**Ethanol Production from Hybrid Poplar in Canada: A General Equilibrium Analysis**

by

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**Abstract**

Ethanol has been promoted in Canada as an alternative to fossil fuels in the transportation sector. Future changes in Canada's emerging bioeconomy have the potential to cross industry boundaries, such as agricultural and forestry, and lead to inadvertent economic outcomes. As biofuel production technology develops, further production could come from first-generation grain-based feedstocks, or second-generation cellulosic feedstocks. This study evaluates potential economic impacts due to renewable fuel standards that double current ethanol production from first-generation ethanol, versus cellulosic ethanol produced from hybrid poplar feedstock in Canada. We also investigate the effect of current legislation restricting hybrid poplar growth on crown forestland. Finally, we consider impacts from increased crop productivity and oil prices on our simulated economic outcomes. Impacts are investigated in a general equilibrium economic framework. Overall, we find that doubling ethanol production in Canada results in price and output changes between 0% and 10%, with percentages generally higher in agricultural sectors than in forestry. Results further suggest that cellulosic ethanol leads to relatively lower inter-industry price and output impacts compared to first-generation ethanol, due to the availability of marginal land for hybrid poplar production. For both first-generation and cellulosic ethanol, estimated impacts to Canadian net exports can be substantial for some agricultural sectors. We find that the use of coarse grains for increased first-generation ethanol production leads to an approximately 21% decrease in coarse grain net exports, while increased production with cellulosic ethanol has a relatively larger impact on ruminant trade, with net exports decreasing between 27 – 34%. Results also indicate that the subsidy support required to double current ethanol is costly, at around USD 3.00/gallon. Sensitivity analysis suggests that a crop productivity increase leads to relatively larger benefits to first-generation ethanol, while a

10% oil price increase can double Canadian ethanol production, even without further government support.

## Dedication

For Penny.

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The members of the examining committee are Drs. Vic Adamowicz* (Committee), Grant Hauer* (Arm's Length), Scott Jeffrey* (Chair), Marty Luckert* (Committee), James Rude* (Committee), and Farzad Taheripour** (Committee). *Department of Resource Economics and Environmental Sociology, University of Alberta. **Department of Agricultural Economics, Purdue University.

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# Chapter 1: Introduction

Government support for renewable fuels has been largely driven by the premise that renewable fuels will reduce greenhouse gas emissions and help achieve national climate change targets. With this aim, public policy has been a significant contributor to the growth in ethanol production around the world. Brazil and the United States are the forerunners in terms of global ethanol production, together producing over 80 percent of the world's ethanol supply (Renewable Fuels Association 2015). The Canadian ethanol industry is still in its infancy and, like Brazil and the United States, its growing production has been heavily supported by government policy.

Although the Canadian ethanol industry contributes to less than two percent of global production, government support has existed since the 1980s and growth in domestic production has been exponential over the last decade (Laan et al. 2009). Public support for Canadian ethanol production has been implemented through a combination of supply-side policies, in the form of tax exemptions and production subsidies, and demand side policies, in the form of legislated blending mandates. Therefore, with Canada's expanding production, as well as supply- and demand-side support from provincial and federal governments, the ethanol industry may play a larger role in the Canadian economy in the coming years.

Until recently, all commercial ethanol production on the global market was *first-generation ethanol*, i.e., ethanol produced from starch or sugar feedstock such as corn, wheat, or sugarcane. As first-generation ethanol production involves the use of food-based feedstocks, production expansion can affect associated agricultural markets. In turn, changes in feedstock markets extend to other industries and across regions along the agricultural supply chain, leading to what can be described as "ripple effects" throughout the global economy.

Inter-industry effects of ethanol have already been seen in the United States. It has been argued that the use of corn for ethanol production is contributing to elevated feed prices for livestock and thereby increased prices for human food, resulting in negative nutritional consequences for those with low-incomes (Pimentel et al. 2009). Like the United States, Canadian ethanol production is closely tied to the agriculture industry due to feedstock supply, and therefore the same interconnectedness between ethanol and agriculture markets exists, albeit on a much smaller scale.

Economic impacts of ethanol production are not limited to domestic markets; international markets are affected as well. The increasing use of food-based crops for ethanol production, by major grain exporters like the US, has ultimately affected international food markets. Furthermore, trade interactions related to ethanol and its feedstock have led to significant global impacts on land markets (Hertel et al. 2008).

Given the economy-wide impacts of first-generation ethanol production, governments around the world have been championing the production of *second-generation ethanol*, also known as cellulosic ethanol, which is produced using lignocellulosic feedstock from woody biomass such as trees, grasses, and agricultural residues. The United States government has demonstrated a significant interest in cellulosic ethanol, most notably by introducing a specific cellulosic blending mandate in its renewable fuel standards in 2010. To date, Canadian support for second-generation ethanol has been minimal, with funding for a few plants in British Columbia and financial support in Alberta and Quebec being the only public initiatives thus far (Campbell et al. *in press*). However, with a boreal climate that is highly suitable to forestry and existing forestry infrastructure (i.e. transportation, harvesting, etc.), Canada may have a competitive advantage in cellulosic ethanol production, creating potential for policy interventions just as we have seen with first-generation ethanol. Should Canadian governments follow the lead of the United States and adopt blending mandates for second-generation ethanol production, we could see significant inter-industry and inter-region consequences.

A number of cellulosic feedstocks have been examined in the literature including agricultural waste, grasses, municipal solid waste, and forest resources. In Canada, the potential for plantation forestry to contribute to bioenergy production has been a popular research topic (e.g. McKenney et al. 2014; Yemshanov and McKenney 2008). The current legislative environment in Canada restricts the use of fast-growing exotic tree species on public lands, which make up the vast majority of the Canadian forest sector, leaving plantation forestry limited to slower-growing native species. Hybrid poplar is a fast-growing tree species that has been highlighted as having a number of potential benefits for production in Canada including carbon sequestration (Anderson et al. 2015; Yemshanov et al. 2005) as well as quality bioenergy feedstock (Allen et al. 2013). Indeed, policy evaluation of hybrid poplar plantation use for cellulosic ethanol feedstock in Canada warrants further investigation.

The unintended economy-wide effects that resulted from first-generation ethanol production have set an important precedent for biofuels research. As governments look to cellulosic ethanol as a more sustainable means of diversifying their fuel industries, proactive analysis of second-generation production is a crucial research step. Future changes in Canada's emerging bioeconomy, like in the United States, have the potential to cross industry and regional boundaries and lead to inadvertent economic outcomes. However, because the Canadian ethanol industry is still relatively small, it is the opportune time to undertake an economy-wide analysis of the potential impacts associated with Canada's ethanol drivers, in order to try to avoid unintended consequences (Luckert 2014).

### 1.1 Thesis Objective and Approach

The objective of this research is to evaluate the economy-wide implications of various ethanol policy scenarios in Canada, as well as to conduct sensitivity of these scenarios to external economic shocks. The focus is on effects to land, prices, outputs, and trade of agricultural and forest commodities, as well as changes in taxes and welfare associated with first-generation ethanol compared to cellulosic ethanol produced from fast-growing hybrid poplar trees in Canada. Moreover, the current legislation restricting hybrid poplar growth on crown land is considered. Sensitivity analyses include evaluations of external economic impacts including crop productivity improvement and an increase in the world oil price.

A number of economy-wide analytical techniques have been used to evaluate the economic impact of biofuel policies. Computable General Equilibrium (CGE) modelling is a popular method for analyzing the broad economic impacts of public policy. CGE models can be used to understand the economic impacts (including price, trade, and welfare effects) associated with policies that influence various markets of the economy (Wing 2004). As such, CGE modelling is an effective approach for evaluating direct and indirect economic responses associated with bioenergy policies (Kretschmer and Peterson 2010).

The simulated economy-wide impacts highlighted in this thesis will contribute to an emerging and increasingly important literature on the unintended consequences of bioenergy policy. As such, the results of this research will inform future Canadian public policy decisions regarding cellulosic ethanol as well as land use legislation for exotic tree species.

## 1.2 Thesis Structure

Chapter 2 provides background information regarding ethanol production and policy, as well as a literature review of available methods for economy-wide analysis of biofuels. This includes details on the various economy-wide models that have been used, and will highlight the benefit of using CGE modelling for this study. Chapter 3 provides a description of the methods and data used in this thesis. Specifically, a production structure for hybrid poplar in Canada is constructed and outlined in detail. Modifications are made to an existing CGE model (GTAP-BIO-ADVF) using the hybrid poplar production structure and a number of land-use assumptions. Policy scenarios and sensitivity analysis regarding increased first- and second-generation ethanol production in Canada are also described. The results and discussion for each scenario and the sensitivity analysis are provided in Chapter 4. Finally, Chapter 5 presents a conclusion of the research as well as study limitations and opportunities for future research.

# Chapter 2: Background and Literature Review

This chapter has two main sections. Section 2.1 provides background information on ethanol production and policy. First-generation ethanol and various economy-wide impacts that have been noted in the literature are reviewed, followed by a discussion on second-generation ethanol and the potential future of cellulosic feedstocks.

Section 2.2 includes a literature review on various economy-wide modelling techniques that incorporate biofuels. First, a brief overview of economy-wide modelling, specifically partial and general equilibrium modelling, is presented. Then, descriptions of various partial and general equilibrium models are provided, followed by a summary of the types of research questions that have been addressed with these models in the literature. Finally, a conclusion is provided outlining what the literature is lacking and how this thesis contributes to the gap.

## 2.1 Background: A Brief Review of Ethanol Production and Policy

### 2.1.1 First Generation Ethanol and Economy-wide Impacts

Ethanol production in both Canada and the United States started in the early 1980s and has grown significantly over the past decade (Campbell et al. *in press*; Renewable Fuels Association 2014). Though the scale of ethanol production in the United States is vastly larger than that of Canada, both countries have experienced a similar exponential growth path over time (Figure 1).

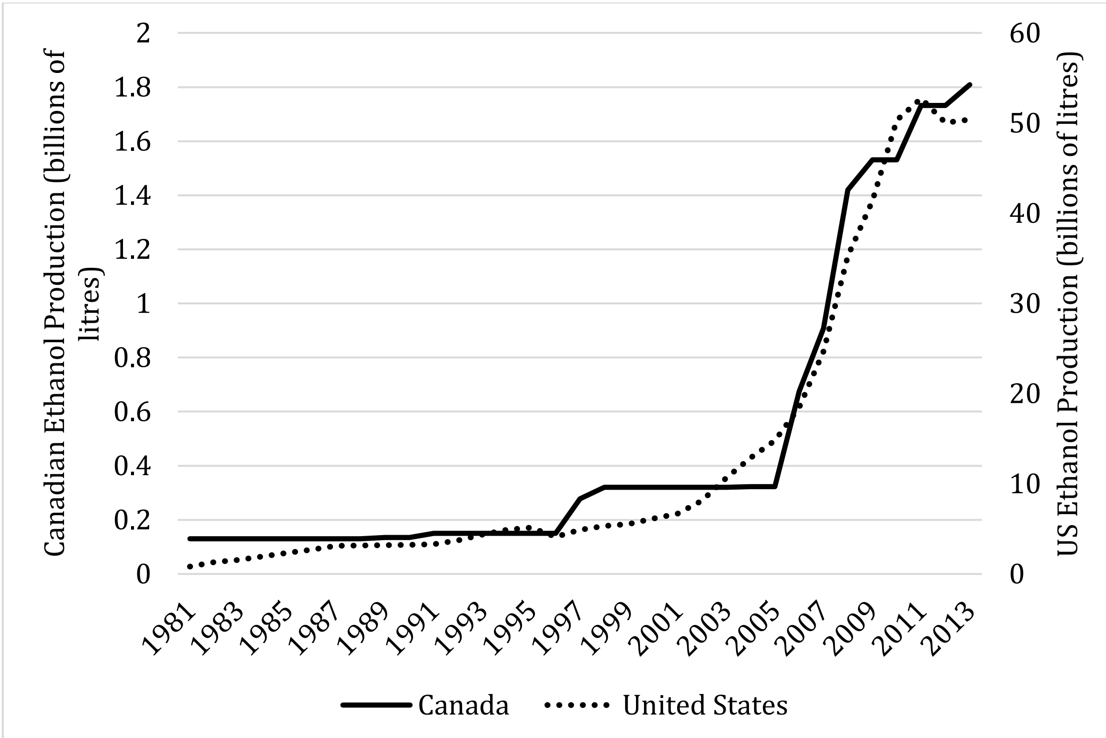



*Figure 1. Canadian and United States Ethanol Production Capacity*

Source: Campbell et al. *in press*; Renewable Fuels Association 2014

Government support for first-generation ethanol in North America has been implemented at various levels of government through a combination of supply-side and demand-side policies (for detailed reviews of government support for ethanol in Canada and the United States, see Campbell et al. *in press* and Koplow 2007, respectively). Supply-side policies have been implemented in the form of tax exemptions and production subsidies. Demand-side policies include blending mandates, requiring a certain amount of ethanol to be blended in gasoline each year. In Canada, the federal mandate is five percent, while the US mandate is approximately 10 percent.

Subsidies and blending mandates have repeatedly been credited for the growth in ethanol industries around the world (e.g.: Tyner and Taheripour 2008). According to Solomon et al. (2007), government support systems in the US have been a “consistent and essential part of the

US ethanol industry for 30 years" (p. 422). Goldemburg et al. (2004) discuss how a major government support program for ethanol in Brazil (PROALCOOL) helped give the industry sufficient momentum to become cost competitive on its own, as it is today. The European Union has also been noted as having government policy effectively drive increased ethanol production (Sorda et al. 2010).

Global ethanol production has predominantly come from first-generation feedstocks like corn, wheat, and sugarcane. However, the use of major agricultural commodities as feedstock for renewable fuel has resulted in peripheral economic impacts across industries (*inter-industry impacts*) and regions (*inter-region impacts*). Inter-industry impacts occur when changes in one economic sector (i.e. biofuels) result in direct and/or indirect changes in other economic sectors. Some of the driving forces of inter-industry impacts include land use changes and the reallocation of resources between sectors. Inter-region impacts occur when economic changes in one region lead to economic changes in other regions. The effects of biofuel production on domestic industries can ultimately extend across borders and impact trading patterns between countries. Impacts can also occur when large exporters make biofuel decisions that significantly affect global markets, which can indirectly cause economic impacts in other countries. Inter-industry and inter-region impacts associated with first-generation ethanol are explained in the following subsections, followed by a brief conclusion.

*Inter-Industry Impacts*

The expansion of first-generation ethanol production has had substantial impacts across economic sectors. Inter-industry impacts have been particularly significant in the US, due to its large corn-ethanol industry. Not surprisingly, the most significant domestic market distortions attributed to the US ethanol industry have been observed in the agriculture sector (e.g. Babcock and Fabiosa 2011; Hochman 2014; Jaeger and Egelkraut 2011; Koplow 2007; Taheripour et al. 2011a). Rising corn prices have led to unintended economic impacts in related markets along the supply chain, including livestock and land markets. Pimentel et al. (2009) argue that increased corn prices have caused higher feed prices for livestock and thereby increased food prices for human consumption, resulting in negative nutritional consequences for those with low-incomes. However, Taheripour et al. (2011a) note that the influence of corn price increases on the US livestock industry (particularly ruminant livestock) is somewhat dampened by the use of distiller's dried grains with solubles (DDGS), a by-product of corn-ethanol production that serves as high quality feed[1].

One of the primary motivations for ethanol production is the potential climate change benefit. Carbon emissions from ethanol relative to gasoline are argued to be lower due to carbon that is removed from the atmosphere during feedstock growth (Searchinger et al. 2008). However, crop price increases can encourage land conversion of carbon rich land-types (old growth forests/grasslands) to cropland, resulting in significant stocks of carbon being released in the conversion process and counteracting the carbon savings associated with feedstock growth (Banse et al. 2011; Fargione et al. 2008; Searchinger et al. 2008). These land conversions have given rise to significant interest in how indirect land-use changes (ILUC) impact the overall carbon effect of ethanol (Banse et al. 2011; Birur et al. 2008; Hertel et al. 2010; Lapola et al. 2010; Rajagopal and Plevin 2013; Taheripour and Tyner 2013).

[1]The amount of DDGS that can substitute for livestock feed depends on the diet of the animal, as different livestock have different abilities to substitute between DDGS and conventional feed. On average, it has been found that 1 metric ton of DDGS can replace up to 1.22 metric tons of feed made from corn and soybean meal (Hoffman and Baker 2011).

Economic effects of biofuels have been noted in the transportation fuel sector as well. Given that ethanol acts as a substitute for gasoline (up to the blend-wall), it follows that ethanol and gasoline prices would have some level of correlation. According to Tyner and Taheripour (2008), the increasing integration between agricultural and energy markets is one of the most important changes in the agriculture industry in recent history. Thompson et al. (2011) also acknowledge the link between ethanol and the petroleum market, arguing that increased biofuel consumption pushes down the prices of petroleum fuels, potentially causing a rebound effect where more petroleum fuels are used.

Clearly, ethanol policy and production has had peripheral economic impacts across sectors. However, the matter becomes further complicated when we consider the economic consequences of domestic policy and production in a multi-region context.

*Inter-Region Impacts*

A number of countries have adopted public policies as a means to promote ethanol production and consumption in their regions. An assortment of blending mandates, subsidy programs, and tariffs have existed in countries such as Brazil, Canada, the European Union, and the United States (Lane 2012).

Recall that agricultural markets are significantly impacted by domestic ethanol policies, but given the interconnectedness of our global food and fuel markets, these impacts are not bound within domestic borders. According to Banse et al. (2011), increases in global biofuel production ultimately lead to increased world grain prices. Major changes to global agricultural markets can have disproportionate effects on developing countries. The authors assert that rising world food prices are not distributed equally across countries, and those with consumers who spend proportionately more of their income on food (e.g. African countries) are ultimately worse off than higher income countries.

Inter-region impacts have also occurred as a result of trade agreements between ethanol and feedstock producers. For example, import tariffs have been used as a means to support domestic ethanol production; however, research has suggested that there are benefits associated with trade liberalization of ethanol whereby countries with higher ethanol production costs could take advantage of importing ethanol from lower-cost producers (Bouet et al. 2010; Le Roy et al. 2011). de Gorter and Just (2010) argued that the US import tariff on Brazilian ethanol of USD 0.54 per gallon, which ended in 2012, inhibited the energy and environmental goals of US ethanol policy, as low-cost Brazilian sugarcane ethanol has significant carbon savings compared to US corn ethanol.

The trade of ethanol and ethanol feedstocks have also led to inter-regional impacts on land markets. Hertel et al. (2008) evaluated global land-use changes due to US and EU biofuel policies. As domestic biofuel production increases in the US and EU, these countries increase both domestic production of feedstocks, as well as imports of feedstocks. The authors note that as US and EU ethanol production increases, regions such as Latin America, Africa, and Oceania are likely to export feedstocks, causing crop cover in these regions to rise significantly at the expense of carbon rich land-types (pastureland and forests). Emissions-leakages across countries can therefore result from single-region biofuel policies (Bento et al. 2012; de Gorter and Just 2010).

Overall, the literature highlights that large-scale first-generation ethanol production has led to unintended consequences for food, land, welfare, and carbon emissions at both domestic and global levels. As a consequence, many have argued for the development and support of second-generation ethanol production (Babcock et al. 2011; Hill et al. 2006; Wyman 2007).

### 2.1.2 Second-Generation Ethanol

Second-generation ethanol, often referred to as cellulosic ethanol, is ethanol produced from lignocellulosic feedstocks such as wood, agricultural residues such as corn stover, and grasses. Wyman (2007) describes a number of benefits associated with cellulosic ethanol. These include, but are not limited to: low-cost and abundant feedstocks, high-octane content, and environmental benefits. However, there are a number of serious barriers that have inhibited cellulosic ethanol production from reaching a commercial scale. The primary problem is that technological barriers have kept production costs high relative to first-generation ethanol. Governments have therefore started to adopt policies to promote second-generation production, similar to those adopted for first-generation. The US introduced a category specific to cellulosic ethanol in its' renewable fuel standards. In Canada, provincial governments in Alberta and Quebec have introduced subsidy programs that provide per litre production subsidies specific to cellulosic ethanol. The government of British Columbia has also demonstrated its support of cellulosic biofuel by issuing grants to cellulosic ethanol plants in the province.

As government support and research expands, it appears that cellulosic ethanol will become more competitive in the fuel market. The first commercial scale production of cellulosic ethanol in North America began in the summer of 2014 with a two million gallon per year add-on operation to an existing first-generation plant. In September 2014, the world's largest cellulosic ethanol plant opened in Kansas, with a production capacity of 25 million gallons per year (Lane 2014).

There are two primary sources of lignocellulosic feedstocks: 1) residues (from agriculture and forest sources) and 2) dedicated energy crops. Agricultural residues are waste products from crop production. In Canada, wheat straw is the most abundant agricultural residue (Li et al. 2012), whereas corn stover is common in the United States (Graham et al. 2007). Agricultural residues have the advantage of being a relatively inexpensive source of lignocellulosic biomass as it is a by-product of crops that are already being produced. According to Li et al. (2012), agricultural crop residues represent a considerable source of lignocellulosic biomass in Canada. The authors' estimated that up to 47.9 million tonnes of agricultural residue could be available to the cellulosic ethanol industry each year (Li et al. 2012). However, transportation of this biomass resource can be a significant barrier, as residues exist in low densities across wide geographic regions. To help bring costs down and improve the feasibility of agricultural residues as bioenergy feedstock, novel transportation options, such as pipelining of residues transformed into slurries, are gaining research interest (Luk et al. 2014).

Forest residues are another potential Canadian source of second-generation ethanol feedstock. Compared to agricultural residues, forest residues may result in higher fuel yields by mass, as woody biomass has a relatively higher sugar content (Mabee et al. 2011). Forest harvest operations produce the largest amount (15.6 million tonnes) of dry forest residues in Canada, while approximately 5.8 million tonnes come from forest products manufacturing (Mabee et al. 2011).

Unlike agriculture and forest residues, dedicated energy crops are produced in large volumes with high densities, because the primary intention is to provide feedstock for bioenergy production. Many different energy crops have been researched in the literature, including grasses (miscanthus and switchgrass) and woody crops such as hybrid poplar, willow and eucalyptus (see: Miao and Khanna 2014; Brechbill et al. 2011; McKenney et al. 2014; Stephen et al. 2013).

In Canada fast-growing, non-native tree species, including hybrid poplar, are considered exotic species. Current provincial forest legislation restricts exotic species from public land, with the exception of small areas in Quebec where exotic trees are privately managed on public land (Derbowka 2012). Therefore, non-native short-rotation woody crops (SRWCs) have to be established on private land in Canada. The intention of current forest regulations regarding exotic trees on public land in Canada is to protect the native gene pool of Canada's forests (Anderson et al. *in review*). There is also some fear that amending these regulations will not only allow the planting of hybrid species but, more controversially, introduce genetically engineered trees as well (Anderson et al., *in review*). Smith et al. (2013) highlighted that many of the characteristics desired for SRWCs, such as high yields and rapid growth rates, are often found in invasive species. They stress that a current lack of research on the potential consequences of increased regulatory tolerance for invasive plants jeopardizes the development of a sustainable renewable fuel industry.

Overall, the literature highlights a growing interest in cellulosic ethanol production, and a number of potential avenues for Canada to develop a cellulosic ethanol industry. However, the current legislative barriers restricting exotic trees from the majority of public land in Canada may reduce the viability of SRWCs as cellulosic feedstock.

### 2.2 Literature Review: Economy-wide Modelling of Biofuels

Studies have evaluated the economic impacts of biofuels using methods such as cost benefit analyses (de Gorter and Just 2010; Hahn and Cecot 2007), and firm level evaluations (Outlaw et al. 2007; Schmit et al. 2011). However, these methods provide results that are typically isolated in scope and thus provide little insight as to policy effects on the economy as a whole. Consequently, an economy-wide perspective is essential when evaluating the outcomes of bioenergy policy (Kretschmer and Peterson 2010).

Equilibrium models, both partial and general, can be effective tools for analysis of biofuel policy. As the name suggests, partial equilibrium (PE) models are more concentrated in scope compared to general equilibrium models. PE models typically involve the modelling of one or more commodities within one target industry (often agriculture) across regions. General equilibrium (GE) models, on the other hand, are often both multi-industry and multi-regional, and include both product and factor markets, providing a more general overview of peripheral impacts associated with economic shocks.

The following sections provide descriptions of PE and GE modelling approaches that have been adapted to evaluate biofuel policies. We then provide examples of research applications that have used these models. Finally, we conclude with a brief explanation of how this study contributes to the literature.

### 2.2.1 Partial Equilibrium Models

Equilibrium analyses of biofuel impacts have often been evaluated in the context of the agriculture industry, as agricultural crops have provided the vast majority of commercial biofuel feedstock to date. PE models have thus been a popular choice for biofuel policy analysis, as they are able to capture detailed impacts of bioenergy production on feedstock prices, land-use changes, and environmental effects specific to the agriculture sector (Kretschmer and Peterson 2010).

Below, section 2.2.1.1 contains descriptions of major PE models that have been used to evaluate biofuels. Section 2.2.1.2 then provides a summary of popular biofuel research topics that have made use of PE models.

#### 2.2.1.1 Partial Equilibrium Model Descriptions

*AGLINK-COSIMO*

The AGLINK-COSIMO model is one of the world's most comprehensive PE models of global agriculture, developed by the Organization for Economic Co-operation and Development (OECD) in collaboration with the Food and Agriculture Organization (FAO) of the United Nations. The model is a recursive dynamic model of world agriculture that treats all other economic sectors as exogenous (OECD 2007). The model is primarily used to evaluate the potential medium-term effects of agriculture and trade policies on agriculture markets (OECD 2007).

*CAPRI*

The Common Agricultural Policy Regionalised Impact Modelling System (CAPRI) is a static, partial equilibrium model developed by the University of Bonn in collaboration with the European Commission. The model focuses on the global agricultural markets, with a particular emphasis on Europe (CAPRI 2014). As such, the model has been primarily used to evaluate the impacts agricultural and trade policies in the European Union. The model was recently modified to explicitly incorporate the global production and trade of both first- and second-generation biofuels (Blanco et al. 2013).

*ESIM*

The European Simulation Model (ESIM) is another comparative static, multi-regional PE model of the agriculture market (Blanco et al. 2010). The model has included first-generation biofuel commodities since 2006, and has been used to evaluate biofuel policy impacts on the agriculture sector, particularly in Europe (Blanco et al. 2010).

*FAPRI*

The Food and Agriculture Policy Research Institute (FAPRI) developed a static multi-region, multi-commodity PE model for global agriculture, food, fibber, and bioenergy markets (Fabiosa et al. 2010). The FAPRI model includes a system of sub models, where markets for various agricultural commodities such as temperate crops, ethanol, and livestock/meat products are connected through price linkages (Fabiosa et al. 2010). The US portion of the FAPRI model, which includes crops, livestock and dairy models, was developed by the University of Missouri.

*GLOBIOM*

The Global Biosphere Management Model (GLOBIOM) is a recursive, dynamic PE model for global agriculture, bioenergy, and forestry (IIASA 2014). The model was developed by the International Institute for Applied Systems Analysis (IIASA) for the purpose of evaluating global land use competition caused by the production of food, bioenergy (both first- and second-generation), and forest fibre.

*IMPACT*

The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) was developed by the International Food Policy Research Institute (IFPRI) in the early 1990s.  IMPACT is a static PE model that was initially developed as a means to evaluate the impact of government policies on the global food sector. The model has since been expanded to analyze other topical issues such as water demand, climate change, and biofuels (Rosegrant 2012).

#### 2.2.1.2 Partial Equilibrium Biofuel Research

PE models have been used to address a variety of biofuel research questions. In this section, we discuss and categorize the broad research topics that have employed PE models.

*Agricultural Impacts*

Many of the above PE models have been used to evaluate the impact of national biofuel policies on agricultural markets. Banse and Grethe (2008) use an extended version of the ESIM model to evaluate EU biofuel policy impacts on agriculture. Similar studies are conducted using the IMPACT model (Rosegrant 2008; Rosegrant et al. 2008). The FAPRI model has been used frequently to analyze the impact of US corn ethanol production on grain and livestock sectors (Elobeid et al. 2007; Hayes et al. 2009; Babcock 2012). Research conducted by the United Kingdom's Department for Environment, Food and Rural Affairs used the AGLINK-COSIMO model to simulate the removal of US and EU biofuel mandates during major grain price surges as a means to mitigate global food and animal feed price volatility (Durham et al. 2012).

*Land-use Impacts*

PE models have also been used to evaluate the consequences of land use changes associated with biofuel policies. For example, Havlik et al. (2011) used the GLOBIOM model to investigate the impacts of indirect land use changes resulting from increased biofuel production. The authors looked at both first- and second-generation biofuels, considering second-generation production from both existing forests as well as dedicated plantations. A similar study by Mosnier et al. (2013) evaluated the land use changes owing to the US renewable fuel standards. The authors focussed on the potential greenhouse gas emissions caused by land use changes from various biofuel policy scenarios in the US. Finally, Burrell et al. (2012) employed the AGLINK-

COSIMO model to evaluate the potential land-use change effects from the elimination of EU tariffs on imported biofuels.

*Trade*

The role of trade has been another focus of PE biofuel research. Fabiosa et al. (2010) used the FAPRI model to compare the cropland changes associated with an increase in first-generation ethanol demand in the US, versus an increase in world ethanol demand, given existing trade restrictions. Another study focussed on the effect of trade barriers on increased Canadian ethanol consumption, using a customized version of the FAPRI model (Le Roy et al. 2011). A study by Fridfinnson and Rude (2009), using the AGLINK-COSIMO model, focussed on how first-generation biofuel production in Canada, the US, and the EU effected agricultural feedstock prices and the corresponding trade flows of those commodities.

*Other Partial Equilibrium Models*

Some researchers have taken to developing their own PE models. For example, McPhail and Babcock (2011) developed a stochastic PE model to examine the effect of US biofuel policy on the variability of corn and gasoline prices. In a paper by de Gorter and Just (2008), the authors developed a PE model to evaluate the effects of a US import tariff on biofuels under tax credit and blending mandate policies. Tyner and Taheripour (2008) also modelled ethanol production policies in the US by developing a PE model with integrated agriculture and energy markets.

### 2.2.2 General Equilibrium Models

GE models can be used to understand economic impacts (such as welfare and distributional effects) associated with policies that influence various markets and regions of the economy (Wing 2004). Kretschmer and Peterson (2010) emphasize the benefits of using GE modelling for the analysis of bioenergy policy due to its broad scope and usefulness in determining direct and indirect policy consequences. Though GE models provide a wider scope of analysis compared to PE models, the trade-off is a high level of aggregation and less detailed economic information (Kretschmer and Peterson 2010).

Section 2.2.2.1 contains descriptions of major GE models that have been used to evaluate biofuels. In section 2.2.2.2, we categorize a number of biofuel research topics that GE models have been used to address.

#### 2.2.2.1 General Equilibrium Model Descriptions

*DART*

DART (Dynamic Applied Regional Trade) is a dynamic-recursive GE model of the world economy developed by the Kiel Institute for World Economics (Kiel Institute 2015). The model was designed to evaluate international climate change policies. Like many GE models, DART has been extended to incorporate biofuel production.

*EPPA*

The Emissions Prediction and Policy Analysis (EPPA) model is a recursive dynamic GE model of the world economy. The model is built on the GTAP database (explained below), with additional data on greenhouse gas and urban gas emissions (Palstev et al. 2005). EPPA was designed as a tool to simulate economic growth and associated anthropogenic greenhouse gas emissions.

*GTAP*

Arguably the largest and most frequently used GE model is the Global Trade Analysis Project (GTAP) (GTAP 2015a). GTAP was first developed in 1993 by the Center for Global Trade Analysis at Purdue University. The project is centered on a large global database that includes production, consumption, and bilateral trade patterns. The model is a multi-sector, multi-region GE model that has been extended a number of times for different applications. For example, the GTAP-E model was developed to evaluate pollution abatement costs and incorporate greenhouse gas impacts associated with regional and industry interactions (GTAP 2015b). The GTAP-E model was further extended to incorporate first-generation (GTAP-BIO) and second-generation (GTAP-BIO-ADVF) biofuels (Taheripour et al. 2007; Taheripour et al. 2011b).

*MIRAGE*

In 2001, the Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) developed a GE model called MIRAGE (Modelling International Relationships in Applied General Equilibrium) as a means to evaluate global impacts of multilateral trade agreements (MIRAGE 2011). The model makes use of the GTAP 7 database and can be used under a dynamic or static approach (MIRAGE 2011). In 2008, the MIRAGE model was modified to incorporate biofuels and has been frequently used to evaluate the economic impacts of EU biofuel policy.

*WORLDSCAN*

The Netherlands Bureau for Economic Policy Analysis (CPB) developed the WorldScan GE model in the 1990s for policy analysis. WorldScan is a recursive dynamic GE model of the world economy, and like the MIRAGE model, it uses data provided from the GTAP database (Lejour 2006). More recently, WorldScan has been used to evaluate various first-generation biofuel policies.

#### 2.2.2.2 General Equilibrium Biofuel Research

As with PE models, GE models have been used to evaluate numerous biofuel research questions. Below are a categorization and brief description of some major biofuel-related research topics that use the GE models described above.

*Agricultural Impacts*

The relationship between first-generation biofuels and world agriculture markets has been an area of focus for much GE research. Many studies have employed the GTAP-BIO model for this work (Taheripour et al. 2011a; Birur et al. 2008; Hertel et al. 2008). The WorldScan model was used by Al-Riffai et al. (2010) to simulate potential changes to EU biofuel trade policies and the consequences for global agriculture, as well as the overall environmental performance of EU biofuel policy. Kretschmer et al. (2009) used the DART model to investigate economic and welfare impacts of the EU biofuel policy, with a focus on the agriculture sector.

*Land-use Impacts*

Land use changes due to biofuel policy have been studied with the GTAP-BIO model (Banse et al. 2011; Hertel et al. 2010; Keeney and Hertel 2009; Taheripour et al. 2012). Bouët et al. (2010) used a modified version of the MIRAGE model to evaluate the indirect land use change effects of biofuel policies in the US and the EU. Malins (2013) focused on the indirect land use change emissions associated with EU biofuel policies. Boeters et al. (2008) analyzed economic impacts and greenhouse gas emissions associated with EU biofuel policy using the WorldScan model. Reilly and Paltsev (2007) used an extended version of the EPPA model to analyze economic impacts and land use changes associated with biomass production as an input for electricity and liquid fuel.

*Second-generation Biofuels*

With the recent growth in second-generation biofuel, many GE models are being modified to include second-generation biofuels. The GTAP-BIO-ADVF model has been used to analyze induced land use emissions associated with second-generation biofuels (Taheripour and Tyner 2013). In particular, the model includes biofuels produced from corn stover, miscanthus, and switchgrass. Gurgel et al. (2008) extended the EPPA model to study second-generation biofuels as well. The authors simulated cellulosic biofuel and bioelectricity development with and without potential greenhouse gas mitigating policies.

## 2.3 Conclusion

The use of PE and GE models for first-generation biofuel policy evaluation has been extensive. Second-generation biofuel production and policy are increasing, but the economy-wide evaluation of second-generation biofuels is still in its infancy. In particular, there have been minimal equilibrium analyses that explicitly model the use of fast growing tree plantations (the exception being Havlik et al. 2011). There has also been little work focusing on Canada's potential role in the global cellulosic feedstock market.

This research contributes to the existing literature by employing a well-established GE model, GTAP, to closely examine cellulosic ethanol policy in Canada. Specifically, this research modifies the current GTAP-BIO-ADVF model to include a new forest feedstock for ethanol production: hybrid poplar. Furthermore, this study evaluates the potential use of Canadian crown land for fast-growing hybrid poplar production.

A GE model was chosen for this study due to the inter-industry nature of this research. Specifically, the need for a multi-sectoral analysis here is important. PE models that incorporate biofuels, like those described above, typically focus on the agriculture sector. For this research we conduct simulations evaluating the use of forestland for poplar production, necessitating a more comprehensive multi-sectoral model. The most well developed CGE model and database for the analysis of biofuel policy is the Global Trade Analysis Project (GTAP). In this study we use the GTAP-BIO-ADVF model. With the capacity to simulate changes to both first- and second-generation ethanol production, the GTAP-BIO-ADVF model provides an ideal foundation to investigate the peripheral economic impacts of potential ethanol policies in Canada.

There are two important dimensions to this research. First, the literature has indicated that SRWCs are a potentially significant source of feedstock for cellulosic ethanol production. But there have been no economic studies evaluating the economy-wide impacts of SRWC use for ethanol production in Canada; a gap that this work intends to fill. Second, the current legislation constraining the growth of hybrid poplar on crown land is an important restriction to assess. As such, this thesis also evaluates the use of public forestland for hybrid poplar production as an ethanol feedstock.

# Chapter 3: Methods

## 3.1 General equilibrium modelling

General equilibrium models incorporate product and factor markets in a multi-market economy, while accounting for the interdependencies that exist between all economic sectors and regions. At its core, a general equilibrium model consists of two primary economic agents: households and producers. Typically, it is assumed that these agents prescribe to neoclassical optimization behaviours, whereby households maximize utility while producers maximize profits. General equilibrium models are constructed and solved for prices and quantities using a system of equations for expenditure, production, and market clearing identities. The theory operates under the premise that there exists a particular set of prices that clear all markets and lead to economy-wide equilibria. Computable general equilibrium (CGE) models are general equilibrium models that are solved using computer algorithms. The most common softwares used to solve CGE models include GAMS/MPS-GE and GEMPACK.

## 3.2 The GTAP-BIO-ADVF Model

The Global Trade Analysis Project (GTAP) is arguably the largest publicly available global CGE model and database. GTAP was initiated in 1992 by Thomas Hertel at Purdue University's Department of Agricultural Economics. The GTAP database begins with country-level input-output data on inter-industry interactions.  Economic relationships between regions are characterized through global bilateral trade, transport, and protection data. The GTAP model is composed of a large system of equations, with includes two main types of equations: *i)* accounting relationship equations that ensure a balance of receipts and expenditures by economic agents, and *ii)* behavioural equations that specify optimization actions by consumers and producers (Brockmeier 2001). On the consumer side, expenditure for each region is determined by a regional household, which operates under a Cobb-Douglas utility function to determine expenditures for the private household, savings, and government. On the production side, a nested constant elasticity of substitution function dictates producer decisions for each sector represented in the model. A more detailed description and illustration of the multi-region GTAP model is provided in Appendix 1.

First-generation biofuels were originally incorporated into 6$^{th}$ version of the GTAP database, which represented the world economy in 2001 (Taheripour et al. 2007). Birur et al. (2008) then introduced these biofuels into the GTAP modelling framework, creating a new model labelled GTAP-BIO. In 2010, Taheripour et al. (2010) further modified the GTAP-BIO model to incorporate biofuel by-products. Shortly after, second-generation biofuels including ethanol and a drop-in advanced biofuel (bio-gasoline) produced from corn stover, miscanthus, and switchgrass feedstocks, were added to the model in order to evaluate potential land-use changes due to cellulosic ethanol policy (Taheripour, Tyner and Wang 2011). To accommodate these additions, the original GTAP-BIO database was upgraded to 2004 (based on version 7 of the GTAP database) and the model was modified to account for second-generation ethanol and biogasoline production from each of the three new feedstocks, with the new modelled labelled GTAP-BIO-ADVF. The GTAP-BIO-ADVF model incorporates the new biofuels into the demand structures for households and input-demand structures for producers. Details of the demand structures and the introduction of biofuels are provided in Appendix 1.

In addition to the adjustments made to the demand structures, land allocation was altered in the GTAP-BIO-ADVF model to represent land transformation options for the additional cellulosic feedstocks. From Figure 2, we see that the old GTAP-BIO model differentiated land into forest, pasture, or cropland. Cropland is further differentiated into cropland-pasture, Conservation Reserve Program (CRP) land (specific to the United States), and traditional crop production (which include wheat, coarse grains, oilseeds, and other agricultural goods). There are only two elasticities of transformation affecting the supply of land (Φ1 and Φ2). In the new GTAP-BIO-ADV model, the major land categories remain (forest, pasture, and cropland), but cropland is further divided into two groups: crop group 1 includes all traditional crops as well as CRP land, while crop group 2 includes cropland-pasture and the newly introduced dedicated energy crops miscanthus and switchgrass. As neither miscanthus nor switchgrass is produced on a commercial scale in North America, these changes were introduced under the assumption that these feedstocks would be more likely to compete with cropland-pasture (i.e. marginal land) than more successful traditional crops. In the new model, there are four elasticity of transformation parameters governing the distribution of land supply[2]. For Canada, these elasticities are assumed the following values, based on a calibration process developed by Taheripour and Tyner (2013):

- Ω1 – Elasticity of transformation among forest, pastureland, and cropland = -0.02
- Ω2 – Elasticity of transformation among crop group 1 and crop group 2 = -0.75
- Ω4 – Elasticity of transformation among crop group 1 = -0.25
- Ω5 – Elasticity of transformation among crop group 2 = -10

[2]Ω3 is not included here as it refers to the elasticity of transformation between land for beef and milk and is not relevant to this study.

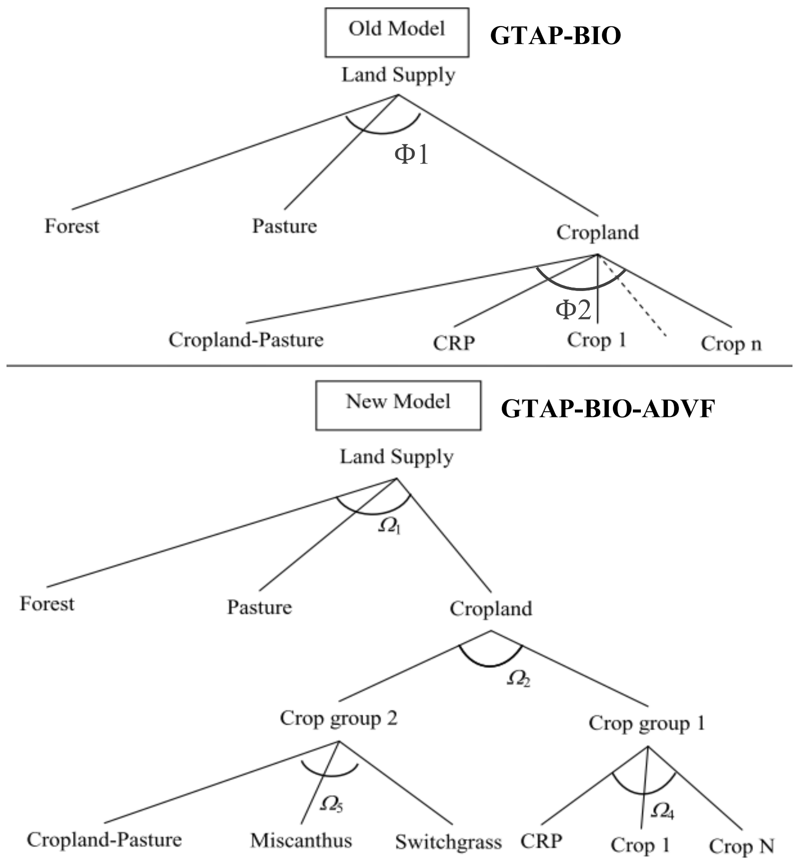



*Figure 2. Land Supply Structures in GTAP-BIO and GTAP-BIO-ADVF Models*

Source: Adapted from Taheripour and Tyner 2011

### 3.3 Model Modifications for this Thesis

Numerous scenarios are run with the GTAP-BIO-ADVF model for this research, which will be explained in more detail below in section 3.4. First, a baseline simulation is performed to bring the GTAP base data up to current (i.e. 2013) first-generation ethanol production in Canada. Then, we compare the use of first-generation and cellulosic ethanol to double current Canadian production, restricting all feedstock growth to private land. We also model the allowance of hybrid poplar trees on crown forestland, which is currently restricted by provincial legislation.

Finally, we conduct sensitivity analyses on crop productivity and an increased world oil price. To perform these scenarios, modifications are made to the GTAP-BIO-ADVF model, specifically to the ethanol feedstock and land use assumptions.

### 3.3.1 Modifications to Feedstock

The GTAP-BIO-ADVF model is modified in this thesis to include a forest-based feedstock (hybrid poplar) for cellulosic ethanol production in Canada. Hybrid poplar is included in the model by altering the model assumptions for an existing cellulosic feedstock (switchgrass). To modify the model, a cost structure for hybrid poplar is estimated using establishment and management cost data from the Canadian Wood Fibre Center (Keddy 2013). The original costs were presented in ranges; the averages of those ranges are used here. A number of steps are needed so that the data fits the GTAP-BIO-ADVF model. Costs are converted from dollars[3] per hectare to dollars per oven-dried tonne (ODT) and then separated into materials and value-added (capital, labour, and land) costs. Cost details are provided in Table 1, while the final cost structure is provided in Table 3. The model is properly adjusted to include this new cost structure.

In Table 1 the silvicultural costs are transformed from $/ha to $/ODT (columns 3 and 4) assuming an annual mean annual increment (MAI) of 7 ODT/ha/year. The MAI of hybrid poplar differs across Canada depending on the management regime and bioclimatic conditions, so there is no single national growth rate. However, because this research is aggregated to a national level it requires a national average growth rate of hybrid poplar. Studies have reported yields as low as 1 ODT/ha/year in the prairies (Samson et al. 1999), and as high as 10 ODT/ha/year in Ontario

[3]Dollars ($s) are assumed to be Canadian dollars, unless otherwise stated.

(Allen et al. 2013) and 12 ODT/ha/year in British Columbia (Samson et al. 1999). In this research, an MAI of 7 ODT/ha/year is chosen as an average representation of hybrid poplar growth across Canada.

*Table 1. Silvicultural Costs of Hybrid Poplar Production in Canada (2013 prices)*

| *1* | | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* |
|---|---|---|---|---|---|---|---|---|---|
| *Cost Item* | | *Year* | *Total Cost ($/ha)* | *Total Cost ($/ODT)* | *Compounded Total Cost[a] ($/ODT)* | *Cost of Materials ($/ODT)* | *Cost of Capital+Labour ($/ODT)* | *Capital (35%) ($/ODT)* | *Labour (65%) ($/ODT)* |
| *Site Preparation* | *Deep discing* | 1 | 182.50 | 1.30 | 2.75 | 0.68 | 2.06 | 0.72 | 1.34 |
| | *Shallow discing* | 1 | 87.50 | 0.62 | 1.32 | 0.31 | 1.00 | 0.35 | 0.65 |
| | *Marking* | 1 | 82.50 | 0.59 | 1.24 | 0.04 | 1.20 | 0.42 | 0.78 |
| | *Planting stock (rearing trees)* | 1 | 920.00 | 6.57 | 13.85 | 13.85 | 0.00 | 0.00 | 0.00 |
| | *Planting operations[b]* | 1 | 368.00 | 2.63 | 5.54 | 2.77 | 2.77 | 0.00 | 2.77 |
| | *Vegetation management* | 1 | 387.50 | 2.77 | 5.83 | 0.00 | 5.83 | 2.04 | 3.79 |
| | | 2 | 310.00 | 2.21 | 4.49 | 0.00 | 4.49 | 1.57 | 2.92 |
| | | 3 | 232.50 | 1.66 | 3.23 | 0.00 | 3.23 | 1.13 | 2.10 |
| | | 4 | 155.00 | 1.11 | 2.07 | 0.00 | 2.07 | 0.73 | 1.35 |
| | *Harvesting* | 20 | 3500.00 | 25.00 | 25.00 | 3.25[c] | 21.75 | 7.61 | 14.14 |
| | *Transportation[d]* | 20 | 4900.00 | 35.00 | 35.00 | 3.25[c] | 31.75 | 11.11 | 20.64 |
| | **TOTAL** | | **11125.50** | **79.46** | **100.31** | **24.15** | **76.16** | **25.69** | **50.47** |

Source: Keddy 2013; Sidders and Joss 2010

Notes:

[a]Costs are compounded to year 20.

[b]Because seedlings are planted manually, there is no capital cost associated with the planting operations. Instead, it is assumed that labour costs and materials costs are each 50% of total planting costs.

[c]The cost of materials for transportation and harvesting is the fuel cost. The fuel share ($6.5/ODT) was estimated from Statistics Canada (2013) as the share of vehicle fuel relative to total expenses in the logging industry: approximately 6%.

[d]The transportation cost is assumed to be $35/ODT to be comparable to the transportation cost of cellulosic feedstocks in the GTAP-BIO-ADVF model.

The optimal economic rotation (OER) of a tree is defined as the rotation age which results in the highest land expectation value given a specific yield function, timber price, reforestation cost, and interest rate (Buongiorno and Gilless 2003). In the GTAP-BIO-ADVF model, the timber price is assumed to be a breakeven price (i.e. equal to the production cost of the feedstock). As such, there is no internally consistent way to calculate the OER for hybrid poplar as the rotation period is required to convert the production costs to a per ODT value. Therefore, an OER of 20 years is assumed based on a recent Canadian hybrid poplar analysis (Anderson et al. 2015).

Because harvest does not take place until the end of the OER, the costs are compounded ahead so that the values are represented in the same year as the harvest (column 5); this accounts for the opportunity costs associated with having to wait 20 years before the product can be sold. Following Buongiorno and Gilless (2003), an interest rate of 4 percent is assumed and the costs are adjusted according to Equation 1.

*Equation 1.*

$$C = C_0 * ((1 + r)^{20-n})$$

where:
C = Compounded cost
$C_0$ = Original cost in year *n*
*r* = 4% interest rate
*n* = year in which the cost occurs

Next, silvicultural costs are separated into cost of materials, and capital plus labour costs, as provided with the original data (columns 6 and 7). The capital plus labour values are further separated using primary factor shares for the forestry sector in GTAP (columns 8 and 9). Endowment values for capital and labour are used to estimate these shares, shown below in Table 2.

*Table 2. GTAP Primary Factor Shares – Forestry Sector in Canada in 2004*

| *Factor* | *Endowment Value (USD)* | *Share (%)* |
|---|---|---|
| Capital | 747,552,673 | 35 |
| Labour | 1,390,504,257 | 65 |
| **Total** | 2,138,056,930 | 100 |

Source: Narayanan and Walmsley 2008

From Table 1 we can see that transportation and harvest are the most significant cost components for hybrid poplar production, together costing $60/ODT in 2013 prices. Vegetation management for the first four years of plantation growth is the second most costly item, costing $15.62/ODT. Rearing trees for planting is another costly component at $13.85/ODT, while all other items cost a total of less than $6/ODT. Furthermore, Table 1 indicates that hybrid poplar production in Canada is capital and labour intensive, with the total capital plus labour costs of $76.16/ODT surpassing materials costs of $24.15.

To complete the production cost structure for hybrid poplar, land rents are estimated. The land rent in the modified model is assumed to equal the rent for marginal quality cropland, considered economically feasible for hybrid poplar growth. First, the area-weighted average land value for cropland (wheat and coarse grains) in Canada for AEZ 15 is calculated from the GTAP model ((2004) USD 23.06/ha). This value is then reduced by 23 percent to represent a marginal quality cropland. The reduction amount is estimated by comparing poorer quality classed agricultural land values with higher quality land values along the edge of the white and green zones in AB, an area where there is likely both high quality and marginal quality cropland to compare. The data used are based on the Canada Land Inventory rating system (Alberta Agriculture and Forestry 2015a). Again, because it takes 20 years for the biomass to be produced, rental rates are compounded ahead at a 4 percent interest rate, then converted to $/ODT.

Using the estimated land rent, as well as the costs provided in Table 1, a final cost structure for hybrid poplar production in Canada is obtained (Table 3). The total cost of hybrid poplar production in Canada is estimated to be $90.05/ODT in 2004 prices. Of the value added cost items, labour is the most expensive at $42.90/ODT, followed by capital at $21.83/ODT, and land rent at $4.78/ODT. Rearing trees has the highest materials cost, costing $11.77/ODT.

*Table 3. Hybrid Poplar Production Cost Structure (2004 prices)*[4]

| *Cost Item* | *Value ($/ODT)* |
|---|---|
| **Cost of Materials** | |
| Transportation (*fuel*) | 2.76 |
| Harvest (*fuel*) | 2.76 |
| Planting operations | 2.35 |
| Other: | |
| Rearing trees | 11.77 |
| Site preparation | 0.85 |
| Marking | 0.04 |
| Vegetation management | 0.00 |
| **Materials Total** | **20.53** |
| **Value Added** | |
| Capital | 21.83 |
| Labour | 42.90 |
| Land | 4.78 |
| **Value Added Total** | **69.52** |
| **TOTAL** | **90.05** |

Notes:
Values are deflated from 2013 to 2004 using a CPI deflator of 0.85 (Bank of Canada 2014).

Finally, as the GTAP-BIO-ADVF model assumes an ethanol conversion rate of approximately 83 gallons per ODT (75 gallons per dry short ton) regardless of feedstock, the conversion rate is adjusted to 88 gallons per ODT[5] of hybrid poplar to better reflect ethanol conversion from woody feedstock, which has a relatively higher sugar content than first-generation feedstocks.

[4]As the GTAP-BIO-ADVF model operates in the 7th version of the GTAP database, all costs were deflated to 2004 prices (Bank of Canada 2014).

[5]Estimated using a weight volume ratio midpoint of 0.345 ODT per $m^3$ (Huda et al. 2014) and a biomass to ethanol conversion rate of 334 litres per ODT (Phillips et al. 2007). Note that this calculation follows work done by Hauer et al. (*in progress*).

### 3.3.2 Modifications to Land Use

The GTAP model and database adopt the Food and Agriculture Organization of the United Nations and the International Institute for Applied Systems Analysis' agro-ecological zoning methodology. Agro-ecological zones (AEZs) are subdivisions of land that are segmented according to their agro-ecological features, whereby each AEZ has similar land-use potential (Lee et al. 2005). Figure 3 below depicts global AEZ distribution.

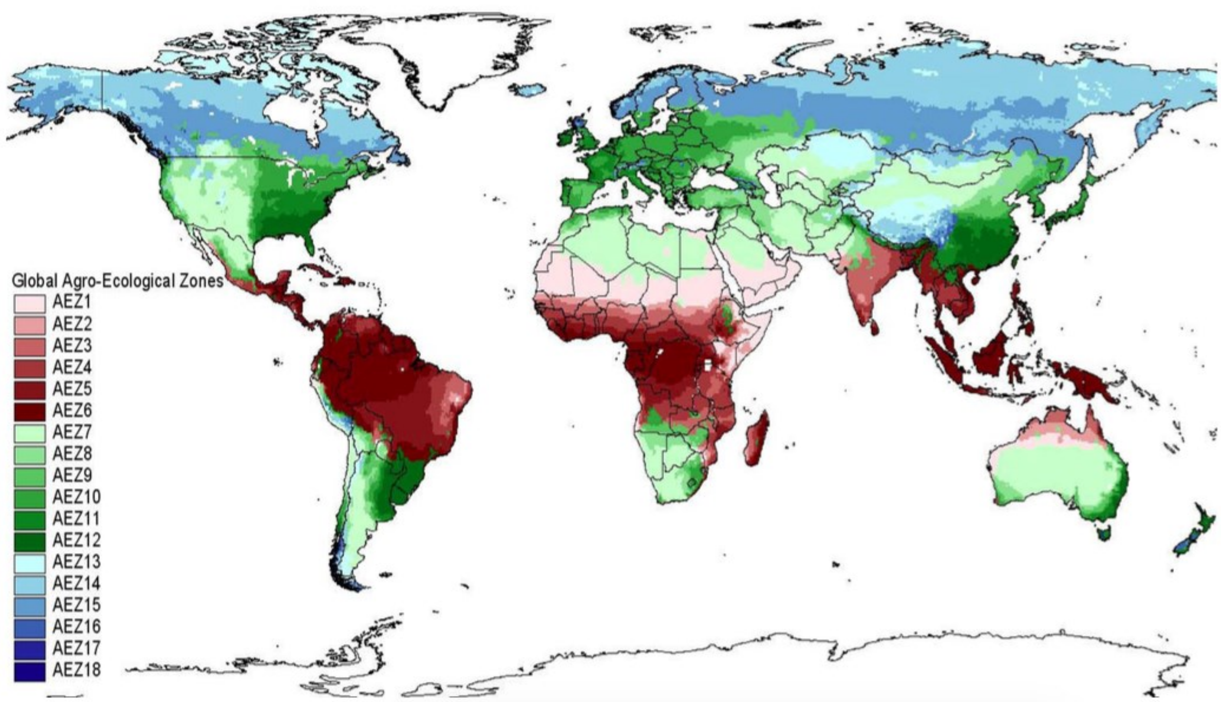



*Figure 3. Global Agro-Ecological Zones*
Source: Adapted from Lee et al. 2005

Global AEZs are subdivided into three climatic zones: tropical (red), temperate (green), and boreal (blue). Each climatic zone is then divided into six categories, determined by length of growing period (LGP). The LGPs are calculated as the amount of time, under sufficient temperature and moisture, to grow crops, with each category representing a 60-day LGP (i.e. LGP1= 0-59 days, LGP2= 60-119 days, etc.). Each of the six LGPs are depicted in each climatic zone by the gradient of colours (i.e. darker shades imply longer growing periods). A more detailed map of North American AEZs is provided below in Figure 4.

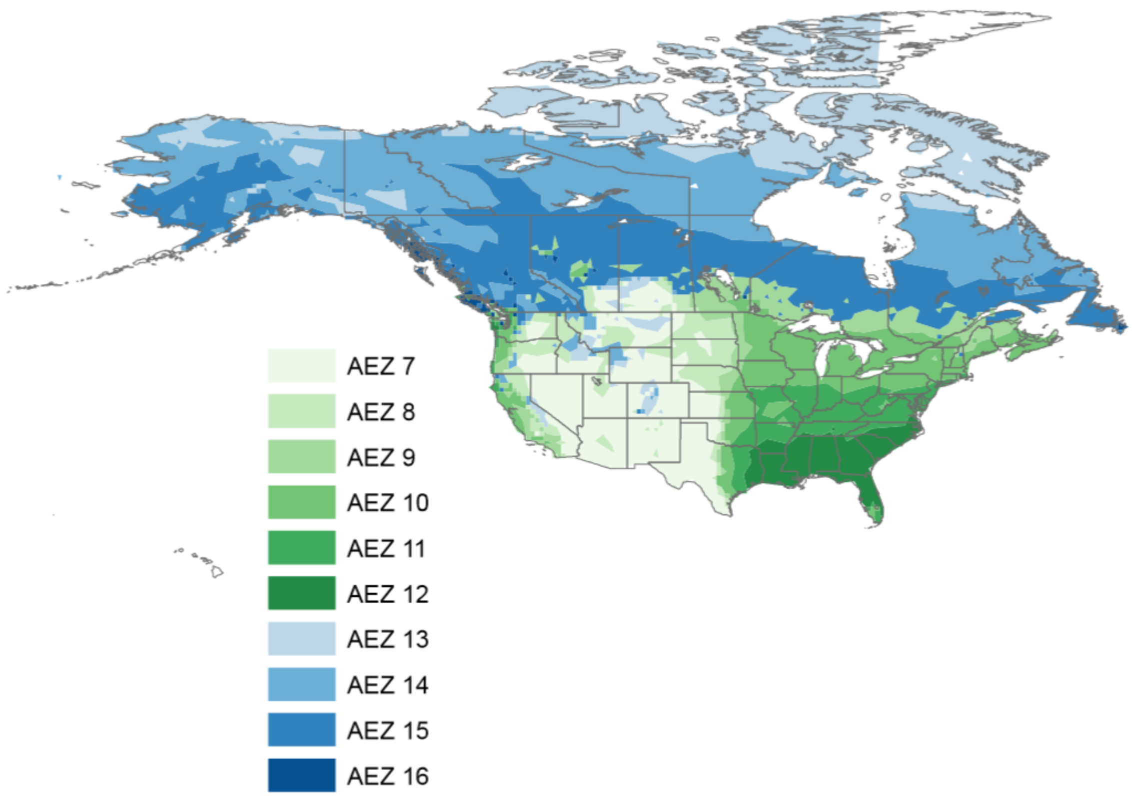



*Figure 4. North American Agro-Ecological Zones*
Source: GTAP 2015c

The GTAP land use data are organized by AEZ and land activity (i.e. crops, livestock, and forestry); allocated land is immobile across AEZs, but can be reallocated across activities within an AEZ depending on relative returns (Lee et al. 2005). We assume that hybrid poplar will grow in AEZ 15 in Canada, a boreal climate zone with a moist semi-arid moisture regime (Lee et al. 2005).

According to Table 5, AEZ 15 in Canada has just over 47 million hectares of land. Over half of this land is forest (69 percent), while approximately 17 percent is cropland, 11 percent is pasture, and 3 percent is unmanaged.

*Table 4. Land Cover Details for AEZ 15 in Canada*

| | *Land Cover Type* | | | | |
|---|---|---|---|---|---|
| | *Forest* | *Cropland* | *Pasture* | *Unmanaged* | **TOTAL** |
| Land Cover (hectares) | 32,701,778 | 7,821,960 | 5,222,736 | 1,322,857 | **47,069,330** |
| Land Cover (percentage) | 69 | 17 | 11 | 3 | **100** |

Source: Narayanan and Walmsley 2008

For this study, we model AEZ 15 to incorporate a marginal land type suitable for hybrid poplar growth. The GTAP-BIO-ADVF model includes marginal land under the category cropland-pasture, which is nested under cropland. In the original model, this land type did not exist in Canada; here, the model was modified to take 2 million hectares of pastureland in the base data and move it into cropland-pasture (hereafter referred to simply as “marginal land”). Thus the pasture-using sectors (ruminant and dairy) now make use of both pastureland and marginal land. The amount of marginal land assumed is chosen by estimating areas that would likely be available to an exotic tree species, given that Canadian government regulations restrict the use of exotic tree species on the vast majority of crown land. As such, it could be argued that the edge of the green and white zone, which delineates public and private land, could be the most feasible area of marginal land available for hybrid poplar growth. A buffer zone along the edge of the green and white zone with a width of 10km is used to estimate potentially available marginal land in Alberta, depicted below in Figure 5.

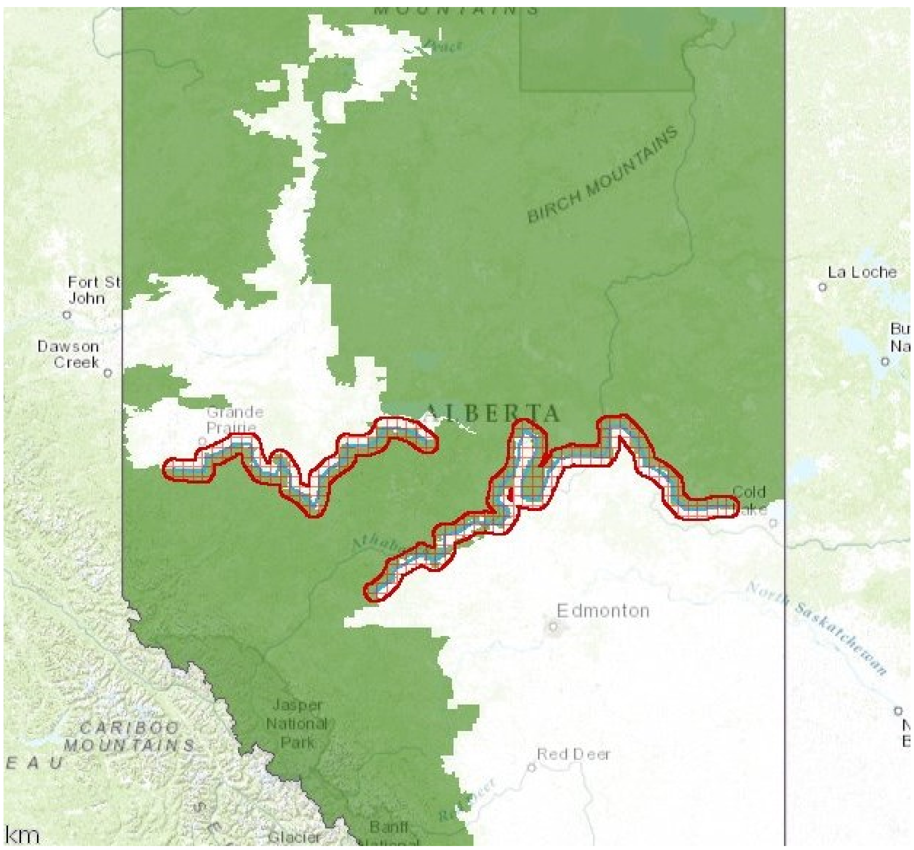



*Figure 5. Estimated Area of Marginal Land in Alberta*

Source: Alberta Agriculture and Forestry 2015b

The area depicted in Figure 5 totals approximately 1.5 million hectares. Given that there are likely other areas of available marginal land in Canada, but still remaining conservative, we assume a total amount of marginal land of 2 million hectares. Note that the area depicted above is used simply as a means to estimate a reasonable amount of marginal land. The GTAP-BIO-ADVF is not adequately disaggregated to actually restrict marginal land to this region; instead, the model will assume that the entirety of AEZ 15 has 2 million hectares of available marginal land, without any further spatial information.

### 3.4 Tax and Welfare Calculations

In order to increase the output of a given commodity in the model, the model requires that the output variable, which is originally endogenous in the model, be swapped with a tax/subsidy variable, which is originally exogenous in the model. This swap effectively makes the commodity's output exogenous, allowing it to be increased to a desired level. In the GTAP-BIO-ADVF model, we swap the output of ethanol with a tax on private household consumption of ethanol. Ethanol production can then be increased, and the tax on private household consumption of ethanol becomes endogenous and determined within the model. Therefore, as ethanol output is increased, consumer and producer prices are automatically adjusted to account for the necessary consumer tax or subsidy. We calculate the respective consumer ethanol tax per unit of production using the following equation:

*Equation 2.*

$$Tax = \frac{VDPA - VDPM}{\Delta\ output}$$

where:
VDPA = Household domestic purchases at agent's (consumer) prices
VDPM = Household domestic purchases at market (producer) prices
$\Delta\ output$ = Change in ethanol production

According to Equation 2, if *VDPA>VDPM*, then a positive value will result and the (2004) USD per gallon value will represent a consumer tax, if the opposite occurs then we have a consumer subsidy. When increasing ethanol production, it follows that a consumer subsidy will result in order to encourage the consumption of the additional production. In the GTAP-BIO-ADVF model, the resulting consumer subsidy is offset by an equivalent tax on fuel, so that the net change to household income is zero.

In the GTAP model, equivalent variation (EV) is used as the metric for welfare for the regional household. It is calculated by measuring the difference between the regional expenditure needed to achieve the post-simulation utility level with the original prices ($Y_{EV}$), and the original level of expenditure ($\bar{Y}$) (Huff and Hertel 2000):

*Equation 3.*

$$EV = Y_{EV} - \bar{Y}$$

Although it is possible to decompose the influences of different factors on the change in EV in the GTAP model, here we simply highlight the change in EV associated with the policy scenarios for comparative purposes.

### 3.5 Scenarios

Descriptions of each scenario are described in sections 3.5.1 to 3.5.5 below. The GTAP commands used to perform the simulations are included in Appendix 2. Note that subsidy support for first-generation ethanol in Canada has changed over time, varying by province and based on specific levels of production. According to Campbell et al. (*in press*), virtually all direct production subsidies for ethanol will be phased out in Canada by 2017. Therefore, the scenarios assume zero subsidy for first-generation ethanol. For cellulosic ethanol, we adopt the same subsidy assumption that has been applied to cellulosic ethanol in the US of (2004) USD 1.01 per gallon (Taheripour et al. 2011b).

#### 3.5.1 Baseline Simulation

According to the GTAP-BIO-ADVF base data, the amount of first-generation ethanol production in Canada in 2004 was approximately 200 million litres. But, according to Campbell et al. (*in press*), the 2013 annual production capacity of Canadian ethanol was approximately 1.8 billion litres, which equates to a blend of 4.4% domestic ethanol in gasoline[6]. Therefore, the baseline simulation involves increasing first-generation ethanol production in Canada from the model's

[6]The blended percentages are based on the net sales of gasoline in Canada in the year 2013, totalling approximately 41 billion litres (Statistics Canada 2014).

2004 base data up to the current (i.e. 2013) production level, creating new starting conditions for policy scenarios. Since Canada is not currently exporting ethanol to the US, Canadian ethanol exports to the US are held constant[7]. Feedstock for first-generation ethanol production is constrained to cropland (excluding marginal land) and pasture. As approximately 94% of Canadian forestland is publicly owned (i.e. crown land) (Canadian Forest Service 2014), we assume that all forestland in the GTAP-BIO-ADVF model is Canadian crown land and thus unavailable for ethanol feedstock growth. The new starting conditions resulting from the baseline simulation are used for the following policy scenarios.

### 3.5.2 First-Generation Ethanol Scenario

The first-generation ethanol scenario involves modelling a potential policy that would increase first-generation ethanol production in Canada. The scenario raises first-generation ethanol production by 1.8 billion litres to bring total ethanol production up to 3.6 billion litres. In order to simulate a potential blending mandate for the domestically produced first-generation ethanol, ethanol consumption is restricted to Canada. As such, exports of first-generation ethanol to the US are constrained to zero. The public ownership of forestland in Canada makes forestland unavailable for crop production. Therefore, land available for coarse grain production in this scenario is restricted to cropland (including marginal land) and pasture, leaving forestland unavailable for ethanol feedstock production.

[7]Canada does import some ethanol from the US (Campbell et al. *in press*); however, in the interest of focusing on the direct economic impacts of Canadian ethanol production, US production is not updated to current levels and there is no change to exports from the US to Canada, which are virtually zero in the base data.

### 3.5.3 Cellulosic Ethanol on Private Land Scenario

This scenario involves increasing ethanol from hybrid poplar feedstock in Canada to 1.8 billion litres on top of the updated baseline data to bring total ethanol production up to 3.6 billion litres. As per the previous scenario, Canadian ethanol exports to the US are fixed. Forestland will not be considered in this scenario in compliance with Canadian forestry legislation that restricts the growth of exotic trees on crown lands. In other words, land available for hybrid poplar growth is private cropland (including marginal land) and pasture.

### 3.5.4 Cellulosic Ethanol on Crown Land Scenario

Canadian forest legislation forbids the planting of exotic trees on the vast majority of crown land (i.e. forest lands). In this scenario, we model a potential policy where Canadian governments allow hybrid poplar plantations on crown lands for the purpose of producing ethanol feedstock. The model is identical to the previous scenario, but the constraint restricting the use of forestland is lifted. Furthermore, in an effort to directly compare the use of private land and crown land for hybrid poplar production, cropland is made unavailable so that hybrid poplar is restricted to forest land, marginal land, and pasture.

### 3.5.5 Sensitivity Analysis

It is important to evaluate how changes to key model assumptions impact the results of this study. In the original scenarios, it is assumed that the ethanol production increases happen in isolation of other economic changes. In reality, we know that there are countless other economic effects that could happen alongside these potential policies. Here, we simulate two sensitivity analyses. The first analysis models a crop productivity change in Canada potentially resulting from climate change; the original policy scenarios are re-run under an increased crop productivity, and the results are compared. The second sensitivity analysis evaluates the emergence of ethanol under an increase in the price of oil, without an introduced blending mandate.

#### 3.5.5.1 Crop Productivity Sensitivity

Changing crop productivity has been noted as a potentially significant outcome of our changing climate. In a highly cited article by Parry et al. (2004), the authors simulated a number of potential climate change scenarios under various socio-economic conditions. They suggest that the impacts of climate change to crop yields will vary by region, with developed countries at higher latitudes seeing benefits from climate change due to less extreme temperature increases and higher atmospheric carbon dioxide, which can act as a fertilizer for crops. For Canada, their results indicate that yields could increase somewhere between 2.5 percent and 10 percent by 2080. In this sensitivity analysis, we evaluate the original results under a 10% increase in crop productivity for wheat, coarse grains, and oilseeds.

#### 3.5.5.2 Oil Price Sensitivity

A number of studies have evaluated the relationship between oil prices and renewable fuel markets (Hedenus et al. 2010; Zafeiriou et al. 2014; Tokgoz et al. 2008). Indeed, an increase in the price of crude oil has been noted as being a major driver for the ethanol industry (Birur et al. 2008). Ethanol could become much more viable under high oil prices, stimulating production around the world. However, many countries have employed government policy, like blending mandates and production subsidies, as a means to stimulate domestic ethanol production. In Canada, domestic ethanol production has emerged and grown in step with government support since the 1980s (Campbell et al., *in press*). But without the support of government mandates, how does the Canadian ethanol industry react under a high price of oil? In this sensitivity analysis, we simulate a 100% increase in the world price of oil and allow ethanol production to change endogenously in the model.

# Chapter 4: Results and Discussion

The results of this study are divided into four main sections. Section 4.1 includes results for the baseline simulation used to update the starting conditions for policy scenarios. Section 4.2 includes results and discussions for the three policy scenarios, described through effects on land, prices, outputs, trade, taxes, and welfare[8]. Finally, Section 4.3 includes sensitivity analyses of crop productivity and oil price changes.

## 4.1 Baseline Simulation

In this simulation, first-generation ethanol production in Canada is updated from the 2004 level to the 2013 level. The post-simulation results are used as the updated base data for policy scenarios modelling ethanol production beyond 2013. Therefore, the results that follow are relative to the updated data.  The new starting conditions are provided in Appendix 3, Table 9.

Updating first-generation ethanol production to 1.8 billion litres in the baseline simulation results in approximately 500,000 hectares of cropland redirected from wheat, oilseeds, other agricultural goods[9], to coarse grains. In the 2014-2015 season, the total harvested area of coarse grains in Canada was approximately 4,407,000 hectares (Agriculture and Agri-Food Canada 2015). Therefore, an increase in harvested area of 500,000 hectares represents an approximately 11% increase of the current harvested area devoted to coarse grains.

[8]Recall that welfare is calculated as equivalent variation.

[9]Other agricultural goods include other crops such as flowers, spices, fodder roots, hay; plant fibres including cotton, flax, and hemp; fruits and vegetables, and more.

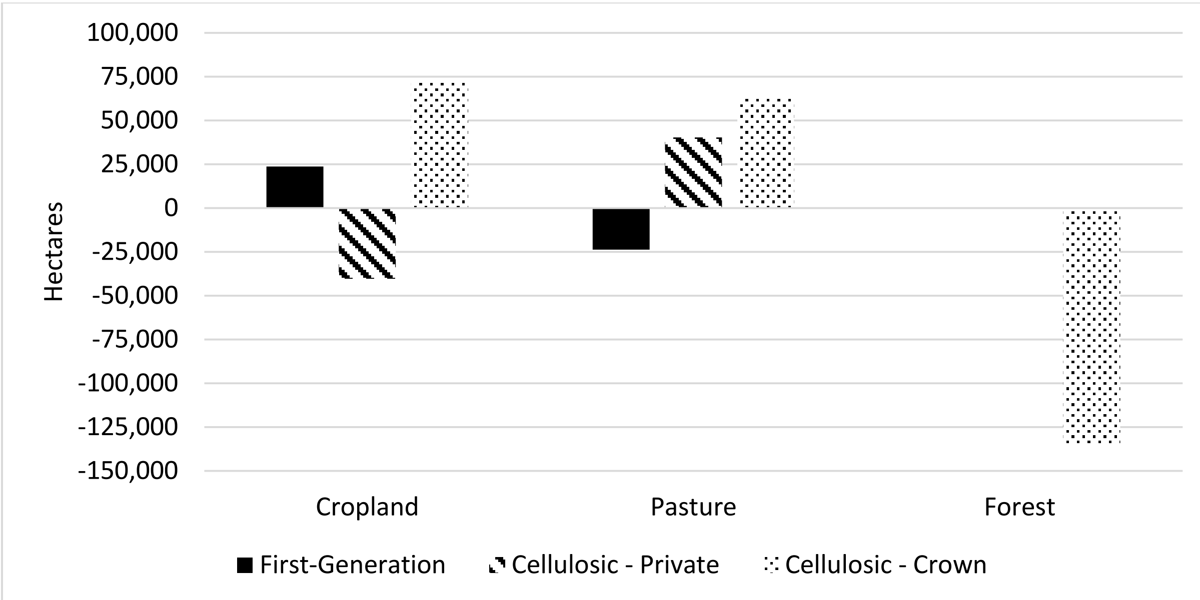
### 4.2 Policy Scenario Results

The policy scenarios involve modelling future ethanol production from first- and second-generation feedstock sources, with and without various land restrictions. The first-generation ethanol scenario doubles current ethanol production using only coarse grain feedstock on private cropland or pasture. The cellulosic on private land scenario doubles current ethanol production from hybrid poplar feedstock, while also not allowing use of forestland. Finally, the cellulosic on crown land scenario doubles current ethanol production using hybrid poplar feedstock without allowing the use of cropland and instead allows hybrid poplar to grow on crown forestland in order to directly compare the trade-offs associated with private and public land use for hybrid poplar growth[10]. The results and discussions of the policy scenarios with respect to land, price, output, trade, tax, and welfare effects are detailed below, respectively, in subsections 4.2.1 to 4.2.4.

#### 4.2.1. Land Effects

Total land area in the GTAP-BIO-ADVF model is allocated across into 3 broad categories: cropland, forest, and pasture. Figure 6 depicts land use changes occurring to the 3 major land categories for each scenario.

[10]We also ran the scenario without holding cropland constant, and the results were not meaningfully different.

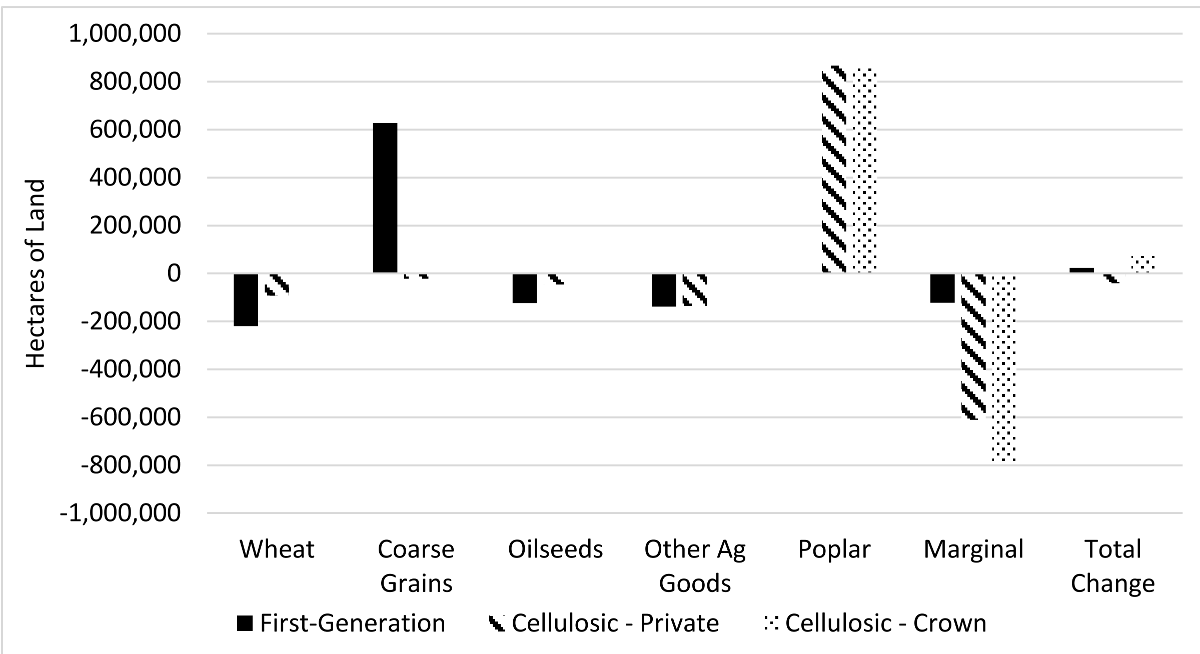



Notes: The policy scenarios depicted in the legend are described in detail in section 3.5.
Forest area does not include hybrid poplar, which is categorized under the cropland category. Here, changes to forest area would affect the production of conventional forest products.

*Figure 6. Change in Area of Major Land Categories in Canada for Policy Scenarios*

Figure 6 shows that the first-generation ethanol scenario results in an increase in area devoted to cropland of approximately 24,000 hectares, and an equivalent decrease in area used for pasture. In the cellulosic on private land scenario, approximately 40,000 hectares of cropland is converted, with area devoted to pasture use increasing by the same amount. The cellulosic on crown land scenario results in land use increases for both cropland and pasture of approximately 72,000 hectares and 62,000 hectares, respectively, while approximately 135,000 hectares of forest area is converted to another use.

It is important to note that the model does not track specific changes to areas of land, but rather captures the net change of land transitions across the three major land categories. For example, as we see one major land category decrease and another increase, it is not necessarily true that former land type is being converted to the latter. But, because the cropland category is further disaggregated into various cropland components including wheat, coarse grains, oilseeds, other agricultural goods, hybrid polar, and marginal land, we can observe movements within the cropland category.  Figure 7 depicts changes occurring to the individual cropland categories, as well as the total change to cropland overall, for each policy scenario.




Notes: The policy scenarios depicted in the legend are described in detail in section 3.5.

*Figure 7. Change in Area of Cropland Categories in Canada for Policy Scenarios*

Figure 7 shows that the first-generation ethanol scenario requires approximately 628,000 hectares of cropland to produce the necessary amount of coarse grain feedstock, an increase of over 8%. Cropland used for wheat, oilseeds, other agricultural goods, and marginal land is converted. The largest conversion occurs to the wheat sector, at approximately 220,000 hectares, followed by other agricultural goods, oilseeds, and marginal land, each with less than 150,000 hectares in decreased land use. There is a larger area of land required for coarse grain production in the first-generation scenario than is converted from other cropland-using commodities, indicating that additional land from non-cropland sources (i.e. forestry or pasture) is converted. Figure 6 depicted the additional conversion, showing 24,000 hectares of pastureland being converted to cropland to satisfy the demand by the coarse grain industry.

The cellulosic on private land scenario requires approximately 867,000 hectares of land to produce hybrid poplar feedstock. Approximately 610,000 hectares of marginal land is converted, with less than 150,000 hectares of land coming from each of the other uses of cropland. In total, there is a larger area of cropland being converted than the increase in area devoted to hybrid poplar, indicating that some cropland is being converted for uses other than hybrid poplar production. Figure 6 shows that approximately 40,000 hectares of cropland is being converted to the pasture area. We know that marginal land, a component of cropland, is able to revert back to pasture (where it was originally converted from in the model). Recall that the parameter dictating this land substitution is labelled "EPSR". In this model, EPSR is assumed a value of 2, implying an elastic substitution between marginal land and pasture. It is likely that some of the marginal land being converted is being used for hybrid poplar production, and some for pasture.

The cellulosic on crown land scenario requires about 861,000 hectares of land for hybrid poplar growth, with about 788,000 hectares of marginal land being converted, and no conversion of cropland. The cellulosic on crown land scenario is relatively more complex than the first two scenarios, as all land categories (cropland, forest, and pasture) change. In Figure 7 we saw a net positive cropland balance for the crown land scenario of approximately 72,000 hectares, thus the required land for poplar growth is slightly larger than the area used from marginal land. Additionally, we know that not all of that marginal land is necessarily converted to poplar growth, but may have converted to pasture. Figure 6 showed that approximately 62,000 hectares of land is gained in the livestock sector, and about 135,000 hectares of land is lost from the forest sector. Therefore, we can conclude that the increase in poplar and pasture area is being satisfied by both marginal land and forestland conversion.

The ethanol industry's impact on land use change has been a point of contention for ethanol opponents. The use of prime agricultural land and crops for ethanol feedstock growth has been heavily criticized. Indeed, one of the primary arguments supporting cellulosic ethanol is that cellulosic feedstock can alleviate some of the cropland pressures that first-generation feedstocks have caused (Hill et al. 2006). The land-use results presented above indicate notable differences in cropland impacts between first- and second-generation ethanol. The first-generation ethanol and cellulosic on private land scenarios negatively impact land availability of non-feedstock crop commodities due to required cropland conversion for ethanol feedstock. However, the land impact to wheat, oilseeds, and other agricultural goods is relatively larger in the case of first-generation production, as coarse grains require higher quality land and thus cannot use as much of the lower quality marginal land as hybrid poplar in the cellulosic scenarios. Therefore, the availability of marginal land plays a key role in these results. Hybrid poplar requires more land area than coarse grains to produce the same amount of ethanol.

Without the availability of marginal land, the cellulosic scenarios would likely result in the conversion of higher quality cropland.

### 4.2.2 Price and Output Effects

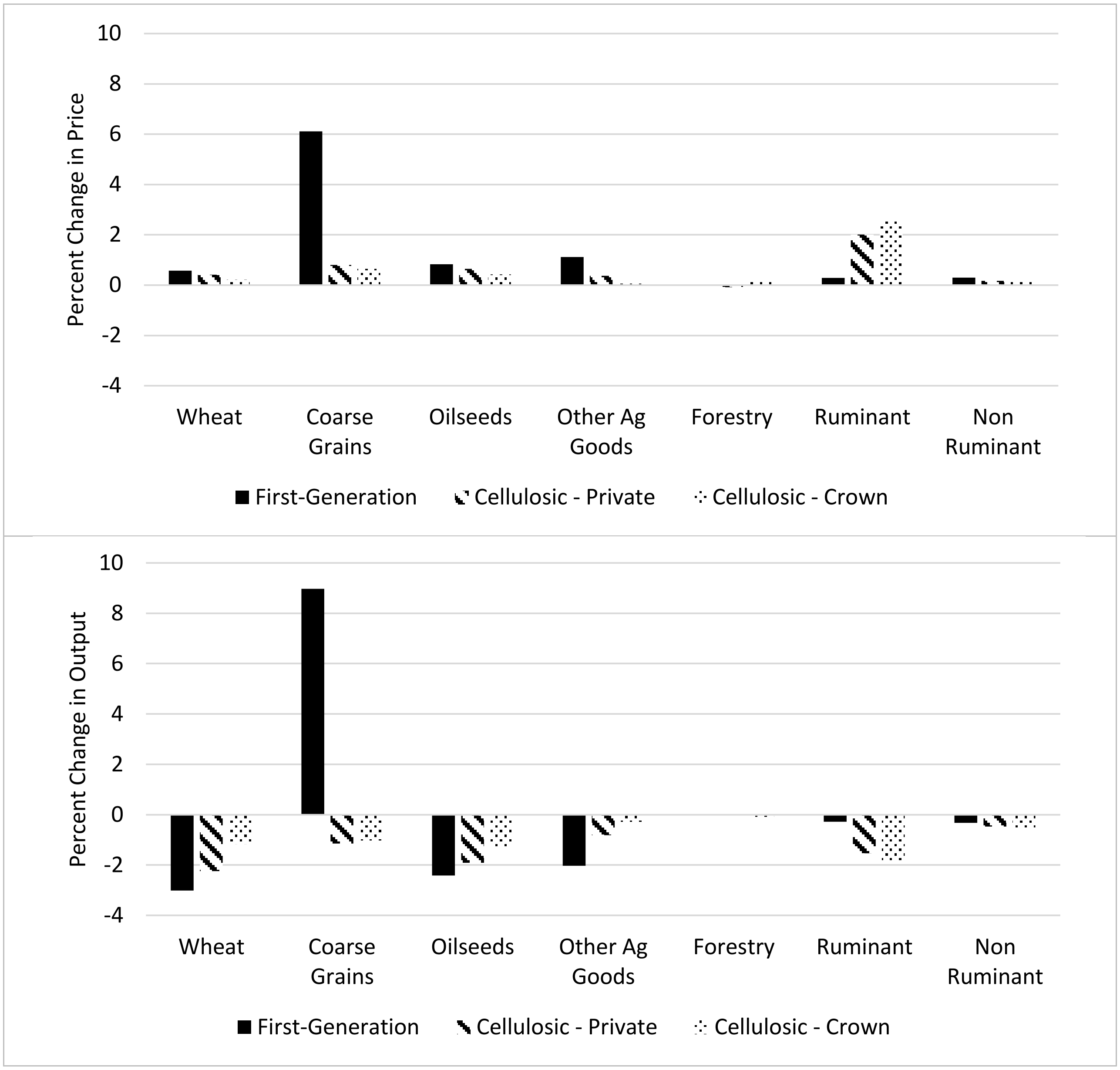
Figure 8 illustrates key differences in price and output impacts between the policy scenarios. The first-generation ethanol scenario results in increases of approximately 6% and 9% for the output and price of coarse grains, respectively. Furthermore, there are output decreases and price increases for all other agricultural products. Coinciding with the largest loss of land depicted in Figure 7, wheat experiences the largest output decrease of approximately 3%, but the smallest price increase of approximately 0.6%. Output decreases for oilseeds and other agricultural goods are approximately 2.4% and 2%, with prices increases of approximately 0.8% and 1.1%, respectively.

For the cellulosic on private land scenario, we see the largest price impacts occurring to ruminant[11] goods, associated with a decrease in output. This scenario also results in output decreases and price increases for wheat, oilseeds, and other agricultural goods, but to a lesser extent than the first-generation scenario.

The cellulosic on crown land scenario leads to the smallest output decreases and price increases for agriculture commodities of all the policy scenarios. Reduced output and increased prices for wheat and oilseeds in the private land scenario are almost double those of the crown land scenario, whereas impacts to the ruminant industry are slightly larger in the crown land scenario.

[11]Note, the dairy sector is ignored here as it is regulated by supply management in Canada and thus any changes that may occur in the model would not be an appropriate representation of reality.

As the private land scenario restricts the use of forestland, there are very minimal output and price changes occurring in the forest sector. Although the crown land scenario does cause conversion of forestland, the price and output impacts to forest products are also quite small. None of the policy scenarios appear to have much impact on the non-ruminant industry, with output decreases and price increases of less than 0.5%.




Notes: The policy scenarios depicted in the legend are described in detail in section 3.5.

*Figure 8. Percent Changes in Prices (top) and Output (bottom) of Agriculture and Forest Commodities in Canada for Policy Scenarios*

Land use changes contribute to changes in commodity production and prices. First-generation ethanol causes greater price impacts on crop commodities than cellulosic ethanol, particularly for the coarse grain feedstock. However, it is important to note that the GTAP-BIO-ADVF model assumes all Canadian first-generation ethanol is produced from coarse grain feedstock, i.e. corn. In fact, over 25% of Canadian ethanol production comes from wheat feedstock, with 475 million litres produced from wheat feedstock plants in Saskatchewan and Manitoba (Campbell et al. *in press*)[12]. Therefore, these results likely overestimate the impacts on coarse grains and subsequent effects across crop commodities. Nonetheless, the use of coarse grains for ethanol production pushes coarse grain prices upward and subsequently reduces production of other commodities, increasing their prices as well.

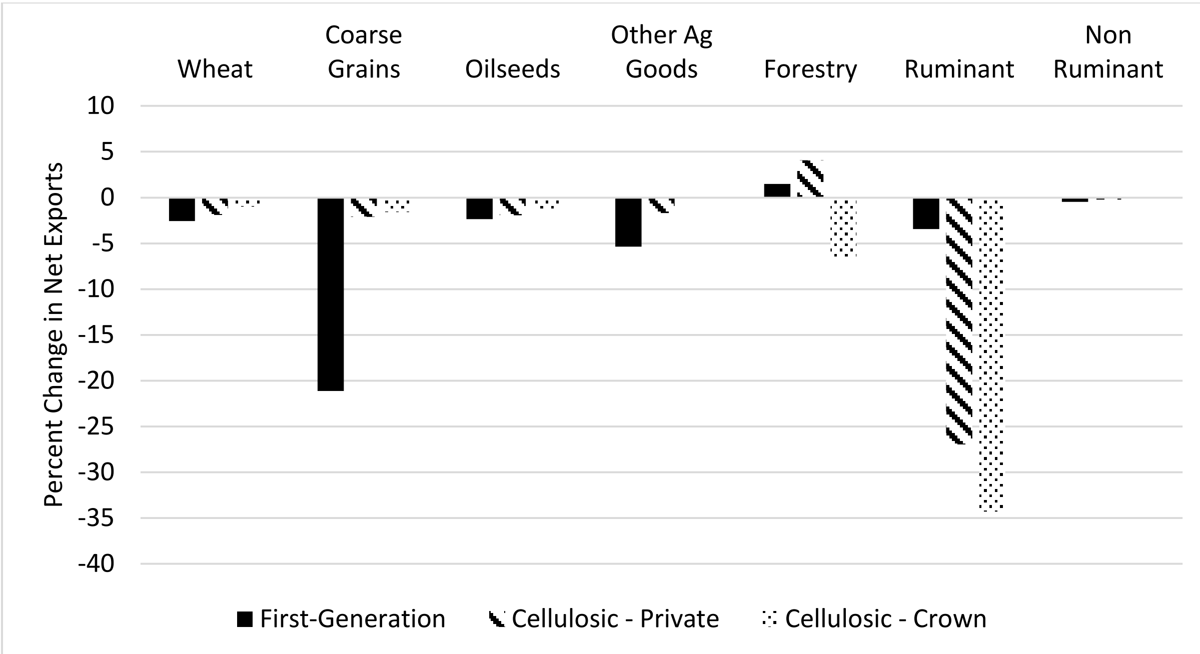
The cellulosic scenarios also raise crop prices, but only slightly, with no increase over 1%, unlike first-generation ethanol, which increases coarse grain prices by over 6%. Alternatively, cellulosic ethanol appears to have more of an impact on the ruminant industry relative to first-generation ethanol. In both cellulosic scenarios, pasture area (used by the ruminant industry) increases, which at first glance would seem like a positive impact on the sector. However, the conversion of marginal land (which is also used by the ruminant sector) to hybrid poplar production ultimately shrinks ruminant output and leads to an increase in price. Furthermore, the increased price of crop commodities contributes to more expensive livestock feed. In the GTAP-BIO-ADVF model, distiller's dried grains with solubles (DDGS) are produced as a by-product of first-generation ethanol and are available to the ruminant and non-

[12]Future work could include an additional adjustment to the GTAP-BIO-ADVF model to account for the use of wheat feedstock for first-generation ethanol production.

ruminant industries as an imperfect substitute feed in place of coarse grains. In the first-generation ethanol scenario, the large increase in coarse-grain production coincides with a large increase in DDGS production. Thus, the ability of the ruminant industry to shift to DDGS for livestock feed in place of high priced coarse grains dampens the expected negative impact on that industry. This result is corroborated by Taheripour et al. (2011a), who found that first-generation ethanol by-products such as DDGS play a significant role in protecting the ruminant industry from the increased prices of feed inputs resulting from coarse grain ethanol production. In the case of ethanol from hybrid poplar feedstock, DDGS are not produced as a by-product; therefore, the negative impact that poplar production has on the coarse grain industry raises feed prices and has a relatively larger impact on the livestock commodity than that of first-generation ethanol.

#### 4.2.3 Trade Effects

Figure 9 illustrates changes in net exports for all scenarios. All scenarios result in decreased net exports for all agriculture (non-forest) commodities relative to the baseline scenario. The first-generation ethanol scenario has a particularly large impact on the coarse grains sector, with a net export decrease of approximately 21%, and relatively small impact on the forest sector, with a net export increase of approximately 1.5%.




Notes: The policy scenarios depicted in the legend are described in detail in section 3.5.

*Figure 9. Percent Change in Net Exports of Agriculture Commodities in Canada for Policy Scenarios*[13,14]

The cellulosic scenarios both cause decreased net exports for the ruminant industry (as a consequence of reduced domestic production) with large declines of 27% and 34% for the private land and crown land scenarios, respectively. The small price changes of forest products occurring in both cellulosic scenarios result in some changes to net exports, with the private land scenario experiencing about a 4% increase and the crown land scenario resulting in a decrease of

[13]The GTAP-BIO-ADVF model makes use of the Armington assumption for bilateral trade, where imported goods are differentiated by their country-of-origin. In reality, not all goods are necessarily differentiated to such a large degree. If foreign agricultural goods are treated more homogeneously by the importer, then the effect of increased domestic prices on Canada's net exports may be less severe than the results presented here.

[14]The percent changes in net exports were calculated using the resulting level change in the value of net exports (provided by the "DTBALi" variable) and the original value of net exports in the updated data calculated at world prices.

approximately 6%. None of the policy scenarios appear to have a substantial impact on net exports for the non-ruminant industry.

The negative impacts on domestic agricultural commodity prices that occur in all policy scenarios extend to Canada's competitiveness in global markets. Both first- and second-generation ethanol negatively affect Canadian trade of agriculture goods, but there are important differences to note. The relatively larger crop price increases that occur in the first-generation ethanol scenario result in larger net export reductions for Canadian wheat, coarse grains, oilseeds, and other agricultural goods, whereas the cellulosic scenarios have a larger impact on ruminant trade. However, when we consider the value of ruminant trade in the updated base data (Appendix 3, Table 9), we can see that imports and exports for the Canadian ruminant sector are relatively small compared to other agricultural goods. Therefore, for the Canadian agriculture sector as a whole, first-generation ethanol production seems to be less favourable for the sector's competitiveness internationally, compared to the cellulosic scenarios.

#### 4.2.4 Tax and Welfare Effects

Welfare effects in the GTAP-BIO-ADVF model are calculated through equivalent variation. However, it is important to note that there are a number of other externalities that these calculations do not consider, such as potential environmental benefits associated with ethanol production, as well as additional economic changes that could change the policy landscape for renewable fuels.

The tax and welfare results provided below in Table 5 show that all policy scenarios require a consumer subsidy (i.e. a negative tax), which contributes to reduced welfare. For all policy scenarios, the consumer subsidy is financed through an equivalent tax increase on fuel;

thus the net impact to consumer income is zero. Nonetheless, there are inefficiencies associated with the provision of the subsidy and collection of the tax, leading the economy away from its initial equilibrium and reducing welfare.

*Table 5. Tax and Welfare Changes for Policy Scenarios*

| | *Policy Scenario* | | |
|---|---|---|---|
| | *First-Generation* | *Cellulosic - Private Land* | *Cellulosic - Crown Land* |
| Tax ([2004] USD/gallon) | -3.03 | -2.10 | -2.13 |
| Welfare (EV - [2004] USD) | -981,114,868 | -1,598,174,072 | -1,615,396,240 |

The first-generation ethanol scenario reduces welfare by almost USD 1 billion, while the two cellulosic scenarios result in welfare decreases of approximately USD 1.6 billion. Recall that cellulosic ethanol also has a producer subsidy of approximately USD 1.01 per gallon. There are a number of factors contributing to these welfare reductions. As mentioned, the provision of a consumer subsidy and collection of a fuel tax causes economic inefficiencies that reduce welfare. Additionally, the policy scenarios ultimately force the economy to produce and consume a relatively more expensive fuel, which negatively affects welfare. There are also inefficiencies associated with the reallocation of land, labour, and capital resources resulting from increased ethanol production. Finally, decreases in net exports for some commodities (e.g. crop sectors) also have negative welfare implications.

The resulting consumer subsidy for the first-generation ethanol scenario is the largest, at approximately USD 3.03 per gallon. The estimated consumer subsidies for the cellulosic scenarios, which also have producer subsidy support, are approximately USD 2.10 and USD 2.13 per gallon for the private land and crown land scenarios, respectively. Relative to the current price of ethanol, which is approximately USD 1.45 per gallon (US Energy Information Administration 2015), these subsidy values represent a significant amount of government support. Furthermore, compared to the estimated social cost of carbon, which has been estimated to be around USD 0.21 per gallon of gasoline (Ackerman and Stanton 2012), the magnitude of these subsidies is certainly substantial. Recall that in the model, consumer subsidies are offset by consumption tax on fuel. Without an equivalent fuel tax, subsidy support would need to come from general government revenue, which can be costly to increase. For example, Fullerton (1991) found that the marginal cost of increasing one extra dollar of tax revenue is approximately USD 1.3. Therefore, consumer subsidy support for ethanol could have larger welfare implications than those presented here.

The estimated consumer subsidies depend on the consumption elasticity of substitution between ethanol and gasoline, which in this study is assumed to have a value of 2. However, as the Canadian ethanol industry grows, and infrastructure becomes more established, a higher elasticity of substitution could be assumed and the necessary consumer subsidy would decline.

### 4.3 Sensitivity Analysis

The above scenarios assume isolated ethanol production increases with no other economic changes occurring. Here, two sensitivity analyses are performed to evaluate important uncertainties in the model. Section 4.4.1 provides the welfare results and discussion for a crop productivity sensitivity analysis, while section 4.4.2 provides the results for an oil price sensitivity analysis.

### 4.3.1 Crop Productivity Sensitivity

This sensitivity analysis replicates the results for all policy scenarios under a 10% yield increase for wheat, coarse grains, and oilseeds. Table 6 shows that, in spite of the improved crop productivity, the mandated ethanol production still results in reduced welfare in all policy scenarios. However, compared to the original results, all scenarios experience less of a welfare reduction under the improved crop productivity. For the first-generation ethanol scenario, the welfare reduction improves by approximately 67%, while the cellulosic scenarios both experience relatively smaller improvements of approximately 38%. Here, we can see that the first-generation ethanol scenario benefits the most from the improved crop productivity. With more efficient production of crops, less land is required to produce the necessary coarse grain feedstock for ethanol production.

*Table 6. Welfare Changes Under 10% Increase in Crop Productivity*

| | *Policy Scenario* | | |
|---|---|---|---|
| | *First-Generation* | *Cellulosic - Private Land* | *Cellulosic - Crown Land* |
| Welfare (EV - [2004] USD) | -326,114,136 | -989,985,596 | -995,113,770 |

For the cellulosic on private land scenario, hybrid poplar is competing for cropland use and as crop productivity improves, cropland becomes more valuable. However, the original cellulosic on private land scenario did not result in full use of marginal land, therefore hybrid poplar feedstock uses relatively more marginal land than the original scenario and less cropland, which is left for more valuable crop production.

The cellulosic on crown land scenario restricts changes to cropland area (except for marginal land) in order to constrain hybrid poplar to marginal land, pasture, and forestland. Improved crop productivity improves the welfare losses relative to the original scenarios since more crops can be produced from the same area of land, weakening the negative impact caused by the mandated ethanol production.

### 4.3.2 Oil Price Sensitivity

This sensitivity analysis simulates a 100% increase in the world price of oil from the updated base data, without any production constraints on ethanol[15]. From Table 7, we can see that there is a substantial increase in Canadian ethanol production under the 100% increase in the world price of oil. Approximately 1.9 billion litres of ethanol production emerges under the oil price increase, without the support of government policy. Here, all emerging ethanol is first-generation ethanol. Hybrid poplar ethanol does not emerge under the oil price increase, likely because both the feedstock and the cellulosic ethanol industries require larger inputs of gasoline than those for

[15]Note that in 2013, a barrel of crude oil was approximately USD 104, so a 100% increase would be approximately USD 208. Although we have not seen an oil price this high, it has reached up to USD 122 within the past decade (Index Mundi 2015).

first-generation ethanol, making hybrid poplar ethanol less competitive under the increased oil price.

*Table 7. Canadian Ethanol Production – 2013 versus 100% Oil Price Increase*

| *Ethanol Production (billions of litres)* | | |
|---|---|---|
| *2013* | *Simulated 100% Oil Price Increase* | *Percentage Change* |
| 1.8 | 3.7 | 106% |

An increased world oil price results in increased ethanol production in other ethanol-producing countries as well, with the US and Brazil experiencing over 100% increases in ethanol production under the higher oil prices to help satisfy the increased global ethanol demand. For Canada, the oil price increase leads to virtually the same level of ethanol production as the imposition of the renewable fuel standard modelled in the original policy scenarios.

# Chapter 5. Conclusions

The objective of this research is to evaluate economy-wide impacts including effects on land, prices, outputs, trade, taxes, and welfare, associated with first- and second-generation ethanol policy scenarios in Canada. Furthermore, current legislation restricting hybrid poplar growth on crown forestland is also considered.

The rising adoption of national ethanol policies to stimulate the domestic production and consumption of renewable fuels has created a need for policy evaluation. The results presented in this research are important because they contribute to a growing literature on the potential for unintended consequences of renewable fuel policies. Indeed, the use of mandates and government subsidies to support domestic ethanol industries have resulted in economy-wide impacts that have stirred much debate regarding the appropriateness of these government interventions. In the United States, inter-industry and inter-regional effects of first-generation ethanol production have been significant, sparking new research on the use of non-food based feedstocks for cellulosic ethanol production. In Canada, the ethanol industry is still in its infancy, but there have been some policies and research projects suggesting a growing interest in cellulosic ethanol production.

This thesis contributes to the literature by examining potential economy-wide impacts in Canada of first-generation ethanol from coarse grain feedstock, and cellulosic ethanol from hybrid poplar feedstock, under various land use constraints. As such, this thesis represents the first formal CGE evaluation of hybrid poplar feedstock for cellulosic ethanol in Canada, and contributes to a small body of literature evaluating Canadian ethanol policy in a CGE framework.

The GTAP-BIO-ADVF CGE model was adopted for this research and was adjusted to include hybrid poplar feedstock in Canada. The inclusion of hybrid poplar into the GTAP-BIO-AVDF model required a number of important assumptions. For instance, a national growth rate for hybrid poplar feedstock had to be assumed. In reality, the productivity of hybrid poplar can vary geographically within Canada, and a more or less conservative assumption for a national average could change the results. A specific land area also needed to be assumed for the model adjustment, limiting the geographic scope of hybrid poplar growth to a specific climatic zone. Again, under different assumptions, the results of this research may differ.

Nonetheless, the results presented in this thesis highlight important differences between first-generation and cellulosic ethanol production in Canada. First-generation ethanol requires relatively more cropland for ethanol feedstock production, resulting in crop price increases of up to 6%, compared to less than 1% for the cellulosic scenarios. Increased coarse grain prices from first-generation ethanol also impacts Canadian trade, with net exports for coarse grains decreasing by over 20%. Rising crop prices can extend to the livestock industry through increased feed costs and result in higher priced meat for consumers (Pimentel et al. 2009). Like Taheripour et al. (2011a), we find that the co-production of DDGS with first-generation ethanol, which can substitute for livestock feed, helps insulate the ruminant industry from the elevated input costs of coarse grains.

Unlike first-generation ethanol, there is no co-production of DDGS with cellulosic ethanol, which contributes to relatively larger impacts to the ruminant industry. The ruminant sector is also negatively impacted in the cellulosic scenarios as a result of marginal land conversion for hybrid poplar growth, which reduces land available for ruminant production.

Ultimately, increased domestic prices in the ruminant sector lead to substantial decreases in net exports between 27 – 34%.

Apart from the relatively larger impacts to the ruminant sector, the cellulosic scenarios appear to result in lower overall domestic and international impacts across agriculture and forest industries, compared to first-generation ethanol. This result hinges on the inclusion of lower quality marginal land in the model. Coarse grain feedstock for first-generation ethanol uses the least amount of marginal land of the policy scenarios, and instead requires the conversion of higher quality cropland for feedstock production. Conversely, hybrid poplar feedstock can make better use of the lower quality marginal land, thus requiring less cropland conversion and causing lower price and output effects to crop commodity sectors. Indeed, under increased crop productivity, the availability of marginal land becomes even more important, as hybrid poplar avoids major competition with valuable cropland in the private land scenario.

For cellulosic ethanol production, the availability of land for fast growing lignocellulosic growth is an important issue given current Canadian land use restrictions. This research highlights two import land use considerations when it comes to cellulosic ethanol feedstock. First, marginal land availability is key for hybrid poplar to compete with first-generation ethanol feedstock. Second, there are important differences between cropland and forestland use for hybrid poplar growth. The results indicate a trade-off regarding impacts to agriculture depending on land use restrictions, where the use of crown land appears to cause smaller inter-industry impacts to agriculture compared to the use of private cropland. However, in an effort to maintain natural biodiversity in Canadian forests, provincial regulations typically require any tree planting on public land to be done with native seeds collected in the area they will be planted (Johnston et al. 2006). Thus, the planting of hybrid poplar seeds on Canadian crown land is essentially not allowed. But there is growing discussion regarding the use of exotic trees in Canada (Anderson et al. *in review*) and the potential benefit of allowing hybrid poplar on crown land for ethanol feedstock is one of many factors that may influence future forest policy.

The tax and welfare results presented in this thesis highlight potentially significant public funding needed to double Canadian ethanol production, coinciding with declined welfare. However, the industry is still in its infancy, and subsidy support would likely decline with technological improvements and decreases in production costs. Furthermore, the negative welfare impacts may not be so severe if we account for additional environmental benefits associated with cellulosic ethanol production.

The economic viability of future ethanol production, whether it be first-generation or cellulosic, is likely to be influenced by the price of oil. The results presented in this research suggest that a 100% increase in the world price of oil leads to over twice as much domestic ethanol production in Canada. How quickly the Canadian ethanol industry is able to react to an oil price change, however, is likely influenced by the established level of production, which is in-turn influenced by existing government policy. Future research might evaluate the role a nation's existing ethanol industry plays in reducing negative economic effects from increased oil prices.

This thesis provides a foundation for future work to improve upon the representativeness of cellulosic ethanol modelling. Two key limitations associated with this study include: *i)* the absence of carbon outcomes of biofuels in the welfare calculation, and *ii)* potential dynamics associated with feedstock and ethanol production that are not accounted for here. Future work could expand on the welfare analysis of cellulosic ethanol production in Canada, specifically by incorporating the carbon benefits of ethanol from hybrid poplar feedstock. Furthermore, future evaluations of cellulosic ethanol in Canada could be performed using dynamic general equilibrium modelling. Indeed, a number of general equilibrium models are recursive dynamic (as mentioned in this thesis), including a dynamic GTAP model called GDyn.

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## Appendix 1. The GTAP Model

Figure 10 provides a graphical representation of the multi-region, open economy GTAP model. At the top of the figure we have the regional household associated with each region (country or other regional aggregation). The regional household collects all income through domestic taxes[16] (*TAXES*), export taxes (*XTAX*), import taxes (*MTAX*), and producer purchases of endowment commodities (value of output at agent's prices, *VOA*). This income is then distributed entirely through three types of final demand: private household (*PRIVEXP*), government (*GOVEXP*), or global savings (*SAVE*). Expenditures from the three sources of demand are distributed to both domestic and foreign producers (producers and rest of world, respectively). For private households, expenditures are characterized by the value of private household purchases, evaluated at agent's prices, on both domestic (*VDPA*) and imported (*VIPA*) commodities. Government expenditures are described in a similar way, with *VDGA* and *VIGA* denoting imported and domestic government purchases. Finally, global savings provide investment for production (*NETINV*).

[16]Taxes or subsidies.

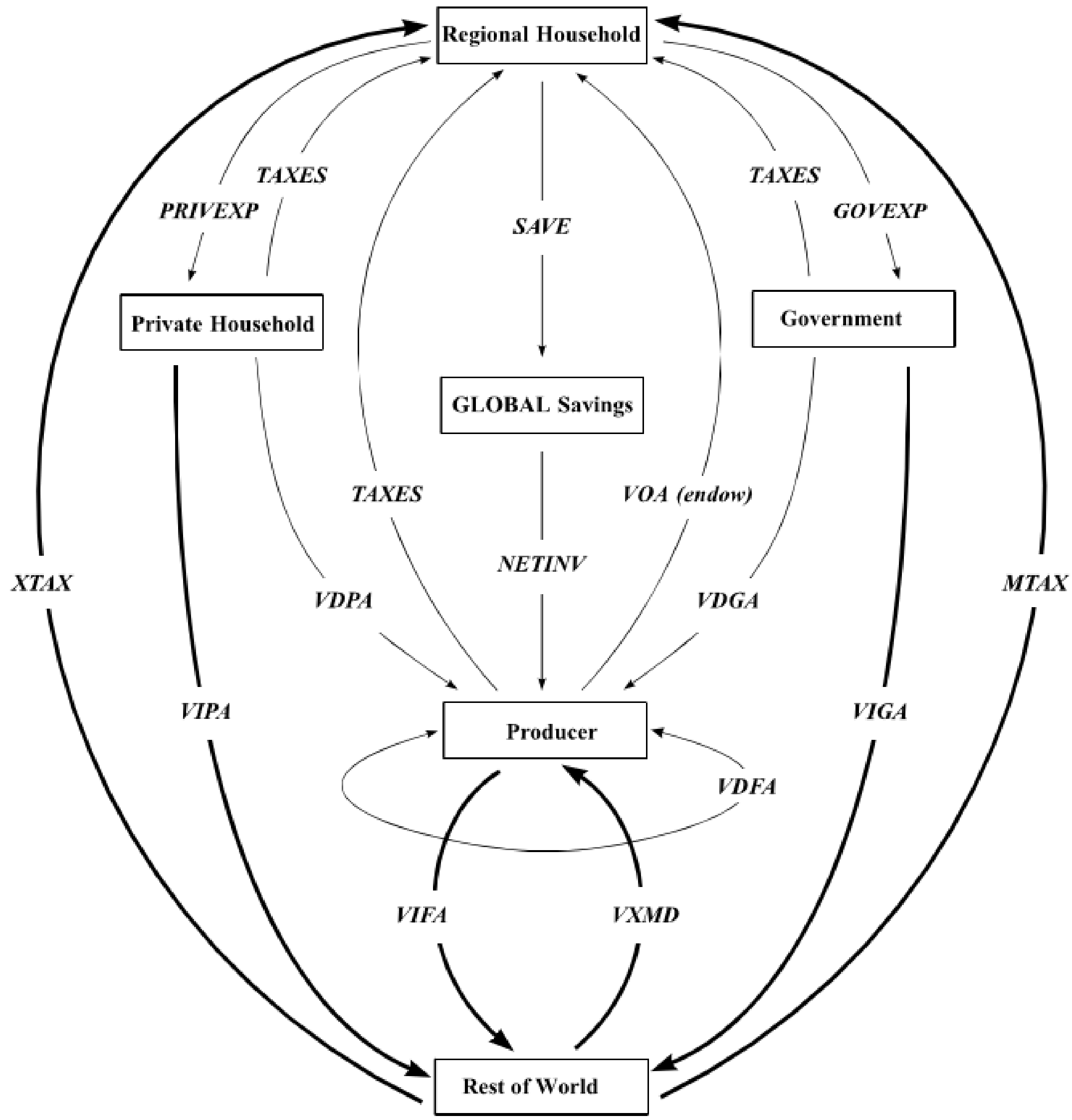


*Figure 10. Multi-Region Open Economy in GTAP Model*
Source: Adapted from Brockmeier 2001

Domestically, producers receive payments through *VDPA, VDGA, NETINV*, and through selling intermediate inputs to other firms (value of domestic firm purchases at agent's prices, *VDFA*). Based on the zero-profit condition, firms exhaust this income through their own expenditure on intermediate inputs (*VDFA*), and through the purchase of endowments (*VOA*). On the international market, firm's purchase imported intermediate inputs (value of imported firm purchases at agent's prices, *VIFA*) and receive income for exporting commodities (value of exports at market prices by destination, *VXMD*).

Finally, the GTAP framework assumes several equilibrium conditions. First, both endowment and tradable goods markets are assumed to clear. Second, a zero pure profit condition is assumed on the production side. Third, households are assumed to have an income-expenditure balance. Finally, there is an assumed balance between savings and investment; this assumption is not imposed but rather assumed indirectly via Walrus' Law, whereby if *n-1* markets are in equilibrium, the final market is in equilibrium as well.

Figure 11 depicts the demand structure for households. As illustrated in the figure, private household demand is structured with a constant difference of elasticity (CDE) functional form[17]. Goods are nested within energy and non-energy commodity groups. Within the energy commodity group, substitution between energy products is more flexible as a constant elasticity of substitution (CES) functional form[18] is the assumed substructure, with an elasticity of substitution *σELEGY*. Biofuels are introduced into this substructure through further nesting and elasticities of substitution (EOS). Here, biofuels compete with petroleum products in the energy commodity group, with the EOS *σELHBIOIL* dictating how easily these products are substituted for one another. Biofuels compete amongst themselves further down the nest with an EOS *σbiofuels*.

[17]For details on CDE demand functional forms, see Hertel (1997).

[18]For details on CES demand functional forms, see Intrilligator et al. (1996), p. 250.

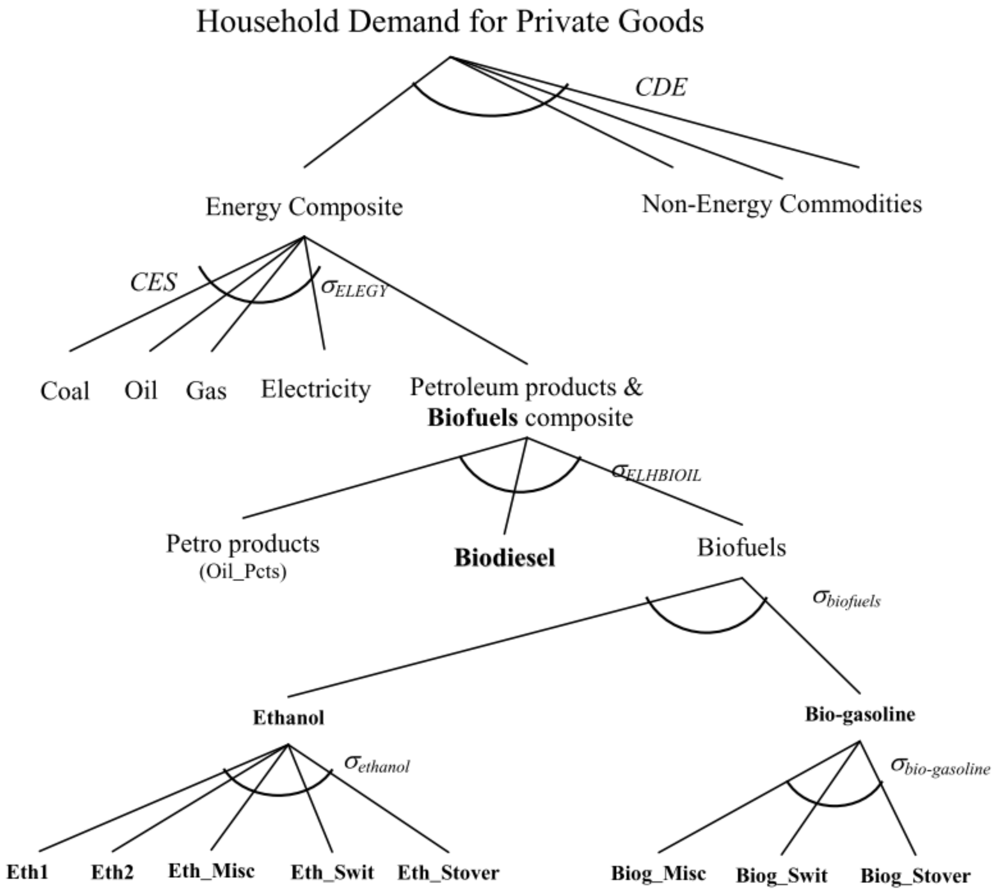


*Figure 11. Household Demand Structure for Private Goods – GTAP-BIO-ADVF Model*
Source: Adapted from Taheripour et al. 2011b

On the production side (Figure 12), biofuels are nested in the firm demand structure for primary and intermediate inputs. A CES demand structure governs the allocation of value added and energy, and non-energy intermediate inputs. Biofuels are incorporated into the capital-energy composite, nested within the petroleum products and biofuels composite. Biofuels compete with petroleum products as an intermediate input for firms with an elasticity of substitution: *σELBIOOL*.

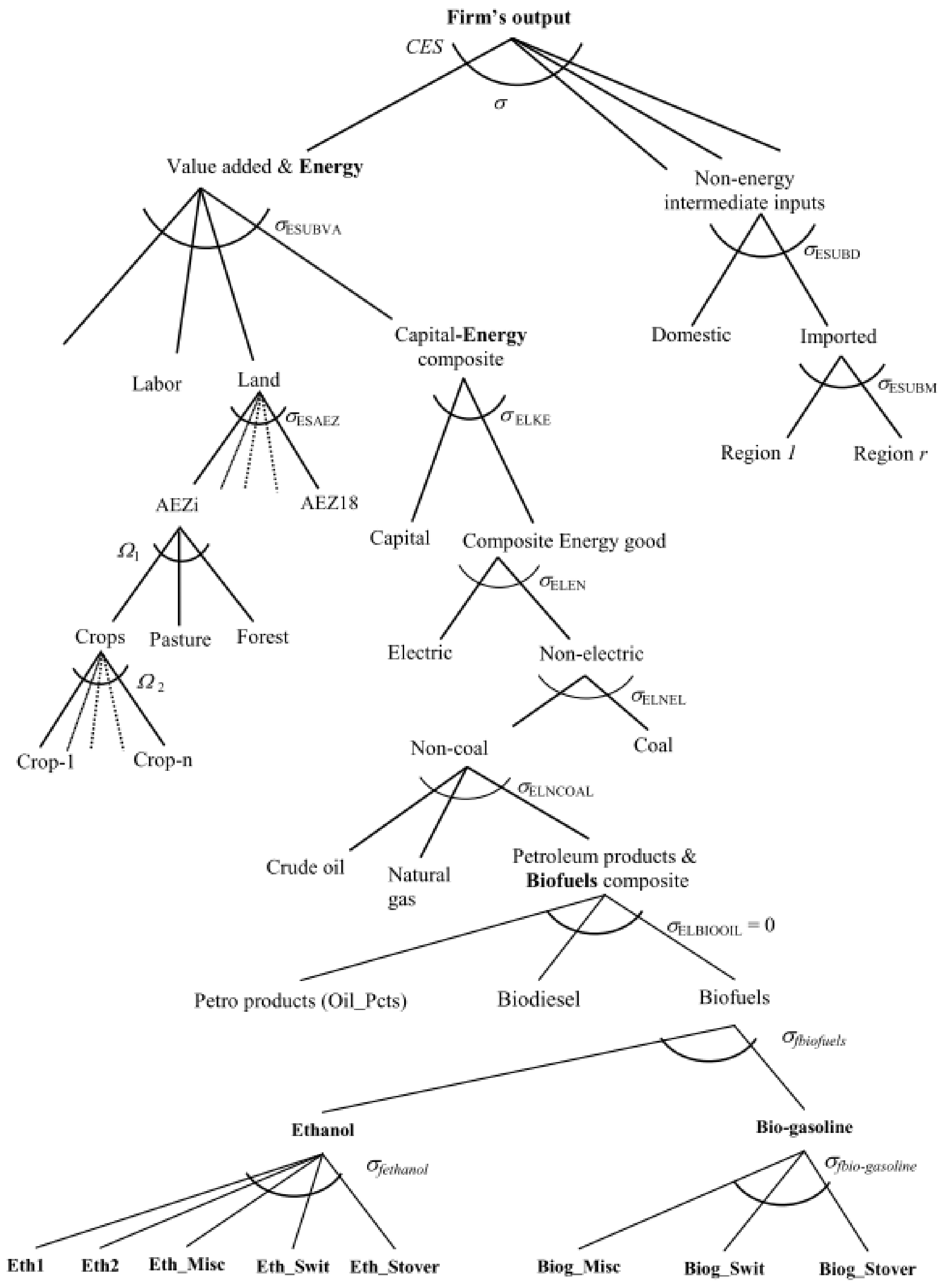


*Figure 12. Firm Demand for Primary and Intermediate Inputs – GTAP-BIO-ADVF Model*

Source: Adapted from Taheripour et al. 2011b

The biofuel products are defined as follows:

*Table 8. GTAP-BIO-ADVF Label Descriptions*

| *Label* | *Fuel* | *Feedstock* |
|---|---|---|
| Eth1 | Ethanol | Corn |
| Eth2 | Ethanol | Sugarcane |
| Eth_Misc | Ethanol | Miscanthus |
| Eth_Swit | Ethanol | Switchgrass |
| Eth_Stover | Ethanol | Corn Stover |
| Biog_Misc | Biogasoline | Miscanthus |
| Biog_Swit | Biogasoline | Switchgrass |
| Biog_Stover | Biogasoline | Corn Stover |

Source: Taheripour et al. 2011b

## Appendix 2. Scenario Commands

The GTAP-BIO-ADVF closure assumes the following variables as exogenous and endogenous:

```
exogenous
    ahenergy
    afenergy
    afall
    afcom
    afreg
    afsec
    ams
    aoall
    aoreg
    aosec
  ! atall                   omitted
    atd
    atf
    atm
    ats
    au
    biodslack
    cgdslack
    consslack
    dpgov
    dppriv
    dpsave
    endwslack
    ethslack
    incomeslack
    pemp
    pfactwld
    pop
    profitslack
    psaveslack
    qo(ENDW_COMM,REG)
    RCTAXB
    tf
  ! tfd                     omitted
  ! tfm                     omitted
    tgd
    tgm
```

```
    tm
    tms
    to
    tpd
    tpm
    tp
    tradslack
    tx
    txs
! add goes nonland
! goes (AEZ_COMM,NLAND_INDS.REG)
    p_LANDCOVER_L(AEZ_COMM, UNMNGLAND,REG)
    tpbio
    ;
Rest Endogenous ;
```

In the following scenarios, variables from the standard closure are "swapped" between exogenous and endogenous and "shocked" according to what impact is being evaluated in the scenario.

**Baseline Simulation**

Commands:

```
!Swap to fix ethanol export from CANADA to US
swap txs("Ethanol1","CAN","USA") = qxs("Ethanol1","CAN","USA");

!Swap: to fix the CRP rents when USDA defends the CRP
swap
tf(AEZ_COMM,"Oth_Ind_Se","USA")=p_HARVSTAREA_L(AEZ_COMM,"Oth_Ind_Se","
USA");

!To boost first-generation ethanol production
swap qo("Ethanol1","CAN") = tpd("Ethanol1","CAN");
Shock qo("Ethanol1","CAN") = 800.0075709;
```

This shock boosts first-generation ethanol production (ethanol1) in CAN from 2004 levels to 1.8 billion litres. The swap and shock ultimately subsidizes ethanol production. To counteract this impact, the following swap is used to increase consumer taxes on fuel as a means to finance the subsidy:

```
!To make the ethanol shock revenue neutral
swap del_taxrpcbio("CAN") = tpbio("CAN");

!To fix cellulosic ethanol (poplar) in Canada
swap qo("advfE_Swit","CAN") = tpd("advfE_Swit","CAN");

!To fix forest landcover in Canada
swap p_LANDCOVER_L(AEZ_COMM,"FORESTRY","CAN") =
tf(AEZ_COMM,"FORESTRY","CAN");

!To fix marginal land area CAN
swap p_HARVSTAREA_L(AEZ_COMM,"PASTURECROP","CAN") =
tf(AEZ_COMM,"PASTURECROP","CAN");

!To fix rice in Canada to help run the model
swap qo("Paddy_Rice","CAN") = tpd("Paddy_Rice ","CAN");

swap pf(AEZ_COMM,"AdvfE_Swit","CAN") =
afall(AEZ_COMM,"AdvfE_Swit","CAN");
```

**First-Generation Ethanol Scenario**

Commands:

```
!Swap to fix ethanol export from CANADA to US
swap txs("Ethanol1","CAN","USA") = qxs("Ethanol1","CAN","USA");

!Swap: to fix the CRP rents when USDA defends the CRP
swap
tf(AEZ_COMM,"Oth_Ind_Se","USA")=p_HARVSTAREA_L(AEZ_COMM,"Oth_Ind_Se","
USA");
```

```
!To boost first-generation ethanol production
swap qo("Ethanol1","CAN") = tpd("Ethanol1","CAN");
Shock qo("Ethanol1","CAN") = 100;

!To make the ethanol shock revenue neutral
swap del_taxrpcbio("CAN") = tpbio("CAN");

!To fix cellulosic ethanol (poplar) in Canada
swap qo("advfE_Swit","CAN") = tpd("advfE_Swit","CAN");

!To fix forest landcover in Canada
swap p_LANDCOVER_L(AEZ_COMM,"FORESTRY","CAN") =
tf(AEZ_COMM,"FORESTRY","CAN");

!To fix rice in Canada to help run the model
swap qo("Paddy_Rice","CAN") = tpd("Paddy_Rice ","CAN");

swap pf(AEZ_COMM,"AdvfE_Swit","CAN") =
afall(AEZ_COMM,"AdvfE_Swit","CAN");
```

**Cellulosic on Private Land Scenario**

Commands:

```
!Swap to fix ethanol export from CANADA to US
swap txs("Ethanol1","CAN","USA") = qxs("Ethanol1","CAN","USA");

!Swap: to fix the CRP rents when USDA defends the CRP
swap
tf(AEZ_COMM,"Oth_Ind_Se","USA")=p_HARVSTAREA_L(AEZ_COMM,"Oth_Ind_Se","
USA");

!To boost poplar ethanol production
swap qo("advfE_Swit","CAN") = tpd("advfE_Swit","CAN");
Shock qo("advfE_Swit","CAN") = 57419.05165;

!To make the ethanol shock revenue neutral
swap del_taxrpcbio("CAN") = tpbio("CAN");
```

```
!To fix first-generation ethanol in Canada
swap qo("Ethanol1","CAN") = tpd("Ethanol1","CAN");

!To fix forest landcover in Canada
swap p_LANDCOVER_L(AEZ_COMM,"FORESTRY","CAN") =
tf(AEZ_COMM,"FORESTRY","CAN");

!To fix rice in Canada to help run the model
swap qo("Paddy_Rice","CAN") = tpd("Paddy_Rice ","CAN");

swap pf(AEZ_COMM,"AdvfE_Swit","CAN") =
afall(AEZ_COMM,"AdvfE_Swit","CAN");
```

**Cellulosic on Crown Land Scenario**

Commands:

```
!Swap to fix ethanol export from CANADA to US
swap txs("Ethanol1","CAN","USA") = qxs("Ethanol1","CAN","USA");

!Swap: to fix the CRP rents when USDA defends the CRP
swap
tf(AEZ_COMM,"Oth_Ind_Se","USA")=p_HARVSTAREA_L(AEZ_COMM,"Oth_Ind_Se","
USA");

!To boost poplar ethanol production
swap qo("advfE_Swit","CAN") = tpd("advfE_Swit","CAN");
Shock qo("advfE_Swit","CAN") = 57419.05165;

To make the ethanol shock revenue neutral
swap del_taxrpcbio("CAN") = tpbio("CAN");

!To fix first-generation ethanol in Canada
swap qo("Ethanol1","CAN") = tpd("Ethanol1","CAN");

!To fix wheat harvest area in CAN
swap p_HARVSTAREA_L(AEZ_COMM,"Wheat","CAN") =
tf(AEZ_COMM,"Wheat","CAN");

!To fix coarse grains harvest area in CAN
swap p_HARVSTAREA_L(AEZ_COMM,"CrGrains","CAN") =
```

```
tf(AEZ_COMM,"CrGrains","CAN");

!To fix oilseeds harvest area in CAN
swap p_HARVSTAREA_L(AEZ_COMM,"Oilseeds","CAN") =
tf(AEZ_COMM,"Oilseeds","CAN");

!To fix other ag goods harvest area in CAN
swap p_HARVSTAREA_L(AEZ_COMM,"OthAgri","CAN") =
tf(AEZ_COMM,"OthAgri","CAN");

!To fix rice in Canada to help run the model
swap qo("Paddy_Rice","CAN") = tpd("Paddy_Rice ","CAN");

swap pf(AEZ_COMM,"AdvfE_Swit","CAN") =
afall(AEZ_COMM,"AdvfE_Swit","CAN");
```

**Crop Productivity Sensitivity**

Commands:

This simulation involves re-running the original scenario models with the following lines of command added:

```
!To shock crop yields
shock aoall("CrGrains","CAN") = 10;
shock aoall("Wheat","CAN") = 10;
shock aoall("Oilseeds","CAN") = 10;
```

**Oil Price Sensitivity**

Commands:

```
!Swap: to fix the CRP rents when USDA defends the CRP
swap
tf(AEZ_COMM,"Oth_Ind_Se","USA")=p_HARVSTAREA_L(AEZ_COMM,"Oth_Ind_Se","
USA");
```

```
!To fix rice in Canada to help run the model
swap qo("Paddy_Rice","CAN") = tpd("Paddy_Rice ","CAN");

!To shock oil price
swap pxwcom("Oil") = aosec("Oil");
shock pxwcom("Oil") = 100;
```

## Appendix 3. Updated Starting Conditions

*Table 9. New Starting Conditions from Baseline Simulation*

| *Good* | | *Area (hectares)* | *Market Price (2004 USDs)*[19] | *Millions of (2004) USDs* Output | *Imports* | *Exports* |
|---|---|---|---|---|---|---|
| Wheat | | 9193999 | 1.0039 | 2972 | 7 | 2857 |
| Coarse Grains | | 7265749 | 1.0341 | 1603 | 310 | 483 |
| Oilseeds | | 6780643 | 1.0055 | 2603 | 338 | 1751 |
| Other Ag Goods | | 10282469 | 1.0071 | 9010 | 4792 | 2266 |
| Forestry | | 10282483 | 0.9999 | 12631 | 487 | 548 |
| Ruminant | Livestock | 18329096 | 1.0018 | 3112 | 47 | 89 |
| Non Ruminant | | | 1.0024 | 5107 | 361 | 1228 |

[19]Note that initial prices in the GTAP model change relative to the model's numeraire, which in the GTAP-BIO-ADVF model is the global primary factor price index labeled "pfactwld".