into policy, the tangible environmental and pecuniary effects will offer a first step into establishing a framework for a full cost-benefit analysis.

1.3 Objectives of Study

This thesis will evaluate the Australian experience in which SEC-based moratoria, established as a result of industry worries pertaining to possible trade effects from the adoption of GM canola, was included into national regulatory policy after a science-based risk assessment approved two GM canola varieties. This ex-post analysis evaluates the effects after the SEC-based moratoria were eventually removed, to illustrate the impacts of the SEC compared to if it were not instituted- a counterfactual argument. This analysis will incorporate the Canadian experience, in which GM canola was approved and adopted after a risk assessment based on scientific evidence was conducted, to construct the counterfactual and compare the impacts.

This research measures the environmental and economic impacts of incorporating an SEC into Australia's national GMO policy. The impacts within this analysis offers insight into the opportunity costs of incorporating SECs and delay into the regulatory policy of GM crops. This thesis accomplishes these objectives through six steps.

1. Establishes the background regarding the adoption of GM canola policy in Canada and Australia,
2. Creates a counterfactual scenario of adoption in Australia without an SEC, based on the Canadian experience with GM canola adoption without an SEC,
3. Conducts a weighted analysis to create a basket variable of the non-GM canola varieties to compare to the GM variable,
4. Evaluates the GM and non-GM variables' environmental impact through the active ingredients applied, the environmental impact of herbicides, and greenhouse gas emissions,

5. Evaluates the GM and non-GM variables' economic impacts on variable costs, yield, and producer margins,
6. Determines the cumulative Australian and state-level impact of these factors as the opportunity cost of an SEC-based moratoria incorporated into GM regulation.

1.4 Organization of Research

This thesis contains five chapters including the current one. The following chapter lays out the regulatory environment for the adoption of GM crops in Canada and Australia, with specific regard to GM canola. Chapter Three lays out the methodology that is used, a description of the construction of the counterfactual, the data analyzed, the methods for evaluation, and the environmental and economic variables used in the analysis. Chapter Four discusses the resulting impacts of the environmental and economic variables and the cumulative opportunity costs of the SEC-based moratoria on Australia in the 2004 to 2014 period. Chapter Five concludes with a summary of the thesis, conclusions from the results and the associated policy implications, limitations of thesis, and areas for future research.

Chapter 2. Literature Review and Background

2.1 Introduction

The development of GMOs and the regulatory policy that accompanies it varies across jurisdictions and cultural environments. Comparing the development and effect of regulations in jurisdictions with many similarities, but some key differences, can offer insight into the impact of those policies. The national similarities between Canada and Australia, developed commonwealth nations that have resource-based economies with large-scale agricultural farm production, allows for an analysis of GMO policy and its impacts in two broadly homogenous countries.

The path to adoption of GM canola has followed two distinctly different paths for dealing with broadly similar issues in the Canadian and Australian contexts. The Canadian framework made use of existing regulatory departments; Australia developed a new regulatory office for biotechnology. The Canadian canola industry came together to ensure access to international markets through self-regulation; the fractured Australian grains industry worried about trade implications and lobbied the government to impose a moratorium. The Canadian government assessed GM canola on scientific-evidence-based policy; the Australian government used science-based policy in GM canola approval and then allowed SEC-based moratoria on its cultivation due to the international trade concerns of industry stakeholders.

The regulatory process on the assessment of GM crops in the Canadian and Australian jurisdictions, however, do have strong parallels. Both use two agencies to assess GM crops, one on the environmental impact of unconfined release for production and impact to livestock and the other on the health impacts to humans. The analogous science-based regulatory approval process of GM crops provides for a comparison in which the adoption of an SEC is the main policy difference, and the focus of this analysis.

2.2 Canada

The development of new GM varieties of canola with herbicide tolerance began in the 1980s, and culminated in the approval of Monsanto's glyphosate tolerant Roundup Ready® (RR) canola and AgrEvo's, now Bayer CropSciences, glufosinate ammonium tolerant LibertyLink® canola in 1995 (Health Canada, 1999, 2000). Canada was at the forefront in the adoption of the first generation of GM crops along with the US, with GM canola, corn, cotton, and soybeans varieties approved in 1995 (Smyth and Phillips, 2001).

The approval of GM crops is conducted using scientific-evidence-informed policy, more commonly referred to as science-based policy. GM crops are assessed using a risk assessment framework (RAF) that measures the hazard, exposure, and variability of results to evaluate potential adverse effects. The environmental and human health and safety risk factors of impacts to non-target organisms, toxicity, allergenicity, and nutrition are used as they are scientifically measurable and universally defined. This science-based policy is the standard mechanism to assess whether a policy is regarded as a trade barrier within the World Trade Organization (WTO) and is the method with which trade disputes on GM crops are compared under obligations within the Sanitary and Phytosanitary (SPS) Agreement (Isaac, Phillipson and Kerr, 2002; Isaac, 2007).

2.2.1 Regulating GM Crops

The Canadian government's RAF on GM crops is based solely on scientific evidence. The development of Canadian policy on transgenic crops began in 1988 in which a forum regarding a regulatory framework was established and evolved into a formalized structure in 1992. This structure led to a proposal for draft regulations and a workshop on amendments to the regulations, ultimately culminating in a regulatory framework in 1994. The framework utilized already existing departments and organizations and charged them with the evaluation of Plants with Novel Traits (PNTs). PNT applications extend beyond GM varieties, which make up the majority of assessments, to include non-GM varieties bred through mutagenesis and varieties that do not have a history of production in Canada, (Andree, 2002; Smyth and McHughen, 2008).

The RAF on PNTs is conducted by the Canadian Food Inspection Agency (CFIA) and Health Canada (HC). The CFIA analyzes the impacts of the PNT on the natural environment and its use as an animal feed. HC reviews the PNTs impact on human health and safety, as well as the environmental assessment of products regulated under the Food and Drug Act that are not reviewed by the CFIA (Smyth, Falck-Zepeda and Ludlow, 2014). This separation of assessments allows the CFIA to evaluate crops that will be commercially cultivated in Canada, while HC evaluates all food products containing PNTs before they can be marketed in Canada.

The application for the unconditional release of a new GM crop begins with an application to the CFIA, in which it conducts assessments on five main environmental impacts categories.

1. Potential of the PNT to become a weed of agriculture or be invasive of natural habitats.
2. Potential for gene flow to sexually compatible plants whose hybrid offspring may become more weedy or more invasive.
3. Potential for the PNT to become a plant pest.
4. Potential impact of the PNT or its gene products on non-target species, including humans.
5. Potential impact on biodiversity. (CFIA, 2012)

PNTs are assessed under directives on environmental safety, novel feed, and environmental release in confined field trials before certification. In complying with these directives a PNT that is intended for commercial cultivation or livestock feed, as GM canola is, is first evaluated in a contained facility.

Following on the successful contained trial, the product developer applies for confined field trials. These trials require notice to the province of trial sites and are conducted over multi-year periods in various locations. The field trial data is collated with other scientific evidence, including peer-reviewed journal articles, international scientifically validated evidence, and any other relevant data, and submitted to the CFIA for a safety assessment. A successful review will end with the receipt of variety approval and registration at the Variety Registration Office (Smyth, Falck-Zepeda and Ludlow, 2014; Smyth and McHughen, 2008). The review of a PNT is a continuing process that allows for the ongoing assessment of CFIA certified events.

HC's approval process has a broader scope than the CFIA, as it evaluates all new PNT foods before they are marketed and sold in Canada. The unique aspect of the PNT classification is that a review process is not required for every GM application, for instance if two traits are cross-licensed into a new variety, rather it only exists for new novel traits. This synopsis will limit its scope to the applications of GM PNTs that are commercially cultivated in Canada, which is the case for GM canola.

The HC review process begins with the submission of data from the product developer on the nutrition, toxicity, and allergenicity of the PNT. The safety assessment of the PNT application evaluates the data on dietary exposure, metabolization, and microbiological safety (Health Canada, 2006). In similarity to, but more accepting of, the CFIA, HC allows for experiential data on the PNT from other national jurisdictions to be admissible into the data package submitted as nutritional aspects are not geographically dependent. In review of the PNT application the novel variety is compared to a generic base variety to test the extent of the novel trait within the natural variability of current approvals. Once the review of data is completed, there can be a request for additional data prior to approval. If accepted it goes to senior management within HC who can also make a request for more data, restarting the review process. Successful approval of the review results in a decision document being posted to the HC webpage and the developer is now able to market the product for sale (Smyth, Falck-Zepeda and Ludlow, 2014).

The CFIA and HC work closely together on the authorization process. The data on food safety, environemtnal safety, and livestock feed safety must be completed before an overall decision is made to approve a crop for Canadian release. In the instance in which there is a split approval, one agency certifies the event while the other does not, the event is not approved for Canadian release until both agencies come to a unanimous decision (CropLife Canada, 2013).

Approval of GM Canola

The CFIA decision to approve glyphosate tolerant and glufosinate ammonium tolerant canola varieties were the first two PNTs approved within the Canadian RAF[2]. These canola varieties were found to have no significant difference in effects on the environment compared to base varieties. There were no adverse effects in the five main environmental impact assessment categories and the comparison to current livestock feed culminated in GM canola varieties within

[2] A third PNT variety of canola was approved in 1995 shortly after the Roundup Ready and LibertyLink varieties. This variety was Pioneer Hi-Bred's imidazolinone tolerant canola, Clearfield®. It is a mutagenesis, non-GM variety evaluated under the same system in Canada (CFIA, 1995b). In Australia however, Clearfield canola did not need to be assessed as rigorously due to its non-GM status and was not restricted by the state-based moratoria imposed on GM canola in 2003.

the same acceptable limits as the base variety. The two GM canola varieties were regarded as 'substantial equivalents' to the base varieties in use (CFIA, 1995a, 1995c).

In conjunction with the CFIA approval, Monsanto's Roundup Ready and AgrEvo's LibertyLink canola were approved for human food use under the HC guidelines. The decision document noted that the method of gene transference and the novel gene traits are not present in the refined canola oil. This absence of the novel trait in refined oil couples with the nutritional and toxicological components which were found to have no statistically significant difference between GM and non-GM canola oils. As the oil is the only part of the canola seed consumed by humans there was no observed safety risks (Health Canada, 1999, 2000).

2.2.2 Adoption of GM Canola

The final approval of the two GM canola varieties in March 1995 came shortly after the completion of the regulatory framework for PNTs. Post-approval of GM canola, the canola industry faced a difficult choice in cultivating canola due to concerns regarding access to international markets. Canadian canola exports were concentrated in Europe, Japan and the US with these markets absorbing 70% to 85% of canola exports between 1990 and 1999 (Smyth and Phillips, 2001). As the US had also approved the same GM canola varieties the considerations were focused on Europe and Japan.

Europe was an inconsistent consumer of Canadian canola exports, between zero and 17% over the period 1990 to 1999, and showed no apparent willingness to pay a premium for certified GM-free exports. With little trust in the EU's regulatory system on GM crops an industry decision was made to forego the added costs of a long-term segregation system to maintain this export market[3] (Smyth and Phillips, 2001). Japan, however, was treated in a different fashion.

Japan was the largest consumer of Canadian canola exports with a regulatory system that was similar to Canada's, albeit slightly slower, and had both GM canola applications pending. The industry had to make a decision on whether to allow for release of the GM canola, and possibly

[3] It should be noted that the Canadian canola industry was not unanimous in its decision to forego the EU market and a system of segregation. Organic canola growers lost access to the EU export market and faced an increased reluctance of organic buyers to purchase organic Canadian canola (Phillips, 2003).

lose the Japanese market; postpone the release; or create a system of temporary segregation. The industry decided to institute a self-imposed coexistence system, as the Canadian government did not hold jurisdiction over the marketing of food products, and await the Japanese decision (Smyth, McDonald, and Falck-Zepeda, 2014; Smyth and Phillips, 2001).

Segregation and Coexistence

The developers of GM canola products, AgrEvo and Monsanto, took a lead in developing and instituting the system of segregation as they awaited Japanese approval. This process involved an investment into developing and maintaining a system of coexistence to maintain the Japanese export market while allowing for the cultivation of the GM canola varieties in Canada. The coexistence system was found to have a cost of CA$33 to CA$41 per metric tonne, including a CA$20 opportunity cost, dispersed among the various players throughout the industry. The investment of approximately CA$3.5 and CA$4.5 million, by Monsanto and AgrEvo respectively, on the coexistence system between 1995 and Japanese approval in late 1996 is estimated to have had a return of nearly CA$100 million (Phillips, 2003; Smyth and Phillips, 2001)

Beyond canola, Canada's other exports of wheat and barley have not been adversely affected by the adventitious presence (AP) of GM canola, as the Canadian restrictions on small is strict with allowable levels of 0.05% and 0.1% percent respectively (Foster and French, 2007). In keeping AP levels below international market standards, such as the EU's 0.1% threshold for non-certified GM events that have been approved in a non-EU country (Hobbs, Kerr and Smyth, 2014), Canada has found ample markets for its canola and other crops without a defined and mandated system of segregation or coexistence.

2.2.3 Post-Adoption Impacts

The resulting adoption of GM canola was rapid, reaching 53% adoption in 1999 and 93% adoption in 2010, and has nearly eliminated conventional canola from production, going from 100% of hectares in 1995 to 29% in 1999 and 1% in 2010, with Clearfield making up the remaining differences (Canola Council of Canada, 2010). The favorable adoption has resulted in large environmental impacts, through the reduction and toxicity of active ingredients applied, and through substantial economic benefits to producers and the canola industry (Beckie et al., 2006; Beckie et al., 2011; Brimner, Gallivan and Stephenson, 2005; Brookes and Barfoot, 2005; Fulton and Keyowski, 1999; Gusta et al., 2011; Mayer and Furtan, 1999; Phillips, 2003; Qaim, 2009; Smyth et al., 2011a, 2011b). The rapid adoption of transgenic and HT canola transformed the industry through a change in cultivation practices and a reduction in herbicides applied and inputs, including the farmer's time saved from those changes.

Impacts on Trade

Beyond the effects for producers there also existed an impact on trade from adopting GM canola. Since 1997 when the commercial cultivation of GM canola in Canada began, the EU has effectively reduced the import of Canadian canola seed to a near zero amount, as it was not an EU certified GM event. The UK Soils Association issued a report in 2002 that went on to say that this blockade has resulted in a CA$300 to CA$400 million loss to the Canadian canola industry between 1996 and 2002 (as cited in Smyth, Kerr, and Davey, 2006). In actuality the fluidity of the market has not resulted in any major negative trade impacts in Canada from the loss of the EU market, as the canola that would have been sent there has been redirected to other importing countries (Smyth, Kerr, and Davey, 2006). In addition, there was still a market for Canadian canola oil within the EU, as there is no detectable GM material in the processed oil.

The minimal amount of trade impacts has seen Canada continue to thrive as the world's primary exporter of canola with no noticeable price effects compared to the secondary exporter of Australia. Cumulatively these two countries maintain a share of over 90% of the world canola export market (ABARES, 2015). With the only noticeable difference between these two countries being Australia's 'GM-Free' canola status until 2008, the similarity in prices indicates that the science-based policy underlying Canada's adoption of GM canola has not resulted in any adverse effects.

2.3 Australia

Nationally, Australia approved the commercial cultivation of these same two HT varieties of GM canola in 2003. Shortly after approval the Australian government enacted a new SEC-based regulation that allowed Australian states to enact moratoria to grant safety to the grain industry against possible negative trade effects from GM canola's adoption, and not on the grounds of human or environmental health or safety issues. This incorporation of an SEC into policy is the main difference between Canada and Australia's adoption of GM canola. Philip Glyde, the Executive Director of the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), commented that:

> [T]he development and adoption of genetically modified (GM) food crops in Australia are being slowed by perceptions of consumer resistance to GM foods in both Australia's domestic and export markets. The view that there could be market disadvantages with GM food crops has led to moratoriums being imposed on the commercial cultivation of GM canola in the states and territories, with the exceptions of Queensland and the Northern Territory. *This is despite positive assessments by the Gene Technology Regulator of the safety of two varieties of GM canola, for human consumption and the environment* [emphasis added]. (Foster and French, 2007, p. 3)

Three out of six of these moratoria were repealed upon review of the economic and market impacts of the adoption of GM canola, in conjunction with an industry suggested system for the segregation and coexistence of GM and non-GM crops within the Australian market place. Of note is that the three states of New South Wales (NSW), Victoria, and Western Australia that repealed their moratoria are also the largest canola producers, and that South Australia is the only large canola producing state to maintain its moratoria.

2.3.1 Regulating GM Crops

The cultivation of GM crops in Australia began with the GM cotton variety Ingard® developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO) using Monsanto's IR Bt trait in 1996. GM cotton varieties were approved with minimal consumer resistance or industry problems, reaching nearly 100% adoption in 2012 encompassing additional GMIR cotton varieties approved in 2003 and 2009 and GMHT cotton varieties approved in 2001 and 2006. (Agricultural Biotechnology Council of Australia, 2012). The approval process was conducted by the Genetic Manipulation Advisory Committee, which was a precursor to the

Australian government's development of a department dedicated to the licensing and approval of GMOs (Ross, 2007)

In 2000 Australia began to build a rigorous framework for regulating and analyzing the effects of biotechnology and GMOs, the outcome was the *Gene Technology Act 2000* (the Act).

> [T]he object of this Act is to protect the health and safety of people, and to protect the environment, by identifying risks posed by or as a result of gene technology, and by managing those risks through regulating certain dealings with GMOs. (*Gene Technology Act 2000*, 2011, p. 1)

The Act stipulates the method GMOs are reviewed under to assess their risk to the health and safety of people and the environment (Mccauley and Davies, 2012). To assess this risk a new division was created within the Ministry of Health, the Office of the Gene Technology Regulator (OGTR), to conduct a Risk Assessment and develop a Risk Management Plan (RARMP) to be used in the review process for certification of new GMOs. The OGTR grants certification, or denies it, for all GMO applications for commercial crop introduction based off of these RARMPs (*Gene Technology Act 2000*, 2011; OGTR, 2010), and operates in a role similar to the CFIA.

The RARMP takes into account the advice of local councils, Commonwealth agencies, the Environmental Minister, and other relevant bodies, in addition to the research and analysis conducted by the OGTR on the risks to the environment and human safety from the introduction of the GMO under review (*Gene Technology Act 2000*, 2011). The RARMP is a science-based, transparent assessment in which the results must be published in the national newspaper and the main regional newspaper of each state, as well as on the OGTR website. Following this distribution of the assessment, the OGTR allows for the submission of additional advice from all bodies, including producers and other stakeholders, for a minimum of 50 days. It should be noted that a RARMP is a continuing process that allows for the ongoing assessment of OGTR certified events. For example, the RARMPs conducted on the two GM canola varieties certified have undergone repeated assessments in which "[n]o information has arisen, either domestically or internationally, to indicate the commercial GM canola licenses issued in 2003 should be varied, suspended or cancelled" (OGTR, 2010, p. 2).

Beyond the OGTR licensing of a product for cultivation, all new novel foods must be assessed by Food Standards Australia New Zealand (FSANZ) before the product can be marketed, and is analogous to HC. The FSANZ novel product assessment for GM products evaluates the nature of the genetic modification, safety issues of the novel protein and its potential gene transfer through human digestion, toxicological issues, and nutritional issues. The precursor to FSANZ was the Australia New Zealand Food Authority (ANZFA), which had the same role and was the body that assessed GM canola (FSANZ, 2016).

Approval of GM canola

ANZFA's successful assessment of Monsanto's Roundup Ready and Aventis CropScience's, currently Bayer CropScience, InVigor[4] varieties were completed in 2000 and 2001 respectively. These two GM canola variety assessments found there to be no allergenic concerns, no significant differences in nutritional impacts, and that the refined oil for human consumption contained no proteins or GM traits, indicating that these GM canola varieties posed no safety or public health concerns (ANZFA, 2000, 2001). The ANZFA assessments also took into account the possible effects of GM canola grown in other jurisdictions and imported, namely Canada, and predated the OGTR assessment and cultivation of these two GM canola varieties in Australia.

Australia's first approval of a GM food crop was the 2003 approval of InVigor canola, with Roundup Ready canola approved later that year (OGTR, 2003a, 2003b). The certified commercial cultivation of these two GM canola varieties was on the basis that the risk of health and safety issues pertaining to people and the environment is minimal, able to be effectively managed by the industry, and lower than the societal and environmental benefits arising from their approval (OGTR, 2010).

In response to the certification of GM canola in 2003 representatives and stakeholders in the grain industries, specifically the wheat sector, grew concerned about the potential international trade impacts that could arise due to the AP of GM material in non-GM grains (DAFF, 2007; Mccauley and Davies, 2012). These trade worries influenced the Gene Technology Ministerial Council who enacted an SEC-based amendment to the Act, known as the *Gene Technology (recognition of Designated Areas) Principle 2003* (ACT Health, 2013). This amendment allowed states to enact moratoria on:

[4] InVigor refers to hybrid canola while LibertyLink refers to the open-pollinated canola that contain the same GM traits.

(a) ethical issues relating to dealings with GMOs;

(aa) recognizing areas, if any, designated under State law for the purpose of preserving the identity of one or both of the following:

(i) GM crops;

(ii) non-GM crops; for marketing purposes. (*Gene Technology Act 2000*, 2011)

In 2003 moratoria were adopted in the main canola growing states of NSW, Victoria, South Australia, Tasmania, Western Australia (WA), and the Australian Capital Territory, but not in Queensland or the Northern Territory. These moratoria were instituted to allow producers time to evaluate the possible impacts on trade, market effects, benefits to producers from planting GM compared to non-GM canola, and methods for segregation and coexistence of GM and non-GM canola. During the period of moratoria on the commercial cultivation of GM canola, industry stakeholders finally came together and began a process to mitigate possible trade effects through supply chain management for the coexistence of GM and non-GM crops (Single Vision Grains Australia, 2007b).

Figure 2-1 Market Choice Criteria

MARKET CHOICE CRITERIA – GM CANOLA		
Step	**Action**	**Status**
1	Australian regulatory approval gained GM canola varieties were approved by the OGTR in 2003	✓
2	Market requirements identified Need for segregation to meet the various requirements of domestic and international consumers	✓
3	Threshold levels established • Australian AP thresholds have been established for the presence of GM traits in canola at 0.5% for seed (Australian Seed Federation) and 0.9% for grain (NACMA CSO1 Canola standard) • AP thresholds established in key trading partners, such as Japan (5%) and Europe (0.9%) – for contractual or labelling purposes	✓
4	Importing market approvals in place GM canola varieties have approvals in key importing countries	✓
5	Supply chain processes to meet market requirements Protocols available to segregate throughout the supply chain (Attachment I)	✓

Source: Single Vision Grains Australia, 2007a, p. 5

In 2007 Single Vision Grains Australia (2007b) issued a set of principles for the coexistence of GM and non-GM crops under which GM canola would be satisfactorily introduced. Single

Vision took these principles and conducted an analysis on the Australian grains industry to measure the industry's ability to meet the requirements of segregation and coexistence under the proposed introduction of GM canola, Figure 2-1. The results detailed the grains industry's ability to meet all the desired principles and satisfy all the requirements for market choice within a system of coexistence involving GM and non-GM canola, and advised for the removal of the moratoria, Figure 2-1 (Single Vision Grains Australia, 2007a).

Step 3 in Figure 2-1 is significant as it acknowledged the need for congruity in regulation with the EU on the AP of GM canola, a hurdle that possibly led to the introduction of the moratoria initially. Step 4 builds off this harmony in regulation as it highlights that the EU had approved for importation both OGTR approved GM canola varieties, and that fears of trade loss to the EU were no longer a threat from strict zero-tolerance regulations on unapproved GM events (Hobbs, Kerr and Smyth, 2014; Smyth and Phillips, 2014).

The potential cross supply chain mingling is acknowledged through the use of Steps 3 and 5. Step 5 acknowledges that the protocols of segregation for specialty crops throughout the supply chain were able to be effectively transferred to GM segregation. While Step 3 aligns Australia's AP of GM varieties to be in congruence with the main international markets and the thresholds of GM canola varieties allowed in exports of other non-GM grains.

The grains industry created a viable framework for adopting GM canola technologies by acknowledging producers' worries regarding trade impacts from the EU and other countries with zero-tolerance for non-approved GM events. The approach was designed to give producers the choice on which type of canola to grow to capitalize on their previous status as non-GM or on the benefits of GM canola. Building off this framework the Australian Oilseeds Federation (AOF) created a new trading standard, whereby producers can certify their canola as non-GM (2009). In conjunction with this new standard, the AOF outlined the protocol on how to achieve this certification based off of testing and segregation practices throughout the supply chain.

An example of how the grains industry's reaction changed from the institution of the moratoria until its respective repeal comes from Western Australia. The Kondinin Group conducted a series of surveys on growers' perception of GM technology bi-annually, from 2002 onwards. These surveys found that in 2002 45% of growers opposed the adoption of GM crops, while 19% supported its adoption. By 2009 those numbers had reversed with only 24% of growers being opposed to GM technology adoption, while 51% of growers were now in support of the adoption of GM crops (Griffiths as cited in Mccauley and Davies, 2012). This change in perspective was felt throughout much of Australia as a review of current practices was begun.

2.3.2 Adoption of GM Canola

In 2006 the OGTR conducted a review to analyze the impacts of the moratoria and

> [N]oted that there was no evidence of adverse impacts on markets, and concluded that the moratoria were having detrimental rather than beneficial impacts, as the moratoria were creating regulatory uncertainty and impeding the path to market for GM crops licensed for commercial release by the [OGTR]. (ACT Health, 2013, p. 7)

That this report found the moratoria to have strikingly negative effects on producers is an indicator of the impact an SEC-based policy can have on society. This report affected state governments as it sought to reaffirm a nationally consistent framework on GM crops, which resulted in the states with moratoria conducting a review of their policies between 2007 and 2008 (ACT Health, 2013).

The OGTR review occurred in close proximity to two other significant events relevant to the cultivation of GM canola. The first event was the EU's approval for importation of both Australian certified GM canola varieties, InVigor and Roundup Ready (Commission Decision of 26 March 2007, 2007; Commission Decision of 31 August 2005, 2005; OGTR, 2003a, 2003b). The second event was the Australian government's 2005 introduction of rules on the mingling of GM crops in non-GM certified products. The rules were developed to be congruent to the EU's rule of 0.9% mingling on approved GM varieties and ensure access to export markets (Foster and French, 2007; Mewett et al., 2008).

For non-GM grain certification the OGTR instituted a level of 0.5% AP of GM material at the seed purchase level and 0.9% AP at the grain distribution level (Single Vision Grains Australia, 2007b). This level of AP and low level presence in non-GM certification is consistent with Australia's main canola importing trade partners. The EU has a tolerance of 0.9% AP on the GM canola varieties certified by the OGTR in Australia, as they have been approved for importation by the EU for industrial use and food and feed (Commission Decision of 26 March 2007, 2007; Commission Decision of 31 August 2005, 2005). Japan has a threshold of up to 5%

AP of GM material in non-GM classified canola, and 1% AP in varieties not certified for feed in Japan but certified elsewhere (Ministerial GMO Industry Reference Group, 2009). All other important importing countries have either a regulatory labelling scheme in place or do not maintain a certification or segregation process for non-GM crops (Mewett et al., 2008). With all of the significant pieces in place state reviews began to occur.

The Moratoria

Victoria was the first state to establish an Independent Review Panel to evaluate the impact of their moratorium, the *Control of Genetically Modified Crops Act 2004*. The Panel advised the Victorian government that there was "no compelling market or price advantage that can be attributed to Australia's non-GM status as a bulk canola exporter" and that the moratorium should be allowed to expire (Victorian Government, 2007). Under this advisement, the government allowed the moratorium on GM canola to lapse in February 2008 and has left the segregation of GM and non-GM crops up to the supply chain and marketers, including all testing requirements for specific markets and certification (Mewett et al., 2008). This system of segregation is similar to the method used in Canada. Victoria is the only state that enacted a moratorium but no longer has one.

In 2007 NSW amended their moratoria, *Gene Technology (GM Crop Moratorium) Act 2003*, from strictly covering GM canola to cover all GM crops, excluding GM cotton. With the new blanket moratoria in place the government began to accept applications for assessment on an industry's preparedness and ability to manage a GM crop as well as its impacts (Armstrong, Adams and Reeves, 2007). In that same year a representative of the canola industry applied believing that the grain industry met all the required criteria. Under the advice of the independent application reviewal committee, the NSW Primary Industries Minister announced that the canola industry identified the key obstacles and was able to maintain the segregation and coexistence of GM and non-GM canola and grains (Mewett et al., 2008). It should be noted that only OGTR approved GM canola has been granted commercial cultivation status in NSW and that the blanket moratoria on all other GM food crops, including those approved by the OGTR, remains in place until 2021.

Western Australia's moratorium, *Genetically Modified Crops Free Areas Act 2003,* saw a slower, stepped process to the commercial cultivation of GM canola. The moratorium enacted a complete ban on all GM crops in the state. In 2008 Western Australia made an exemption to this moratorium that allowed for the commercial cultivation of GM cotton (ACT Health, 2013). A further partial exemption in 2009 allowed for a limited trial basis of GM canola to see if the industry was able to segregate GM from non-GM canola and other non-GM crops to ensure access to international markets. This limited trial was seen as a strong success under the management of the Department of Agriculture and Food of Western Australia (DAFWA). DAFWA reported that the "trials program demonstrated… the industry's ability to maintain segregation of GM and non-GM canola throughout the supply chain" (Mccauley and Davies, 2012, p. 6). This led to the full exemption of GM canola within the moratorium and allowed for commercial production of GM canola to begin in 2010. Although there have been exemptions made to the moratorium for the commercial cultivation of OGTR approved GM cotton and GM canola, the broader moratorium still remains in place with no expiry date. The moratorium encompasses all other GM crops, including those approved by the OGTR (ACT Health, 2013).

The states and territory of South Australia, the Australian Capital Territory, and Tasmania have seen the continuation of their moratorium after their respective reviews were conducted. The South Australian government requested that the Genetically Modified Crop Advisory Committee review the market and trade impacts of the moratorium in 2008. The committee made recommendations to the South Australian government that the moratorium be lifted. The government stayed those recommendations and decided instead to extend the length of the moratorium indefinitely under the *SA Genetically Modified Crops Management Regulations 2008* (ACT Health, 2013). South Australia is the only major canola producing state to maintain its moratorium.

Tasmania's 2008 review by the Joint Select Committee recommended that the moratorium be extended for an additional five years, to November 2014, to maintain a market advantage as being 'GMO-Free' (ACT Health, 2013). The 2013 Review of GMOs in Tasmania suggested the Tasmanian government continue to maintain its moratorium in regard to the marketing advantage of being 'GMO-Free'. The *Tasmanian Gene Technology Policy 2014-2019* heeds those suggestions and will extend its moratorium a further five years to 2019 (Tasmanian Government, 2014). It should be noted that Tasmania's annual area dedicated to canola production is often less than 1,000 hectares, with a peak level of 1,700 hectares reached in 2008 (ABARES, 2015)

The Australian Capital Territory was the last state or territory to review its moratorium. The territory is not a major player in the canola industry, and has had little reason to change its moratorium. Within this setting the Australian Capital Territory has opted to maintain its moratorium, although it may remove the moratorium at a future date to remain consistent with NSW, the state that surrounds it (ACT Health, 2013; OGTR, 2010).

Segregation and Coexistence

The barrier to adopting GM canola slowly evolved from mitigating market effects to how to allow for market choice in GM and non-GM crops. The OGTR took into account that zero-tolerance in comingling is not feasible. Absolute zero is not a responsible level of tolerance as the non-GM certification of crops can change over time as the level of testing technology advances, without a change in policy or AP (Hobbs, Kerr and Smyth, 2014). The allowance of some degree of GM material within a non-GM certified product is necessary to prevent situations such as those that transpired in Victoria in 2005. A sporadic test found trace levels of OGTR certified canola in a shipment of conventional canola during the period that the moratorium was in place. This unexpected event during the moratoria, thought to be the by-product of pre-moratoria site testing of OGTR certified events, led to the federal institution of AP thresholds for national consistency (Mewett et al., 2008).

A consistent level of testing and certification for non-GM canola and other grain is a necessary of the coexistence of GM and non-GM crops, the other barrier is of course the costs of segregation. It is estimated that the cost of segregation in Australia, not including testing, is between five and nine percent of the farm-gate price, or between approximately AU$11.50 and AU$17 per metric tonne (Crowe and Pluske, 2006; Ministerial GMO Industry Reference Group, 2009). For Canadian canola it has been estimated that the costs of segregation were between 12 and 15 percent of the post-farm gate price between CA$31 and CA$41, approximately CA$14 to CA$24 not including opportunity costs and subsidies (Smyth and Phillips, 2001).

The range of these costs is dependent upon the different methods of maintaining a coexistence system throughout GM canola adopting states. The segregation system was market led in Victoria, while NSW and Western Australia incorporated much of the AOF's proposal for coexistence (AOF, 2009). The resulting capability to undertake segregation was conducted and imposed in different manners throughout the Australian GM canola adopting states.

In conjunction with the removal of their moratoria on GM canola, Victoria did not adopt the coexistence framework of the AOF into state law. This is the result of their review panel's suggestion that the market should decide if segregation is required. The Victorian government accepted the recommendation that there was not an identifiable market failure, thus did not institute governmental regulation on the segregation or testing of canola seeds (Mewett et al., 2008). The absence of a government instituted framework for coexistence leaves the segregation of GM and non-GM canola entirely up to industry self-regulation. Victoria has a strong system of specialty seed segregation with testing conducted at points of arrival and departure coupled with a highly concentrated supply chain that has indicated the use of specialized sites for GM canola (Victorian Government, 2007). The transportation of grain is required to be labelled appropriately at the farm-gate, and the handler "[m]ust use dedicated transport units where possible where there is a risk of contamination of subsequent loads" (Grain Trade Australia, 2013, p.20). In the case of accidental mixing at a bulk handlers storage site "any remedial actions and associated costs would be at the cost of the storage network owner" (Ministerial GMO Industry Reference Group, 2009, p. 31).

NSW has adopted the regulatory guidelines set out by the AOF's segregation proposal as a framework upon which to build their system. The AOF trade standard for segregation of non-GM canola, CS01-A, has reassured the government of the industry's ability to maintain market choice (AOF, 2009). A review of the management procedures used to maintain the standard in 2008 indicated that the standards were being met and the industry was succeeding in delivering market choice (Mccauley and Davies, 2012). Farmer perception was also an indicator of this success as the results of a survey by the Grains Research and Development Council (GRDC) found that a:

> [M]ajority of non-GM canola respondents who were aware of a GM canola crop being grown by a neighbour or other farmers in the district indicated that the GM canola crops being grown did not have an impact on their farming/business operation. (GRDC, 2012, p. 45)

Both cases indicate that the mitigation strategies and protocols being undertaken have succeeded in allowing market choice in the growing and marketing of GM and non-GM canola in NSW.

Following upon the experience in NSW, Western Australia also incorporated much of the AOF's plan for the segregation and coexistence of GM and non-GM crops, but on a limited scale to make amendments specific to the state. Western Australia allowed restricted plantings in 2009 to assess the industry's ability to segregate and maintain the coexistence of GM and non-GM canola. The limited trial run of GM canola was used to evaluate areas that could be improved upon within the AOF protocol (Mccauley and Davies, 2012). The success of the initial trials, as audited by DAFWA, resulted in only 11 minor incidents, the most severe of which were a small seed spill and incorrectly provided paperwork (Mccauley and Davies, 2012). The audit established new protocols to ensure segregation of GM and non-GM canola based off of the experience of the limited trial plantings. The 2010 growing season in Western Australia saw the enactment of additional procedures and the effective segregation of GM and non-GM canola. Once again the planting of GM canola was audited by DAFWA to ensure segregation, of which the only recommendation made was to a non-GM grower not to save seeds within 400m of a GM crop (Mccauley and Davies, 2012).

2.3.3 Post-Adoption Impacts

The post-moratoria adoption of GM canola was slow in Australia in comparison to the uptake of GM cotton. GM cotton with traits of IR were approved for cultivation in 1996, with further IR and HT traits approved thereafter, and reached a level of 92% adoption by 2006 (Foster and French, 2007). The high level of GM cotton plantings, the near absence of separation between GM and non-GM cotton, and the use of cottonseed oil as a preferred cooking oil in deep frying, indicate that there is not a consistent public outcry against GM crops in Australia. Aside from cotton lint, cotton seed is used analogously to canola seed (Victorian Government, 2007). The ability of farmers to appreciate the advantages of GM crops and the willingness of consumers to consume GM products, cannot be aspects hindering GM canola adoption as they run counter to the GM cotton experience.

The slow uptake of GM canola may be the by-product of the availability of the HT conventional strain Triazine Tolerant (TT) canola. TT canola was first commercialized for production in 1993 and quickly gained a dominant foothold due to its excellent weed control (Hudson and Richards, 2014), despite its associated 10 to 30% decrease in yield (Robertson et al., 2002). The presence of TT canola varieties and the prevalence of zero-tillage min-tillage (ZTMT) practices may have already exposed Australian farmers to the benefits that were strongly correlated with the adoption of GM canola in Canada (Beckie et al., 2006; Llewellyn and D'Emden, 2009; Phillips, 2003; Smyth et al., 2011a).

A further impediment to GM canola's adoption in Australia may have been that growers were limited in their options of GM canola varieties. Bayer did not offer seed of its InVigor hybrid canola on a commercial scale in Australia as it had terminated its canola breeding program when the GM canola moratoria was instituted. This meant that all of the 10,000 hectares of GM canola planted in 2008 by the early adopters in NSW and Victoria were limited to Monsanto's Roundup Ready GM canola and its associated weed management system. Bayer has only recently reentered the Australian canola market with the 2013 release of a Roundup Ready cross licensed variety (Bayer CropScience Australia, 2014). A probable reason for Bayer's prolonged absence is largely due to a lack of R&D due to the uncertainty associated with the state based moratoria inhibiting investment (Pike, 2005).

Impacts on Trade

Beyond the slow adoption of GM canola, it is insightful to see the post-adoption impacts in world markets. Counter intuitively, the EU has increased the share of Australian canola exports it accepts since the commercialization of GM canola in 2008, as shown in Table 2-1. The resulting increase in demand for canola to the EU likely has two main sources. The first is the biofuel industry, stemming from the EU's adoption of greener, more sustainable technology. The EU has mandated that biofuels continue to make up a larger percentage of fuel usage, of which canola is the main input into the production of biofuel in the EU (Ministerial GMO Industry Reference Group, 2009). With approximately 40% of domestic EU rapeseed crushed for biodiesel in 2007, and targets of biodiesel use increasing from 2% in 2007 to 10% in 2020 (Foster and French, 2007), the increased demand for Australian canola seems to be correlated with these goals.

The other cause of the increase in demand of canola is its use as a livestock feed. Canola meal is a valuable, cheap source of livestock feed, due to its nature as the by-product of oil extraction and its high protein content (Ministerial GMO Industry Reference Group, 2009). The EU's strict restrictions on the labelling of GM feed is not carried forward through the supply chain, meaning that livestock fed GM feed are not labelled GM (Foster and French, 2007). In all instances of labelling it is done for consumer information and not for safety reasons. Here the EU is likely trying to stop complaints and lobbying against GM imports, while maintaining their regulatory regime in place.

Table 2-1 Volume of Australian Canola Exports by Destination ('000 mt)

	Bangladesh	**EU**	**China**	**Japan**	**Pakistan**	**Other**	**Total**
2003/04	100.57	-	2.19	545.84	284.28	115.90	1,048.78
2004/05	67.95	-	39.62	495.23	387.24	28.53	1,018.56
2005/06	41.30	119.70	0.00	370.27	97.46	255.53	884.27
2006/07	15.23	0.37	3.23	190.47	25.00	3.31	237.60
2007/08	3.55	169.97	0.00	121.54	166.78	57.29	519.14
2008/09	3.39	685.47	43.54	96.47	120.55	23.58	972.98
2009/10	75.88	315.27	0.00	214.16	552.61	80.50	1,238.41
2010/11	8.88	1,346.75	0.00	70.84	1.87	42.39	1,470.74
2011/12	15.01	1,960.52	0.00	74.31	161.93	111.07	2,322.84
2012/13	104.50	1,893.17	382.63	111.56	551.57	444.37	3,487.80
2013/14	0	1,492.81	946.92	179.3	241.43	360.92	3,194.39
2014/15	10.88	1,060.75	532.79	308.09	145.94	386.42	2,444.87

Adapted from ABARES, 2006, 2013, 2015

What goes along with this growing demand for Australian canola is the increasingly limited number of non-EU countries that produce and segregate non-GM canola for export. With a global import market of 15.3 million metric tonnes (mt) in 2013/14 the EU is facing fewer options on where to fill their demand for canola. In 2013/14 Canada exported approximately 9.2 million metric tonnes of canola to the world market, Australia supplied 2.9 million metric tonnes, and the rest of world supplied the remaining 3.2 million metric tonnes on the international trade market. Thus, it is apparent the EU is limited in finding sources for their demand of 3.5 million metric tonnes of canola (ABARES, 2015), as they have strong barriers against Canada's canola regarded as GM[5].

[5] This barrier may stem from the virtual moratorium on the approval of new GM products in the EU between 1998 and 2004, and the associated lost WTO ruling against this EU moratorium (Foster and French, 2007). Or it may be long held biases against Canada and their decision to forego the EU market as stated earlier in this chapter.

The world market has shown acceptance of GM canola from Australia, following upon the experience of Canada. The trade impacts that caused the institution of the moratoria were never realized, possibly due to the moratoria but more likely due to the grains industry finally coming together to create a system to deal with comingling and coexistence impacts that meet international regulations and market desires. The impact of the moratoria on GM canola adoption may not have been affected by trade, but the moratoria did have other environmental and economic opportunity costs.

2.4 Summary

This chapter has outlined the regulations of Canada and Australia pertaining to the approval of GMOs, and canola in particular. Canada's regulatory policy on PNTs, of which GMOs are one aspect, was developed using departments that were already in place to assess environmental and human health and safety. The assessment of environmental hazards and risks in animal feed are conducted by the CFIA, while the assessment of human health effects are conducted by HC. Post-approval of the Roundup Ready and LibertyLink varieties of GM canola in 1995 resulted in trade worries that led the Canadian canola industry to institute a short-term, self-imposed system of coexistence. This system of segregation was removed upon Japanese approval of those varieties in 1996, and thus forewent the EU market due to lack of trust in their regulatory system and fluctuating export levels.

The Australian policy on GMOs is conducted by the OGTR, a department put in place specifically to assess RARMPs on environmental and human health and safety. The OGTR approval of GM Roundup Ready and InVigor canola in 2003 was followed by lobbying from the grains industry, due to trade worries from adopting GM canola, and an amendment that allowed states to impose moratoria on GM canola cultivation. These moratoria were eventually removed in the largest canola producing states of NSW and Victoria in 2008 and Western Australia in 2010, while the other large canola producing state of South Australia has opted to maintain its moratoria along with the very small canola producing states of Tasmania and the Australian Capital Territory.

Chapter 3. Methodology

3.1 Introduction

This thesis will assess the environmental and economic impacts of GM and non-GM canola and will construct a counterfactual to evaluate the opportunity costs of the SEC-based moratoria in Australia compared to if they were not instituted, with a comparison of these results to the Canadian experience. This counterfactual and comparison uses three data sets collected from Canada and Australia in similar time periods post-approval of GM canola.

Canada's survey data was collected in 2007 by researchers at the University of Saskatchewan to evaluate the impact of HT canola in Western Canada for the 2006 crop year. The two data sets from Australia had surveys conducted by the Birchip Cropping Group on behalf of the GRDC annually for three years, 2009 to 2011 in NSW & Victoria and 2011 to 2013 in Western Australia, for the crop years 2008 to 2010 and 2010 to 2012 respectively. These data sets and respective countries offer insight into the adoption of GM canola through their strongly correlated surveys, as the Australian survey was based off of the Canadian[6]. The two countries are the leaders in world canola exports, Australia 19.1% and Canada 61.3% in 2013/14 (ABARES, 2015).

The Australian opportunity costs of delay are measured through a normalized S-curve, constructed from the Canadian experience, using environmental and economic impacts. The environmental impacts will assess the amount of active ingredients applied, the toxicity of those ingredients through the Environmental Impact Quotient, fuel use, and greenhouse gas emissions. The economic impacts will assess the variable cost of weed control, yield, gross margins, comparative margins, and contribution margins. The aggregate of these impacts between the actuality and the counterfactual are the opportunity costs of delay.

[6] David Hudson, Pers. Comm. (August 10, 2015)

3.2 Constructing a Counterfactual

The counterfactual argument is a method for evaluating hypothetical scenarios with economic applications in policy analysis, econometric modelling, macroeconomics, and economic history (Fogel, 1964; Hoover, 2001; Manski and Nagin, 1998; Reiss and Cartwright, 2003). An infamously controversial counterfactual analysis comes from economic historians Fogel and Engerman (1974) on the impacts of American slavery in the South, compared to its absence. They received a great deal of criticism and media attention for their findings on such a controversial issue (Baldasty, 1975; Haskell, 1979; Weiss, 2001).

The counterfactual argument assumes that if the first object had not occurred the resulting effect would have never existed, similarly it may take the form that "[i]f E were true, then C would have been true" (Balke and Pearl, 1995). This thesis constructs a counterfactual of the second form to assess the impact if the Australian government had not allowed states to impose moratoria on the adoption of GM canola cultivation, then what are the environmental and economic effects. This thought experiment is coupled with data from a post GM canola adoption world to gain insight into the opportunity costs of delay.

The policy counterfactual is established through three steps; 1) Establish the scientific theory; 2) Identify the factors; 3) Define the results (Heckman, 2005). These steps are tackled as follows: 1) The counterfactual assumes the moratoria were never imposed in Australia and follows the scientific theory of the S-curve outlined by Rogers (1983) using the Canadian experience to develop the scenario of adoption, outlined in Section 3.4; 2) The factors are the set of environmental and economic factors described in Section 3.5; and 3) The results of the environmental and economic factors through the data, Section 3.3, use the S-curve to express the opportunity cost of the moratoria compared to the counterfactual absence of the moratoria, outlined in Chapter 4.

3.2.1 The Counterfactual and Causal Relationship

The counterfactual theory of causality according to Lewis (1973a) assumes that if C and E are distinct events that occur, that C is causally dependent upon E if, and only if, E did not occur then C would also have not occurred. The causal dependence in this theses' counterfactual argument is that the impact of GM canola, C_1, is only possible if there is not a moratoria preventing its cultivation, E_1. This causal relationship assumes E_1 is the direct precursor to C_1. The absence of a moratoria, however, may not necessarily be followed by the adoption of GM canola, as there may be other effects that inhibit the adoption whether the moratoria were instituted or not.

This analysis will compare a set of binary events to evaluate "the impact of historical interventions on outcomes including their impact in terms of welfare" (Heckman, 2005, p. 8). The model will evaluate the outcome, C, as a product of the event, E, and the impact on agricultural land planted to canola, W. The function takes the form C(E,W). The binary nature of the parameter E is limited to two states, E{0,1}. E_0 is the actuality when the moratoria on GM canola were imposed, and E_1 is if the moratoria on GM canola were not imposed. The agricultural aspect of the parameter W is composed of the individual hectares devoted to canola. If there are z hectares in canola production, then parameter W is composed of the elements $\{w_1 ... w_z\}$. The outcome of the two states, $C_0(E_0,W)$ and $C_1(E_1,W)$, will be evaluated through the impacts observed in the Australian data sets.

$$\Delta = C_0(E_0,W) - C_1(E_1,W) \tag{3.1}$$

The opportunity cost of the counterfactual on canola hectares will be measured as the change, Δ, between the two outcomes. This implies that a positive Δ is a reduction in the factor evaluated and a negative Δ value is an increase in the factor evaluated.

3.2.2 Review of the Counterfactual Model

Hausman (1996) explores counterfactuals within an economic framework discussing their value and necessity in analysis, in a review of the philosophical work on counterfactuals by Lewis (1973a, 1973b). Counterfactuals should be causally connected and predictable in such a way that the "[k]nowledge of counterfactual dependencies should be reflected in our expectations about what will happen" (Hausman, 1996, p. 65). The knowledge of the counterfactual dependency on the adoption of GM canola in the absence of a moratoria is obtained through Canada's adoption in a similar socio-cultural realm and the Australian experience of adoption post-removal of the moratoria in 2008, NSW and Victoria, and 2010, Western Australia.

Limitations of evaluating a policy through a counterfactual include the degree of certainty of the model, the use of constant effects, and endogeneity problems. Firstly, the "degree of certainty about our counterfactual judgments can be no higher than our degree of certainty that our causal model is correct" (Cartwright, 2007). This causal model is constructed with a singular change on the institution of the moratoria ceteris paribus[7]. As there is experience of Australia adopting GM canola post-moratoria, as well as the Canadian experience, there is a justifiable degree of certainty for the validity of this counterfactual.

Secondly, the constant effects assumed over the duration of the counterfactual are a necessary assumption to be kept in mind. There are exogenous variables, such as weather, that would affect the annual effects. As this model uses the same data set for calculating the GM and non-GM impacts, the relative impacts should remain constant through the inclusion of percentage changes as the values received may be over or under stated.

Lastly, the endogeneity problems of the counterfactual are the result of the variables being evaluated depending upon the adoption of a policy. Such problematic issues depend on the framing of the question. Taxation, for instance is endogenous in the data collection and analysis phase as the government is reacting to a variety of indicators and pressures, yet exogenous when attempting to predict the impact of a decision, such as to lower tax (Balke and Pearl, 1995). The factors evaluated in this thesis are exogenous to the counterfactual as the factors' are a constant aspect in the production of canola, although the impacts from the GM canola variety are endogenous as the impacts of this variety can only be obtained through the absence of moratoria.

Beyond these limitations the counterfactual is necessary to assess policy as without a hypothetical scenario the policy has no reference for comparison, and thus cannot be evaluated. The use of the counterfactual should be taken as an approximation as "[m]odels are not empirical statements or descriptions of actual worlds. They are descriptions of hypothetical worlds obtained by varying— hypothetically—the factors determining outcomes" (Heckman, 2005, p. 3). It is within this framework of counterfactual policy analysis that this thesis is constructed.

[7] Ceteris paribus refers to the concept of 'all else equal' or to keep the other factors unchanged. It is often used in the economic literature to isolate the effects of individual variables' impacts, and "captures the essential idea underlying causal models" (Heckman, 2005, p. 2).

3.3 Data

3.3.1 Canadian Data Set

The Canadian data set was collected through a four-page, 80 question survey distributed in the Western Canadian provinces of Alberta, Saskatchewan, and Manitoba. The survey consisted of open, closed, and partially-open questions[8] surrounding producers' experiences farming canola. Forty thousand surveys were distributed through Canada Post's unaddressed ad-mail service in 2007, collecting information on the 2005 and 2006 crop years. This survey was originally used in an industry report and three papers analyzing the economic and environmental impacts of HT canola in Western Canada (Gusta et al., 2011; Smyth et al., 2011a, 2011b; Smyth et al., 2010).

In total 685 surveys were received, which were then limited to only include producers with cropland of 80 acres (32.4 ha) or greater. In the original publications this original n=685 responses were reduced down to n=571 after eliminating surveys based on outliers and population criteria. For the full, original methodology see Textbox 3.1.

Textbox 3.1. Original Publications' Canadian Data Methodology

Methodology[9]

The collection of data on agricultural practices in Canada often employs a survey instrument. The present research was based on a four page, 80 question survey that was developed and distributed to agricultural producers. The time required to complete the survey was estimated to be 30–45 min. The survey 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; crop and liability insurance; and general demographics. Open, closed and partially open questions were included in the survey. Space was provided to enable producers to more fully explain changes within the production system to facilitate a more complete understanding of producer choices. Where a

[8] Open ended questions allow respondents to provide their own answer with no predefined categories. Close ended questions limit respondents to a defined set of responses provided in the survey. Partially-open questions are similar to close ended questions but have an 'other' category that allows for an unlisted response.

[9] It should be noted that the table numbers and footnote numbers have been adjusted to reflect their use in this thesis opposed to their placement in the original published papers.

Textbox 3.1. Original Publications' Canadian Data Methodology

quantification of producer attitudes was required, a simple three point scale was used, which allowed for positive, neutral and negative responses. The University of Saskatchewan's Research Ethics Board approved the survey design (BEH# 06-318).

Forty thousand surveys were distributed across the three Prairie Provinces in March and April 2007. Distribution of the survey was through Canada Post's un-addressed ad-mail service providing a cluster sampling method. This allowed for a selection of farms as defined by Canada Post within the postal code system. Participant selection was based upon geographic location in five targeted regions separated by provincial boundaries and based on historic canola production levels. High production and low production regions in each of Alberta and Saskatchewan and a high production area in Manitoba were surveyed. The target population was producers having over 40 hectares of cropland. Surveys were randomly distributed through the regions.

Table 1 Distribution of usable survey responses (N = 571)

	Low production (%)	***High production (%)***	***Total (%)***
Alberta	*14*	*11*	*25*
Manitoba	*NA*	*16*	*16*
Saskatchewan	*32*	*27*	*59*
Total	*46*	*54*	*100*

To increase the response rate a lottery prize was employed. The lottery consisted of two draws, among eligible survey respondents, for consumer electronic goods valued at $250 each. In total 685 surveys were received with 571 meeting the population criteria. Outliers within the database were identified and removed utilizing the box plot method as developed by Tukey (1977) and outlined by NIST/SEMATECH (2006). Extreme outliers, or upper outliers, were identified based on the amount of hectares treated by the herbicide. Table 1 outlines the distribution of usable responses across the three Prairie Provinces and between areas of low and high canola production[10]*. Canada is a large nation with numerous eco-regions, but most canola is grown in three main regions. A small amount of canola is produced in the Boreal Shield West eco-region, located in the very eastern part of Manitoba. While the number of respondents relative to the number of surveys distributed indicates a low response rate (1.71%) it is important to note that the Canada Post's un-addressed ad-mail service delivers surveys to all mail addresses within the identified region. There is no way to know how many households received surveys that were not farmers or did not produce canola. Therefore, the actual response rate is unknown and is most certainly greater than*

[10] High and low production zones were based upon historical canola production data for the three prairie provinces.

Textbox 3.1. Original Publications' Canadian Data Methodology

what can be calculated here. The important point is that demographically, our respondents are very representative of the national agriculture census data.

The demographics of the sample population are similar to the source population as reported in the Statistics Canada 2006 Farm Census (Table 2) (Statistics Canada, 2006). The average age of farmers is 52 in Saskatchewan and Alberta, and 51 in Manitoba. Our survey population has a substantially higher level of post-secondary education, where the census data identifies the percentage of producers with a university degree in Manitoba at 8%, Saskatchewan at 8% and Alberta at 9%.[11] *Average farm size of the sample population was greater than that of census data, where the average Alberta farm size was 427 hectares, Saskatchewan 589 hectares and Manitoba 405 hectares.*

Table 2 Producer Demographics

		Alberta	***Saskatchewan***	***Manitoba***	***Total/Avg***
Number of respondents to survey		*144*	*335*	*92*	*571*
Average age	*Sample*	*45 to 54*	*45 to 54*	*45 to 54*	*45 to 54*
	Census	*52*	*52*	*51*	*52*
University degree	*Sample (%)*	*14*	*21*	*7*	*14*
	Census (%)	*9*	*8*	*8*	*8*
Average farm size (hectares)	*Sample*	*669*	*705*	*549*	*670*
	Census	*427*	*589*	*405*	*473*
Average canola hectares		*205*	*193*	*162*	*190*
Average experience with canola		*19.3*	*20.6*	*20.8*	*20.3*
First year with GMHT canola		*1999*	*1999*	*1998*	*1999*

Source: Survey; Statistics Canada, 2006

The survey respondents had relatively large operations (670 hectares), with, on average, over one-quarter of their operation dedicated to canola (Table 2). The average respondent has farmed for 30 years and belongs to the 45–54 age group. These producers reported growing canola for an average 20 years and adopting GMHT canola first in 1999; on average they reported that they removed conventional canola varieties from their crop rotations by 2000. For the 2005 and 2006 crop years, farmers reported that 48% of their land was allocated to

[11] The number of respondents with a university degree is substantially higher in Saskatchewan than is reflected in the census data. A variety of factors contribute to this. The farm size is larger than average and producers are slightly younger than the average, which tend to be correlated with higher levels of education. Moreover, the affiliation of this research with the University of Saskatchewan may have triggered a greater response from graduates than from others.

Textbox 3.1. Original Publications' Canadian Data Methodology

> *Roundup Ready™ varieties, 37% used Liberty Link™ and 10% used Clearfield®. These adoption rates are consistent with the adoption rates provided by the canola industry, which identifies Roundup Ready™ market share at 44%, Liberty Link™ at 40% and Clearfield® at 11% (Anderson, 2008).*[12]
>
> Source: Smyth et al., 2011b

Canadian Survey Changes from Original Publications

The Canadian survey master data set received did not contain the aforementioned n=571 surveys, rather the data contained n=582 survey data points. These n=582 data points were reduced down to n=577 after surveys from non-canola producers were eliminated. After careful review these n=577 surveys could not be reasonably and justifiably decreased down to n=571 data points without full knowledge of what has already been eliminated. This analysis will accordingly consist of n=577 responses.

A further change from the original methodology is the omission of the Boxplot method developed by Tukey (1977) for the removal of outliers. The Boxplot method in the original publications was applied on variables within the n=571 included surveys, opposed to elimination of the full survey data point containing outlier data. This method creates inconsistencies in the data as it has the potential to nullify certain survey data points, while including other variables from the same survey in the analysis.

An additional review of the data using the Boxplot method of eliminating extreme outliers resulted in no consistent and justifiable method for the removal of the additional six surveys to attain the n=571 data points in the original publication. This analysis maintains the sample size of n=577 in order to ensure that the per hectare analysis takes into account large farm sizes, even if they are slightly larger but not exceptionally large. This inclusion is justified as a 4000 hectare farm should have the same weight as forty 100 hectare farms, with the added aspect that large farms have the greatest impact on the average Canadian hectare.

Greene (2012) states that outliers may be the result of the data generating process, here it is the mail-survey method, or of incorrect data input. Assuming that we believe the survey method is applicable and that incorrectly inputted surveys are eliminated, further elimination of outliers

[12] Personal communication with Program Manager, Canola Council of Canada

due to relative magnitude compared to other observations is not justified. As the variables of the Boxplot outlier elimination are in reference to types of total crop land, the inclusion of outliers that are not extreme will add to the information of the impact on a per hectare basis. This analysis will evaluate the economic and environmental impacts per hectare so the inclusion of large crop sizes will add to the actual story being told as they have the largest impact.

The inclusion of upper outliers, the elimination of surveys with less than 80 acres (32.4 ha), and a possible education bias may be the cause of increased values of certain producer demographics within this analysis over the Census data, see Table 3-1. The impact of upper outliers should have an equal effect on all canola varieties and thus not affect the proportional differences between varieties. The decision in this thesis to forego the Boxplot method of nullifying outliers on a per variable basis, instead of eliminating the entire survey of outliers, has resulted in an increase in many producer demographics.

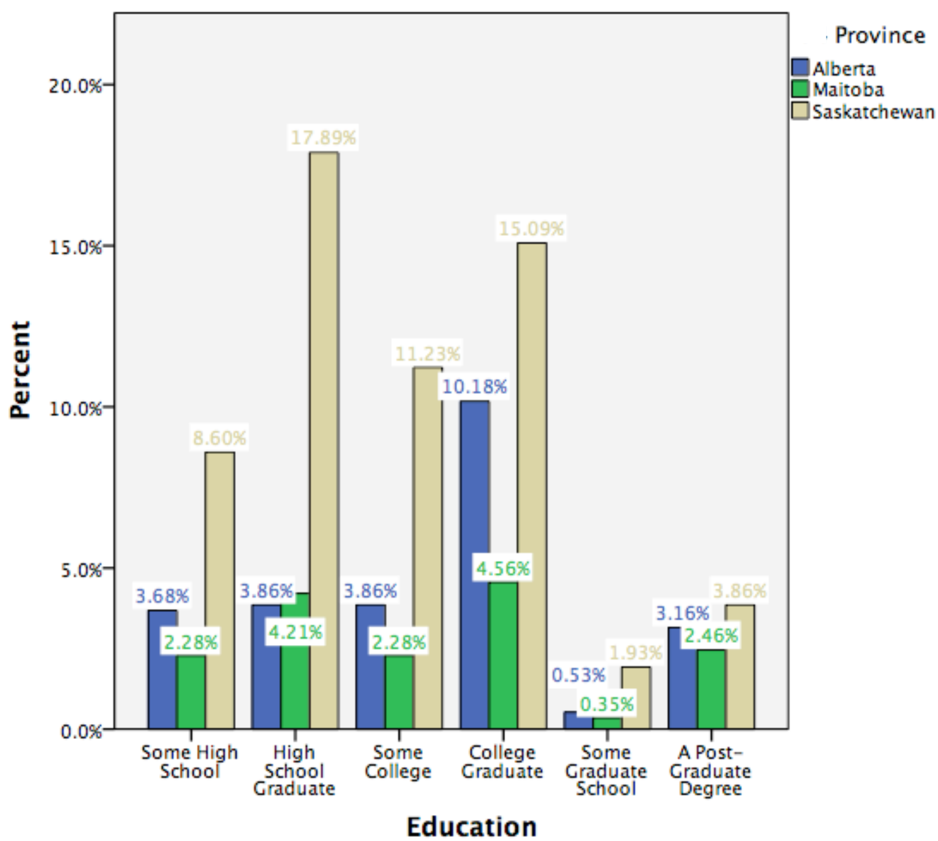
Table 3-1 Canadian Producer Demographics

		Alberta	**Saskatchewan**	**Manitoba**	**Total/Avg**
Number of Survey Respondents	This analysis	145	339	93	577
	Original	144	335	92	571
Average Age	This analysis (Mode)	45 to 54	45 to 54	45 to 54	45 to 54
	Original	45 to 54	45 to 54	45 to 54	45 to 54
	Census	52	51	52	52
University Degree (College Grad or Higher)	This analysis	54%	35%	45%	42%
	Original	14%	21%	7%	14%
	Census	9%	8%	8%	8%
Average Farm Size (ha)	This analysis	801	865	549	798
	Original	669	705	549	670
	Census	427	589	405	473
Average Canola Acres (ha)	This analysis	200	242	171	219
	Original	205	193	162	190
	Census	164	161	157	162
Average Experience with Canola	This analysis	19.3	20.6	20.8	20.3
First Year with HT Canola	This analysis	1999	1997	1997	1998
First year with GMHT canola	Original	1999	1999	1998	1999

Source: Statistics Canada, 2006

One strong difference between this analysis and the original published papers is the producer demographics. The largest differences are in university education, farm size, and number of canola hectares. In the published papers the provincial producer percentage of those with university degrees' is found as the number of provincial producers with a degree as a proportion of the number of respondents across all provinces, rather than the number of provincial respondents with a degree as a percentage of total respondents within that province. The SPSS output chart that indicates this has been included as Figure 3-1, the aggregate of all provincial percentages of education levels is 100% rather than 100% per province. This error has been rectified and is the cause of the percentage of respondents with University Degrees to be higher in the producer demographics table. This bias of increased levels of university education may be the result of having strong feelings about the nature of the survey or having a high value on data information gained through a post-secondary education (Albaum and Smith, 2012). This education bias is common in mail-survey data as the more educated an individual is the more likely they are to complete a survey (Henninger and Sung, 2012).

Figure 3-1 SPSS Provincial Education Levels as Percentage of All Provinces



The large farm size and number of hectares devoted to canola may stem from the education bias and contribute to the considerably larger number of hectares compared to the census data. The education bias may reflect producers that operate as managers that run their farm like a business, in which 14% of all farms are run as family corporations (Statistics Canada, 2006). The increased farm size and canola hectares may also be influenced by the elimination of surveys answered by hobby farmers with crop land less than 80 acres (32.4 ha). While the difference in hectares between the sample data and the census may be considerable at points, it will likely offer a better insight into canola producers in general as canola tends to be a large scale crop opposed to a niche hobby crop.

A further difference between this analysis and the original's producer demographics is in the field of the producer's first year planting GMHT canola. This appears to be an incorrect description of the data as there is no question in the survey that specifies initial year of GMHT canola planting. Question 34 in the survey asks the first year of HT canola cultivation. The data contains a number of initial experiences between 1984, the year TT canola was registered in Canada, and 1995 when the first GMHT varieties were approved. There are only two outliers for 1976 and 1980 which may represent trial sites for TT canola. The numbers indicated in Table 3.1 reflect the average producer's first experience with HT canola, it is unclear if Mode was used previously.

3.3.2 Australian Data Sets

The Australian canola data sets were collected annually in the GM canola adopting regions in the three years following initial adoption of GM canola. NSW and Victoria data was collected between 2009 and 2011 and Western Australia data was collected between 2011 and 2013 on farmers' experience in the years 2008 to 2010 and 2010 to 2012 respectively. The survey was composed of 35 open, closed, and partially open questions on canola farmers experience and thoughts towards conventional, TT, Clearfield, and Roundup Ready canola[13] varieties. The telephone survey targeted jurisdictions with GM canola growers to maximize the interviews of non-GM canola growers that were impacted or had contact with GM canola growing neighbors.

[13] Roundup Ready being the only commercially available GM canola seed at the time.

The data sets were initially used for industry reports on the impact of GM canola adoption (GRDC, 2012, 2014), and a resulting publication on the post-adoption agronomic, environmental, and economic impacts of GM canola in NSW and Victoria (Hudson and Richards, 2014).

The initial survey separated growers into GM and non-GM growers to reach the desired 95% confidence interval in the analysis of results. The distribution of surveys in NSW and Victoria are amalgamated in the first data set while the second is comprised solely of Western Australia. The data sets were not reduced for outliers nor for farm size, rather the original analysis limited results to the main combination of weed systems and made use of simple averages to evaluate the average farm level experience.

Australian Survey Changes from Original Publications

The Australian survey data sets received did not entirely match the original data set as NSW and Victoria had n=383 survey participants for 2008 in the reports, yet the master data file only contained n=377 surveys, this discrepancy occurred in only this one year. Following the methodology used in the Canadian surveys in the data set with less than 32.4 hectares (80 acres) of total crop land were removed, to limit our evaluation to non-hobby farms. Outlier surveys were removed if a variable gave the impression of a data input error[14]. One such input error is observed yield per hectare of greater than 6 metric tonnes as this is three times the highest average canola yield and an extremely unlikely event (ABARES, 2015). In similar fashion to the Canadian data set, surveys were removed if they did not contain data beyond producer demographics[15].

A further change to the survey data comes in response to a seemingly lack of clarity in the classification of canola types. Throughout most years of the data sets there are a handful of surveys who report conventional canola hectares with triazine and simiazine herbicide use that would be toxic to all but TT canola varieties. Although it may be better reclassified in the TT variable, the manipulation of data may be misconstrued and has been kept in the original

[14] Input errors that resulted in a surveys elimination included hectares input as undefinable numbers such as '28,00'

[15] In the NSW and Victoria data set surveys that did not indicate the producers state were removed in parallel to the removal of Canadian producers' surveys who did not indicate their province.

producer volunteered category. This seeming misclassification of non-GM varieties will not impact final results as the per hectare analysis is a cumulative weighted average of the conventional, TT, and Clearfield varieties combined into a single non-GM canola variable. This non-GM canola basket will be compared to GM canola, which is limited to Roundup Ready canola as the only available GM variety during the course of this analysis. As there is only one GM canola variety, Roundup Ready and GM canola will be used synonymously throughout this research.

Table 3-2 Australian Producer Demographics

	NSW	**Victoria**	**Western Australia**	**Total/Avg**
# of Survey Respondents	689	615	1322	2626
Average Age				
Sample (Mode)	-	-	-	-
Census*	52	52	51	52
Average Farm Size (ha)				
Sample	1263	1296	2726	2007
Census**	458	337	1201	800
Average Canola Hectares (ha)				
Sample	254	290	553	412
Census	-	-	-	-

Source:*Australian Bureau of Statistics, 2006; **Land Commodities Research, 2011

Australian producer demographics, Table 3-2, have been calculated in accordance with the Canadian data set. The Australian data, however, did not include as thorough a line of demographic questioning and, thus, has numerous blank observations. Similarly, there is an absence of relevant farm statistics resulting in additional demographic blanks. Of note is the similarity in the farm size between the Australian census and Canada's census data. The samples in Canada and Australia do contain a parallel in the number of hectares devoted to canola annually.

3.4 S-Curve

Ryan and Gross's (1943) evaluation of the adoption of hybrid maize varieties in two Iowan communities was the seminal paper establishing the sigmoid curve (S-curve) for diffusion of agricultural innovations. Griliches (1957) expanded upon their research with an analysis on the adoption of hybrid maize varieties throughout the United States, establishing a framework for the differences in regional adoption patterns. The adoption of hybrid maize seeds in the United States followed a standardized path to a ceiling level of adoption in each corn growing state as it was adopted. This suggested that the universally fluid path of these curves "should phrase our questions in terms of the beginning of the movement, its rate, and its destination" (Griliches, 1957, p. 503), implying that although S-curves follow different elasticities their shape is universal. The periods of introduction were not homogenous as each region required its own series of varieties specific to its local, followed by S-curves that grew flatter as the period from initial introduction increased.

While Griliches uses the logistic distribution[16] in creating his S-curve model, he acknowledges that the cumulative frequency normalized bell-curve has the same result. Griliches' conclusion, that "the rate of acceptance is a function of the profitability.... defined as the increase in yield …, times the price of [that yield], and minus the difference in the cost" (Griliches, 1957, p. 516), is strongly indicative of the quick adoption in Canada and the slow adoption in Australia.

Canada's adoption of GM canola coincided with, and increased the adoption of, ZTMT cultivation practices. The strong benefits of ZTMT were associated with GM canola adding to the economic gains and positive views held by producers towards the new seed (Smyth et al., 2011a). On the other hand, at the point of GM canola introduction Australia already had high adoption of ZTMT cultivation, a strong presence of conventional HT canola, and a high Technology Access Fee[17]. The cumulative impact of these factors seems to reflect Griliches conclusion, in which rapid adoption in one country and slow adoption in another likely stems from profitability. The application of Griliches study on hybrid seed adoption closely correlates to that of GM seed adoption as hybrids are developed through genetic manipulation, inbreeding of varieties and the eventual cross-breeding of two inbred varieties to create a high yielding new variety, and both require the annual purchase of seeds.

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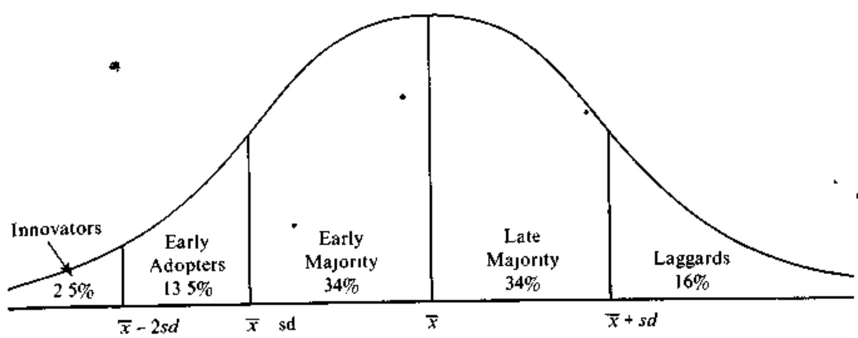
[16] The logistic distribution is a continuous probability distribution function that resembles, but has fatter tails than, the standard normal distribution (Greene, 2012).

[17] See Table 4-11 for a breakdown of the annual breakdown of the Technology Access Fee in Australia over the first years of GM canola adoption.

Rogers (1983) refined the theory on the diffusion of innovations to identify five adopter types within a bell distribution, 1) innovators, 2) early adopters, 3) early majority, 4) late majority, and 5) laggards, see Figure 3-2. The main separating factors between these adopter groups tends to be their interaction with new technologies, associated with urban connections[18]; risk aversion and financial assets to mitigate possible short-run losses; and communication, which is associated with the search for and dispersal of knowledge. These factors operate in a continuum with the greatest degree being held by the innovators and decreasing in each category through to the laggards.

Figure 3-2 Adopter Categorization on the Basis of Innovativeness

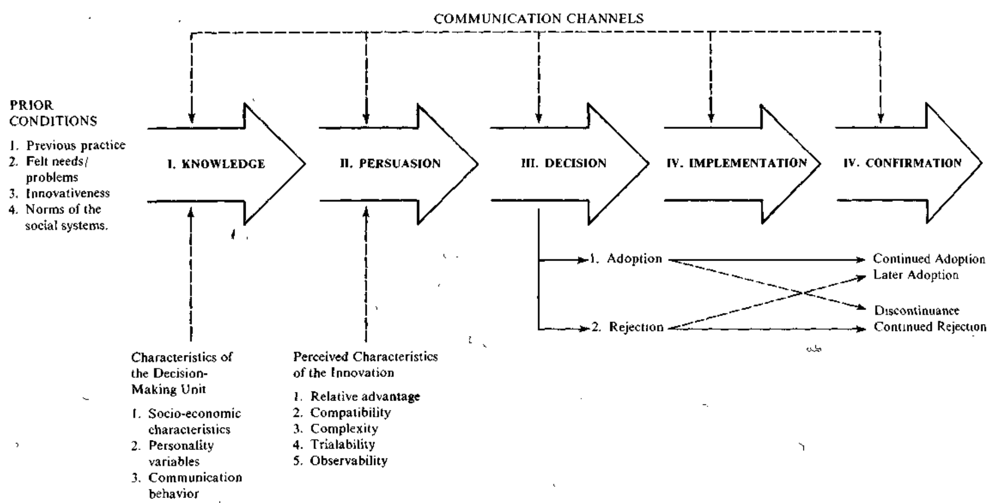


Source: Rogers, 1983, p. 247

The adopters in these categories undergo an innovation decision process that involves: 1) knowledge, first awareness and understanding of the innovation; 2) persuasion, in-depth information is sought out through interpersonal networks; 3) decision, engagement in the activity that results in adoption or rejection of the innovation; 4) implementation, the act of trialability and putting the innovation to use; and 5) confirmation, the evaluation of the post-trial experience and decision to adopt or reject the innovation, see Figure 3-3.

[18] The intuition behind this correlation between exposure to new technologies and urban connections is that increased travel to areas outside of the home social network leads to greater exposure to new ideas and innovations.

Figure 3-3 Communication Channels



Source: Rogers, 1983, p. 165

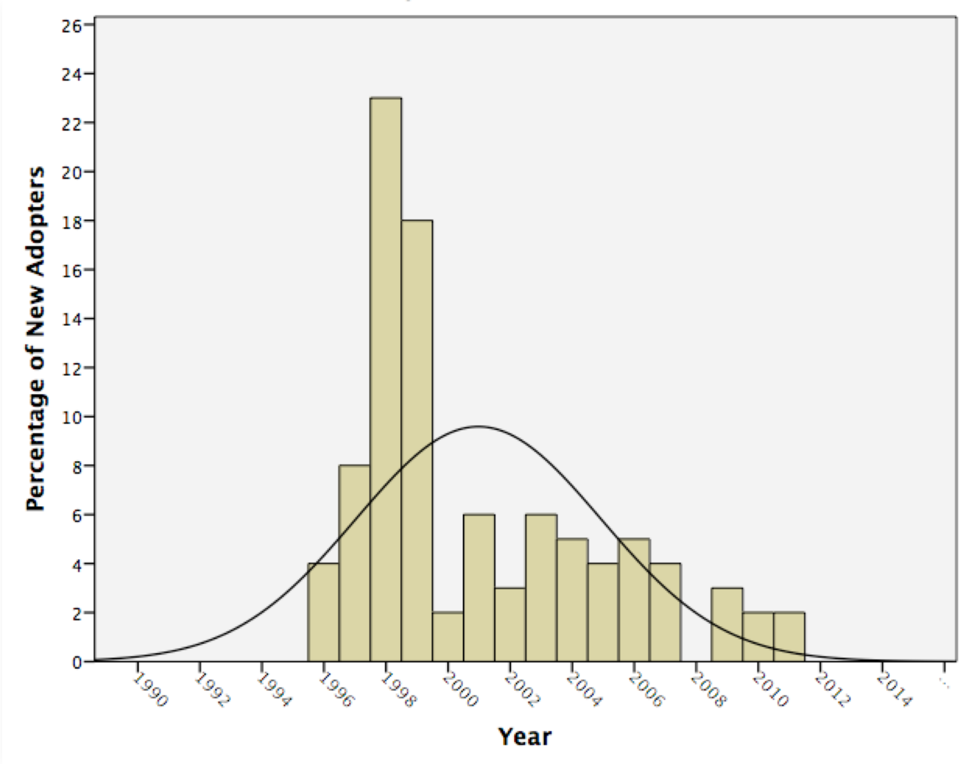
This decision process is strongly correlated to the adopter types, whereby the different facets of this process are sought out in different methods and circles. The impacts of the adopter types and the innovation decision process are the two main influences in the determination of the slope of the S-curve and the fatness of the bell-curve. The normality of the curve is assumed as an aspect of the diffusion effect, an effect similar to the learning curve in humans which follows a normal distributions and is extended to societal learning, and reinforced by a body of literature that crosses social systems and innovation types (Kerr, 1982; Rogers, 1983, pp. 244–245; Schmitz and Seckler, 1970).

Canada's first ten years post-adoption of GM canola forms a strongly, positively skewed distribution of new adopters. Adhering to Rogers (1983) and Griliches (1957) description of new adopters of innovations following a normalized bell-curve, and respective S-curve of cumulative adoption of the innovation, Canada's experience will be used to establish a normalized frequency bell-curve for the theoretical Australian experience[19], see Figure 3-4. The bell-curve will then be truncated to allow for the first year of adoption to be approximately 2.5%, which Rogers (1983) calls the innovators, see Figure 3-2. This truncation is used as the data gathering process for the dissemination of knowledge is conducted as the varieties are being built up, thus the innovators

[19] The normalized bell-curve has been chosen over the accelerated, skewed bell curve, which is more apparent in the Canadian data, as a conservative scenario of adoption that will likely underestimate possible impacts.

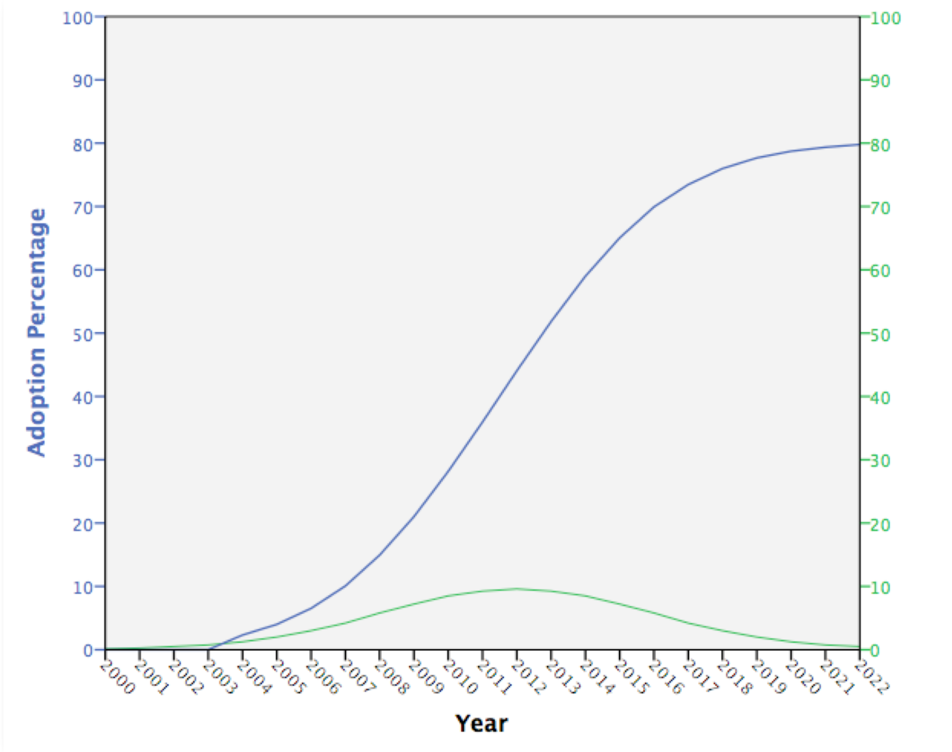
are assumed to be those building up seed for commercial release. This will follow a similar path to what was observed in Canada as GM canola approval was in 1995, seed build up occurred in 1996 with four percent new adopters, and unrestricted commercial release was in 1997 with eight percent new adopters and 12% of total canola hectares (Canola Council of Canada, 2010).

Figure 3-4 Canadian New Adopters and Normalized Bell-Curve



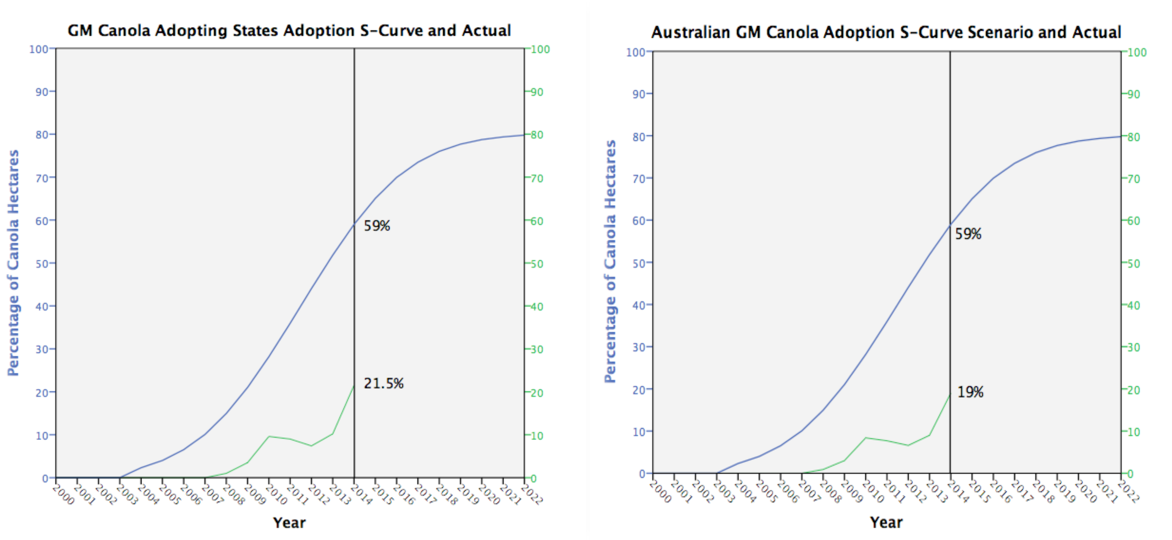
The frequency based normalized bell-curve constructed from the Canadian experience will be used in cumulative form as the normalized S-curve. This S-curve will serve as the scenario for adoption of GM canola in Australia had it not allowed the institution of an SEC-based moratoria to delay adoption. This bell-curve and respective S-curve will be weighted such that the ceiling for cumulative adoption will be 80%, as observed in Figure 3-5. This ceiling follows on the work of ACIL Talisman's cost-benefit analysis on the adoption of GM canola in Victoria, in which an 80% ceiling for adoption was found, and the GRDC's analysis on the diffusion of ZTMT adoption which is expected to peak between 80 and 90% (Llewellyn and D'Emden, 2009; State of Victoria, 2007). The ceiling will be applied to the whole of Australia to ensure that the resulting economic and environmental effects are on the low side of estimates. The reasoning for an 80% ceiling stems from the presence of high-yielding conventional varieties and the presence of effective conventional HT varieties that have been in use since 1995, and were not as strongly present in Canada at the advent of GM canola's introduction.

Figure 3-5 Australian Normalized Bell-Curve and S-Curve Scenario



The S-curve will be used in conjunction with the annual Australian observed canola hectares over the time period of 2004 until 2014, in two counterfactual scenarios of comparisons, Scenario 1) the GM canola adopting states of NSW, Victoria, and Western Australia's canola hectares and Scenario 2) Total Australian canola hectares. Scenario 1) is used to indicate the opportunity costs of the moratoria that were eventually repealed. Scenario 2) is used as an indicator of the opportunity costs of Australia allowing the institution of SEC-based moratoria. The area below the theoretical scenario and above the actuality is the opportunity cost of adopting an SEC into policy, Scenario 1) and Scenario 2) are highlighted in Figure 3-6.

Figure 3-6 S-Curve Scenarios of Adoption in GM Canola Adopting States and Australia



Source: *AOF Annual Reports, n.d.*; *AOF Crop Reports, n.d.*; GRDC, 2012, 2014

3.5 Evaluation of Impacts

The impact analysis of non-GM canola compared to GM canola will follow a weighted per hectare evaluation of differences in environmental and economic factors. In the weighting process the relevant variable will be multiplied by its respective number of canola hectares, the product will be summed up and divided by the total number of hectares of that canola variety to create a per hectare evaluation of all relevant practices for each canola variety. This weighting method offers a deeper insight into the cumulative annual effects happening per hectare of canola land. This method allows farms with a larger number of canola hectares to have a larger weight in the study as their practices impact a larger degree of crop land as a whole.

The observed canola impacts will follow four progressive steps of aggregation. First the varietal impacts will be summed up on an annual basis. Second, these varietal impacts will be aggregated on a state basis to find the average effect over the three years of study within the data sets. Third, the state based aggregations will culminate in the varietal impacts simplified into weighted non-GM and GM canola variables. Fourth, the per hectare impacts in the NSW and Victoria data set and the impacts in the Western Australia data set will then be combined using a simple average method. The simple average is preferred for combining the state impacts as the difference in farm size would cause the Western Australian experience to have a greater weight in the results, whereas the total canola hectares are similar across both regions (ABARES, 2015). This equality in hectares indicates that the state averages should hold an equal weight in the net Australian experience.

The final non-GM and GM per hectare impact will be used as representative of the average canola hectare's impact in Australia. The difference between the two non-GM and GM variables is the net effect per hectare, which is multiplied by the total difference in hectares that would have been planted to GM canola under the counterfactual scenario minus the actual number of GM canola hectares planted[20]. The cumulative result of the analysis of all variables will be the environmental and economic opportunity costs of the moratoria, and the costs of delay from the inclusion of an SEC in policy decisions.

The Canadian data will follow the same method of analysis as the protocol used on the Australian data. The Canadian variables will be found where the data allows for a comparison to observe the differences in impacts between Canada and Australia. This additional level of analysis between Canada and Australia will not be an in-depth comparison. Rather, it will be used to highlight the impact effects observed between these two international jurisdictions and possible similarities that are inherent to GM canola.

3.5.1 Environmental Impact

The environmental impact of GM canola will be measured by two main components, the Environmental Impact Quotient (EIQ) and greenhouse gas (GHG) emissions, as the by-product of fuel usage from the number of passes in cultivations and spray applications. The EIQ complements the amount of active ingredients (AI) applied to a hectare from herbicide usage, offering insight into the toxicity of the different varietal herbicides applied and the associated

[20] A different way of conducting this analysis is to create a cumulative impact in the two scenarios and the actuality. The cumulative impact is the sum of the number of non-GM hectares multiplied by the non-GM variable plus the number of GM hectares multiplied by the GM variable. The opportunity costs are then measured by subtracting the counterfactual from the actuality.

impacts those ingredients have on farm workers, consumers, and environmental ecology. The second indicator, the impact on GHG emissions, is calculated through diesel fuel use and is indicative of the change in machinery practices and the degree of environmental externalities between GM canola and the non-GM canola varieties.

Environmental Impact Quotient

The first indicator for evaluating the environmental impact of GM canola is the EIQ developed by Kovach et al. (1992), which compares the relative toxicity of chemical programs. The EIQ was developed as a measure to collate the data on the variety of chemicals used in Integrated Pest Management (IPM) systems. The toxicological and environmental impact data on chemicals were previously available but dense and not readily accessible to the average user of an IPM system, due to separation of results throughout multiple databases. The EIQ evaluates the effects chemicals have on farm workers, consumers, and ecology, and is updated annually by Cornell University to take into account the findings of new toxicological studies on the impact of chemicals.

Potential drawbacks for the use of the EIQ exist as it was first developed for the small scale evaluation of fruit and vegetable crops. This affects the evaluation of large broad scale crops as the impacts are not directly transferrable across these crop types and scale as application methods and exposure vary with the different techniques used. A further potential drawback is the assumption of herbicides maintaining a systemic nature of one in the EIQ, implying that herbicide presence is homogenous and present throughout the plant. As herbicide use is less common in the production of fruits and vegetables, and more likely to end up in a final unrefined product compared to cereal crops which tend to be refined and processed before consumption, the systemic assumption may not be accurate in canola. Similarly, the EIQ maintains a plant surface half-life of one for pre-emergent herbicides and a three for the impact of post-emergent herbicides. This method takes into account the residue that persists on plants and makes the consumer component more realistic for vegetable and fruit crops. These two herbicide assumptions on the systemic nature and residue levels may be a slight distortion of the actual effects in canola as the vast majority of seed is crushed for oil or meal for livestock feed, with very little seed ever used for direct human consumption. The processing of canola holds the potential to greatly reduce these two effects and minimize their actual impact on consumer health.

The simplicity of the EIQ, aggregating the entire environmental effect of a chemical down to a single number, may be regarded as a limitation, but it also adds a deeper understanding of relative effects when combined with the amount of AI applied. The strength of the EIQ comes from its approximation of pesticide[21] effects used in similar contexts, whereby a relative comparison of the impacts between chemicals can take place. It should be noted, that the EIQ is an indicator only, allowing for comparison, and does not take into account all possible environmental effects. The description of limitations and benefits is based on Kovach et al. (1992).

The application of the EIQ within the context of comparing GM to non-GM crops has a well-established framework within the literature. Brookes and Barfoot evaluate the global impacts of GM crops through their associated economic and environmental effects, with the EIQ as the main indicator of the environmental impact (2005, 2012, 2014). Kleter at al. (2007) offers a similarly large global evaluation of transgenic crops, limited in scope to the environmental effects of the change in pesticide use. A narrower approach was conducted on the impacts of HT canola up to 2000 in Canada. It examined the cumulative environmental impact through the EIQ indicator (Brimner, Gallivan, and Stephenson, 2005). Additional investigations into the environmental impacts of canola using the EIQ indicator were conducted separately on the data sets used in this analysis, which evaluated the time period of approximately five to ten years post-approval of GM canola (Hudson and Richards, 2014; Smyth et al., 2011a).

$$EIQ=\{C[(DT*5)+(DT*P)]+[(C*((S+P)/2)*SY)+(L)]+[(F*R)+(D*((S+P)/2)*3)+(Z*P*3)+(B*P*5)]\}/3 \quad (3.2)$$

DT = dermal toxicity
C = chronic toxicity
SY = systemicity
F = fish toxicity
L = leaching potential
R = surface loss potential
D = bird toxicity
S = soil half-life
Z = bee toxicity
B = beneficial arthropod toxicity
P = plant surface half-life

[21] Pesticide in the EIQ refers to the broader context of herbicides, fungicides, and insecticides.

The EIQ is composed of three main categories of agricultural production, the Farmworker, Consumer, and Ecological impact. These three components are given an equal weight in the final pesticide EIQ, in which a simple average is used. Within the components, weights are used to give a greater impact to factors with greater potential effects, with high impact factors multiplied by five, medium-impact factors multiplied by three, and low-impact factors holding a weight of one. The equation attempts to ensure that the environmental impact of the components increase with potential exposure, thus short-lived compounds have a lower impact value than long-lived compounds, which exhibit greater possibility for exposure through their longevity.

$$EIQ_f = C \times (DT \times 5) + C \times (DT \times P) \quad (3.3)$$

The Farmworker component (EIQ_f) evaluates the health impacts in the two main periods of exposure, the applicator and the harvester. The applicator effect assesses the chronic toxicity (C) and dermal toxicity (DT) to the applicator and is multiplied by a factor of five to indicate the increased exposure impact from directly handling the equipment and chemical. The harvester effect assesses contact to chemical residues as the product of chronic toxicity (C), dermal toxicity (DT), and the plant-surface half-life (P). In the case of harvesting canola contact with the chemical residue comes from contaminants in the air during the swathing and threshing processes (Smyth et al., 2011a).

$$EIQ_c = \{C \times [(S+P) / 2] \times SY\} + L \quad (3.4)$$

The Consumer component (EIQ_c) is composed of the exposure potential health effects from consumption of plant parts and from groundwater contamination. The consumption of plants parts is the product of chronic toxicity (C), the average residual potential in soil and on plant parts (S+P), and the systemic potential of the herbicides absorption (SY). This consumption component is combined with the potential of groundwater contamination (L), which is used as a metric in consumer effects due to the greater potential effects from consumption through wells and drinking water.

$$EIQ_e = (F \times R) + \{D \times [S+P] / 2 \times 3\} + (Z \times P \times 3) + (B \times P \times 5) \quad (3.5)$$

The Ecological component (EIQ_e) is the sum of the aquatic and terrestrial impacts to fish, birds, bees, and beneficial arthropods. The aquatic effect is the product of the chemicals toxicity to fish (F) multiplied by the potential for ground runoff (R). The terrestrial effect in birds is the product of the toxicity towards birds (D), the average residual in the soil and on plants (S+P), and a factor of three to allow for the medium potential impact from exposure. The impact to bees is the product of bee toxicity (Z), the residual plant surface half-life (P), and a factor of three. The effects to beneficial arthropods are the product of beneficial arthropod toxicity (B), residual plant half-life (P), and a factor of five. The use of additional factors in the terrestrial components take into account the greater exposure of these species to agricultural practices than the aquatic impact. The beneficial arthropods receive the greatest factor due to nearly their entire lives existing in the agricultural production ecosystem, while birds and bees receive a medium impact factor as they have the potential for migration outside of and between agricultural production areas.

$$EIQ_{Field}(/ha) = \Sigma\left(\frac{EIQ_f + EIQ_c + EIQ_e}{3}\right)(/kg) * AI\ (kg/l) * Use\ Rate\ (l/ha) \quad (3.6)$$

The environmental impact of the herbicides applied will highlight the EIQ Field Use Rate (EIQ_{Field}) per hectare as well as the associated subcomponents. The EIQ_{Field} is composed of the herbicide EIQ, multiplied by the amount of active ingredient applied, multiplied by the application rate per hectare, culminating in the summation of all herbicides applied per hectare. This field use rating allows for a more thorough assessment on how the type of herbicides used in GM canola have changed, and the subcomponents which are most affected. The representative EIQ_{Field} of the non-GM and GM canola weed management systems will be used in conjunction with the amount of AI applied per hectare. This combination broadens the story on the environmental impact of the weed management systems as it allows for a glance into the various amount of AI applied and the relative toxicity of those AI on the average non-GM and GM canola hectare.

The EIQ will be found by using a weighted analysis of the rate of each type of herbicide applied annually by variety. These are categorized as conventional, TT, Clearfield, and Roundup Ready canola. These annual tables will culminate in a further weighted three-year state average. The state averages will then be combined using a simple average, as the differences in farm size create distortions in an inter-state weighted average where Western Australia has both more survey data and larger farm-sizes.

Each herbicide's use rate will be developed through a weighted average of the indicated rate per hectare multiplied by the number of hectares receiving that application. The summation per herbicide will then be divided by the number of hectares planted to the canola system, to have a per hectare application rate. The AI for the herbicides will be found through the labels of the most popular and common concentrates in Australia and standardized into kilograms per litre (kg/l). Table 3-3 indicates the type of AI, AI concentrations, and the associated EIQ of the ingredient. The Active Applied Rate is the product of the application rate multiplied by the amount of AI to give the average amount of AI by herbicide type applied per hectare. The Active Applied Rate is then multiplied by the EIQ to illustrate the approximate environmental impact effect of each herbicide per hectare, which is summed up into our EIQ_{Field} per hectare.

Table 3-3 Classification of Herbicides and EIQ

	Herbicide	**Active Ingredient**	**Active Ingredients (kg/l)**	**EIQ**
Knockdown	(a)Glyphosate	Glyphosate	0.54	15.33
	(b)Roundup	Glyphosate	0.54	15.33
	(c)Sprayseed	Parquat	0.135	31
		Diquat	0.115	31.7
Pre-Emergent	(d)Trifluralin	Trifluralin	0.48	18.83
	(e)Dual®	S-metolachlor	0.96	12.5
	(f)Select®	Clethodim	0.24	17
	(g)Hammer®	Carfentrazone	0.24	21.5
	(h)Atrazine	Atrazine	0.9	22.85
	(i) Simazine	Simazine	0.9	21.52
	(j) Edge®	Propyzamide	0.5	36
	(k) Logran B®	Triasulfuron	0.75	-
	(l)Glean®	Chlorsulfuron	0.75	9.33
	(m) Chaser®	Metolachlor	0.96	22
	(n) Boxer Gold®	S-metolachlor	0.12	12.5
		Prosulfocarb	0.8	18.7
Post-Emergent	(o)Select®	Clethodim	0.24	17
	(p)Verdict®	Haloxyfop	0.52	20.2
	(q)Lontrel®	Clopyralid	0.3	18.12
	(r)Atrazine	Atrazine	0.9	22.85
	(s)Simazine	Simazine	0.9	21.52
	(t)Intervix®	Imazomox	0.033	19.52
		Imazapyr	0.015	22.3
	(u)On Duty®	Imazapic	0.525	21.2
		Imazapyr	0.175	22.3
	(v)Targa®	Quizalofop	0.2	22.14
	(w) Roundup Ready®	Glyphosate	0.69	15.33

The EIQ_{Field} is shown in conjunction with the summation of the Active Applied Rate. The Active Applied Rate of GM canola and the non-GM canola will be used with the S-curves in Figure 3-5 to show the cumulative difference in amount of AI applied during the moratoria. The pinnacle of this EIQ analysis will conclude with the cumulative difference in amount of AI applied in the two different counterfactual scenarios, as well as the proportional difference in environmental impact from the EIQ of those ingredients. This will show the environmental impact of the SEC-based moratoria as a by-product of the change in herbicide programs used between the non-GM and GM canola varieties.

Greenhouse Gas Emissions

The second environmental indicator will evaluate the effects to GHG emissions as a by-product of change in diesel fuel use. The emissions will measure the change in machinery practices between the non-GM and GM canola varieties. The adoption of GM crops in Canada has been associated with the widespread adoption of ZTMT through the increased use of glyphosate as a pre-emergent knockdown application, which combines with the direct drill air seeder to reduce cultivations as a land preparation, weed control measure (Awada, Lindwall, and Sonntag, 2014). The displacement effects of ZTMT are not solely correlated to GM crops, but evaluating how cultivation practices are being adopted between non-GM and GM canola allows for insight into the positive externality associated with the adoption of GM canola.

Brookes and Barfoot's (2005) review of the literature on GHG emissions and GM crops found an association between tillage practices and biotechnology. Their framework on biotech and tillage practices included GHG emissions, using an emissions effect of 2.67 kg of carbon dioxide per litre of tractor diesel burned, in the environmental impact studies of biotechnology, and will be a framework carried on in this analysis (Brookes and Barfoot, 2012, 2014). Further studies of the adoption of ZTMT associated with GM crops corroborate these positive effects on GHG emissions (Hudson and Richards, 2014; Smyth et al., 2011b).

The Australian survey data included questions pertaining to the type of seeding practices, inquiring whether the method used was cultivation or direct drilling. The seeding practices were heavily dominated by the direct drilling method, to such a degree that the few producers of any variety that indicated the cultivation method had, in effect, a zero impact on the cumulative seeding impact. The cumulative effects per hectare were less than 0.005 litres lower than the direct drill method in the two years where comparable data was available in the NSW and Victoria data set. This lack of data for four out of the six survey years and a continued increase in the percentage of producers using direct drilling has resulted in this analysis generalizing all varietal seeding as having been directly drilled. The assumption made is that there is a constant use of 5.04 litres of fuel per hectare for seeding, the amount for direct drilling. The costs of the direct drilling method are used across all varieties.

Cultivations will be categorized as chisel plough, scarifier, cultivator, disc, and deep ripper. Due to limitations of the data, a weighted average will be developed from the NSW and Victoria data set for 2009 and 2010. The average of the 2009 and 2010 cultivations will be applied to years where the number of cultivations are stated but not delineated and where the respondents indicated cultivating instead of direct drilling. The result will indicate the rate of fuel use per hectare for cultivations.

To calculate the impact of cultivations a weighted average of the number of cultivations per hectare was done for 2008 to 2010 in NSW and Victoria. A similar method was used to find the weighted average of fuel consumed per cultivation pass in 2009 and 2010 in NSW and Victoria, using the fuel use by cultivation implement developed by Hudson and Richards (2014). The year 2008 is not included in the fuel use analysis as the survey conducted did not allow for description of cultivation type. A weighted average was used to combine the total number of cultivations and total fuel use to find the average per hectare impact. The resulting averages are treated as representative of the program used by respondents who declared cultivations instead of direct drilling, but which their corresponding detailed data is missing from the data sets in Western Australia. A table of the values obtained and used in the cultivation analysis can be found in Appendix A, Table A-6

The spray applications will be a weighted average of producers' indicated number of herbicide spray applications. Spraying application fuel use weights the number of sprays of each herbicide by the number of hectares receiving the application, which will be summed up and divided by the total number of hectares by variety. This method assumes that there is no tank mixing, unless a producer opted to include the application rate for the chemicals tank mixed, but stated the number of applications under only one herbicide. The impact may cause the number of passes to be overestimated, but with no method for determining actual tank mixing practices it is a simple limitation that may or may not be present. The weighted average of sprays per hectare will use the approximate fuel use per spray application as used in Hudson and Richards (2014).

The change in fuel use will be measured by the cumulative differences of seeding, cultivations, and spray applications between non-GM and GM canola. The per hectare fuel use will be used with the associated number of non-GM and GM canola hectares within the S-curve scenarios in Figure 3-6 to find the total opportunity costs of fuel use. These cumulative foregone fuel costs will be further broken down by type of GHG emissions associated with the burning of each litre of tractor diesel fuel.

3.5.2 Economic Impact

The economic impact between non-GM and GM canola will be measured as the difference in the variable costs of the weed control programs (herbicide + cultivation + spray + Technology Access Fee), the change in yield per hectare, and the overall gross margins. These factors of production are chosen as Qaim (2009) found that:

> Overall, HT technology reduces the cost of production through lower expenditures for herbicides, labor, machinery, and fuel. Yet, because HT crops were developed and commercialized by private companies, a technology fee is charged on seeds, which varies among crops as well as countries. (p. 670)

This method is used to tease out producer impacts of the main economic factors associated with adopting GM technology. This analysis will not delve into the net economic impacts of GM canola's adoption (Phillips, 2003), nor will it attempt to disaggregate the ZTMT effects from the aggregate GM canola effects. Rather, this analysis will seek to assess a basic per hectare impact in the Australian environment which is correlated to the difference in treatments between the non-GM and GM canola varieties, and use this impact to assess the economic opportunity costs of delay from incorporating an SEC into policy.

Variable Cost of Weed Control

The variable cost of weed control programs will begin by taking into account the per litre costs of herbicide multiplied by the amount of herbicide applied per hectare found in the EIQ analysis. The cost of cultivation, seeding, and spraying will be found by weighting the variable cost of the machine implement by the number of hectares it is applied to, which will then be aggregated into a per hectare cost. The herbicide price list and cost per pass of machinery will be based on those collated by Hudson and Richards (2014), and will incorporate the same AU$0.80 cost per litre of diesel.

The final aspect of the variable cost of the weed control program will involve the technology fee for GM Roundup Ready canola. The technology fee varies throughout the years of the data sets, so an average tech fee will be applied. The fee was initially charged based on a Planting Seed Fee and an End Point Royalty Fee (EPR) that together aggregated into the Technology Access Fee (TAF). In 2012 the TAF was simplified to a Planting Seed Fee, a breakdown of the fee and its progression is included in Table 3-4.

Table 3-4 Roundup Ready Canola Technology Access Fee Breakdown

	2008	**2009**	**2010**	**2011**	**2012**
Planting Seed Fee	$3.00/kg seed	$3.00/kg seed	$3.00/kg seed	$3.00/kg seed	$6.00/kg seed
End Point Royalty	$12.60/t yield	$13.50/t yield	$13.20/t yield	$13.20/t yield	-

Source: GRDC, 2012, 2014

Yield Effects

The second factor in the economic impact is the difference in yield per hectare. While it has been found that there are few potential yield gains associated with many GM crops (Qaim, 2009), GM canola has been found to have moderate yield increases over its non-GM counterparts in Canada (Brookes and Barfoot, 2005; Phillips, 2003). The presence of three conventionally bred non-GM varieties, conventional, TT, and Clearfield, and two distinctly different growing regions, south eastern Australia and south western Australia, make teasing out yield benefits hard to specify as the presence of high yielding varieties are not displaced and it is difficult to take into account inherent yield differences between and within regions.

To ensure the yield changes are not over estimated a weighted average of producer's yield will be calculated annually by variety, and then aggregated into a weighted state varietal average. The state varietal average will be aggregated into non-GM and GM canola yield averages, which will be combined across regions in a simple average. The simple average is done to give equal weight to the two growing regions, which have similar total canola hectares but largely divergent crop sizes per farm and canola variety mix, to create the Australian average. The Australian per hectare yield average of the non-GM and GM canola variables will be used to find the difference in canola output.

The yield differences in output will be used in conjunction with the S-curve scenarios to find the opportunity costs in production within GM canola adopting states and Australia. The difference in output will highlight export impacts. Australia is predominantly a price taker, as Canada sets the worlds benchmark price for canola (Ministerial GMO Industry Reference Group, 2009), so it is assumed that any yield effects will not affect world price and, thus, canola producer revenue is calculated using the annual Australian import price from the *Agricultural Commodity Statistics* reports (ABARES, 2006, 2013, 2015).

Gross Margins

The final factor of the economic analysis will revolve around the variance in gross margins between the non-GM and GM canola systems. The Australian survey included an open ended question for producers to declare their calculated gross margins. The validity of the responses and outcome to this question in the survey have possible issues such as a low response rate, negative gross margins, and possible impacts from the TAF. To mitigate the possible downfalls of the volunteered gross margins, frequency results will be included on a close ended question, in which a simple 'Better', 'Same', or 'Worse' response was available, directed to Roundup Ready producers comparing the margins between non-GM varieties to GM canola. A final comparison on the margins will use the contribution margins, as calculated from the separate variables found within this analysis. This calculation will evaluate the revenue from output minus the variable costs to find the contribution costs and net revenue to cover fixed costs and profit.

The gross margins are calculated in a weighted per hectare analysis divided by the cumulative number of hectares from those that responded to the question. This method will follow the same procedure as mentioned with the other variables, the results will be weighted annually across varieties, followed by a weighted average of varieties by state, then combining the state level varieties into non-GM and GM canola categories, and then a simple average between states calculated to find the Australian impacts. The final outcome of this gross margin variable should be taken with a grain of salt due to other factors that may impact its validity.

The low response rate of the gross margin survey question may affect the story in the economic comparison between the canola varieties. With a limited number of producers calculating the gross margin on their crops, it is possible that one of the hindrances to adoption is a lack of observable results for farmers. The low response rate may imply that adopters are unaware of their defined profit from the variety of canola they grow, and that the results are skewed by the limited number of responses and may not reflect the average Australian experience.

The volunteered gross margin variable includes a number of data points with negative gross margins per hectare, which may be on account of a significant natural disaster event such as drought or flooding. It is unlikely that the negative gross margins received a form of financial assistance such as a crop insurance to mitigate the risk of such events, thereby eliminating post-insurance negative gross margins. These negative margins are included as they reflect what the average canola producer experiences, although their relevance to other jurisdictions with crop insurance programs may cause a negative bias in the gross margins.

The final reason to be wary of the volunteered gross margin results is a by-product of the TAF. The TAF is used by the seed developer to capture some of the returns to producers to recoup costs and profit from their R&D investments. The fluctuating TAF is likely to have been set too high initially, which is a reason for slow adoption. The imposition of an EPR caused high yield years to have exceptionally high costs making evaluation of net input costs at seeding hard to factor in. The elimination of the EPR and simplification of the TAF to the Planting Seed Fee, effectively reduced per hectare costs and increased their predictability. This impacts the gross margin results as those effects are only incorporated into 2012 in Western Australia. Yet the observed effects from the higher price fees from five out of six years of data are used to forecast the effects for multiple years when a lower tech fee is in place. If the effects can be assumed to follow the same route in the S-curve scenarios, the TAF would have been changed by 2008, with the highest share of the S-curve thus facing a lower TAF and cumulative economic impacts being significantly different from the results observed.

The inclusion of a comparative margin, a frequency based close-ended question that allows for the experience of producers with undefined calculations to be taken into account, allows for an experiential perspective of the generalized observed differences. The results of the frequency will be illustrated in percentage form to add further insight into how farmers perceive the economic benefits between GM canola compared to non-GM varieties. The close ended questions limited responses of ‘Better’, ‘Same’, or ‘Worse’ helps tease out what kind of economic benefits are being experienced by producers. The effects of this question helps to fill in some of the gaps arising from the low response rate to the gross margins question. It should be noted that the comparative margin question is limited to producers that have grown GM canola, as they are the sole individuals that can accurately compare the various canola systems.

In conjunction with the volunteered gross margins and comparative margins, this analysis calculates a contribution margin. The contribution margin is a simple revenue minus variable cost calculation and will follow the framework developed by Fulton and Keyowski (1999) on the producer benefits of HT canola in Canada. This framework has been incorporated into an analysis on the economic impact of HT canola in Canada (Phillips, 2003), and used to assess the changes in the Canadian canola sector and consequences of biotechnology (Brewin and Malla, 2012). The contribution margin is used to estimate the annual variable income which is used to cover the fixed costs, such as land, and farmer earnings. The reason for the inclusion of this margin is to offer insight into to what the average producer experiences based off survey questions with a high response rate.

The revenue per hectare is found by multiplying the average yield per hectare by the AU$ per metric tonne price of canola. The price of canola is found by using a simple average of the annual import price of canola, in US$ per metric tonne, multiplied by its respective year-end exchange rate, aggregated to find an average canola price in AU$ per metric tonne for the period 2004 to 2014 (ABARES, 2015; Australian Taxation Office, n.d.). This converted price per metric tonne for canola combined with the average yield creates an approximate revenue per hectare by variety.

In the contribution margin we assume that there is not a price premium for non-GM canola. This assumption comes from Canada’s market dominance as the primary exporter of canola, with approximately 70% market share, whereby they set the benchmark international price (Ministerial GMO Industry Reference Group, 2009). Canada and Australia’s canola prices tend to fluctuate around parity in Japan, with no evidence of price premiums observed for non-GM status. Rather, the price fluctuations tend to revolve more around seasonality issues and transportation costs, leading to no verifiable evidence that non-GM status receives a price premium over GM canola (Foster and French, 2007; Ministerial GMO Industry Reference Group, 2009; State of Victoria, 2007).

The variable costs will be constructed using the average variable cost of the weed control program used, the seed cost, the TAF, and pre-farm-gate segregation cost limited to GM canola hectares. The variable weed control program costs use the values found earlier in this analysis. The seed costs are found using gross margin information guides for the non-GM canola varieties and a Roundup Ready guide for GM canola (GRDC, 2016; Pritchard et al., 2009). The segregation costs are the low-end of pre-farm gate prices, but are only applied to GM canola instead of the suggested universal application in an attempt to impose the costs solely on GM canola adopting farmers for which on-farm segregation is required (Ministerial GMO Industry Reference Group, 2009). Supply chain costs and post-farm-gate segregation costs have been foregone to remain consistent with the Canadian framework, and under the assumption that these are constant variable costs that will be applied at a constant rate per metric tonne across varieties.

The final impact of the contribution margin will be compared to the volunteered gross margins of the different canola varieties. The contribution margins should be greater than the volunteered gross margins overall, due to their omission of fixed costs, but offer a more controlled result for comparison. The contribution margin should closely align with the experiences in the variable weed management costs and yields, minimizing the effects from the low sample size and wide variance in the gross margins section.

3.6 Summary

This thesis will construct a counterfactual to evaluate the opportunity costs of delay resulting from the SEC-based moratoria on GM canola. The Canadian and Australian data surveys were conducted in similar time periods post adoption of GM canola, and are largely correlated in the line of questioning. The Canadian experience in the adoption of GM canola is used to create a normalized S-curve with an 80% ceiling to evaluate the counterfactual scenario of Australia not allowing SEC-based moratoria on GM canola. The environmental impact factors evaluate the AI applied; the EIQ, the varietal herbicide programs impact to farm workers, consumers, and ecology in a relative comparison; and GHG emissions, as a by-product of fuel use from the change in cultivation and spray application practices. The economic impact factors evaluate variable costs of the canola varietal weed control programs, consisting of the cost of cultivations, spray applications, herbicides, and TAF; yield effects; and producer margins. The margins of which are survey respondent volunteered gross margins, comparative margins of GM canola producers, and a contribution margin from the yield and variable costs found in this analysis.

Chapter 4. Results and Discussion

4.1. Introduction

The opportunity costs of including an SEC into policy will be measured through the cumulative impact to the foregone hectares that would have been planted to Roundup Ready GM canola had the state-based moratoria not been imposed in this counterfactual exercise. Table 4-1 illustrates the percentage adoption rates of hectares being planted to GM canola, with a notable decline in adoption between 2011 and 2013 in Australia. As can be readily observed the adoption rates of GM canola have a wide disparity in the narratives through the different jurisdictions in Australia and Canada. The adoption percentages observed in the GM canola adopting states of NSW, Victoria, and Western Australia strongly contrast those of the Canadian experience, in which five years post-approval of GM canola the adoption level had reached over 50% of total canola hectares. The Australian states' experience five years post-approval of GM canola was that they were reviewing the validity of their moratoria, and rescinding them in NSW and Victoria.

Table 4-1 Percent of Canola Hectares Planted to GM Canola

Year	NSW and Victoria	Western Australia	GM States	Australia	S-Curve Scenario	Canada*
2003/2004	-	-	-	-	-	-
2004/2005	-	-	-	-	2.3%	4.0%
2005/2006	-	-	-	-	4.0%	12.0%
2006/2007	-	-	-	-	6.5%	35.0%
2007/2008	-	-	-	-	10.1%	53.0%
2008/2009	2.6%	-	1.0%	0.9%	14.9%	55.0%
2009/2010	8.9%	0.1%	3.5%	3.0%	21.0%	61.0%
2010/2011	11.1%	8.7%	9.6%	8.4%	28.2%	64.0%
2011/2012	6.4%	11.4%	9.0%	7.7%	36.0%	70.0%
2012/2013	4.3%	12.1%	7.4%	6.6%	44.0%	75.0%
2013/2014	5.6%	14.2%	10.2%	9.0%	51.8%	79.0%
2014/2015	11.5%	30.0%	21.5%	19.0%	59.0%	84.0%

*Canada's adoption starts from 1995, opposed to Australia's in 2003, the year GM canola was approved

Source: *AOF Annual Reports 2003/04- 2014/15*; *AOF Crop Report 2003-2015, n.d.*; Canola Council of Canada, 2010; GRDC, 2012, 2014

The S-curve scenario in Australia uses a normalized frequency bell-curve based upon the Canadian experience but follows a more moderate adoption curve than was experienced in Canada, as it is further limited to an 80% adoption ceiling. This GM canola adoption path will be applied to the canola hectares in the two Scenarios of comparison, Scenario 1) GM canola adopting states and Scenario 2) Total Australian adoption. The only difference between these two scenarios is the inclusion of South Australia in Scenario 2), indicating that the difference between Scenario 1) and Scenario 2) is the opportunity cost to South Australia of maintaining their SEC-based moratoria. The relevant hectares in Table 4-2 illustrate total canola hectares, total GM canola hectares, the theoretically planted GM canola hectares, and the difference between the theoretical and the actual. The difference between the theoretical scenarios and the actual observations of canola hectares in the final column are the annual number of foregone hectares.

Table 4-2 Australian GM and non-GM Canola Hectares By Year ('000 ha)

	Total Hectares		**Actual GM Hectares**	**Theoretical GM Hectares**		**Difference (Scenario - Actual)**	
Year	**GM States**	**Australia**	**Australia**	**Scenario 1) GM States**	**Scenario 2) Australia**	**Scenario 1) GM States**	**Scenario 2) Australia**
2003/2004	825	1,005	0	0	0	0	0
2004/2005	1,129	1,439	0	26	33	26	33
2005/2006	810	960	0	32	38	32	38
2006/2007	793	943	0	52	62	52	62
2007/2008	900	1,060	0	91	107	91	107
2008/2009	1,000	1,165	10	149	174	139	164
2009/2010	1,206	1,390	42	253	292	211	250
2010/2011	1,395	1,592	134	393	448	259	314
2011/2012	1,560	1,815	140	561	653	421	512
2012/2013	2,384	2,687	177	1,050	1,183	873	1,006
2013/2014	2,180	2,480	223	1,130	1,285	907	1,062
2014/2015	2,305	2,607	495	1,360	1,538	864	1,042
Total	16,487	19,143	1,222	5,097	5,813	3,874	4,591

Source: *AOF Annual Reports 2003/04- 2014/15*; *AOF Crop Report 2003-2015, n.d.*; GRDC, 2012, 2014

The cumulative of these foregone hectares is the opportunity cost of delay from including the SEC-based moratoria on possible trade and market impacts in policy. The 3.874 million foregone hectares in Scenario 1) are the difference arising between NSW, Victoria, and Western Australia adopting GM canola for planting in 2004, following the federal approval in 2003, instead of adopting in NSW and Victoria in 2008 and Western Australia in 2010. This scenario is used to measure the opportunity costs to these states from the delay in adoption. The Australian opportunity cost in Scenario 2) includes the hectares from Scenario 1) with the addition of the other main canola growing state of South Australia for a total of 4.591 million foregone hectares of GM canola. This scenario makes the assumption that South Australia allowed the commercial cultivation of GM canola in 2004 under a system of national approval. In actuality, the moratorium still exists in South Australia counter to the 2007 recommendations of the independent moratorium review panel, which found that there may be negative market impacts from maintaining a ban on GM canola production (ACT Health, 2013). This Australian scenario focuses only on the four main canola producing states to simplify the impacts and allow for an interpretation of the effects for South Australia. The cumulative of the other canola producing states have an annual negligible amount of hectares in the thousands, compared to hundreds of thousands and millions in the four main canola producing states (ABARES, 2015).

The cumulative amount of foregone hectares in the two scenarios is used in the final analysis of each impact category. The opportunity costs are simplified into a single value which is the respective cost or benefit of adopting an SEC into regulatory policy. The discussion concludes with a simple table of the cumulative environmental and economic impacts measured over the course of the moratoria in the two scenarios, and a delineation of the impacts to the state level.

4.2 Environmental Impact

4.2.1 Environmental Impact Quotient

To evaluate the costs of adopting an SEC into regulatory policy this analysis will start with the type of weed management system that is being foregone and evaluate the impact of the systems that fill in that void. The Australian experience of postponing the adoption of GM canola prolonged the use of conventional varieties that have varying impacts and versatility. The comparison between herbicide programs will illustrate what impact the displaced varieties have and the net differences between their cumulative impact in a non-GM canola variable and the observed impacts of the GM canola Roundup Ready.

In Table 4-3, the environmental impacts of the canola varieties are illustrated through the annual EIQ of the programs used during the first three years of GM canola's introduction in the associated GM canola adopting states. In NSW and Victoria TT canola experienced a 20% increase between year one and year three in its EIQ field rate per hectare (EIQ_{Field}). The large increase may be an effect of areas with less severe weed problems transferring to other weed control programs, while the areas with the most severe weed problems and highest application rate remain, leading to a higher average herbicide use rate in TT canola. This theory correlates to the percentage of total canola hectares dedicated to TT canola throughout the study with a net decrease between year one and year three. Most of the decrease in TT canola is accounted for by the increase to Roundup Ready's share of canola hectares. A description of the changes in canola hectares and the distribution between variety within each state can be found in Appendix A, Table A-1. The state level field rate EIQ remains relatively constant within the other canola varieties in NSW and Victoria throughout the three years of this study and its average.

Table 4-3 EIQ_{Field} ha^{-1} by State and Variety

		Year 1	**Year 2**	**Year 3**	**Weighted Average**
NSW & Victoria	Conventional	27.137	29.955	27.168	28.020
	TT	65.454	70.060	78.685	71.805
	Clearfield	19.534	20.556	20.708	20.443
	RR(GM)	29.430	25.816	26.841	26.698
	Non-GM*	51.680	48.714	49.641	49.900
Western Australia	Conventional**	42.450	56.555	52.398	50.762
	TT	75.304	78.823	69.271	74.063
	Clearfield	26.984	27.297	29.316	26.636
	RR (GM)	25.552	23.206	26.131	24.010
	Non-GM*	70.969	73.843	65.040	69.624

* The non-GM variable is a weighted average of the conventional, TT, and Clearfield varieties.
** A number of conventional herbicide application rates used atrazine levels that are consistent with TT varieties, indicating this EIQ rate may be excessively high due to an ambiguity in what defines a conventional variety. See Appendix A and Table A-4 for a breakdown.

The state of Western Australia exhibits predominantly higher EIQ rates than its east coast counter-parts. The reasons for the more harmful herbicide programs may be prevalent ryegrass and wild radish weed problems that have grown resistant to the current herbicide weed management programs (GRDC, 2014). GM canola has maintained a relatively constant field rate EIQ throughout the Australian regions it has been adopted. The field rate EIQ of Roundup Ready canola is the lowest of all varieties in Western Australia and only slightly higher than Clearfield in NSW and Victoria. The Clearfield canola variety is known for its high-yielding capacity in crop land with low weed problems. This may account for the low EIQ_{Field} per hectare and be the reason that Clearfield has maintained a relatively constant share of five to ten percent of total canola area in Canada and Western Australia and an approximate 25% of hectares in NSW and Victoria (Canola Council of Canada, 2010). For a more in-depth view into the market share of the canola varieties over the three years of this survey see Table A-1 in Appendix A.

The environmental impact of the herbicide programs between the cumulative non-GM canola variable in the two regions is substantial. The disparity between the cumulative non-GM variable's EIQ may be an indicator of the severity of weed problems that canola producers are facing, whereas the congruency of the canola varieties' EIQ across regions indicates the universality of the environmental impacts of the herbicide weed management programs. The high share of hectares planted to TT canola in Western Australia strongly influences the cumulative non-GM EIQ_{Field}, indicative of a prevalent weed resistance problem that is not as overwhelming in NSW and Victoria, where high yielding conventional and Clearfield varieties maintain a 40% share of canola hectares. Whether evaluating the cumulative non-GM canola variable's EIQ_{Field} against GM canola or the non-GM varietal $EIQ_{Field,}$ Roundup Ready GM canola's herbicide weed management program has a comparatively low environmental impact. For further information on the impact of each herbicide within the per hectare EIQ field rate by state and variety see Appendix A, Tables A-2 to A-5.

Following the impact in the Australian GM canola producing states, the national environmental impact sees GM canola have less than half the impact of its cumulative non-GM canola basket counterpart. This impact is influenced by the percentage share of each canola varietal system in place, which is a naturally changing variable that will continue to fluctuate as GM canola's share increases and displaces varieties with higher environmental impacts.

This displacement effect of GM canola for non-GM canola will result in the EIQ_{Field} per hectare of non-GM canola varieties decreasing over time as GM canola claims a larger share of total hectares with greater weed problems. The adoption of GM canola will have a strong impact in decreasing the EIQ Field Rate of the cumulative impact of all canola hectares. This assertion comes from the environmental effects that have occurred in cotton, in which the proliferation of GM Bt cotton has resulted in a 25% reduction in pesticides applied to all cotton hectares globally (Brookes and Barfoot, 2012).

The subcomponents of the EIQ_{Field} per hectare, Table 4-4, tell an interesting story regarding how the various herbicide programs affect farm workers, consumers, and the ecology. GM Roundup Ready canola has the lowest impact on consumers from its weed management program. This runs counter to much of the rhetoric against Roundup Ready canola, as consumers often fear the impact that increased levels of glyphosate herbicide has on health (Baden-Mayer, 2016; Cox, 1998; Friends of the Earth Europe, 2013).

Table 4-4 Australian Environmental Impact Components per Hectare

	AI Applied (kg/ha)	EIQ_f ha^{-1}	EIQ_c ha^{-1}	EIQ_e ha^{-1}	EIQ_{Field} ha^{-1}
Conventional	2.055	17.896	11.268	84.440	39.391
TT	3.424	29.438	23.802	164.834	72.934
Clearfield	1.311	12.147	6.367	51.360	23.539
RR (GM)	1.442	14.977	5.690	54.983	25.354
non-GM*	2.860	24.657	18.869	134.736	59.762

* The non-GM variable is a weighted average of the conventional, TT, and Clearfield varieties.

The other subcomponents of the EIQ_{Field} reinforce the low impact GM canola has compared to the non-GM variable. Although Roundup Ready canola has a marginally higher effect than Clearfield on farm workers and the ecology, it is substantially lower than the other more prevalent non-GM varieties. That there is a 65% difference in the EIQ_{Field} between Roundup Ready and Triazine Tolerant canola, the most planted canola variety, is indicative of the significant cost that postponing GM canola's adoption has had on the environment, through the perpetuation of environmentally harmful varieties.

In the analysis of the environmental impact of the herbicide weed programs used in canola it is useful to compare the amount of active ingredients applied as well as the EIQ toxicity impacts. In Australia the amount AIs applied per hectare in Roundup Ready canola exhibits similar characteristics to its EIQ. GM canola uses approximately half the amount of AIs per hectare, with an associated per kilogram EIQ of 17.8, compared to the non-GM varieties, which have a per kilogram EIQ of 20.9. The disparity in the amount of AI applied per hectare indicates a sizable decrease in the amount of herbicide applied. The EIQ per kilogram of the herbicides applied to GM canola supplant the non-GM canola herbicide programs with a low impact, more sustainable program which offers an improvement for farmers, consumers, and the Australian environment.

Canada's experience has shown similar environmental benefits from the adoption of GM canola varieties. Table 4-5 shows the very low EIQ_{Field} per hectare associated with the top five herbicides applied to HT crops[22]. This low-level of herbicide application may be a consequence of the 2006 crop year, in which only 75% of respondents reported applying herbicide. The low level of producers using herbicides may be the result of achieving good weed management through tillage or a strong early canopy associated with warm weather and good moisture levels. In 2006 the weather patterns indicated above average temperatures and excellent moisture, making for ideal canopy development that inhibits the growth of weeds and results in a reduced need for post-emergent herbicide (Canadian Wheat Board, 2006 as cited in Smyth et al., 2011b).

Table 4-5 Canada's Top Five GM Herbicides Environmental Impact per Hectare

	Active Ingredient	**AI Applied (kg/ha)**	**EIQ_f ha^{-1}**	**EIQ_c ha^{-1}**	**EIQ_e ha^{-1}**	**EIQ_{Field} ha^{-1}**
Roundup	Glyphosate	0.765	6.121	2.295	26.779	11.729
LibertyLink	Glufosinate	0.067	0.808	0.404	2.868	1.360
2,4-D (Amine or Ester)	Dimethylamine	0.007	0.163	0.047	0.210	0.140
Trifulralin	Trifularlin	0.009	0.077	0.047	0.361	0.162
Horizon	Clodinafop-Propargyl	0.001	0.010	0.003	0.034	0.016
Total		0.848	7.179	2.797	30.252	13.407

[22] The herbicides listed here exclude Imazamox and Imazethapyr as they are associated with the non-GM HT variety of Clearfield. This was done to give the EIQ_{Field} ha^{-1} a stronger correlation to the GM varieties and their associated impact per hectare.

The Canadian survey data may be an anomaly in its low environmental impact in 2006. However, GM canola's proportional comparison to the approximate environmental impact of non-GM conventional canola varieties is nearly equivalent in its results between the two jurisdictions. Brimner, Gallivan, and Stephenson (2005) compared the herbicide EIQ_{Field} per hectare in HT canola to that of conventional varieties and found a similar contrast between GM and conventional with approximately half the EIQ_{Field} and half the amount of active ingredients. This comparison may not be directly transferrable as it does include Clearfield canola in the HT analysis, but as Clearfield makes up a small portion of the HT canola hectares in Canada it is rather indicative of the GM to non-GM comparative effects.

The results of the EIQ field rates in Australia and Canada indicate that a direct comparison of varieties in the two jurisdictions is not reasonable. The results do however illustrate a correlation in EIQ_{Field} per hectare between GM and non-GM varieties within nations. This regional analysis indicates that the level of relative benefits between varieties can be observed across nations and regions. This allows for the separate regional conditions that affect canola growth, such as weather, soil, and weed proliferation, to be taken into account while allowing for the broad effects to be analyzed in international comparisons.

To assess the environmental impact of the moratoria on GM canola, and thereby the SEC regulatory policy that created it, the AIs applied and their respective EIQ will serve as the first indicator. The differences (Δ), measured as the Actual minus the Scenario, in AIs applied allows for an extrapolation of the environmental impacts between the counterfactual without the moratoria and the actual with it in place, while the EIQ allows for a cumulative impact of harm from those ingredients. Table 4-6 highlights the cumulative impact in the two scenarios.

Table 4-6 Difference in Cumulative Environmental Impact Between Actual and Scenarios

	Actual GM States	**Scenario 1) GM States**	$\%(\frac{Scenario}{Actual})$	**Actual Australia**	**Scenario 2) Australia**	$\%(\frac{Scenario}{Actual})$
AI Applied (kg)	45,414,269	39,921,305	87.90%	53,009,573	46,500,612	87.72%
Difference (Δ)	5,492,964		12.10%	6,508,961		12.28%
Cumulative EI	943,233,767	809,933,889	85.87%	1,101,961,443	944,005,980	85.67%
Difference (Δ)	133,299,878		14.13%	157,955,463		14.33%

In Scenario 1), analyzing the impact to GM canola adopting states if they had adopted GM canola in 2004 instead of in 2008 and 2010, there is a 12.1% decrease in the amount of active ingredients applied in those states. The moratoria resulted in excess of 5.49 million kg applied over the 2004 to 2014 period as a result of the continued use of the available non-GM canola varieties. The environmental impact of those active ingredients' application resulted in a foregone reduction in environmental harm to farmworkers, consumers, and the ecology. Ecological factors are the most affected by the SEC-based moratoria on GM canola, absorbing 75% of the foregone benefit[23].

In Scenario 2), in which the impacts to Australia are represented by the main canola growing regions of NSW, Victoria, Western Australia, and South Australia, we see a marginally higher percentage of effects compared to those observed in Scenario 1. The moratoria had an opportunity cost of a 12.3% reduction in AIs applied, and an associated foregone 14.3% decrease in the cumulative environmental impact of those ingredients to the Australian environment. The resulting cost to Australia of allowing the SEC-based moratoria, opposed to a policy of national full adoption, is an additional 6.51 million kg of AIs applied.

The main difference between these two scenarios is South Australia. The difference between these scenarios implies that there was an extra 1.02 million kg of AIs applied in South Australia over the 2004 to 2014 period. The effects for the 2.66 million canola hectares in South Australia between 2004 and 2014 are an extra 0.383 kg of AIs per hectare. The estimated environmental impact of the moratoria is equivalent to 22.861 EIQ_{Field} per hectare for every hectare that has been planted to canola. This large environmental impact is a significant externality of the GM canola moratoria and the South Australian government's rejection of the independent review committee's suggestions to eliminate the moratorium, opting instead to believe that there exists a market advantage and price premium. The existence of such an advantage or premium has not yet been verified by any Australian committee (ACT Health, 2013; Foster and French, 2007).

Tasmania, in which 1,200 total hectares of canola were grown in the state in 2013, may be reaching a niche market that does receive a premium. Evidence, however, is not conclusive and the limited quantity of production in the state makes for a weak comparison to the large-scale canola producing states in which NSW, Victoria, and Western Australia had 2.42 million hectares of canola grown in that same year of 2013 (ABARES, 2015). The price premium hoped

[23] This distribution of effects is extrapolated through Table 4-4 and Table 4-6.

for in South Australia thus has a clear environmental cost from the herbicide programs employed.

4.2.2 Greenhouse Gas Emissions

The environmental impact between non-GM and GM canola varieties extends beyond that of the herbicide programs. The use of GM canola affects the practices used in cultivation and herbicide spraying. These differences in practices in turn involve different machinery and number of applications associated with GM canola. A breakdown of the fuel use by machinery and the annual use of cultivations and sprays by state can be found in Appendix A, Tables A-6 to A-13.

The seeding practices in this analysis are assumed to be direct drilling at the rate of 5.04 litres of diesel per hectare. This is done to minimize the ambiguity in the results of a survey question asking whether the canola crop was cultivated prior to planting or direct drilled. The question seems to imply the use of cultivation as a weed management method, opposed to a planting method. The air seeder in the 'Other Implement' category has a similar 4.48 litres per hectare impact. The inclusion of the air seeder and harrows as seeding implements had a minimal effect on the cumulative per hectare impact within a variety as it was done on a minimal amount of hectares overall. The resulting effect of including harrow and air seeder with direct drilling was less than 0.005 litres per hectare difference in NSW and Victoria, and less in Western Australia where direct drilling is the dominant choice.

The use of cultivation implements in Australia is broadly similar across canola varieties. The minimal variance between varieties in the fuel per pass subcomponent of cultivations ranges from 5.311 to 5.642 litres of fuel per pass, as found in Table 4-7. The use of cultivations was most common in the conventional and Clearfield canola varieties, 0.143 cultivations per hectare and 0.105 cultivations per hectare respectively. The least common use of cultivations was in TT canola with 0.048 cultivations per hectare, marginally fewer than Roundup Ready GM canola at 0.058 cultivations per hectare. The impact of TT canola's market share resulted in the non-GM canola variable having a lower fuel per pass effect as compared to GM canola.

Table 4-7 Australian Fuel Use per Hectare

		Conventional	TT	Clearfield	RR (GM)	Non-GM*
Seeding	Fuel ha^{-1} (litres)	5.04	5.04	5.04	5.04	5.04
Cultivations	Cultivations ha^{-1}	0.143	0.048	0.105	0.058	0.081
	Fuel per Pass	5.642	5.311	5.560	5.564	5.414
	Fuel ha^{-1} (litres)	0.806	0.254	0.582	0.325	0.444
Spraying	Sprays ha^{-1}	3.531	4.795	3.368	2.934	4.455
	Fuel ha^{-1} (litres)	4.131	5.610	3.941	3.433	5.213
Total	Passes ha^{-1}	4.674	5.843	4.473	3.992	5.536
	Fuel ha^{-1} (litres)	9.977	10.904	9.563	8.798	10.696

* The non-GM variable is a weighted average of the conventional, TT, and Clearfield varieties.

The fuel use per hectare from cultivations has a non-trivial 36.6% higher rate of fuel consumption in the non-GM variable compared to the GM canola variable. This comparison ignores a more interesting story. The low use of cultivations in TT canola and GM canola overall seems to imply that these HT technologies are correlated with a decrease in cultivations in favour of ZTMT. Clearfield and conventional appear to receive adequate weed control from tillage, which corresponds to the low EIQ_{Field} per hectare. This use of cultivations further aligns with the expectation that the higher yielding conventional and Clearfield varieties are planted in crop land with fewer weed issues.

The number of sprays per hectare is inversely correlated to the number of cultivations per hectare in the non-GM varieties. The higher number of cultivations in conventional and Clearfield canola have the reciprocal low levels of spray passes per hectare at 3.531 and 3.368 respectively. Triazine Tolerant canola, on the other hand, has a substantially higher 4.795 spray passes per hectare, further correlating the exchange of ZTMT and herbicides for the use of tillage[24].

[24] The atrazine spray applications, and other soil residual herbicide applications, are likely not multiple herbicide spray applications, but rather soil incorporation passes, such as harrowing. The generalized fuel use per hectare of a spray application is assumed for all sprays, which will result in an underestimation of the fuel impacts in the canola varieties that use these herbicides and techniques.

GM canola, however, does not conform to the inverse correlation between the high use of cultivations and low level of spray applications. The low level of cultivations is coupled with the lowest level of spray passes at 2.934 spray passes per hectare. The culmination of cultivations and sprays indicates that superior weed control is achieved through the use of post-emergent glyphosate applications, or that GM canola is planted on crop land with the lowest level of weed problems. As we have seen, the increase in Roundup Ready canola hectares is largely at the expense of TT canola, the benefit of the GMHT variety appears to be achieving better weed control with fewer inputs.

The fuel impacts per hectare in GM canola associated with a decrease in inputs is highlighted through the low cumulative fuel use of 8.798 litres of diesel per hectare for seeding, cultivating, and spraying. This compares to the cumulative impact in non-GM canola varieties, which used 22% more fuel in their weed control programs, the burning of 10.696 litres of diesel per hectare. This difference is linked primarily to the number of herbicide spray applications, and to a lesser extent the lower level of cultivations. The lower level of fuel use per hectare in Roundup Ready canola, approximately 10% lower than conventional and Clearfield, indicates the benefits of an effective post-emergent spray application with low levels of cultivations as the most environmentally sustainable option.

TT canola's use of one litre more fuel per hectare, 10.904 litres, than the other non-GM varieties, 9.563 litres in Clearfield and 9.977 litres in conventional, coupled with a high EIQ_{Field} per hectare to make TT canola the most environmentally harmful canola variety in Australia. The increased level of fuel use in TT is solely connected to the number of herbicide spray applications. This seems to imply that the atrazine herbicide has lost some of its effectiveness since its 1995 introduction, requiring more applications and more herbicide to maintain the equivalent level of weed control. It also seems to indicate that farmers are not willing to give up the strong weed control system associated with HT varieties and the benefits it provides over a higher use of cultivations and tillage.

The change in fuel use between the GM and non-GM canola varieties has a significant impact on the environment as a result of the introduction of the moratoria against GM canola's cultivation, as can be seen in Table 4-8. The resulting effect from postponing the adoption of GM canola in NSW, Victoria, and Western Australia has resulted in 5.98 million additional passes over canola crop land, as compared to the scenario in which these states adopted GM canola in

2004 at the initial point of national approval. The moratoria in Scenario 1) had an opportunity cost of a 6.7% reduction in passes and an associated 4.2% decrease in fuel use, approximately 7.353 million litres of diesel.

Table 4-8 Difference in Cumulative Fuel Use Between Actual and Scenarios

	Actual GM States	**Scenario 1) GM States**	$\%(\frac{\text{Scenario}}{\text{Actual}})$	**Actual Australia**	**Scenario 2) Australia**	$\%(\frac{\text{Scenario}}{\text{Actual}})$
Number of Passes	89,384,600	83,402,959	93.31%	104,088,216	97,000,191	93.19%
Difference (Δ)	5,981,641		6.69%	7,088,025		6.81%
Fuel Used (litres)	174,024,780	166,671,700	95.77%	202,433,356	193,720,226	95.70%
Difference (Δ)	7,353,080		4.23%	8,713,130		4.30%

The cumulative effects of the SEC-based moratoria on Australia as a whole had a proportionally similar opportunity cost in passes and fuel use as the GM canola adopting states in Scenario 1), although the actual difference between the two scenarios is large. The cumulative impact of the moratoria resulted in an opportunity cost of a 6.8% decrease in passes, approximately 7.1 million, on canola hectares. The foregone passes consequently led to the burning of an addition 8.713 million litres of diesel. The opportunity cost to South Australia is in excess of 1.360 million litres of diesel over the ten years of their moratorium, approximately 0.512 litres for every canola hectare planted in that state between 2004 and 2014.

The fuel burned in the GM canola adopting states in Scenario 1) has a large impact through GHG emissions. The excess diesel burned has contributed 19,633 metric tonnes of carbon dioxide GHG emissions. There is an additional effect on GHG emissions from farm machineries' combustion of diesel fuel. The burning of diesel in farm machinery, such as tractors, produces organic and inorganic compounds that have negative environmental impacts (GRDC, 2012, 2014), the net emissions per litre of diesel are illustrated in Table 4-9. The cumulative effects from the incomplete burning of diesel in farm machinery released an additional 774 metric tonnes of GHG emissions and compounds. The opportunity cost from the delayed change in tillage and spraying operations in GM canola has resulted in NSW, Victoria, and Western Australia emitting 20,406 tonnes of GHG emissions and compounds between 2004 and 2014 due to the imposition of their SEC-based moratoria.

Table 4-9 Greenhouse Gas and Compound Emissions

	Substance	Emissions Factor		Environmental Emissions	
		Kg/KWh	Kg/litre Diesel	Scenario 1) (mt)	Scenario 2) (mt)
Greenhouse Gas Emissions	Carbon Dioxide	0.809090909	2.67	19,632.72	23,264.06
Greenhouse Compounds Emissions	Carbon Monoxide	0.0098	0.03234	237.80	281.78
	Formaldehyde (methyl aldehyde)	0.00038	0.001254	9.22	10.93
	Oxides of Nitrogen	0.016	0.0528	388.24	460.05
	Particulate Matter: 2.5um	0.0016	0.00528	38.82	46.01
	Particulate Matter: 10.0um	0.0017	0.00561	41.25	48.88
	Polycyclic aromatic hydrocarbons	0.00000094	0.000003102	0.02	0.03
	Sulfur dioxide	0.0000073	0.00002409	0.18	0.21
	Volatile Organic Compounds	0.0024	0.00792	58.24	69.01
	Total Compound Emissions			773.77	916.89
Total Emissions				20,406.49	24,180.95

Adopted from Brookes and Barfoot, 2014; GRDC, 2012, 2014

The diesel fuel burned in machinery is significant, however, the effect it has on the environment in the form of GHG emissions is the end cost we will use to evaluate the opportunity cost of adopting the SEC into federal policy on GM canola. The carbon dioxide emissions from the superfluous burning of diesel fuel was 23,264 metric tonnes in Australia. This level of carbon dioxide emissions is equivalent to nearly 5,000 cars being taken off the road in the US for one year (United States Environmental Protection Agency, 2014). The machinery emissions of GHG compounds from the burning of diesel fuel resulted in an additional 917 metric tonnes released due to the moratoria on GM canola. The opportunity cost of delay from the SEC-based moratoria imposed in Australia has resulted in an additional 24,181 metric tonnes of pollutants released into the atmosphere. An environmental cost of such magnitude offers a contrast to the worries of GM crops' probable effects to biodiversity with the strong effects of anthropogenic climate change on biodiversity (Thomas et al., 2004).

4.3 Economic Impact

4.3.1 Variable Cost of Weed Control

The first aspect of the economic opportunity cost begins with the same measure as the environmental impact, the weed management system. The variable cost of the weed control program will be evaluated as the sum of the variable costs of cultivations, herbicide spray applications, herbicides used, and the Technology Access Fee imposed on GM canola seeds. Table 4-10 illustrates these component costs and offers a cumulative cost for the different varietal weed control programs.

Table 4-10 Australian Variable Costs of Weed Control (AU$ ha^{-1})

	Conventional	**TT**	**Clearfield**	**RR (GM)**	**Non-GM***	**Canada GM** (CA$ ha^{-1})**
Cultivation***	$1.47	$0.49	$1.09	$0.61	$0.83	-
Sprays***	$7.17	$9.73	$6.84	$5.96	$9.04	-
Herbicide****	$47.21	$55.85	$61.59	$30.88	$55.06	-
Cost of Weed Control	$55.86	$66.07	$69.51	$37.44	$64.94	$30.93
TAF	-	-	-	$27.28	-	$37.07
Variable Cost of Weed Control Program	$55.86	$66.07	$69.51	$64.72	$64.94	$67.99

* The non-GM variable is a weighted average of the conventional, TT and Clearfield varieties.
** Canada's variable cost of weed control is from the Roundup Ready canola variety in the 2006 survey data and includes the cost per hectare of labor, equipment, and fuel. The Technology Use Agreement (TUA) fee used is $15/acre (Phillips, 2003).
*** Variable machinery costs use prices from GRDC (2012, 2014) developed from the NSW Department of Primary Industry's guide on calculating machinery costs (2009, 2012). See Appendix A, Table A-14 for further information
**** Herbicide costs are collated from the Birchip Cropping Group as used in GRDC (2012, 2014). Missing herbicide costs were found using the Herbiguide (2016)

The variable cost of cultivations is based on the findings reported in Table 4-7 in which the number of cultivations per hectare was greatest in conventional and Clearfield canola. The per hectare cost of cultivations in these varieties is 240% and 179% greater than GM canola respectively. TT canola has the lowest cost of cultivation at a level 20% lower than GM canola. The use of cultivations as a weed management tool has a low cost per hectare due to its minimal use. The cumulative non-GM cost of cultivation is AU$0.83 per hectare while the cost of cultivations per hectare in GM canola is AU$0.61. The net impact of cultivations is negligible compared to the costs of herbicide, which is the dominant form of weed control. A breakdown of the cost per pass per hectare can be found in Appendix A, Table A-14.

The application of herbicide is broken up into two categories, the spraying application costs and the cost of the herbicide applied. The first aspect, the spraying application, uses the number of spraying passes per hectare multiplied by the variable cost of the tractor and spraying implement. The heavy reliance on herbicide, with multiple applications, causes TT canola to have the largest spraying cost at AU$9.73 per hectare. In contrast, the other main HT canola, Roundup Ready, has the lowest per hectare spray application cost of only AU$5.96. The difference is likely a by-product of the effectiveness of glyphosate as a post-emergent spray application, where GM canola requires less herbicide through an associated lower number of applications.

The cost of herbicides consists of the summation of relative herbicide use rates and the cost per litre of the herbicide. The cost of the herbicides is the largest component of the variable cost of a weed control program. The cost of herbicide is highest in Clearfield canola, due largely to its use of Intervix, a herbicide to which Clearfield is tolerant, and the combination of herbicides used in pre-seeding knockdown. Conventional canola has a low herbicide cost leading to the conclusion that the relatively higher use of cultivations is delivering effective weed control.

Roundup Ready canola has a substantially lower cost herbicide program compared to the other canola varieties. The effectiveness of glyphosate combined with its relatively low cost, owing to a low level of markup for Roundup and the presence of generic alternatives as Monsanto's patent on glyphosate expired in 2000 (Brookes and Barfoot, 2012), are the largest factors in this decrease. The AU$30.88 in GM canola's herbicide costs are largely made up of knockdown and post-emergent applications, AU$12.36 for knockdown herbicides and AU$11.45 for post-emergent glyphosate. The near elimination of pre-emergent and other types of post-emergent herbicides is one of the methods by which GMHT canola reduces input costs. For a complete breakdown of the herbicide costs in Australia by variety and herbicide see Appendix A, Table A-15.

The cumulative variable costs of weed control shows that there is a marked decrease in the average variable cost of GM canola over the non-GM canola varieties. At AU$37.44 Roundup Ready canola is AU$18.42 cheaper than the next lowest cost program used in conventional canola, and AU$32.07 cheaper than the highest cost program of Clearfield canola. This low level of weed control input costs is the method for which the company that conducts the R&D and patents the trait, in this case Monsanto Australia, tries to recoup its investment through its TAF. Reasons for non-adoption may be due to lack of knowledge and fear of the new variety.

The TAF in Australia, as broken down in Table 4-11, was initially based on a Planting Seed Fee and an EPR. The Planting Seed Fee is imposed at the point of purchase of GM seeds at an initial rate AU$3.00 per kg of seed. The associated cost per hectare was AU$10.50 in NSW and Victoria, in which seed is planted at 3.5 kg per hectare, and AU$7.50 in Western Australia, where 2.5kg of seed is used per hectare. The TAF was simplified into a single Planting Seed Fee in 2012 at a rate of AU$6.00 per kg with increases up to AU$7.20 by 2014 (Monsanto, 2014).

Table 4-11 Roundup Ready Canola Technology Access Fee (AU$ ha^{-1})

		2008	**2009**	**2010**	**2011**	**2012**
Planting Seed Fee	**Rate**	$3.00/kg	$3.00/kg	$3.00/kg	$3.00/kg	$6.00/kg
	NSW & Victoria (@3.5kg/ha)	$10.50	$10.50	$10.50	-	-
	WA (@2.5kg/ha)	-	-	$7.50	$7.50	$15.00
End Point Royalty	**Rate**	$12.60/t	$13.50/t	$13.20/t	$13.20/t	-
	NSW & Victoria (@yield/ha)	$12.42 (0.986t/ha)	$22.23 (1.647t/ha)	$26.99 (2.045t/ha)	-	-
	WA (@yield/ha)	-	-	$12.21 (0.925t/ha)	$19.62 (1.486t/ha)	- (1.278t/ha)
TAF	NSW & Victoria	$22.92	$32.73	$37.49	-	-
	WA	-	-	$19.71	$27.12	$15.00
	Average Australia			$27.28		
	Canada TUA (CA$)*			$37.07		

* As found in Phillips (2003)

Adopted from GRDC, 2012, 2014

The variable cost of weed control programs between GM and the non-GM canola varieties become largely similar with the inclusion of the TAF. The per hectare cost of AU$64.72 for GM canola is only marginally lower than that of the two most prevalent canola types of TT and

Clearfield, at AU$66.07 and AU$69.51 respectively. The difference in the variable cost of the weed control programs between GM canola and the non-GM canola variable is a mere AU$0.22 per hectare. This seems to indicate that the TAF was initially set too high in Australia as it absorbed nearly all of producer input cost benefits. With few observable benefits in the variable cost of the weed control program, a big incentive to adopt the GM innovation was eliminated.

The Canadian variable cost of the Roundup Ready GM canola weed control program[25] shows a broadly similar variable cost to that observed in Australia. While the costs cannot be directly compared due to the different currencies and regional differences like yield per hectare, there can still be some relative comparisons made. Firstly, the currency exchange rates between Australia and Canada are largely similar, fluctuating AU$0.05 above and below the Canadian dollar between 2004 and 2014 (Australian Taxation Office, n.d.), and hence, can be interpreted as relatively equal. The regional differences in yields and effectiveness of herbicides could be a reason for the higher TAF in Canada, in which the TAF is AU/CA$10 greater than Australia yet the associated decrease in cost of weed control is only AU/CA$7 lower than Australia.

In Australia as in Canada, the technology licensing fee was initially set very high and captured all of the producer benefits from adopting the new GM technology until the early 2000s (Brewin and Malla, 2012). This seems to indicate that some other force was incentivizing the rapid adoption of GM canola varieties in Canada that was not strictly profit oriented. A possible cause for the adoption of GM canola through a non-direct pecuniary incentive may be the ease of farm operations, easier weed control, time savings, or an increase in off-farm income (Fernandez-Cornejo, Hendricks, and Mishra, 2005; Mauro and McLachlan, 2008). These incentives may not have been as strong in Australia due to the presence of multiple HT canola varieties available with many of those incentives already realized.

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[25] The Canadian program only uses the Roundup Ready variety for comparison and does not include Liberty Link. This is done for a comparison of similar varietal traits with a comparable yield and cost structure. The Canadian survey data found Liberty Link to have a variable weed control program cost of CA$59.88. The Liberty Link variety did not include a TUA at this point in 2006 but had one included by 2011 (Brewin and Malla, 2012). This has been taken into account and resulted in limiting the comparison to Roundup Ready canola opposed to an aggregate of the Canadian GM canola experience into a single variable.

4.3.2 Yield Effects

In evaluating the economic benefits, it is helpful to look at the costs associated with weed control, but perhaps a better indicator is the productive output. The evaluation of benefits from yield output tends to be more advantageous than reducing variable cost. Profit functions and profitability are usually best conducted on output maximization unless there is a limited quota capacity resulting in a ceiling on output, in which case profit maximization is done through cost minimization to meet that capacity (Debertin, 2012). Canola producers do not meet this criterion as a producer's profits from a canola variety are largely a result of its yield capacity. Without yield restrictions and output constraints in canola, cost minimization will be secondary to output and therefore revenue maximization is best done by evaluating yield increases.

The comparative yield effects from the survey data, as observed in Table 4-12, is similar to the ABARES (2015) national statistics of canola yields across states and years. There is a noticeable increase in NSW and Victoria yields in this analysis compared to the government statistics. These increased levels of respondents' yields are not present in Western Australia, in which there is a minuscule difference between the survey and ABARES statistics. The Australian average between 2004 and 2014, the period with which the average is assumed to be representative of, is marginally lower than the non-GM canola variable calculated, which comprises the majority share of canola hectares in our survey. A part of the reason for this may be due to the severe drought year of 2006 in which the Australian national average output was 0.5 metric tonnes per hectare compared to the simple average yield of 1.14 metric tonnes per hectare between 1999/2000 and 2013/14. The overall similarity in yield statistics between the survey results and the ABARES data indicates that the yield findings in this analysis will be representative of the actual Australian experience.

The experience in NSW and Victoria between 2008 and 2010 saw a large increase in all varietal yields, with output doubling per hectare over that period. The drastic difference in yields can be attributed to poor weather conditions. In 2008, widespread frosts across NSW and Victoria resulted in a large amount of damage to crops, while 2009 saw a heat wave and drought for much of the season in many areas. In 2010, however, growing conditions were very favourable and resulted in the highest production over the previous six year period (*AOF Crop Report 2003-2015, n.d.*).

Table 4-12 Average Varietal Yield by State and Nationally (mt ha^{-1}) / Range (Min, Max)

		Conventional	**TT**	**Clearfield**	**RR (GM)**	**Non-GM***	**Canola Yield****
NSW and Victoria	2008	0.856 (0.08, 3.00)	0.942 (0.01, 3.75)	0.949 (0.10, 2.70)	0.986 (0.10, 2.80)	0.933	0.79
	2009	1.592 (0.00, 4.08)	1.091 (0.00, 4.94)	1.440 (0.10, 3.00)	1.647 (0.00, 3.10)	1.279	1.16
	2010	2.132 (0.30, 4.94)	1.988 (0.10, 4.94)	2.139 (0.30, 4.45)	2.045 (0.20, 4.94)	2.065	1.6
	Average	1.731	1.397	1.710	1.753	1.543	1.23
Western Australia	2010	1.466 (0.20, 2.00)	0.715 (0.03, 2.40)	1.088 (0.08, 2.00)	0.925 (0.02, 2.20)	0.762	0.7
	2011	1.412 (0.40, 2.10)	1.366 (0.08, 2.50)	1.587 (0.80, 2.85)	1.486 (0.13, 2.55)	1.385	1.3
	2012	1.092 (0.02, 2.20)	0.993 (0.06, 2.65)	1.304 (0.10, 2.30)	1.278 (0.30, 2.60)	1.018	1.0
	Average	1.263	1.012	1.325	1.297	1.046	0.99
Australia	Average	1.497	1.204	1.518	1.525	1.295	1.23
Canada***	Average	1.57 - 2.4		1.72	1.9 - 2.2		

* The non-GM variable is a weighted average of the conventional, TT and Clearfield varieties.
** The canola yield is cumulative of all varieties and an average of the production over hectares planted. The Australian national yield statistic is an average of production over all hectares between 2004 and 2014 (ABARES, 2015)
*** The Canadian yield data is the range in the 1999 and 2011 crop years (Brewin and Malla, 2012; Phillips, 2003).

Throughout the survey in NSW and Victoria, respondents declared good yields on Roundup Ready GM canola, with the highest yield across varieties in 2008 and 2009. In 2010 the yield was lower than the high yielding conventional and Clearfield canola varieties, which produced nearly 100 kg more per hectare than the GM canola. TT canola had the lowest observed yields in 2009 and 2010, as a 10-30% yield reduction is a common trait of the variety (Hudson and Richards, 2014; State of Victoria, 2007). The initial years of the survey had a large impact on TT canola resulting in the low average of 1.397 metric tonnes per hectare compared to the other varieties range of 1.710 to 1.753 metric tonnes per hectare.

Western Australia's survey respondents reported a similar experience with adverse weather conditions during the first year of the survey, in which drought conditions reduced yields in many areas of the state (*AOF Crop Report 2003-2015, n.d.*; Mccauley and Davies, 2012). The canola yields are lower and more stable in Western Australia than in NSW and Victoria during the years of the survey. The maximum yields observed are less than 3 metric tonnes per hectare across all varieties and years. The low maximum yields couple with substantial yield effects between the drought year of 2010 to the favourable 2011 years, with an associated decreased yield of 0.054 metric tonnes per hectare in conventional canola and an increased yield of 0.651 metric tonnes per hectare in TT canola.

Similar to NSW and Victoria, TT canola in Western Australia consistently had the lowest yield, the inverse of what could be expected given its large market share. That being said, the survey's TT canola yields closely align to the non-GM and ABARES statistics, once again TT canola's relative market share necessitates such an effect. Roundup Ready yields were larger than the average yields of non-GM and ABARES statistics, but tracked Clearfield canola at approximately 0.1 metric tonnes per hectare lower output. The wide variance in conventional canola and which does not follow any apparent pattern may be due to the small number of survey participants in Western Australia that grow conventional canola, associated with its low market share in the state. This low level of data points allows a single large producer to have a disproportionately large influence on the average.

The Australian average from the survey shows a relatively similar yield between conventional, Clearfield, and Roundup Ready Canola. The approximate 25% yield advantage these varieties have over TT canola in the survey follows the expected yield advantage, with up to a 32% yield increase compared to mid-season TT varieties (Ministerial GMO Industry Reference Group, 2009), that is an accepted cost for the advantages TT canola offers in weed control. The impact of the lower yielding TT variety on the non-GM statistic and both of their similarities to the ABARES canola yield suggests that, in part due to its large market share, TT canola strongly influences the national average.

The Australian experience has a noticeably lower collective yield than the Canadian experience, which has been relatively constant in the 1.5 to 2 metric tonnes per hectare range (Brewin and Malla, 2012; Mayer and Furtan, 1999; Phillips, 2003). The advantages of adopting GM canola in Canada earlier may have affected production through an initial yield lag that occurred prior to 1999 with yield increases thereafter (Phillips, 2003). The Australian survey, however, is based on those first three years of GM canola adoption in which the yield lag for new varieties occurs, causing a lower net effect on which the forecasts and interpretations in this analysis are based. The yield lag in non-GM varieties may have been exacerbated due to the investment in GM varietal build-up prior to 2004, which came at the expense of decreased investment in non-GM varieties[26]. The low level of non-GM R&D investment resulted in a lower availability of non-GM canola varieties due to the time lag and development buildup pushing down yields in canola during the initial years after the institution of the GM canola moratoria.

This time lag on variety buildup similarly affected GM canola in 2008 and 2010 as the review and removal of the moratoria was a relatively quick process in which GM canola breeding programs were caught off guard and struggled to fill the newly opened market (Pike, 2005; Victorian Government, 2007). A further reason for the yield disparity between Canada and Australia may be attributed to the regional differences in weather, soil, and farm management that affect output (Fulton and Keyowski, 1999). Regardless of actual yields between countries, the relative yields between varieties are similar across the two jurisdictions.

Table 4-13 Difference in Cumulative Yield Between Actual and Scenarios (mt)

	Actual GM States	**Scenario 1) GM States**	$\%(\frac{\text{Scenario}}{\text{Actual}})$	**Actual Australia**	**Scenario 2) Australia**	$\%(\frac{\text{Scenario}}{\text{Actual}})$
Total Yield	21,628,776	22,520,793	104.12%	25,067,755	26,124,763	104.22%
Difference (Δ)	(892,017)		(4.12%)	(1,057,007)		(4.22%)

The Australian average indicates a yield benefit in adopting GM canola over the non-GM canola basket, which is a finding similar to Canada where better weed control and hybrid seeds had a positive effect on output (Brewin and Malla, 2012; Phillips, 2003). The moratoria on GM canola had a sizable effect on foregone output in the GM canola adopting states of NSW, Victoria, and Western Australia. Over the 2004 to 2014 period these states had an opportunity cost in yield of 892,017 metric tonnes of canola. The resulting yield opportunity cost of delay to the GM canola adopting states is a 4.12% loss in output from the institution of the moratoria on GM canola cultivation.

The Australian yield effects on total production are slightly higher than the GM canola adopting state's due to the inclusion of South Australia, and their foregone canola output of 164,990 metric tonnes. The cumulative yield impact to Australia is an opportunity cost of 1.06

[26] David Hudson, Pers. Comm., Aug.10, 2015

million metric tonnes of forgone canola output between 2004 and 2014. This foregone output would not likely have impacted world canola prices due to its spread over a ten year period in a world export market of 5.1 to 15.0 million metric tonnes annually, and to Canada's role as the dominant producer setting the benchmark price (ABARES, 2006, 2015). A further assumption for the minimal expected effects for price stem from the EU's growing demand for rapeseed in biofuel, which has seen large increases in world production coupled with increasing world prices (Foster and French, 2007).

The yield impact of the moratoria in Australia has resulted in a not insignificant level of foregone canola output. The opportunity cost for revenue is approximately AU$551 million, using a simple average of the world canola price for the 2004 to 2014 period, AU$521.59 per metric tonne (ABARES, 2015; Australian Taxation Office, n.d.). The estimated cost of delay from the SEC-based moratoria has a sizable price tag paid for by decreased potential incomes for producers.

4.3.3 Gross Margins

Following upon the variable costs of weed control programs and yield impacts, evaluating producers' margins provides the conclusion of this research on the economic opportunity costs of delay arising from the SEC-based moratoria. The calculated gross margin questions in the Australian surveys had a low response rate for individuals that had conducted a per hectare calculation. These respondents accounted for 12.2% to 15.4% of annual canola hectares in NSW and Victoria and 2.2% to 16.4% of annual canola hectares in Western Australia, across all varieties. The comparative margins are used to gain a better sense of farmers margins without requiring exact calculations, thereby increasing the amount of responses and comparison between varieties. The comparative margin, of course, is just for GM canola adopters comparing GM canola margins to their experiences with non-GM canola varieties. The marginal impacts will finish with a calculation of the contribution margin, revenue minus variable costs, which is the margin that covers fixed costs and is used to derive profits. In these state and Australian averages, it is best to keep in mind that the survey results for GM canola are primarily based off of a high TAF that was later decreased by approximately AU$5 to AU$15 per hectare.

Table 4-14 Australian Canola Varieties' Gross Margins (AU$ ha^{-1}) / Range (Min, Max)

		Conventional	TT	Clearfield	RR (GM)	Non-GM*
NSW and Victoria	2009	$402.07 (-240, 1000)	$241.57 (-266, 900)	$302.15 (-186, 1000)	$366.18 (-250, 1100)	$286.67
	2010	$941.35 (400, 1300)	$719.23 (-400, 1500)	$773.65 (-150, 2000)	$632.50 (-75, 1250)	$785.20
	Average	$798.10	$540.29	$580.29	$528.02	$602.77
Western Australia	2010	-	$116.91 (-350, 887)	$486.92 (-245, 887)	$313.75 (-245, 710)	$144.57
	2011**	-	$397.94 (-100, 1600)	$616.91 (1.10, 1650)	$104.31 (0, 800)	$411.49
	2012	$0 (0, 0)	$254.77 (-98, 1200)	$426.18 (0, 1400)	$529.32 (-105, 1600)	$255.81
	Average	$0.00	$265.27	$519.08	$269.00	$276.64
Australia	Average	$399.05	$402.78	$549.68	$398.51	$439.71
Canada*** (CA$ ha^{-1})	Average	$598 - $725	-	$756	$556 - $858	-

* The non-GM variable is a weighted average of the conventional, TT and Clearfield varieties.
** The 2011 year in Western Australia for GM is dominated by a single farmer who had a near zero yield, and whose canola hectares represented 70% of the total GM hectares of respondents who volunteered information on their gross margins.
*** Lower prices are for 1999 and higher prices are for 2011 (Brewin and Malla, 2012; Phillips, 2003).

The outcome in Table 4-14 contains a large range of results with average gross margins that are heavily distorted by a single large producer. Western Australia's 2011 GM canola gross margin is such an example, in which a single producer declaring an AU$0 per hectare margin on 4,000 hectares comprised 70.2% of the GM hectares with gross margin information that year and 35% of all GM canola hectares in Western Australia that had gross margin information. The weighted average in 2011 is far lower than the simple average of AU$390.29 and the next lowest gross margin of AU$182 per hectare. Conventional canola's lack of response in Western Australia had a similarly large distortion in which a single respondents gross margin of AU$0 in 2012 has the same weight on the Australian conventional canola average as the cumulative of all conventional canola respondents in NSW and Victoria. The use of the weighted gross margin table still offers insight into the economic impacts of the different canola varieties in generalized terms, if we ignore abnormal results that appear to be relative outliers.

Western Australia experienced a wide range of zero and negative gross margins in TT canola, with 40% of respondents' hectares in 2010 and 25% of respondents' hectares in 2012. The prevalence of these negative and zero margins in TT canola strongly affected the non-GM variable, but are in accordance with the adverse weather conditions in those years (*AOF Crop Report 2003-2015, n.d.*). No other variety experienced such a high percentage of negative and zero margins except GM canola in 2010. In 2010 one GM canola producer's AU$0 gross margin accounted for 70% of reported hectares, with further effects on the state average due to the producer's relative share of 35% of all GM hectares reporting gross margins between 2010 and 2012. The Western Australian average finds TT, GM, and the cumulative variable of non-GM canola at similar levels between AU$265 and AU$$277. The relative proportion of gross margins among these variables is consistent with the relative proportions in NSW and Victoria, although for that same reason the actual gross margins are likely closer to Clearfield's AU$519 margin if outlier years were excluded.

The Australian average finds the gross margins of conventional, TT, and GM canola to be within AU$5 of each other, AU$398.51 for GM and AU$402.78 for TT. The presence of outlier distorting survey data in these variables seems to have resulted in the improbable outcome that their margins are in fact quite similar in general. The consistency in Clearfield as a top grossing variety, with no obvious anomalies in the data points, resulted in the gross margin being significantly higher than the other canola varieties at AU$549.68 per hectare. Coupled with the high gross margins in NSW and Victoria the cumulative non-GM canola variable maintained a gross margin advantage of AU$41.20 over GM canola.

Table 4-15 evaluates the comparative margins of GM canola growers' experiences with GM compared to the non-GM varieties. The results are slightly different than those of Table 4-14 as the respondents are limited to those growing GM canola. This evaluation is a relative frequency of responses and does not weight the results by their respective number of canola hectares.

Table 4-15 Australian Canola Varieties' Comparative Margins

	Year	Response	Conventional	TT	Clearfield	Non-GM*
NSW and Victoria	2009**	Better	-	-	-	42.57%
		Same	-	-	-	28.71%
		Worse	-	-	-	28.71%
	2010	Better	8.00%	25.58%	16.67%	18.27%
		Same	40.00%	32.56%	41.67%	37.50%
		Worse	52.00%	41.86%	41.67%	44.23%
	Average	Better	-	-	-	30.24%
		Same	-	-	-	33.17%
		Worse	-	-	-	36.59%
Western Australia	2010	Better	50.00%	37.50%	42.86%	39.19%
		Same	0.00%	39.29%	42.86%	37.84%
		Worse	50.00%	23.21%	14.29%	22.97%
	2011	Better	50.00%	46.43%	47.62%	46.84%
		Same	50.00%	16.07%	33.33%	21.52%
		Worse	0.00%	37.50%	19.05%	31.65%
	2012	Better	0.00%	45.71%	35.71%	42.53%
		Same	66.67%	32.86%	42.86%	35.63%
		Worse	33.33%	21.43%	21.43%	21.84%
	Average	Better	33.33%	43.41%	42.86%	42.92%
		Same	33.33%	29.67%	38.78%	31.67%
		Worse	33.33%	26.92%	18.37%	25.42%
Australia	Average	Better	-	-	-	36.58%
		Same	-	-	-	32.42%
		Worse	-	-	-	31.00%

* The non-GM variable is a weighted average of the conventional, TT and Clearfield varieties.
** The year 2009 in NSW and Victoria did not delineate the comparison along varieties, but rather was grouped as non-GM varieties compared to GM. The Australian varietal experience was omitted as the NSW and Victoria data contained only the 2010 year for comparison that strongly contrasts the cumulative non-GM experience of 2009.

The comparative margins of NSW and Victoria indicate that 42.6% of respondents in 2009 declared better margins in GM than non-GM canola. This result is analogous to the gross margin results for that year in Table 4-14. Further, the 2010 comparison, where only eight percent of conventional growers and 18.3% of the cumulative non-GM variable respondents report better margins in GM canola, strongly parallels the results on gross margins in which the non-GM varieties have substantially higher margins than GM canola. The resulting impact of experiences with GM canola in NSW and Victoria found a fairly even split among respondents' comparison, with a slightly larger proportion of respondents, 36.6%, indicating that they faced lower gross margins producing GM canola compared to non-GM canola.

Western Australia tells a different story in which producers have experienced benefits growing GM canola. The low response rate in conventional canola had four respondents the first year, two respondents the second year, and three in 2012, with a perfect split of observed benefits between the 'Better', 'Same', and 'Worse' categories. The comparison of GM to TT and Clearfield canola varieties indicates benefits from growing GM canola, with 35.7 % to 47.6% of respondents achieving better margins. The counter side of canola producers indicating worse margin was in the 14.3% to 23.2% range, except for TT canola in 2011 which reported a rate of 37.5% of respondents indicating worse margins using GM canola. Clearfield's higher number of respondents indicating better margins for GM than TT canola seems to indicate the bias in the gross margins results, as the gross margin was AU$175 greater in Clearfield and AU$197 less in TT than the average in GM canola. The reported 'Better' margins in 2011 further indicate such a bias as there was 46.4% and 47.6% of respondents indicating better margins in GM, despite the tabulated gross margins of AU$398 and AU$617 in TT and Clearfield respectively compared to the AU$104 reported in Roundup Ready GM canola.

The average experience in Western Australia shows an increase in comparative margins between GM and non-GM canola varieties. 74.6% of GM canola producers have signalled that they have achieved better or equal margins in GM canola as compared to the non-GM varieties. The 25.4% of respondents indicating worse margins when using GM are largely from TT canola, which had 26.9% of respondents declare worse margins. The low level of respondents declaring worse margins in GM compared to Clearfield, 18.4%, is surprising due to the higher volunteered gross margins in Clearfield compared to Roundup Ready canola. One interpretation is that the high margin conventional producers are not adopting new varieties but are continuing with the proven profitable crops that they are familiar with. Whereas the Clearfield producers that are using multiple systems may find the weed control system to be more effective in GM canola, with more pronounced effects in areas with difficult weed problems.

The Australian comparative average of GM canola to non-GM canola has a fairly even split, with a slightly larger percentage observing better margins in GM canola, 36.6%. The number of producers reporting similar margins between non-GM and GM canola is 32.4%. That only 31% of farmers indicate worse margins seems to run counter to the observation in volunteered gross margins, in which GM canola has a marginally lower gross margins. Although this, of course, does not include a comparison of how much better or worse those margins are for each producer, the distribution of comparative margins between GM and non-GM canola seems to negate each other implying that economic benefits are neutral in the short-term period post-adoption of GM canola, a similar observation to that in Table 4-14.

The contribution margin established in Table 4-16 is the estimated amount of revenue minus the variable costs used to cover the fixed costs and derive producer profits. In the contribution margin, it is assumed that there is not a price premium for non-GM canola (Foster and French, 2007), so this analysis uses a constant average price of AU$521.59 per metric tonne of canola between 2004 and 2014 across all varieties and regions based off import prices and currency exchange rates to illustrate per hectare revenue (ABARES, 2015; Australian Taxation Office, n.d.). The contribution margin is greater than the gross margin in all varieties except conventional canola in NSW and Victoria indicating that this calculated margin is a reasonable representation of the actuality, as they do not include fixed costs.

Table 4-16 Australian Canola Varieties' Contribution Margins (AU$ ha^{-1})

		Conventional	**TT**	**Clearfield**	**RR (GM)**	**Non-GM***
NSW and Victoria	Revenue** (Yield mt)	$902.70 (1.731)	$728.45 (1.397)	$891.75 (1.710)	$914.57 (1.753)	$805.08 (1.543)
	Seed Cost***	$54.00	$63.00	$58.00	$63.00	$60.00
	Variable Cost of Weed Control	$47.62	$64.13	$65.07	$39.03	$61.68
	TAF	-	-	-	$33.79	-
	Segregation Cost****	-	-	-	$11.51	-
	Margin	$801.08	$601.32	$768.68	$767.24	$683.40
Western Australia	Revenue** (Yield mt)	$658.59 (1.263)	$527.96 (1.012)	$691.30 (1.325)	$676.34 (1.297)	$545.64 (1.046)
	Seed Cost***	$54.00	$63.00	$58.00	$63.00	$60.00
	Variable Cost of Weed Control	$64.09	$68.01	$73.95	$35.86	$68.19
	TAF	-	-	-	$20.77	-
	Segregation Cost****	-	-	-	$11.51	-
	Margin	$540.50	$396.95	$559.34	$545.20	$417.44
Australia	Revenue** (Yield mt)	$780.64 (1.497)	$628.20 (1.204)	$791.52 (1.518)	$795.46 (1.525)	$675.36 (1.295)
	Seed Cost***	$54.00	$63.00	$58.00	$63.00	$60.00
	Variable Cost of Weed Control	$55.86	$66.07	$69.51	$37.44	$64.94
	TAF	-	-	-	$27.28	-
	Segregation Cost****	-	-	-	$11.51	-
	Margin	$670.79	$499.13	$664.01	$656.23	$550.42

* The non-GM variable is a weighted average of the conventional, TT and Clearfield varieties.
** The revenue uses AU$521.59, a simple average of Australian import price for canola converted to AU$ using the annual foreign exchange rate for the respective year of the canola price (ABARES, 2015; Australian Taxation Office, n.d.).
*** GM seed costs use 3 kg/ha (GRDC, 2016), others varieties are from Pritchard et al. (2009).
**** The segregation costs are based on a shared GM and non-GM system pre-farm gate cost of AU$11.51 borne solely by farmers growing GM canola for on-farm segregation (Ministerial GMO Industry Reference Group, 2009).

In NSW and Victoria, conventional canola has a contribution margin of AU$2.98 higher than its gross margin, which likely stems from the extremely high 2010 year with a gross margin of AU$941.35 impacting the outcome and appears to be a distortion of the results. The similar margins between Clearfield and Roundup Ready canola are present in both contribution and gross margin calculations with Roundup having a slightly higher contribution margin and Clearfield having a higher gross margin. The non-GM variable exhibits a slightly higher result in the contribution compared to gross margin, at AU$683.40 and AU$ 602.77 respectively, yet its relative amount compared to GM canola is decidedly lower in the contribution margin. GM canola's contribution margin compared to its gross margin exhibits an AU$239.22 increase, AU$767.24 and AU$528.02 respectively.

In Western Australia the varieties of conventional, Clearfield, and Roundup Ready GM canola had similar contribution margins in the AU$540 to AU$560 range. This seems to be a more plausible result than the gross margins declared in Table 4-14, as conventional and GM canola's had large outlier years that skewed their results, while Clearfield, which did not, is similar in its contribution margin and its gross margin, with the former AU$40.26 greater than the latter. The comparison between the non-GM canola variable and GM canola results in a contribution benefit in GM of AU$127.76 compared to the non-GM basket of canola.

Australia's contribution margin indicates that the Clearfield and conventional canola varieties maintain their more profitable status compared to the Roundup Ready and Triazine Tolerant canola varieties, which aligns with the previous gross margin results. The most interesting aspect of the contribution margin analysis in Australia is that GM canola has a considerable benefit over TT canola and the non-GM canola variable, AU$157.10 and AU$105.81 respectively. This contribution margin is still based off a variable cost of weed control model that maintains a high TAF, that is approximately AU$5 to AU$10 greater than the simplified TAF that solely uses a Planting Seed Fee.

The large increase in adoption of GM canola between 2012 and 2014, when the TAF was simplified, coupled with an expected yield lag in the first years post-adoption, due to a low level of GM breeding programs and associated varieties, indicates that the contribution margin is the more plausible description of the economic benefits which were not high enough to incur an initial rapid adoption. These adjustments in yield lag and technology fees may have helped canola producers receive more of the economic benefits associated with GM canola, namely a reduction in input costs. The long-term aspects of incorporating a new agricultural innovation requires time to create a system that is specific to the region it is being adopted in, and to ensure that producer benefits are noticeable.

The difference between the cumulative of the gross margins and contribution margins across all canola hectares between 2004 and 2014, AU$2.01 billion in GM canola adopting states and AU$2.30 billion in Australia found in Table 4-18, will be used to assess an average of the cumulative constant variable costs, i.e. fertilizer and machinery maintenance. This cumulative amount divided by the associated number of canola hectares in Scenario 1) and Scenario 2) results in an approximate per hectare constant variable cost of AU$121.61 and AU$120.10 respectively. The calculated constant variable costs are approximately 50% higher than the GRDC's Gross Margin Guide (2016) amount of AU$80, which is composed of the additional cost for fertilizer AU$40 and machine maintenance AU$40. The difference seems to confirm the previous assertion that the gross margins are adversely affected by low outliers. The AU$120.10 amount will be used across all varieties in an attempt to better align and compare these two margins.

Table 4-17 illustrates the gross margins between the single variable asked of producers, and the calculated version from variables within our analysis. The use of the calculated fixed costs and contribution margins results in a balanced mix of gross margins with far less variance than those based on producer volunteered information. Conventional and GM canola see an approximate AU$145 increase in this analysis's calculated gross margins, while TT canola sees a decrease of AU$24 and Clearfield sees a decrease of AU$5 per hectare. The non-GM contribution however stays largely unchanged with an AU$9.33 decrease in the calculated gross margin compared to the producer volunteered gross margin.

Table 4-17 Australian Comparison of Gross Margin and Contribution Margin (AU$ ha^{-1})

	Conventional	**TT**	**Clearfield**	**RR (GM)**	**Non-GM***
Contribution Margin	$670.79	$499.13	$664.01	$656.23	$550.42
Contribution Margin – Constant Variable Cost (AU$120.10)	$550.82	$378.78	$544.12	$536.06	$430.38
Gross margin	$399.05	$402.78	$549.68	$398.14	$439.71

* The non-GM variable is a weighted average of the conventional, TT and Clearfield varieties.

Under the assumption that constant variable costs are homogenous across all varieties and canola hectares, the results presented in proportional percentages will offer insight into economic benefits. This interpretation of the contribution margins scenario over actual proportion will necessarily be underestimated compared to the gross margin, as the assumption of universal constant variable costs results in the same difference existing between the contribution margin through a fixed number of hectares in the theoretical and actual scenarios. The proportional effect will thus only increase if the fixed costs are eliminated in the cumulative contribution margin. For this reason, this thesis will opt to maintain a comparison of the contribution margin opposed to the contribution margin minus the constant variable costs.

The culmination of the gross and contribution margins results in vastly different impacts when compared in the two scenarios. The interpretation will be subject to reader interpretation, but for which some reasonable conclusions are suggested. The limited sample size of volunteered gross margins, in which annual data was impacted by one or two producers, is complemented by the inclusion of the comparative and contribution margins. The contribution margin's net effects, on the other hand, are used under the assumption that through the law of large number the average will gravitate to the population mean. As such, the contribution margin incorporates more calculated variables from the survey and therefore also more possibilities for error. Additionally, the contribution effects will necessarily be larger than the gross margin as they do not take into account all variable costs.

The economic benefits of gross margins in Scenario 1), Table 4-18, suggests that the GM canola adopting states of NSW, Victoria, and Western Australia received an AU$159.6 million benefit between 2004 and 2014 from the delayed adoption of GM canola due to the SEC-based moratoria. The associated impact is that producers were 2.22% better off by not adopting GM canola than if they had adopted. This number is naturally inflated as it assumes a constant set of effects from the three years post-adoption on the entire period of 2004 to 2014. This is an inaccurate as we have seen the TAF simplified with a decreased cost per hectare, indicating that the elastic nature of an imposed fee will change over time to ensure that there are producer benefits in profits from the reduction in input costs.

Table 4-18 Difference in Cumulative Economic Margins Between Actual and Scenarios

	Actual GM States	Scenario 1) GM States	$\%(\frac{\text{Scenario}}{\text{Actual}})$	Actual Australia	Scenario 2) Australia	$\%(\frac{\text{Scenario}}{\text{Actual}})$
Gross Margins	$7,199,095,047	$7,039,486,754	97.78%	$8,366,958,149	$8,177,828,181	97.74%
Difference (Δ)	$159,608,292		2.22%	$189,129,968		2.26%
Contribution Margins	$9,204,108,919	$9,613,986,871	104.45%	$10,666,024,847	$11,151,715,175	104.55%
Difference (Δ)	($409,877,952)		(4.45%)	($485,690,328)		(4.55%)

The contribution margin paints a different picture in the adoption of GM canola in NSW, Victoria, and Western Australia. The contribution margin between 2004 and 2014 shows an AU$409.9 million loss from the state moratoria on GM canola until 2008 in NSW and Victoria and 2010 in Western Australia. This sizable difference is indicative of the increased yield effects and reduction of input costs that have been observed within this analysis. The far more complete data from which the contribution costs are developed should be taken into account when comparing the impacts of these two margins.

The Australian economic impact using the producer calculated gross margins in Scenario 2), in which national adoption of GM canola takes places in 2004, indicate that there was an AU$189.1 million benefit from the institution of the SEC-based moratoria on GM canola. The opportunity cost of the moratoria was a reduction in producer benefits of 2.26% over the 2004 adoption scenario, implying a large financial cost from GM canola that has not been rectified or changed over time. The reality is that if there were not benefits there would not be adoption. The observed reductions in herbicide costs, spray applications, and cultivations signify that there are cost reducing benefits, as well as yield increases over the current non-GM basket, that would naturally lead to an evolution in the pricing scheme of the TAF to ensure producers gain a portion of these benefits and maintain a continued level of adoption. That is of course unless the environmental benefits were considered more valuable than the economic losses at which point the sustained economic loss would still be justified and considered a Pareto improvement among farmers and would be a non-pecuniary benefit inducing adoption (Hausman and Mcpherson, 1993).

The Australian economic impact of using the contribution margins in Scenario 2) finds an AU$485.7 million benefit from adopting GM canola, a monetary result that runs at over twice the inverse effect observed in the gross margin impact. This contribution margin indicates that there are large costs from the delay in the adoption GM canola arising from the SEC-based moratorium, an opportunity cost of a foregone 4.55% increase in producer margins from postponing the adoption of GM canola in NSW, Victoria, and Western Australia and the continuation of the moratorium in South Australia. This opportunity cost in contribution margin fits closer to the observed effects in Canada, in which there was a CA$70 million producer benefit associated with the adoption of GM canola over the four year period 1997 to 2000 (Phillips, 2003), using the framework that this contribution margin is based upon.

Taking into account slower adoption levels and the presence of non-GMHT canola varieties, the cumulative benefits of the contribution margin scenario seem like a better description of the reality than the producer volunteered calculations of gross margins. The Canadian similarities, the response rate, and the cohesive distribution of producer per hectare benefits in the contribution margin illustrates a more likely story on the impacts in Australia arising from the inclusion of the SEC-based moratoria.

The differences between these two margins should be interpreted as canola producers receiving a neutral economic benefit in the first years of GM Roundup Ready canola's adoption. The economic impacts of GM canola are strong enough, through a variable cost of weed control of AU$27 per hectare below the non-GM canola basket, not including TAF, and a yield advantage of 0.23 metric tonnes per hectare above the non-GM canola bundle, that the gross margins of GM canola will be larger than the non-GM canola basket in the long-term.

4.4 Summary

The net impacts of this analysis indicate that the inclusion of an SEC-based moratoria on GM canola into Australian regulatory policy has large environmental and economic opportunity costs. The Australian results in GM Roundup Ready canola have strong similarities to the Canadian experience indicating that the long-run benefits will increase with the passing of time. The counterfactual in this analysis cannot take into account the actual trade impacts that may have occurred had the SEC-based moratoria not been instituted. It does, however, indicate that, as no trade impacts have been observed since the partial lifting of the moratoria, an initial cohesive grains industry could have mitigated the need for a government mandated moratoria and begun incurring the benefits associated GM canola, opposed to the fractured industry that resulted in a delay in adoption and large environmental and economic costs.

The opportunity costs for Australia between 2004 and 2014 of the SEC-based moratoria imposed on the cultivation of GM canola are large with long term environmental and economic opportunity costs, as the effects are still being realized. The opportunity costs in Table 4-19 are the differences between the Actual and the counterfactual, with the difference (Δ) and percent difference (%Δ) calculated as the Actual minus the Scenario. These environmental opportunity costs include a foregone reduction of 6.51 million kilograms of active ingredients applied to canola land; a 14.33% increase in environmental impact to farmers, consumer, and the ecology; 7.09 million more passes of machinery; 8.71 million additional litres of diesel fuel burned; and an additional 24.18 million kilograms of GHG and compound emissions released. The economic opportunity costs of the SEC-based moratoria resulted in foregone output of 1.06 million metric tonnes of canola and an impact to canola farmers' gross margins between a possible loss of AU$189.1 million and the more likely gain of AU$485.7 million.

Table 4-19 Australian Environmental and Economic Opportunity Costs of Moratoria

Differences (Δ)	**GM States Actual - Scenario 1)**	$\%(\frac{\text{Scenario}}{\text{Actual}})$	**%Δ**	**Australia Actual - Scenario 2)**	$\%(\frac{\text{Scenario}}{\text{Actual}})$	**%Δ**
Active Ingredients (kg)	5,492,964	87.90%	12.10%	6,508,961	87.72%	12.28%
EI	133,299,878	85.87%	14.13%	157,955,463	85.67%	14.33%
Passes	5,981,641	93.31%	6.69%	7,088,025	93.19 %	6.81%
Fuel (litres)	7,353,080	95.77%	4.23%	8,713,130	95.70%	4.30%
GHG and Compound Emissions (kg)	20,406,496.31	95.77%	4.23%	24,180,949.10	95.70%	4.30%
Yield (mt)	(892,017)	104.12%	(4.12%)	(1,057,007)	104.22%	(4.22%)
Gross Margin (AU$)	$159,608,292	97.78%	2.22%	$189,129,968	97.74%	2.26%
Contribution Margin (AU$)	($409,877,952)	104.45%	(4.45%)	($485,690,328)	104.55%	(4.55%)

These cumulative impacts of the SEC-based moratoria can also be separated into a state level impact, as is done in Table 4-20. The state level impacts of the moratoria are unevenly distributed depending upon level of adoption of GM canola post-moratoria. In Western Australia the impacts of the moratorium are lower than those in NSW and Victoria due to the faster adoption and greater proportion of GM canola hectares that have been planted, thereby having already captured a larger degree of the benefits from GM canola's adoption. In the instance of South Australia however, the impacts of the moratorium are the cumulative opportunity costs that have been foregone as the moratorium on GM canola is currently still in place.

Table 4-20 State Environmental and Economic Opportunity Costs of Moratoria

Difference (Δ) (Actual-Scenario)	**NSW/VIC**	**%Δ**	**WA**	**%Δ**	**SA**	**%Δ**
Active Ingredients (kg)	2,912,729	13.32%	2,580,200	10.96%	1,015,992	13.38%
EI	70684	15.53%	62614	12.83%	24655	15.53%
Passes	3,170,603	7.69%	2,808,634	6.03%	1,105,941	7.52%
Fuel (litres)	3,898,387	4.69%	3,453,331	3.80%	1,359,800	4.79%
Yield (mt)	(473,008)	(4.61%)	(419,008)	(3.68%)	(164,991)	(4.80%)
Gross Margin (AU$)	$84,635,229	2.46%	74,972,924	1.99%	29,521,701	2.53%
Contribution Margin (AU$)	($217,345,313)	(4.98%)	($192,532,280)	(3.98%)	($75,812,441)	(5.19%)

* It should be noted that the cumulative of these state averages in Australia is slightly different than the respective Australian tables due to minor rounding errors.

This analysis finds that the inclusion of socio-economic considerations into national policy can have wide ranging and large opportunity costs. Allowing policy that delays adoption can be a costly method of reducing possible risk from new agricultural innovations. The Canadian experience in an industry-led initiative to ensure market access and mitigate trade effects, compared to the government mandated initiative in Australia, allowed for a wide range of opportunities and choice among canola growers and the grains industry. The resultant benefits in Canada include less herbicide applied per hectare applied to more hectares of land, as canola has predominantly increased its acreage displacing summer-fallow (Derpsch et al., 2010), and large economic benefits borne by producers for a longer period of time.

Chapter 5. Conclusion

5.1 Summary

This thesis developed a framework with which to measure the impact of SEC-based moratoria on GM crops. It illustrated one type of SEC that has been employed and the impact it has imparted through its inclusion into regulatory policy on a GMO. The opportunity cost of delay after scientific approval can be generalized to offer a fuller assessment of benefits and costs of the two policy options. This analysis was organized into five chapters, which will be briefly summarized in this subsection. The following subsections will discuss the limitations of this research, areas of future research, and will conclude with policy implications arising from the results.

Chapter Two establishes the science-based, evidence-informed method of regulating GM crops, with canola in particular, in Canada and Australia. It outlines the regulatory bodies and the experience that the two countries had post-approval of GM canola, in which Canada had a temporary, self-imposed system of segregation and Australia had state-government imposed SEC-based moratoria on GM canola cultivation, both of which were due to trade worries. The jurisdictional background is rounded out with the post-adoption effects of GM canola and the absence of noticeable trade impacts.

Chapter Three constructs the counterfactual, describes the Canadian and Australian data sets, and discuss the methodology of the analysis. The opportunity cost of the SEC-based moratoria in Australia are evaluated through a normalized S-curve based upon the Canadian experience in adopting GM canola using strictly science-based policy. The opportunity costs of environmental and economic impacts are evaluated using a GM canola and non-GM canola weighted basket variable in two counterfactual scenarios in which the SEC-based moratoria were not imposed, Scenario 1) the impact to GM canola adopting states and Scenario 2) the impact to Australia. The environmental impacts include the toxicological effects of the herbicides applied and the greenhouse gas emissions as a result of fuel consumption from cultivation and spray applications. The economic impact assesses variable costs, yields, and the gross margins of production.

Chapter Four illustrates the resulting opportunity costs of the moratoria for Australia and its respective canola producing states. The results section highlights the difference in environmental and economic impacts at the varietal and state level per hectare, as well as a cumulative difference in the opportunity cost of the SEC-based moratoria. The environmental impacts illustrate the decrease in the amount of active ingredients applied per hectare, environmental impact of herbicides applied, fuel use, and greenhouse gas emissions. These environmental effects are summarized to show the large environmental opportunity cost of delay, and the level of environmental damage that arises from the continued cultivation of the non-GM canola varieties that would have been partially displaced by GM canola.

The economic impacts stemming from the SEC-based moratoria are not as consistent and straight forward as the environmental impacts. In GM canola, there was a consistently high yield with a definitive decrease in the variable costs of its weed control program compared to the non-GM varieties. These impacts resulted in mixed results in the gross margins and contribution margins. The assessment of these two margins indicates a story in which the short-term economic impacts appear to be neutral, as time is required to properly set the Technology Access Fee, so producers receive some of the economic benefit of cost decreases, and overcome yield lag post-adoption. This story continues in the long-term with positive economic benefits, as the reduction in input costs and increase in yield require a Technology Access Fee that ensures producer profits and continued adoption.

The paper concludes that there are significant opportunity costs associated with the delay in adoption of GM canola. The environmental costs in the period from 2004 to 2014 resulted in over 6.5 million kilograms of herbicide active ingredients applied to canola hectares, associated with a 14% increase in environmental impact damage to consumers, farm workers, and ecology. Additionally, the foregone change in machinery usage associated with GM canola resulted in the an additional 8.7 million litres of diesel burned with greenhouse gas emissions of over 24,000 metric tonnes. The economic opportunity costs to producers include over 1 million metric tonnes in foregone canola output. The combination of foregone yield and decrease in inputs has resulted in a long-term cost of AU$485 million to canola producers.

5.2 Limitations

Based upon the survey data available, this thesis offers an initial insight into the impacts SECs can have in GMO regulation. However, there are a number of limitations in this analysis that could be addressed to expand upon the story of GM regulatory impacts. Firstly, the garnering of data sets in two similar jurisdictions provided an opportunity for a rigorous analysis. The Australian data sets, however, are limited to the first three years of GM canola adoption in the two respective Australian regions. The effect is such that yield lag and limited variety availability minimize the long-term impacts of GM canola's potential. The forecast thusly evaluates the long-term impacts using short-term effects.

A second limitation is that the counterfactual scenario cannot fully take into account adverse effects of the moratoria had it never been instituted. This is peculiar to the grain industry's worries of potential trade impacts. While we can assume that since trade was not adversely impacted post-adoption of GM canola upon removal of the SEC-based moratoria, that the same absence of effects would have been realized if the moratoria had never been imposed. This may not necessarily be true as the trade impacts may have been mitigated through the moratoria, although other jurisdictions seem to reinforce the minimal degree of adverse trade impacts.

Further, this analysis is limited in scope to a single scenario of evaluating the opportunity costs. The addition of a sensitivity analysis on the results could offer an added degree of strength to the results. The addition of real options pricing to evaluate the cost of the moratoria using the time series data to create a comparison on the ex-post, ex-ante costs may have shown when the benefits of delay would have switched from positive to negative.

A final limitation of this research pertains to its assessment of a large-scale farming crop in developed countries. In the application of this research to inform countries of potential opportunity costs from adopting SEC-based moratoria the impacts will not be directly transferrable to developing countries and small-scale farming. This is, in part, due to the nature of the genetically modified herbicide tolerant trait assessed, and partially in regard to the returns to scale. With higher input and machinery use opposed to labour intensity, the economic and environmental benefits in this analysis do not offer the same insight into the benefits that may be accrued in developing country jurisdictions or farm types.

5.4 Future Research

Building on the limitations of this research, further analysis between these two jurisdictions could be complemented by an additional Australian data set in a similar time period post-adoption of GM canola, opposed to the current post-approval period. The insights from such a data set would serve to complement the long-term economic effects calculated within this study. This would serve to minimize the effects from yield lag, that are common in the first years of adoption of a new agricultural technology, and would allow for a more defined Technology Access Fee that is appropriate for the region. This area of research would help to solidify the story around the short- and long-term economic impacts.

Beyond building upon this study, an advantageous area of research would be to conduct a study on the environmental and economic impacts in developing countries. To attain such a comparison, the country would need to have incorporated delay into policy that prevented a GMO's adoption, and would also need to have rescinded that moratorium with the eventual adoption of the GMO. While this scenario may not necessarily be available, it could possibly be conducted in two neighboring regions in which one adopted a GMO and the other did not. Such a comparison would allow for the socio-cultural and socio-economic parallels for such an analysis to conduct a similar discussion on the impacts and opportunity costs of an SEC-based moratorium, or delaying GM adoption in general.

The advantage of complementing this work with additional research on the impacts observed in developing countries will allow for stronger assessments of the opportunity cost of delay, including SEC-based moratoria. The presence of analyses on the impact of delay in developed and developing countries would offer global insight into the costs of delay compared with the benefits of post scientific approval adoption. This is especially valuable with the rise of the Cartagena Protocol on Biodiversity (CPB) and this global agreements allowance of SECs that run counter to the WTO's regulation.

5.3 Policy Implications and Conclusion

This thesis offers a set of environmental and economic opportunity costs associated with the institution of an SEC-based moratorium on a GMO. The impact of this research offers insights to national regulators incorporating policy delay- in this case an SEC- into regulation once scientific approval has been achieved. It is especially relevant to regulators contemplating the ratification of the CPB as the main take away is that not adopting a GM HT crop in favor of a continuation of current varieties has large environmental costs through higher herbicide use of more harmful herbicides and additional machinery passes resulting in the release of more greenhouse gas emissions.

The CPB is, in theory, an agreement to protect biodiversity from the potential risks of GMOs; however, it has evolved to include other aspects of risks to human health and the international movement of GMOs. This broadening of scope is justified under the CPB's Article 26 on Socio-Economic Considerations (Secretariat of the Convention on Biological Diversity, 2000), in which SECs value of biodiversity on local communities can allow for ethical issues to arise that may have nothing to do with biodiversity but rather a societal preponderance to avoid the use of GMOs. The ambiguity on how an SEC is evaluated in the international context is an aspect of the framework that has not been clarified. The particular methodologies of adopting, regulating, and assessing biotechnology and GMOs are no longer universally applicable. With the ability of consumers, producers, and industry to now have a say on regulation, there is a gap in the literature on what the opportunity costs are of allowing groups with vested interests to impact GMO policy (Ludlow, Smyth and Falck-Zepeda, 2014).

This research finds that the environmental opportunity costs of incorporating a delay into policy, in this case in the form of an SEC-based moratorium on the cultivation of GM canola[27], is substantial. The continuation of non-GM pesticide programs results in a large opportunity cost in which farm workers, consumers, and the ecological environment are negatively affected. The postponement of the adoption of GMOs impedes the reduction of pesticides and the change of machinery practices, which is shown to result in a decreased level of diesel fuel being burned with a corresponding substantial decrease in the emissions of greenhouse gases and compounds.

[27] This SEC-based moratorium in Australia on industry trade worries is not conducted on the most common type of SEC under the CPB, which largely apply to biodiversity Since the CPB is an international agreement on trade the essence of this SEC is arguably at the core of all SECs that could be applied under the CPB. With the resulting substantial environmental impacts in this analysis it may be argued that the incorporation of a delay into policy can actually cause greater harm to biodiversity, through pesticide use and GHG emissions impact on anthropogenic climate change, than strictly science-based policy.

The economic impacts are less clear in the short-term impacts of privately patented GMOs, as the necessity of recuperating R&D investments requires a technology fee that is set to obtain a portion of the input cost reductions and output benefits which are not well understood at the onset of adoption. In the long term there are economic gains from GM canola which are attained through better yields and a decrease in variable costs, as well as the non-pecuniary benefit of less time required in production which is often correlated with higher off-farm incomes. These long-term costs are substantial, with an estimation in this research of AU$485 million in the 10 years analyzed. With largely negative opportunity costs, the incorporation of SEC-based moratoria on GMOs have significant impacts to the environment and to the producers of the nation adopting these policy measures. The opportunity costs of this counterfactual exercise are based on a conservative normalized S-curve of adoption, as such they should be regarded as indicative of one hypothetical world and not as conclusive evidence of the environmental and economic impacts.

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Appendix A

Throughout the comparison of the NSW and Victoria region and the Western Australia region there is a notable decrease in the share of canola hectares dedicated to the TT canola variety. The share of hectares from TT canola is predominantly connected to the change in Roundup Ready's share. This share transfer may have to do with TT canola producers being familiar with the weed management systems of HT canola. A familiarity with HT varieties combined with possible weed resistance to the current system used, allows for an optimal transfer into the new GM system. The sizable differences in EIQ between TT canola and GM canola may further reinforce this story.

Table A-1 Australian Share of Canola Hectares by Variety (%)

		Year 1	Year 2	Year 3	Average
NSW and Victoria	Conventional	11	13	16	14
	TT	63	43	40	47
	Clearfield	19	24	28	24
	Roundup Ready (GM)	7	20	15	15
	Total	100	100	99	100
WA	Conventional*	3	5	7	5
	TT	84	74	76	78
	Clearfield	6	6	5	6
	Roundup Ready (GM)	7	15	12	12
	Total	100	100	100	101

* A number of conventional herbicide application rates used atrazine levels that were consistent with TT varieties, indicating the share of hectares dedicated to non-HT conventional canola is higher due to an ambiguity in what defines a conventional variety

A.1 EIQ

The development of the EIQ Tables in Chapter 4 followed a consistent amalgamation of data by herbicide and active ingredients. Table A-2 illustrates the herbicide amount of kilograms of active ingredient per litre multiplied by the use rate of that respective herbicide to find the amount of active ingredient applied per hectare.

$$\text{AI Applied (kg/ha)} = \text{AI (kg/litre)} \times \text{Use Rate (litre/ha)} \qquad (A.1)$$

This active ingredient applied is further summed across all herbicides to find the total varietal amount of active ingredients applied per hectare. The amount of active ingredients applied per herbicide are multiplied by the EIQ of each of those ingredients to find the environmental impact per hectare of that herbicide.

$$EI\ /ha = AI\ Applied\ (kg/ha) \times EIQ\ /kg \tag{A.2}$$

The herbicide environmental impact per hectare is further summed to find the total varietal amount of environmental impact per hectare. The tables here are simplified so that herbicides, such as Boxer Gold, with two active ingredients have been combined into a single amount. Their respective EIQ value is a summation of the active ingredient's share of kilograms per litre multiplied by its respective EIQ value. This has been done here to limit table size, the full table used for calculations is Table 3-3.

Tables A-2 and A-3 offer a full breakdown of environmental impact per hectare for NSW and Victoria. The breakdown shows the prevalent use of Glyphosate and Roundup as a pre-emergent knockdown herbicide in the non-GM varieties that is comparable to that of the GM Roundup Ready canola. The other main chemical used in all canola varieties is Trifluralin. With an EIQ_{Field} per hectare between 6.58 and 11.05, Trifluralin is an integral component of all herbicide weed management systems.

The prevalence of the TT canola varieties has a strong impact on the environment. The high application of atrazine as a pre-emergent and post-emergent herbicide has a large environmental impact due to its EIQ toxicity. The environmental impact of atrazine alone in TT canola is higher than the cumulative environmental impact of any other canola variety. These high dose rates of atrazine coupled with TT canola's approximate 50% share of canola plantings strongly influences the cumulative environmental impact of non-GM varieties.

In Roundup Ready GM canola, the environmental impact of glyphosate as a generic and branded herbicide make up 60% of the varieties environmental impact. Half of this is a result of post-emergent application, the knockdown impact in GM canola is actually lower than all of the non-GM varieties. This low knockdown rate may be a product of waiting until the two or three leaf stage to gain the most effective use of the herbicide and to reduce needless costs.

Table A-2 NSW and Victoria 2008-2010 Environmental Impact of Non-GM Herbicides

			Conventional			TT			Clearfield		
	AI (kg/l)	EIQ /kg	Use Rate (ml/ha)	AI Applied (kg/ha)	EI/ha	Use Rate (ml/ha)	AI Applied (kg/ha)	EI/ha	Use Rate (ml/ha)	AI Applied (kg/ha)	EI/ha
(a)Glyphosate	0.54	15.33	159.94	0.09	1.32	216.72	0.12	1.79	200.30	0.11	1.66
(b)Roundup	0.54	15.33	863.01	0.47	7.14	719.30	0.39	5.95	761.36	0.41	6.30
(c)Sprayseed	0.25	31.3862	25.00	0.00	0.20	33.38	0.00	0.26	21.76	0.00	0.17
(d)Trifluralin	0.48	18.83	1222.42	0.59	11.05	782.01	0.38	7.07	1021.07	0.49	9.23
(e)Dual®	0.96	12.5	25.65	0.02	0.31	3.29	0.00	0.04	18.41	0.02	0.22
(f)Select®	0.24	17	3.89	0.00	0.02	1.08	0.00	0.00	2.74	0.00	0.01
(g)Hammer®	0.24	20.18	0.37	0.00	0.00	0.64	0.00	0.00	1.29	0.00	0.01
(h)Atrazine	0.9	22.85	129.51	0.12	2.66	1079.33	0.97	22.20	10.86	0.01	0.22
(i) Simazine	0.9	21.52	64.25	0.06	1.24	360.23	0.32	6.98	0.35	0.00	0.01
(j) Edge®	0.5	19.36	3.41	0.00	0.03	3.46	0.00	0.03	28.37	0.01	0.27
(k) Logran B®	0.75	-	0.00	0.00	0.00	0.00	0.00	0.00	0.48	0.00	0.00
(l)Glean®	0.75	26.57	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00
(m) Chaser®	0.96	22	0.00	0.00	0.00	0.00	0.00	0.00	3.25	0.00	0.07
(n) Boxer Gold®	0.92	17.891	1.63	0.00	0.03	9.22	0.00	0.15	3.45	0.00	0.06
(o)Select®	0.24	17	212.58	0.05	0.87	174.87	0.04	0.71	169.87	0.04	0.69
(p)Verdict®	0.52	20.2	27.87	0.01	0.29	10.26	0.01	0.11	11.21	0.01	0.12
(q)Lontrel®	0.3	18.12	85.93	0.03	0.47	16.23	0.00	0.09	45.86	0.01	0.25
(r)Atrazine	0.9	22.85	92.38	0.08	1.90	1080.41	0.97	22.22	10.76	0.01	0.22
(s)Simazine	0.9	21.52	17.13	0.02	0.33	208.16	0.19	4.03	26.82	0.02	0.52
(t)Intervix®	0.048	20.39	8.08	0.00	0.01	5.57	0.00	0.01	273.74	0.01	0.27
(u)On Duty®	0.7	21.475	0.00	0.00	0.00	0.20	0.00	0.00	6.46	0.00	0.10
(v)Targa®	0.2	22.14	4.61	0.00	0.02	1.03	0.00	0.00	0.69	0.00	0.00
(w) Roundup Ready®	0.69	15.33	11.98	0.01	0.13	14.02	0.01	0.15	4.05	0.00	0.04
Total				1.55	28.02		3.42	71.81		1.18	20.44

Table A-3 NSW and Victoria 2008-2010 Environmental Impact of Herbicides

			Non-GM*			Roundup Ready (GM)		
	AI (kg/l)	**EIQ /kg**	**Use Rate (ml/ha)**	**AI Applied (kg/ha)**	**EI/ha**	**Use Rate (ml/ha)**	**AI Applied (kg/ha)**	**EI/ha**
(a)Glyphosate	0.54	15.33	202.67	0.11	1.68	64.50	0.03	0.53
(b)Roundup	0.54	15.33	755.01	0.41	6.25	633.80	0.34	5.25
(c)Sprayseed	0.25	31.3862	28.67	0.00	0.10	497.63	0.07	3.90
(d)Trifluralin	0.48	18.83	922.95	0.44	8.34	727.94	0.35	6.58
(e)Dual®	0.96	12.5	11.30	0.01	0.14	6.52	0.01	0.08
(f)Select®	0.24	17	2.02	0.00	0.01	0.00	0.00	0.00
(g)Hammer®	0.24	20.18	0.78	0.00	0.00	0.16	0.00	0.00
(h)Atrazine	0.9	22.85	617.23	0.56	12.69	0.00	0.00	0.00
(i) Simazine	0.9	21.52	208.53	0.19	4.04	0.67	0.00	0.01
(j) Edge®	0.5	19.36	10.58	0.01	0.10	4.68	0.00	0.05
(k) Logran B®	0.75	-	0.14	0.00	0.00	0.00	0.00	0.00
(l)Glean®	0.75	26.57	0.03	0.00	0.00	0.82	0.00	0.02
(m) Chaser®	0.96	22	0.93	0.00	0.02	0.00	0.00	0.00
(n) Boxer Gold®	0.92	17.891	6.32	0.00	0.01	0.00	0.00	0.00
(o)Select®	0.24	17	179.65	0.04	0.73	12.66	0.00	0.05
(p)Verdict®	0.52	20.2	13.43	0.01	0.14	3.21	0.00	0.03
(q)Lontrel®	0.3	18.12	36.19	0.01	0.20	2.96	0.00	0.02
(r)Atrazine	0.9	22.85	611.68	0.55	12.58	0.00	0.00	0.00
(s)Simazine	0.9	21.52	124.82	0.11	2.42	0.00	0.00	0.00
(t)Intervix®	0.048	20.39	82.69	0.00	0.05	0.00	0.00	0.00
(u)On Duty®	0.7	21.475	82.69	0.00	0.03	0.00	0.00	0.00
(v)Targa®	0.2	22.14	1.96	0.00	0.01	0.00	0.00	0.00
(w) Roundup Ready®	0.69	15.33	10.83	0.01	0.11	962.16	0.66	10.18
Total				2.47	49.90		1.53	26.70

* The non-GM variable is a weighted average of the conventional, TT and Clearfield varieties.

Table A-4 Western Australia 2010-2012 Environmental Impact of Non-GM Herbicides

			Conventional			TT			Clearfield		
	AI (kg/l)	**EIQ /kg**	**Use Rate (ml/ha)**	**A.I. Applied (kg/ha)**	**EI/ha**	**Use Rate (ml/ha)**	**A.I. Applied (kg/ha)**	**EI/ha**	**Use Rate (ml/ha)**	**A.I. Applied (kg/ha)**	**EI/ha**
(a)Glyphosate	0.54	15.33	743.03	0.40	6.15	414.94	0.22	3.43	332.05	0.18	2.75
(b)Roundup	0.54	15.33	405.60	0.22	3.36	433.76	0.23	3.59	731.50	0.40	6.06
(c)Sprayseed	0.25	31.3862	379.12	0.05	2.97	225.11	0.06	1.77	267.56	0.07	2.10
(d)Trifluralin	0.48	18.83	679.07	0.33	6.14	303.43	0.15	2.74	841.55	0.40	7.61
(e)Dual®	0.96	12.5	170.31	0.16	2.04	0.00	0.00	0.00	3.34	0.00	0.04
(f)Select®	0.24	17	44.21	0.01	0.18	7.01	0.00	0.03	27.11	0.01	0.11
(g)Hammer®	0.24	20.18	1.31	0.00	0.01	0.89	0.00	0.00	1.45	0.00	0.01
(h)Atrazine	0.9	22.85	662.19	0.60	13.62	1506.10	1.36	30.97	96.92	0.09	1.99
(i) Simazine	0.9	21.52	108.50	0.10	2.10	79.93	0.07	1.55	0.00	0.00	0.00
(j) Edge®	0.5	19.36	110.87	0.06	1.07	21.56	0.01	0.21	148.35	0.07	1.44
(k) Logran B®	0.75	-	0.00	0.00	0.00	0.58	0.00		0.13	0.00	0.00
(l)Glean®	0.75	26.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(m) Chaser®	0.96	22	0.00	0.00	0.00	0.53	0.00	0.01	0.00	0.00	0.00
(n) Boxer Gold®	0.92	17.891	0.00	0.00	0.00	7.66	0.01	0.13	2.78	0.00	0.05
(o)Select®	0.24	17	263.39	0.06	1.07	320.66	0.08	1.31	296.52	0.07	1.21
(p)Verdict®	0.52	20.2	36.26	0.02	0.38	6.02	0.00	0.06	1.99	0.00	0.02
(q)Lontrel®	0.3	18.12	62.46	0.02	0.34	8.66	0.00	0.05	62.68	0.02	0.34
(r)Atrazine	0.9	22.85	523.73	0.47	10.77	1347.61	1.21	27.71	104.45	0.09	2.15
(s)Simazine	0.9	21.52	11.35	0.01	0.22	15.38	0.01	0.30	11.58	0.01	0.22
(t)Intervix®	0.048	20.39	3.97	0.00	0.00	0.43	0.00	0.00	338.85	0.02	0.33
(u)On Duty®	0.7	21.475	0.00	0.00	0.00	0.05	0.00	0.00	1.83	0.00	0.03
(v)Targa®	0.2	22.14	74.24	0.01	0.33	27.86	0.01	0.12	15.66	0.00	0.07
(w) Roundup®	0.69	15.33	0.00	0.00	0.00	6.95	0.00	0.07	11.47	0.01	0.12
Total				1.55	50.76		3.43	74.06		1.44	26.64

Table A-5 Western Australia 2010-2012 Environmental Impact of Herbicides

			Non-GM*			Roundup Ready (GM)		
	AI (kg/l)	EIQ /kg	Use Rate (ml/ha)	A.I. Applied (kg/ha)	EI/ha	Use Rate (ml/ha)	A.I. Applied (kg/ha)	EI/ha
(a)Glyphosate	0.54	15.33	427.30	0.23	3.54	202.49	0.11	1.68
(b)Roundup	0.54	15.33	452.12	0.24	3.74	386.60	0.21	3.20
(c)Sprayseed	0.25	31.3862	236.34	0.06	1.85	469.99	0.12	3.69
(d)Trifluralin	0.48	18.83	359.86	0.17	3.25	561.72	0.27	5.08
(e)Dual®	0.96	12.5	9.51	0.01	0.11	0.00	0.00	0.00
(f)Select®	0.24	17	10.38	0.00	0.04	0.30	0.00	0.00
(g)Hammer®	0.24	20.18	0.95	0.00	0.00	0.51	0.00	0.00
(h)Atrazine	0.9	22.85	1365.94	1.23	28.09	15.83	0.01	0.33
(i) Simazine	0.9	21.52	76.15	0.07	1.47	0.00	0.00	0.00
(j) Edge®	0.5	19.36	34.90	0.02	0.34	96.13	0.05	0.93
(k) Logran B®	0.75	-	0.52	0.00	-	0.00	0.00	0.00
(l)Glean®	0.75	26.57	0.00	0.00	0.00	0.00	0.00	0.00
(m) Chaser®	0.96	22	0.46	0.00	0.01	0.00	0.00	0.00
(n) Boxer Gold®	0.92	17.891	6.92	0.01	0.11	10.39	0.01	0.17
(o)Select®	0.24	17	315.92	0.08	1.29	15.33	0.00	0.06
(p)Verdict®	0.52	20.2	7.40	0.00	0.08	0.03	0.00	0.00
(q)Lontrel®	0.3	18.12	15.20	0.00	0.08	1.77	0.00	0.01
(r)Atrazine	0.9	22.85	1219.63	1.10	25.08	14.64	0.01	0.30
(s)Simazine	0.9	21.52	14.91	0.01	0.29	0.00	0.00	0.00
(t)Intervix®	0.048	20.39	23.23	0.00	0.02	0.00	0.00	0.00
(u)On Duty®	0.7	21.475	0.17	0.00	0.00	0.00	0.00	0.00
(v)Targa®	0.2	22.14	29.58	0.01	0.13	0.17	0.00	0.00
(w) Roundup®	0.69	15.33	6.88	0.00	0.07	809.59	0.56	8.56
Total				3.25	69.62		1.35	24.01

* The non-GM variable is a weighted average of the conventional, TT and Clearfield varieties.

The case in Western Australia follows similar trends to those observed in the NSW and Victoria tables, as can be seen in Table A-4 and A-5. The notable exception of which is conventional canola. Conventional canola has a very large cumulative EIQ field rate per hectare. A look at the distribution of herbicides illustrates the high application rate of atrazine. This level of application would be lethal to an average non-TT canola variety, indicating that there was a degree of ambiguity or miscommunication on what a farmer classifies as conventional canola. The pre-emergent use rate of 660 ml and post-emergent use-rate of 525 ml is approximately half to a third of TT canola's use rate. This is assumed to translate to the proportion of survey respondents that maintained that level of ambiguity. Indicating that approximately 28 to 33 of the n=73 respondents in Western Australia were sufficiently broad in classifying TT as a conventional canola variety. The resulting impact of atrazine use had an environmental impact per hectare of 24.4 nearly half of the total EIQ field rate. The environmental impact of atrazine if subtracted from the cumulative impact would result in a cumulative EIQ field rate similar to that observed in conventional canola in NSW and Victoria.

The TT canola variety in Western Australia uses a higher application of atrazine, while showing decreased levels of the herbicide Trifluralin, as compared to TT canola in NSW and Victoria and other varieties in Western Australia. There is also a relatively lower amount of glyphosate applied compared to other non-GM varieties, which seems to indicate producers' preference for atrazine as associated with the HT technology.

The Clearfield variety offers an interesting insight from the breakdown of its herbicide programs. One aspect of which is that the majority of its environmental impact stem from glyphosate, Trifluralin, and Sprayseed. This is significant in that the herbicide Intervix, the active ingredients Imazamox and Imazapyr to which Clearfield is resistant, has a lower application rate, and environmental impact, than the other herbicides. This can follow either the story of Clearfield being selected for its high-yielding trait rather than its herbicide resistance, or that the adoption of knockdown chemicals has replaced ZTMT with better weed management effects that limit the need for post-emergent herbicide applications.

Roundup Ready canola has the lowest level of knockdown glyphosate applied, 588 ml compared to between 849 ml and 1149 ml in the non-GM varieties. The GM canola variety uses similar amounts of Sprayseed and Trifluralin as conventional and Clearfield varieties, approximately 1050 ml per hectare, which combine for just over a third of its EIQ_{Field} rate per hectare. The application of post-emergent Roundup, or glyphosate, at 809ml has an environmental impact similar to Trifluralin and Sprayseed. The result is an effective weed management system that allows GM canola to have the lowest EIQ_{Field} per hectare of all varieties in Western Australia.

A.2 Greenhouse Gas Emissions

A.2.1 Cultivations

The annual survey data for NSW and Victoria lacked a detailed section on the type of cultivation implement used in 2008 so the average fuel use per cultivation in 2009 and 2010 was used to find the fuel use in 2008, Table A-6 has blanks where the information was not complete. To find fuel use this analysis multiplied the number of hectares receiving cultivations by the fuel use per hectares from that machinery by the number of passes per hectare. This varietal fuel use from cultivations is summed and divided by the total number of canola hectares planted to that variety to find the average fuel use per hectare within a variety.

$$\text{Fuel ha}^{-1} = \frac{\Sigma(ha\ x\ machinery\ (l/ha)\ x\ \#\ passes\ )}{ha} \qquad \text{(A.3)}$$

The annual use of cultivations exhibited a gradual decrease in conventional canola, a decrease of 42% from 2008 to 2010. TT canola exhibited marginal differences between years but continually had the lowest level of cultivations per hectare through all varieties. Clearfield had a surprising increase in cultivations over the time period, going from 0.173 to 0.228 cultivations per hectare, with the average number of cultivations by producers who cultivated increasing from 1.69 to 1.9 cultivations per hectare. GM canola had a constant rate of 0.11 cultivations per hectare, with fuel use of 0.61 to 0.63 litres per hectare.

Table A-6 NSW and Victoria 2008-2010 Cultivations and Fuel Use

	2008				2009				2010			
	Conv	**TT**	**Clearfield**	**RR**	**Conv**	**TT**	**Clearfield**	**RR**	**Conv**	**TT**	**Clearfield**	**RR**
Total Passes	4,224	5,821	2,773	654	3,967	3,762	5,219	2,473	6,405	5,124	9,865	2,692
Total ha Cultivated	2,419	4,252	1,640	654	2,415	2,556	3,099	1,435	3,934	4,055	5,172	1,706
Total Fuel Used (litres)	-	-	-		23,596	20,272	30,176	13,729	34,919	26,923	53,690	15,012
Avg. Number Cultivations	1.747	1.369	1.690	1.000	1.643	1.472	1.684	1.724	1.628	1.264	1.907	1.578
Fuel per Pass (litres)	-	-	-	-	5.948	5.388	5.782	5.551	5.452	5.254	5.443	5.576
Fuel ha^{-1} Cultivated	-	-	-	-	9.772	7.930	9.737	9.570	8.876	6.639	10.381	8.799
Cultivations ha^{-1}	0.447	0.107	0.173	0.110	0.260	0.077	0.194	0.111	0.257	0.082	0.228	0.113
Fuel ha^{-1} (litres)	2.521	0.571	0.964	0.612	1.545	0.415	1.124	0.616	1.403	0.432	1.240	0.630

Western Australia lacked all detail of implement use in the survey data for 2010 to 2012, which resulted in the average number of cultivations per hectare by those cultivating and the average fuel use per hectare from the NSW and Victoria analysis being used. The Western Australian producers did indicate their use of cultivations or direct drilling with the respective number of cultivations per hectare used in association with this variable. In contrast to the NSW and Victoria producers, Western Australian producers had very low levels of cultivations with many survey participants indicating zero cultivation passes. This couples with a further oddity in that conventional and Clearfield indicated the lowest use of cultivations, while the use of cultivations in TT and GM canola was slightly higher.

The cumulative state level impact of the canola varieties over the 2008 to 2010 period are shown in Table A-7. The use of cultivations is highest in conventional and Clearfield canola, with Clearfield receiving the highest number of cultivations per hectare by producers who cultivated at 1.802. The number of hectares cultivated in Clearfield is lower than that of conventional, resulting in higher at level of cultivations per hectare on the average varietal hectare at 0.286 in conventional compared to 0.205 cultivations per hectare in Clearfield. The fuel use per hectare is approximately three times higher in conventional and Clearfield canola compared to TT. The result is 40% more cultivations per hectare in non-GM canola than that of GM canola, with cultivation fuel use of 0.848 and 0.611 litres per hectare respectively.

Table A-7 NSW and Victoria Cultivations and Fuel Use

	Conventional	**TT**	**Clearfield**	**RR (GM)**	**Non-GM***
Total Passes	14,597	14,707	17,857	5,819	47,160
Total ha Cultivated	8,768	10,864	9,912	3,795	29,543
Total Fuel Used (litres)	82,348	78,107	99,281	32,380	259,736
Avg. Number of Cultivations	1.665	1.354	1.802	1.534	1.596
Fuel per Pass (litres)	5.642	5.311	5.560	5.564	5.508
Fuel ha^{-1} Cultivated	9.392	7.190	10.017	8.533	8.792
Cultivations ha^{-1}	0.286	0.087	0.205	0.110	0.154
Fuel ha^{-1} (litres)	1.612	0.465	1.141	0.611	0.848

* The non-GM variable is a weighted average of the conventional, TT and Clearfield varieties.

Table A-8 Western Australia 2010-2012 Cultivations and Fuel Use

	2010				2011				2012			
	Conv	**TT**	**Clearfield**	**RR**	**Conv**	**TT**	**Clearfield**	**RR**	**Conv**	**TT**	**Clearfield**	**RR**
Total Passes	-	2,496	180	77	-	474	-	-	-	1,579	-	537
Total ha Cultivated	-	1,844	100	50	-	350	-	-	-	1,166	-	350
Total Fuel Used	-	13,256	1,002	427	-	2,516	-	-	-	8,383	-	2,987
Avg. Number Cultivations	-	1.354	1.802	1.534	-	1.354	-	-	-	1.354	-	1.534
Fuel per Pass	-	5.311	5.560	5.564	-	5.311	-	-	-	5.311	-	5.564
Fuel ha^{-1} Cultivated	-	7.190	10.017	8.533	-	7.190	-	-	-	7.190	-	8.533
Cultivations ha^{-1}	-	0.013	0.012	0.005	-	0.003	-	-	-	0.008	-	0.016
Fuel ha^{-1}	-	0.068	0.069	0.026	-	0.015	-	-	-	0.042	-	0.090

The cumulative state effects observed over the survey years in Western Australia, Table A-9, highlight how wide spread the adoption of ZTMT and herbicide programs are for weed management opposed to the use of cultivations. The net effects have a resulting 0 to 0.008 cultivations per hectare, and fuel use of 0 to 0.043 litres per hectare, essentially indicating that direct drilling and herbicide weed management programs have nearly full displaced cultivating as a weed management operation.

Table A-9 Western Australia Cultivations and Fuel Use

	Conventional	**TT**	**Clearfield**	**RR (GM)**	**Non-GM***
Total Passes	0	4,548	180	613	4,729
Total ha cultivated	0	3,360	100	400	3,460
Total Fuel Used	0	24,156	1,002	3,413	25,158
Number of Cultivations ha^{-1}	0	1.354	1.802	1.534	1.367
Fuel per Pass	0	5.311	5.560	5.564	5.320
Fuel ha^{-1} Cultivated	0	7.190	10.017	8.533	7.272
Cultivations ha^{-1}	0.000	0.008	0.004	0.007	0.007
Fuel ha^{-1}	0.000	0.043	0.023	0.040	0.039

* The non-GM variable is a weighted average of the conventional, TT and Clearfield varieties.

A.2.2 Spray Applications

The application of herbicides through spraying has become the dominant choice in weed control. All canola varieties in NSW and Victoria have followed a steady uptick in the number of spray applications per hectare, Table A-10. The largest increase is observed in TT canola which increased from 3.52 in 2008 to 5.24 sprays per hectare in 2010. One of the environmental benefits of glyphosate tolerant GM canola is the consistently low number of sprays, therefore also fuel use. Sprays in this analysis broadly refers to the application and soil integration of herbicides.

Table A-10 NSW and Victoria 2008-2010 Herbicide Sprays and Fuel Use

	2008				2009				2010			
	Conv	**TT**	**Clearfield**	**RR**	**Conv**	**TT**	**Clearfield**	**RR**	**Conv**	**TT**	**Clearfield**	**RR**
Total Sprays	27,038	190,629	45,848	14,522	48,493	201,601	85,780	65,309	92,810	326,816	144,355	71,941
Total Hectares	9,452	54,161	15,990	5,944	15,274	48,832	26,843	22,283	24,882	62,380	43,292	23,845
Fuel Used (1.17L/ha)	31,635	223,036	53,642	16,990	56,737	235,873	100,362	76,412	108,587	382,374	168,895	84,170
Sprays ha^{-1}	2.860	3.520	2.867	2.443	3.175	4.128	3.196	2.931	3.730	5.239	3.334	3.017
Fuel ha^{-1}	3.347	4.118	3.355	2.858	3.715	4.830	3.739	3.429	4.364	6.130	3.901	3.530

This low level of spray application fuel use can be readily observed in Table A-11, with GM canola burning only 3.35 litres of diesel per hectare compared to the cumulative per hectare rate in non-GM canola of 4.45 litres. The difference in fuel burned per hectare in spray applications is greatest between TT canola, 5.01 litres per hectare, and GM canola in which GM canola burns 1.66 litres less diesel. The lowest difference is between GM and Clearfield, in which GM canola burns 0.36 litres less diesel per hectare.

Table A-11 NSW and Victoria Herbicide Sprays and Fuel Use

	Conventional	**TT**	**Clearfield**	**RR (GM)**	**Non-GM***
Total Sprays	168,341	719,046	275,983	151,771	1,163,369
Total Hectares	51,081	168,081	87,050	53,036	306,212
Fuel Used (@1.17 l ha^{-1})	196,959	841,283	322,900	177,573	1,361,142
Sprays ha^{-1}	3.296	4.278	3.170	2.862	3.799
Fuel ha^{-1}	3.856	5.005	3.709	3.348	4.445

* The non-GM variable is a weighted average of the conventional, TT and Clearfield varieties.

Western Australia experienced heavy use of herbicide spray applications between 2010 to 2012, Table A-12, with two stand outs in particular. Conventional canola had between 3.48 and 4.63 spray applications per hectare, which matches the earlier observation in Table A-4 in which the herbicide program contained atrazine use that would kill conventional varieties indicating the presence of survey respondents classifying their TT canola as conventional. TT canola was the other standout for spray applications, with 2012 having an enormous 7.91 application per hectare. This high rate is the by-product of the majority of producers applying at least three knockdown applications of glyphosate, with similar applications of atrazine in pre- and post-emergent stages. The high level of sprays may be associated with weather conditions in Western Australia in which moisture levels at seeding were poor, preventing a strong early canola canopy that can inhibit weed growth, and exhibited below average moisture levels throughout the season (ABARES, 2012). GM canola experienced very minor variance in its number of sprays annually between 3.00 and 3.03 sprays per hectare.

Table A-12 Western Australia 2010-2012 Herbicide Sprays and Fuel Use

	2010				2011				2012			
	Conv	**TT**	**Clearfield**	**RR**	**Conv**	**TT**	**Clearfield**	**RR**	**Conv**	**TT**	**Clearfield**	**RR**
Total Sprays	32,711	797,622	61,759	49,443	37,725	627,629	36,811	105,563	62,266	1,590,156	55,360	99,553
Total hectares	7,066	193,862	14,526	16,305	10,818	172,783	14,207	35,229	17,346	201,012	14,428	33,141
Fuel Used (1.17L/ha)	38,272	933,217	72,258	57,849	44,138	734,326	43,069	123,509	72,851	1,860,483	64,771	116,477
Sprays ha^{-1}	4.629	4.114	4.252	3.032	3.487	3.632	2.591	2.996	3.590	7.911	3.837	3.004
Fuel ha^{-1}	5.416	4.814	4.974	3.548	4.080	4.250	3.032	3.506	4.200	9.256	4.489	3.515

Table A-13 Western Australia Herbicide Sprays and Fuel Use

	Conventional	**TT**	**Clearfield**	**RR (GM)**	**Non-GM***
Total Spray	132,702	3,015,407	153,930	254,560	3,302,040
Total hectares	35,230	567,657	43,161	84,676	646,049
Fuel Used (1.17L/ha)	155,262	3,528,026	180,098	297,835	3,863,386
Sprays ha^{-1}	3.767	5.312	3.566	3.006	5.111
Fuel ha^{-1}	4.407	6.215	4.173	3.517	5.980

* The non-GM variable is a weighted average of the conventional, TT and Clearfield varieties.

The Western Australian state impact over the survey years, Table A-13, illustrates a minor increase in sprays in most varieties compared to NSW and Victoria, while TT exhibits a larger increase of 1.2 sprays per hectare more. GM canola has a low, steady level of 3.01 sprays per hectare, a considerable 42% lower level compared to the combined non-GM use of 5.11 sprays per hectare in Western Australia. The cumulative non-GM group is strongly influenced by the large market share of TT canola and the considerable impact from TT canola's 2012 year.

A.3 Variable Costs

Table A-14 Variable Costs of Cultivations and Spraying Implements

	Chisel Plough	Scarifier	Cultivator	Off Set Discs	Deep Ripper or Plough	Sprayer
AU$ ha^{-1}	12.53	10.18	7.82	11.96	18.8	2.03

* The values here are developed from the NSW DPI Guide to Tractor and Implement Costs 2009 and 2011. These costs have been used by the GRDC (2012,2014) during this time period and have been chosen over the newer version due to time specificity of prices (NSW Department of Primary Industries, 2012). These are the variable costs of tractor and implement including labour and fuel.

The breakdown of herbicide costs was conducted in a similar manner to the EIQ, Table A-15. The cost per litre of the herbicide is multiplied by its use rate per hectare, found earlier.

$$\text{Herbicide Cost (AU\$/ha)} = \text{Price (AU\$/ml)} \times \text{Use Rate (ml/ha)} \qquad \text{(A.4)}$$

The price per herbicide is then summed up to find a cumulative cost per hectare. Table A-15 is intended to illustrate the relevant price level used per litre of herbicide and the calculation process. As this analysis is focused on the Australian impact of an SEC-based moratoria, the Australian table is only presented as the required data was already developed. Making the inclusion of herbicide cost tables for the respective states redundant as they were not an aspect of the calculation process.

Table A-15 Breakdown of Australian Herbicide Costs (AU\$ ha^{-1})

		Conventional		TT		Clearfield		RR (GM)		Non-GM*	
	Price (AU\$ /litre)**	**Use Rate (ml/ha)**	**Cost**	**Use Rate (ml/ha)**	**Cost**	**Use Rate (ml/ha)**	**Cost**	**Use Rate (ml/ha)**	**Cost**	**Use Rate (ml/ha)**	**Cost**
(a)Glyphosate	11.38	451.485	5.14	315.843	3.59	266.177	3.03	133.493	1.52	314.989	3.58
(b)Roundup	12.92	634.308	8.20	576.573	7.45	746.430	9.64	510.201	6.59	603.587	7.80
(c)Sprayseed	9	202.058	1.82	129.247	1.16	144.657	1.30	483.807	4.35	132.510	1.19
(d)Trifluralin	7.2	950.741	6.85	542.765	3.91	931.311	6.71	644.833	4.64	641.436	4.62
(e)Dual®	8.96	97.979	0.88	1.646	0.01	10.872	0.10	3.260	0.03	10.405	0.09
(f)Select®	23.3	24.048	0.56	4.043	0.09	14.924	0.35	0.148	0.00	6.198	0.14
(g)Hammer®	308	0.838	0.26	0.764	0.24	1.370	0.42	0.334	0.10	0.865	0.27
(h)Atrazine	10.87	395.854	4.30	1292.659	14.05	53.892	0.59	7.913	0.09	991.537	10.78
(i) Simazine	10.87	86.374	0.94	220.041	2.39	0.174	0.00	0.336	0.00	142.313	1.55
(j) Edge®	25	57.142	1.43	12.510	0.31	88.361	2.21	50.406	1.26	22.740	0.57
(k) Logran B®	7.7	0.000	0.00	0.291	0.00	0.305	0.00	0.000	0.00	0.328	0.00
(l)Glean®	47.3	0.000	0.00	0.000	0.00	0.046	0.00	0.408	0.02	0.013	0.00
(m) Chaser®	8.96	0.000	0.00	0.264	0.00	1.626	0.01	0.000	0.00	0.697	0.01
(n) Boxer Gold®	30	0.816	0.02	8.440	0.25	3.113	0.09	5.196	0.16	6.617	0.20
(o)Select®	23.3	237.989	5.55	247.775	5.77	233.194	5.43	13.998	0.33	247.794	5.77
(p)Verdict®	96.6	32.066	3.10	8.141	0.79	6.602	0.64	1.621	0.16	10.418	1.01
(q)Lontrel®	41.8	74.195	3.10	12.444	0.52	54.273	2.27	2.363	0.10	25.697	1.07
(r)Atrazine	10.87	308.055	3.35	1214.073	13.20	57.607	0.63	7.322	0.08	915.672	9.95
(s)Simazine	10.87	14.244	0.15	111.787	1.22	19.201	0.21	0.000	0.00	69.870	0.76
(t)Intervix®	75	6.024	0.45	3.000	0.22	306.297	22.97	0.000	0.00	52.962	3.97
(u)On Duty®	1125	0.000	0.00	0.125	0.14	4.146	4.66	0.000	0.00	1.062	1.20
(v)Targa®	26.61	39.426	1.05	14.449	0.38	8.171	0.22	0.171	0.00	15.551	0.41
(w)Roundup Ready®	12.92	5.992	0.08	10.488	0.14	7.760	0.10	885.878	11.45	8.855	0.11
Total			47.21		55.85		61.59		30.88		55.06

* The non-GM variable is a weighted average of the conventional, TT and Clearfield varieties.
** Herbicide costs are collated by the Birchip Cropping Group and used in GRDC Canola Impact Studies (GRDC, 2012, 2014). Some herbicides were not present in the collated list so these costs were found using the Herbiguide (Herbiguide, 2016)

The cumulative variable cost of weed control in NSW and Victoria indicates the minor level of impact the costs of cultivation and spraying contribute between varieties, Table A-16. The largest difference comes from the cost of herbicide, in which both conventional and GM canola have a cost in the mid AU$30s. The TT and Clearfield varieties cost of herbicide in the mid AU$50s is likely close to what the herbicide costs would have been in GM land before the adoption of GM canola, due to their herbicide tolerance and displacement by GM canola. The TAF on GM canola is larger than the difference in the input costs of weed control, possibly indicating that the TAF was set too high initially as it is greater than the reduction in input costs.

Table A-16 NSW and Victoria Variable Costs (AU$ ha^{-1})

	Conventional	TT	Clearfield	RR (GM)	Non-GM*
Cultivation	$2.95	$0.90	$2.13	$1.14	$1.59
Sprays	$6.69	$8.68	$6.44	$5.81	$7.71
Herbicide	$37.98	$54.55	$56.50	$32.08	$52.38
TAF	-	-	-	$33.79	-
Total	$47.62	$64.13	$65.07	$72.82	$61.68

* The non-GM variable is a weighted average of the conventional, TT and Clearfield varieties.

Western Australia experiences a slightly different story in its cumulative cost of weed control among the canola varieties, Table A-17. In Western Australia GM canola and TT canola had largely similar herbicide costs as in NSW and Victoria, while conventional and Clearfield both experienced cost increases. The resultant effects indicate the TAF was set more appropriately as the TAF is less than the difference in input costs between GM canola and the TT and Clearfield varieties and has the lowest variable cost. In Western Australia the variable costs of weed control in GM canola is AU$11.56 less than the non-GM basket, which is the inverse of GM canola's AU$11.14 higher variable cost than the non-GM basket in NSW and Victoria.

Table A-17 Western Australia Variable Costs

	Conventional	TT	Clearfield	RR (GM)	Non-GM*
Cultivation	-	$0.08	$0.04	$0.08	$0.08
Sprays	$7.65	$10.78	$7.24	$6.10	$10.38
Herbicide	$56.45	$57.14	$66.67	$29.68	$57.74
TAF	-	-	-	$20.77	-
Total	$64.09	$68.01	$73.95	$56.63	$68.19

* The non-GM variable is a weighted average of the conventional, TT and Clearfield varieties.

Table A-18 Contribution Margins

	Australian Contribution Margins (AU$ ha^{-1})					Canadian Contribution Margin (CA$ ha^{-1})**			
Farmer System Costs	**Conventional**	**TT**	**Clearfield**	**RR (GM)**	**Non-GM***	**Conventional**	**Clearfield**	**RR (GM)**	**Liberty Link (GM)**
Seed Cost***	$54	$63	$58	$63	$60	$33.84	$91.64	$97.74	$91.75
Variable Cost of Weed Control	$55.86	$66.07	$69.51	$37.44	$64.94	$74.10	$33.76	$12.35	$28.55
TAF	-	-	-	$27.28	-	-	$30.21	$37.05	$25.56
Segregation Cost****	-	-	-	$11.51	-	-	-	-	-
Total Cost ha^{-1}	$109.86	$129.07	$127.51	$139.23	$124.94	$107.94	$155.61	$147.14	$145.88
Gross Margins									
Yield (mt)	1.497	1.204	1.518	1.525	1.295	1.57	1.72	1.90	1.91
Canola Price (AU$)*****	$521.59	$521.59	$521.59	$521.59	$521.59	$530	$530	$530	$530
Gross Revenue	$780.64	$628.20	$791.52	$795.46	$675.36	$833	$911	$1,005	$1,013
Less System Cost ha^{-1}	($109.86)	($129.07)	($127.51)	($139.23)	($124.94)	($107.94)	($155.61)	($147.14)	($145.88)
Average	$670.78	$499.13	$664.01	$656.23	$550.42	$725	$756	$858	$867

* The non-GM variable is a weighted average of the conventional, TT and Clearfield varieties.
** Analysis from Brewin and Malla using 2011 year (2012), based on Fulton and Keyowski (1999) and Phillips (2003)
*** GM seed costs use 3 kg/ha (GRDC, 2016), others varieties are from Pritchard et al. (2009).
**** The segregation costs are based on a shared GM and non-GM system pre-farm gate cost of AU$11.51 borne solely by farmers growing GM canola for on-farm segregation (Ministerial GMO Industry Reference Group, 2009).
***** The revenue uses AU$521.59, a simple average of Australian import price for canola converted to AU$ using the annual foreign exchange rate for the respective year of the canola price (ABARES, 2015; Australian Taxation Office, n.d.).