IMPACTS OF BIOFUELS PRODUCTION ON FOOD INDUSTRY IN THE PRAIRIE REGION OF CANADA

by

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DEDICATION PAGE

I dedicate my dissertation work to my family and many friends. A special feeling of gratitude to my loving parents, Jiancheng and Qizhen whose words of encouragement and push for tenacity ring in my ears. My brother Bin has never left my side and is very special.

I also dedicate this dissertation to my many friends who have supported me throughout the process. I will always appreciate all they have done, especially Qin Xu for helping me develop my technical skills.

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ABSTRACT

On the Canadian Prairies, canola is a main source for biodiesel production and wheat is the primary feedstock for bioethanol production. To raise biofuel production requires a movement of resources and land away from food and grain crops, which would cause food to become scarcer and increase its price. This paper determines the impact of more biofuels production on the food industry. It considers the simultaneous estimation of share equations from both revenue function and distance function. Econometric results exploit the non-stationary nature of the data and the correlations among shares between primal and dual models are exploited by cointegration techniques. Johansen's maximum likelihood estimator is applied to 1971-2007 data from Manitoba, Alberta and Saskatchewan. Morishima elasticity estimates indicate high long run substitutions among crops (wheat, feed grains and canola). A rise in the production of biofuel crops could cause food prices to increase, both for meat and bread.

Key words: revenue function, distance function, cointegration, morishima elasticity

JEL classification: C0, D24 and Q42

LIST OF ABBREVIATIONS USED

U.S.	United States
OECD	The Organization for Economic Department
GJ	Gigajoule
EJ	Exajoule
PJ	Patajoule
bbl	Barrel
CO_2	Carbon dioxide
BOE	Barrel of oil equivalent
EU	European Union
PPF/PPC	Production Possibility Frontier/Production Possibility Curve
MRT	Marginal rate of transformation
D_0	Distance function
x_i	Inputs
y_i	Outputs
P_i	Output price
θ	Corresponding level of efficiency
q_i	Quantity of output *i*
P(x)	Production Possibility Set
r	Revenue function
HES	Hicks' elasticity of substitution
AES(σ_{ij}^A)	Allen elasticity of substitution or Allen/Uzawa elasticity
ε_{ij}	Cross-price elasticity of demand
MES(σ_{ij}^M)	Morishima elasticity of substitution
α's	Parameters for distance function
β's	Parameters for revenue function
Si	Revenue share of output *i*
ρ_{ij}	Antonelli partial elasticity of complementarity
ADF	Augmented Dickey-Fuller test
VARs	Vector Autoregressions
OLS	Ordinary Least Squares
MLS	Maximum Likelihood Estimation

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CHAPTER 1   INTRODUCTION

1.1 The commodity boom

The international commodity markets have experienced three dramatic price booms since the Second World War (Radetzki, 2006). The first commodity boom was caused by the Korean War (1950 – 1951). A massive inventory buildup increased demand and pushed up commodity prices during the following two years. The second commodity boom occurred in 1973 and it tripled the price of oil. This boom was accentuated by market management by the Organization of Petroleum Exporting Countries (OPEC) and by widespread harvest failures. However, the prices fell back dramatically in 1975. Both commodity booms collapsed with the recession of the global economy and excessive inventories were sold out. The third commodity boom started in 2004 and has not yet run its course. As with preceding booms, this was triggered by a demand shock. The global demand for both oil and copper are much higher in this boom than in the past thirty years (Radetzki, 2006). Radetzki (2006) stated that this boom would be more long lasting as commodity inventories had remained low and the world economy was still briskly expanding two years later.

1.1.1 High agricultural commodity prices

Westhoff's study (2008) shows that the prices of wheat, corn, rice, soybeans and many other farm commodities have significantly increased since 2006. For example, the U.S. producer price of corn had more than doubled from 2006 to 2008.

Several studies by international organizations have stated that the extremely high commodity prices might have devastating consequences for vulnerable populations, such as the less developed or import-dependent countries (Schnepf, 2008). Schnepf (2008) also stated that high commodity prices facilitated record farm incomes and also decreased government farm program costs in the United States. However, the costs for food processors and livestock producers have increased and the flames of food price inflation have been stoked as well. Moreover, the highly volatile prices could raise the risks and costs of merchandising the grains. In particular, the cost of routine hedging activities at commodity future exchanges has significantly increased, which has also resulted in reducing the “forward contracting” opportunities for oilseed and grain producers (Schnepf, 2008).

1.1.2 High fossil fuels prices

A report by Shell Canada Limited (2006) argued that due to the increasing demands for fossil fuels and the depletable nature of finite fossil fuel resources, the prices of fossil fuels accelerated during the past decade. The study of Energy Information Administration (EIA) (2007) showed that steam coal price in the OECD regions was $53 US/tonne in 1990 and it increased to $67 US/tonne in 2005. The price of natural gas increased from $2 US/Gigajoules (GJ) in 1990 to $6.6 US/GJ in 2007, though it has fallen more recently. Moreover, the price of crude oil was $80 US/barrel (bbl) in 2007, which was more than 4-fold of its price of $18 US/bbl in 1990. In 2008, the price of crude oil had increased relentlessly. It had reached $135 US/bbl, which rivals the highest values realized during the two past oil crises in 1973 and 1978.

1.2 The role of fossil fuels in climate change

A study by Andres et al. (1998) showed that the global total emission of carbon dioxide (CO_2) from fossil-fuel production increased by more than 500-fold from 1751 to 1950. The following figure demonstrates the increase of the concentration of CO_2 in the atmosphere during 1750 to 1950 (Figure 1) (Neftel et al., 1985; Friedli et al., 1986; Keeling et al., 1995; Etheridge et al., 1996).

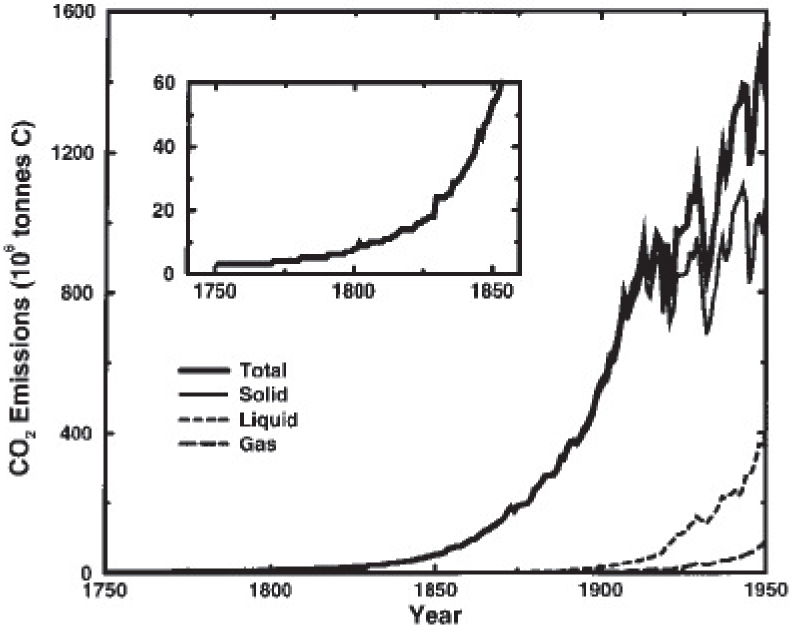

Figure 1: CO_2 Emissions from Fossil-fuel Production, 1751-1950

(Note: the mass of emissions is recorded in terms of C, not CO_2)

Source: Andres et al. (1998, p.762)

The inset is an enlargement of the first one hundred years of data when only solid fuels (i.e., coal, brown coal and peat) were the important sources of emissions. Liquid fuels (i.e., gasoline and diesel) and gaseous fuels (i.e., natural gas) observably increased after 1900. From the record, the emission rate of carbon was 3×10^6 tonnes in 1751. In 1995, the cumulative global total of CO_2 emission from fossil fuel production had reached 250×10^9 tonnes C. Only 25% of this total emission was emitted by 1950, 50% by 1973, and 75% by 1985. As the growth of CO_2 emissions accelerated, a great number of deliberations on the potential for global warming were held (Andres et al., 1998).

Neftel et al. (1985) illustrated that the combustion of fossil fuels is one of the prime contributors to the increase of global CO_2 concentration. With more CO_2 being emitted by the consumption of fossil fuels, the concentration of CO_2 in the atmosphere of the earth is greatly increasing. A study by Keeling et al. (1989a;1989b) indicated that the CO_2 emissions not only interrupt the natural cycling of carbon, but also deepen global warming, which may significantly change the climate of the earth.

Tahvonen and Salo (1999) showed that an agreement to limit the emissions of carbon dioxide and other greenhouse gases was reached by 160 countries in Kyoto, Japan at the end of 1997. As a result, a great number of industrialized countries are facing the problem of determining how to cut down their emissions and at what cost.

1.3 Nonrenewable to renewable energy resources

Renewable, non-depletable energy includes wind energy, hydropower, biomass, geothermal and solar energy (both thermal and photovoltaic). Many of these energy forms have been used since the industrial revolution (Klass, 1998). At an early developmental stage, economies were mainly using renewable energy. However, with the increased usage of fossil fuels, the share of renewable energy decreased (Klass, 1998).

The following figure shows the growth of world population and fossil fuels consumption during the period of 1860 to 1990.

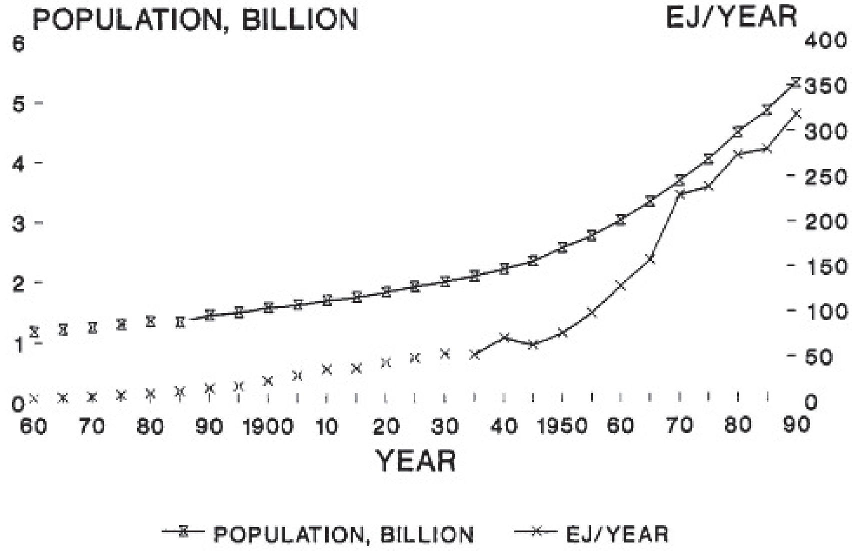

Figure 2: World Population and Consumption of Fossil Fuels, 1860-1990

Source: Klass (1998, p.11)

Klass (1998) stated that the worldwide consumption of fossil fuels grew rapidly in order to meet energy demand in the twentieth century. From 1860 to 1990, the global total energy consumption increased from 16 to 403 exajoules (EJ), and it demonstrated a nearly exponential growth trend (see Figure 2). During this period, the world's population and the fossil fuels consumption per capita passed three and four doubling cycles, but the global consumption of fossil fuels doubled approxiately six times. Because the consumption of energy per-capita in developed or industrialized nations is higher than in developing countries, there is a correlation between a country's energy usage and its living standard (Klass, 1998). Generally, a country with higher living standards would have higher per-capita energy consumption. Thus, the industrialized countries and some of the developing countries with large populations are responsible for most of the fossil fuel consumption. The United States has only 5% of the world's population, but it consumes around 25% of the world's primary energy demand. The energy consumption of the U.S. in 1992 was 56.3 barrel of oil equivalent (BOE)/capita, which was following the top energy consumer of Canada, 69.8 BOE/capita. In 1992, oil, coal and natural gas contributed 41%, 23%, and 25% respectively, to the total U.S. energy demand. Oil, which had been at the top place for many years, remained the largest single source of energy (Klass, 1998).

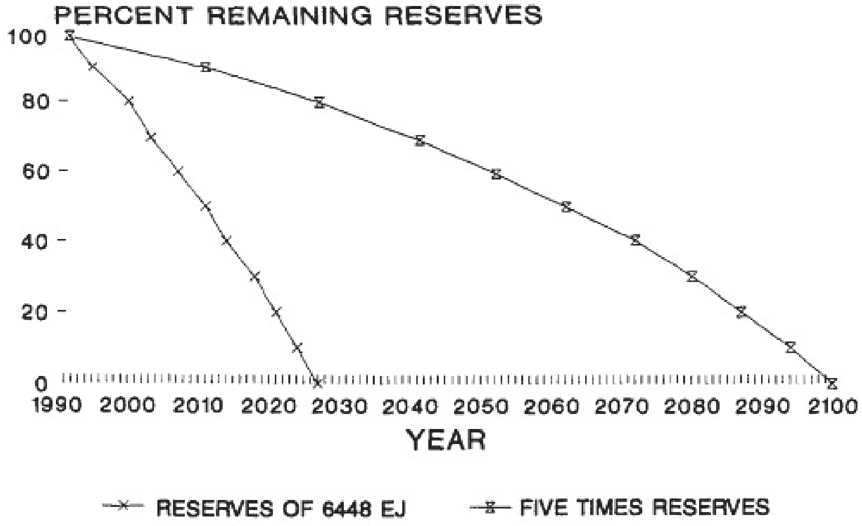

Figure 3: Global Depletion of Petroleum Reserves at Annual Consumption Growth of 1.2%

Source: Klass (1998, p.18)

From Figure 3, it can be seen that the gradual depletion of petroleum reserves is expected to become a severe problem by the middle of the twenty-first century (Klass, 1998). It was suggested by Klass (1998) that the depletion would begin to adversely affect natural gas and petroleum reserves, which might cause the consumption of alternative biomass energy resources to increase. Moreover, the present share of biomass is estimated to be around 15% of the world's energy. Different countries have different situations. The shares of biomass vary from 35% to 90% in some developing nations and they reveal a declining trend as these countries consumed more fossil fuels (Klass, 1998). However, the share of biomass in the European Union is about 5%, but it is steadily increasing. It was predicted by the International Energy Agency in 1997 that biomass-to-fuel energy conversion technology may be applied on a large scale as millions of hectares of former agricultural land is set aside by the agricultural policy. Also, it was suggested by present development and future predictions that developed economies would again move toward renewable energy (IEA, 2004). Biomass is an example of this development. Two other renewable energy forms of wind and hydropower have a long history and also imply appreciable potential for the future (Tahvonen and Salo, 1999).

1.4 Biofuels

Biofuels are those molecules derived from biological sources (plant or animal products) and can be used to carry energy for the production of work (mechanical, electric or transport) (Nickel, 2006). Doucet (2007) stated that the fuels are most commonly hydrocarbons which have a shared characteristic that on their consumption, they only release the carbon that the source plants took up from the atmosphere during their lifetime. Thus, they are one of the most important and controversial substitute fuels for the non-renewable (mainly fossil) fuels currently in use (Doucet, 2007).

A study by Nickel (2006) argued that the amount of global biofuel production was only 4.8 billlion litres in 2000. It was tripled to about 16.0 billion litres in 2007, but still accounted for less than 3% of the global transportation fuel supply. The paper also stated that around 90% of the total biofuels production was concentrated in the United States, Brazil and the European Union. Their major raw materials or feedstocks are corn, sugar, and vegetable oils.

Klass (1998) demonstrated that the biofuel production capacity was largely increasing. If the prices of petroleum stay above $100 per barrel and if there are some supportive policies in place, more of the capacity would be utilized and additional capacity might be needed in the future. The energy and agricultural markets would be linked more closely by the growth of biofuels production. The linkages between petroleum and biofuels prices would be tightened if the price of petroleum was high enough. By mid-May 2008, the ethanol price in United States had already equaled its energy value relative to gasoline after the $0.51 per gallon tax credit was taken into account. In the long run, the biofuel prices are likely to be significantly determined by the petroleum prices and the prices of crops and other feedstocks that are used to produce the biofuels are likely to be affected by the biofuel prices (Klass, 1998).

1.5 Food fuel tradeoff

As shown in the Figure 4, 66 of the 102 countries in the world have high potential for biofuels production with current technologies (Braun, 2007).

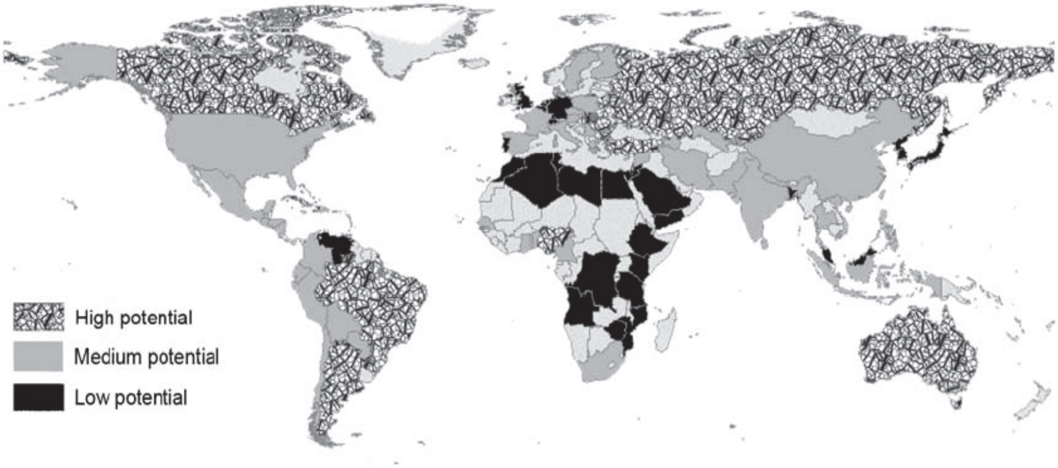

Figure 4: Biofuel Production Potential

Source: Braun (2007, p.3)

However, the development of a robust biofuels industry is fraught with controversy. One of the major criticisms of biofuel crops is that they compete with food crops in a number of ways (agricultural, rural investment, infrastructure, skilled labour etc.) (Ayre, 2007). Commodities like wheat, sugar cane or vegetable oil are used either as food, feed or to make biofuels (Braun, 2007). Currently, U.S. biofuel supply mostly relies on ethanol produced from Midwest corn. Other biofuels that play a less significant role include biodiesel from U.S. soybeans, ethanol from Brazilian sugar and U.S. sorghum (Yacobucci and Schnepf, 2007). In 2007, 25% of the farmland which was formerly used for other crop production in the United States is now cultivated for growing maize for biofuels (i.e., ethanol) production (Kingsbury, 2007). Oxburgh (2008) claimed that the energy markets are effectively placed in competition with food markets for scarce arable land, resulting in higher food prices.

Austria (2009) argued that between 2002 and 2007, world food prices increased by approximately 140% and the increased demand for biofuels was considered as one of the main reasons for the food price increases. Also, Mitchell (2008) concluded that the large increase in biofuels production in Europe and United States was the main reason behind the steep rise in global food prices. However, Braun (2007) showed that the increased biofuels production was not the only factor which contributed to the higher agricultural prices. Other factors included the strong demand in Asia, weak supply due to droughts (for instance in Australia) and slow supply response due to input constraints in Africa. The stocks of agricultural products were then at their lowest levels in 25 years, which resulted in a nervous reaction by world markets. Thus, the food versus fuel tradeoff debate is international in scope, with valid and good arguments on all sides of this issue.

The following two figures demonstrate the increase of bioethanol from 1975 to 2005 and the rise of biodiesel production from 1991 to 2005.

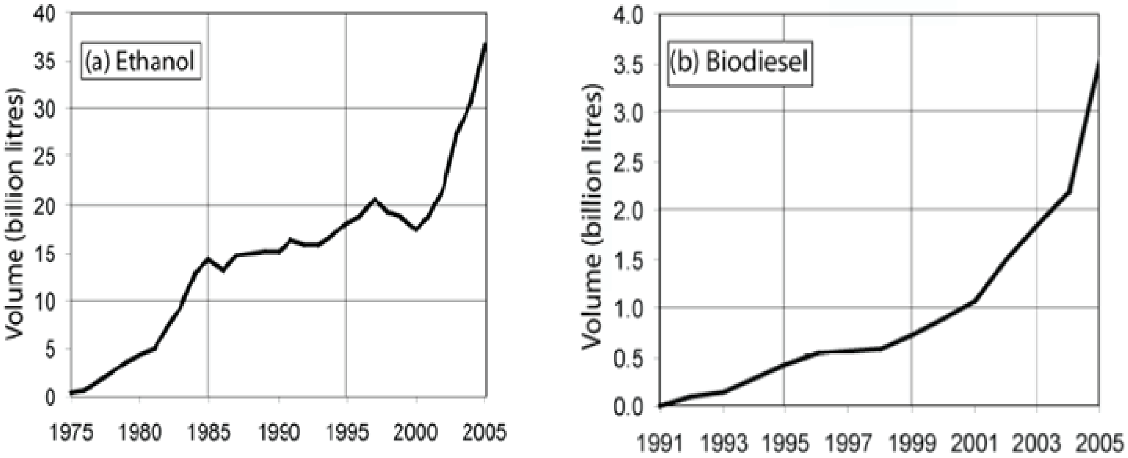

Figure 5: World Ethanol and Biodiesel Production

Source: Worldwatch Institute (2006, p.4-5)

Between 2000 and 2005, global ethanol production doubled and global biodiesel production nearly quadrupled (Figure 5), but global oil production was only increased by

7% (Braun, 2007). Recent proposals aim to increase biofuels supply in the coming decades. Yacobucci and Schnepf (2007) estimated that 113 billion litres of biofuels would be demanded by 2030 and 227 billion litres of biofuels would be required by 2050. Braun (2007) stated that we should expand biofuels production around the world with a target of blending 15% biofuels with the transport fuel. Also, an assessment showed that United States and European Union (EU) would need to use up to 43% of cropland for biofuels production in order to meet the target (IEA, 2004).

To raise biofuels production requires a movement away from food crops, which would cause food to become scarcer and increase prices. If biofuels become a major competitor for resources with other food crops, then the food prices would increase. This would increase the burden on consumers, especially the poor. Lustig (2008) argued that a particularly hard hit group would be poor urban residents and landless rural dwellers. Ivanic and Martin (2008) showed that since 2005, 105 million people from the least developed countries were added to the world's poor due to the increasd food prices. On average, around 60% to 80% of poor people's income is spent on food and a large number of the poor people are net consumers of food (Lustig, 2008).

1.6 The purpose of the project

The purpose of this project is to study the impacts from biofuels production on the food industry in the prairie region of Canada, which includes the provinces of Manitoba, Alberta and Saskatchewan. In the food industry, canola seeds are crushed for producing the cooking oil and the solids (called meal) are used as a feedstock for beef, dairy cattle, swine, poultry, and specialty animals (horses, sheep and aquaculture). In the biofuels industry however, canola is a biofuel plant and its oil is widely used for biodiesel production in Prarie Canada (Canola Council of Canada, 2012).

A report by the Canola Council of Canada (2012) shows that only 25% of the canola seed produced is used for producing canola oil, but the canola oil has accounted for approximately 70% of the vegetable oil consumed by Canadians. The other 75% of the canola seed produced in Canada is exported to other countries such as United States, Japan and others (Canola Council of Canada, 2012).

In the prairie region of Canada, wheat is the primary feedstock for bioethanol production. However, most is widely used for making human food such as bread and pasta. The lower grade wheat is used to to feed the livestock. Rye, oats and barley are feed grains used in meat production. Therefore, the study of these crops encompasses two major biofuel crops (canola and wheat), as well as the main food crop (feed grain) in the prairie region of Canada. Together, these crops accounted for 97.6 % of the total grain production in the prairie region of Canada in 2001 (Grain Trade of Canada, 2002). This paper studies the impacts of the production of biofuel crops (canola and wheat) on other food crops (rye, oat and barley) through the estimation of share equations from revenue function and distance function. The elasticities of substitution, both of partial elasticity and Morishima elasticity are calculated.

CHAPTER 2 Literature Review

A report by the Government of Alberta (2011) defines biofuels as any fuels produced from biological materials such as food crops, agricultural residues and municipal waste. This term generally refers to liquid transportation fuels. These kinds of fuels, especially for corn-based ethanol, grew quickly in the past few years as a component of U.S. motor fuels. Three main kinds of biofuels include biogas, bioethanol and biodiesel.

2.1 Biogas (Methane)

Biogas is produced by the microbes' anerobic digestion of organic materials, which consists of 60-80% methane and 20-40% CO_2. Also, amounts of hydrogen sulphide and ammonia are traced in the biogas. After cleaning, the gas can be used for electrical generation, heat production and low-grade natural gas production (Doucet, 2007).

A study by Doucet (2007) showed that there are a great variety of feedstock source materials which are used for biogas production. They include animal manure, oil, fats, food-processing wastes, silage, biomass, wood fibre, and municipal wastes. Depending on the technology, the feedstock could be either liquid or dry. In order to maximize the digestion process, modern digesters are maintained in highly controlled environments in which the process biology and operating temperature are managed. Alberta operators are primarily using the feedstock of municipal manure (Doucet, 2007).

European producers use mixed feedstocks to increase the biogas production by mixing the manure or wastes with a grown biomass (silage or rapeseed). This adds considerable material input costs to the product. The feed usually stays in the digester for 20-50 days but it might vary with the technology employed and the quality of the feedstock. After digestion, the effluent from the digester is a nutrient rich, odourless bio-fertilizer that can be applied directly to the soil (Doucet, 2007).

2.2 Bioethanol

The United States has invested heavily in ethanol production with the primary feed stock of corn and corn fibre. The corn production is predicted to increase from 14% to 75% of total grain production between 2001 and 2014. Also, large subsidies from government are directed toward facility capital costs of ethanol production (Doucet, 2007). In the United States, a typical ethanol production plant with large-scale facilities can produce 100 million litres per year. However, ethanol production in Alberta is very limited, with only one plant producing 40M litres per year. Generally, Canada remains well behind other nations, not only in ethanol production, but also in regulated renewable content for on-road fuels. Brazil is one of the largest ethanol producers, which has the highest on-road fuel ethanol usage. Fifty percent of Brazil's on-road fuel ethanol comes from a sugarcane feedstock which can produce the most cost competitive ethanol (Doucet, 2007). For Alberta, wheat and straw are used for ethanol production, which have different economies than other feedstocks. Also, ethanol has the characteristics of inferior cold-weather performance and it cannot be moved by conventional pipelines. Therefore, it is costly to transport ethanol (Doucet, 2007).

Wheat is the main feedstock for ethanol in the prairie region of Canada (Grier et.al., 2012). On the Prairies, ethanol accounts for nearly 95% of industrial wheat usage and more than 10% of domestic disappearance of wheat in the last two years. Also, the share of crop dedicated to ethanol for total wheat in the prairie region of Canada grew rapidly during the last five years, and has reached around 3.5% in 2011. Ethanol usage of wheat has played an important role in the western grain market. The ethanol uses lower grade wheat and barley ("feed grade"), which are mostly used for livestock rather than human consumption (Grier et.al., 2012). The ethanol facility in Innisfail, Alberta has received $15 million from the Alberta government. It is estimated that 80% of the feed wheat in Alberta, around 300,000 tonnes, will be used in this ethanol plant per year (Grier et.al., 2012).

2.3 Biodiesel

Biodiesel, a popular kind of biofuels, is made from a combination of vegetable oil (e.g. canola) or animal fat, alcohol (e.g. ethanol or methanol) and a catalyst (e.g. lye). It is a biodegradable transportation fuel for use in diesel engines, which could be used alone or as an additive to diesel fuel (Doucet, 2007). Biodiesel is also beneficial to the operation of farm vehicles and machinery as it acts as a lubricity additive in diesel fuel, which can decrease the wear and tear on an engine (Doucet, 2007).

As biodiesel has a small amount of CO_2 emission, it is much more environmental friendly than the conventional diesel. With different feedstock to be used, the quality of biodiesel can vary greatly. Therefore, accurate product monitoring and implementation of government product standards are required when developing a commercial grade or blended fuel (Doucet, 2007).

Burtis (2006) discussed several environmental advantages of biodiesel compared to normal fossil fuels. First, it is non-toxic and degrades quickly due to biological infestation and growth. Kingwell and Plunkett (2006) showed that pure biodiesel could degrade 85-88% in water within 28 days. Second, it produces fewer emissions than petroleum diesel. Kurki et al. (2006) illustrated that a 20% blend of biodiesel produces around 12-20% fewer emissions than petroleum diesel alone. In addition, biodiesel has a high net energy ratio of 2.5-3.2:1 (depending on the oilseed used). This means that there are 2.5-3.2 units of energy to be produced when one unit of energy is consumed in the production of biodiesel. As a comparison, ethanol only has an energy ratio of 1.2:1, giving biodiesel a clear advantage as an energy source (Burtis, 2006).

Doucet (2007) investigated the development of biodiesel in Canada. The study showed that in 2005, Canada only produced around 6 milllion litres of biodiesel from canola and soy, which was far less than the production of 3.7 billion litres in Europe. In 2006, a new $65 million facility was announced to be built in Fort Saskatchewan, which would be the first large scale biodiesel plant in Canada. In 2008, the first phase of the new facility was located beside Bunge Canada’s canola crushing plant. The annual residuals from the plant were planned to be used as a feedstock to produce 114 million litres of biodiesel and 10,000 tonnes of glycerine. Moreover, other projects are being proposed for Minburn, Lethbridge and Calgary.

2.4 Benefits of biofuels production

The biofuel industries have practically and economically assisted in providing waste management solutions in Alberta. It was estimated by the Levelton report that 50% of the potential bioresources were waste residuals from agriculture (47%), forestry (41%), municipalities (11%), and food processing (1%) (Doucet, 2007). As the food-processing industries have expanded, the conflict between producers and other rural residents regarding odour management has led to increased manure management regulations. Biogas production is an efficient way to address the waste management issue. This is extremely meaningful to large commercial farms and feedlots. It is also beneficial to the commercial food processing facilities that operate near or within municipalities. Also, whether municipal waste management facilities receive operating licences will increasingly be tied to how they deal with their waste by-products and water resources (Doucet, 2007).

Nickel (2006) indicated that a portion of the fossil fuels could be replaced by using currently wasted or underutilized resources as energy sources. The greenhouse gas emissions from the fossil fuels could be reduced and used as carbon credits for greenhouse gas emisions. Moreover, the life of the country’s fossil fuel endowment would be extended.

Traditional energy (coal, oil and natural gas) is available in a limited supply. Even though the volumes of traditional energy currently produced globally are very large, continued use of traditional energy will eventually deplete traditional stocks. This has led to an increasing price for traditional energy, which is a significant driver to push toward biofuels to be the energy generation (Doucet, 2007). Businesses are seeking alternative energy sources that can greatly improve their overall economic efficiency. Currently in Alberta, all biofuel producers are using all, or portions of, their production to either cut down the costs of their energy product or to replace the energy requirements of their facilities (Doucet, 2007).

2.5 Crops production in the prairie region of Canada

Grain trade of Canada (2002) indicated that wheat, barley and canola are the three top crops grown in the prairie region of Canada. During the crop year 2000-2001, wheat accounted for the largest proportion among the total grain crops in the prairie region of Canada, with a production of 14.44 million tones. It was followed by the production of canola (4.87 million tonnes) and barley (1.46 million tonnes). Oats and rye had relatively small productions of 233,000 tonnes and 1380 tonnes, respectively.

According to the report by Agriculture and Agri-Food Canada (2000), Saskatchewan produces around 55% to 60% of total wheat in the prairie region of Canada. Most of the wheat seeded is spring wheat, and it is mainly used to make human food such as bread, pasta and cake. Canola is the second largest crop grown in Saskatchewan. Over 25,000 farmers are growing canola in Saskatchewan, which accounts for 47% of Canada’s canola production. Around 40% of canola seeds are used to produce oil and 60% for meal production. Canola oil is well developed for making cooking oil due to its low content of fat and it is also a good source of biodiesel. Moreover, the area seeded for the most important coarse grain, barley, had reached 2.06 million hectares in 2000, which was a 20% increase over 1999.

Another study by Agriculture in Saskatchewan (2010) shows that Canada is now a world leader in malting barley production, mainly contributed by Saskatchewan, Alberta and Manitoba and most of barley produced is destined for the feed market. Also, around 35% of the barley grown in Saskatchewan is used for producing malt, either for domestic consumption or exportation.

Although a large number of crops could be grown in Southern Manitoba due to its appropriate climate and soil conditions, wheat and barley have dominated since farming began. In the mid 1930s, some rust-resistant wheat had been introduced into Manitoba, and some other disease-resistant crops were added in the mid 1960s. This allowed Manitoba farmers to choose crops best suited to their operation (Honey, 2011). Statistics Canada data shows that in 1883, 215,000 acres of Manitoba farmland were used to produce wheat, 87,000 acres and 60,000 acres were used for oats and barley productions respectively. However, other crops of rye, flaxseed, dry peas and potatoes were not recorded in the province until the early twentieth century when, due to expanded crop area and improved yields, crop production grew rapidly. There was a significant growth in rapeseed production in the late 1960s - early 1970s when canola was used for producing oil which was more palatable for human consumption (Honey, 2011).

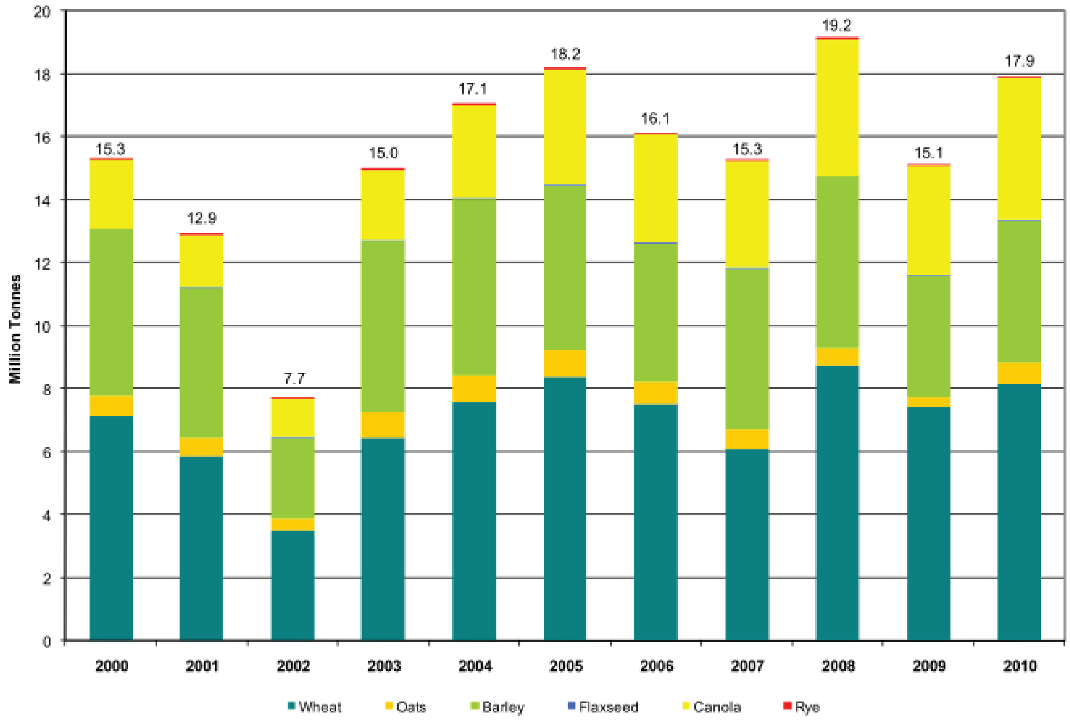

Figure 6: Alberta Major Crop Production, 2000-2010

Source: Alberta Official Statistics (2011, p.1)

In 2010, the estimated total production of major crops in Alberta was 17.9 million tones, which was 17.9% above the 10-year average (2000-09) of 15.2 million tones and 18.4% higher than 2009. Wheat had the largest production with the estimated quantity of 8.2 million tones in 2010, followed by barley and canola both were around 4.5 million tones (Government of Alberta, 2011).

The annual amounts of potential feedstock translated into biofuels can produce 457 PJ of potential energy, accounting for 22.6% of the total energy consumed in Alberta each year. By using this amount of biofuel instead of fossil fuel, 45.6 million tonnes of carbon emissions could be reduced (Doucet, 2007). In Alberta, a great amount of feedstock is available for biofuel generation, which ranges from agricultural products and byproducts to wastes generated in the cities and towns. However, many of these feedstocks are used in small amounts. There are opportunities to develop ways to use those resources economically (Doucet, 2007).

2.6 Barriers to biofuels

2.6.1 Technology and scale

Currently, most of the biofuels systems in Alberta are largely imported from Europe or the United States as Alberta has very limited technologies available. One exception is the Integrated Manure Utilization System (IMUS) in the Highmark Renewable facility in Vegreville and developed by the Alberta Research Council (Doucet, 2007). With these imported technologies for operation, specialized staff and a specialized level of safety standards (hazardous gases, inflammables) and allocated time are required to manage the production process (Doucet, 2007). European operations show that scale plays a significant role in the efficient application of technologies. The scale of the facilities in Europe, which combine heat&power and municipal waste biogas digesters, is up to 200 times the scale of the Alberta facilities (Doucet, 2007).

2.6.2 Biofuels investment cost

Doucet (2007) indicated that for a farm scale facility, the capital investment in production equipment can range from \$0.5 - \$6.0 million. A commercial scale facility that produces in excess of 1 Million Watts may need \$7 - \$15 million for its capital investment. Though the investment cost is extremely high, biofuel development is strongly supported by the waste management or environmental drivers. Also, traditional energy products have high prices which could provide the economic incentive for the demanded investment in bioresources.

However, with the certain economic capital, higher capital costs for oil and gas development mean more economic incentives for the bio-ressources investments. The high oil prices in Alberta have drawn greater investment in oil and gas development. Thereafter, the construction costs are increased and the elasticity of investment capital is tightened. The ethanol production in Alberta is apt to be produced as a secondary product within a cluster production environment (Doucet, 2007)

2.6.3 Greenhouse gas credits

John Hartwick (1977) argued that unless all profits are invested into renewable capital, non-renewable resources are not paying a proper economic rent because their consumption today deprives future generations' consumption. Recently, the Alberta Government introduced a carbon tax on CO_2 emissions, but there is still no economic structure to value the environmental benefits which are created by biofuel production (Doucet, 2007). Moreover, there is no reward for the biofuel producer who has utilized technology and capital to produce a cleaner burning fuel. Therefore, the bio-energy industry will not realize the attributable rents for its products until a more integrated market for carbon credits is developed (Doucet, 2007).

2.6.4 The impact of biofuels plant production on prices of other food crops

Recently, the effects from biofuels' production on food prices have been hotly debated. Schnepf (2008) argued that most of the major U.S. agricultural program crops exhibited high price volatility. High prices of the coarse grains (sorghum, barley, corn, oats, and rye), oilseeds, and oilseed products are due to the strong and sustained demand from the following two sources: 1) the developing countries (e.g. China and India) have achieved a robust economic growth. They demand more meat products and then more feed grains are consumed to produce the meat; 2) the mandated use of biofuels to achieve governments' objectives on agricultural resources have been increased, which lead to the increased demands for agricultural feedstock.

According to Westhoff (2008), biofuels production in 2008 accounted for around 65% of the overall increase in food prices. Nevertheless, from the analysis of Lynch (2008), it was estimated that the increased biofuels' production accounts for only 2% to 3% of the rise in world food prices. The different time periods of study might be part of the reason that the magnitude of the estimated results vary so widely.

As relevant research questions arising from the introduction of biofuels are relatively recent, there is a limited economic literature on this subject. Rajagopal and Zilberman (2007) stated that the "environmental literature is dominated by a discussion of net carbon offset and net energy gain, while indicators relating to impact on human health, soil quality, biodiversity, etc., have received much less attention". A study by Hochman et. al. (2008) discussed the "crowding-out effect" of biofuels on the agricultural sector with results showing that trade liberalization tends to raise the demand for energy, which cuts down food production and leads to losses in forests and other non-agricultural lands. Bahel et.al (2010) studied the effects on the food sector from the usage of biofuels as a substitute of fossil fuels energy. Their results indicated that the price of energy will keep increasing while the stock of oil is being depleted and this will not stop until biofuels becomes the only source of energy. In the meantime, food prices will increase due to the effects from the rising energy prices and population growth.

2.7 Government policy and report in Canada

Doucet (2007) showed that little progress has been made in significant resources or policies directed toward biofuels in Canada. In September 2006, the Federal Minister announced $5 million in biofuels opportunities for Producers Initiative as the first part of a $10 million initiative to determine biofuel feasibility and to assist in the potential biofuel projects which would be farmer operated. Moreover, several government assistance initiatives, including the direct tax relief, subsidies and further investment in research and development, are currently under discussion.

In March 2004, a report of “Bio-energy Opportunities for Alberta: Strategic Feasibility Study” by Levelton Consultants established most of the Alberta government’s current strategies on biofuels. In this project, four main opportunities for bio-energy in Alberta were identified: (1) biogas using only manure products from agriculture; (2) combined heat and power from wood processing by-products and municipal waste management; (3) ethanol from agricultural crop production and straw; and (4) biodiesel from animal fats and agricultural seed oils (Doucet, 2007). In addition, biofuels can make a significant contribution in building rural economies through providing additional revenue streams, building new rural industries, creating jobs and improving economic competitiveness through energy source substitution (Doucet, 2007). A study from Klein (2005) indicated that the usage of biofuels have also been promoted or mandated federally in the other provinces in the prairie region of Canada. By September 2005, it was declared that 85% of gasoline sold must be blended with 10% ethanol in Manitoba and 7.5% ethanol in Saskatchewan.

Grier et.al. (2012) stated that the Canadian government provides more than $250 million of financial support for the ethanol operations and firms every year. Two forms of the financial supports include the capital and operating subsidies. Also, the ethanol industry is supported by federal and provincial mandates that dictate a blend of gasoline and ethanol. Currently, the government mandates a 5% blend of ethanol with gasoline, which results in a stimulus to local Canadian grain demand and higher local grain prices. However, the Canadian livestock and meat industry is negatively affected by the ethanol policy as they would have less competition in buying feed grains without the ethanol industry. The ethanol industry has already contributed to the downsizing of the Canadian livestock industry through its impact on margins and livestock prices (Grier et.al., 2012).

2.8 Future role of biofuels

A paper by Coyle (2007) demonstrated that many uncertainties, such as the competition from unconventional fossil fuel alternatives and concerns about environmental trade-offs, remain for the future development of biofuels. Efficiency grains (higher biomass yields per acre) and technological advances (more gallons of biofuel per ton of biomass) could decrease the economic cost and environmental impacts of biofuel production. Also, biofuel production will probably be most profitable and environmentally benign in tropical areas as these areas have longer growing seasons and higher biofuel yield per acre (Coyle, 2007). In order to minimize the cost of biofuel production, Brazil uses bagasse, which is a byproduct from sugar production, to power ethanol distilleries. The future of biofuels depends on their profitability, which is determined by many interrelated factors. Oil price is a key factor. However, rising feedstock prices (such as corn and vegetable oil) have reduced the sector's profitability. The United States, Brazil and EU have the most significant biofuels production, because of their government supports which reduce the profit uncertainty for this commodity-dependent industry (Coyle, 2007).

CHAPTER 3 Theoretical Considerations

In this chapter, the related economic theories have been represented in three subsections. The first subsection demonstrates the curve of Production Possibility Frontier. The second subsection explains the dual functions of Revenue Function and Distance Function. Last subsection discusses the development of the elasticity of substitution and introduces the Morishima Elasticity of Substitution.

3.1 Production possibility frontier

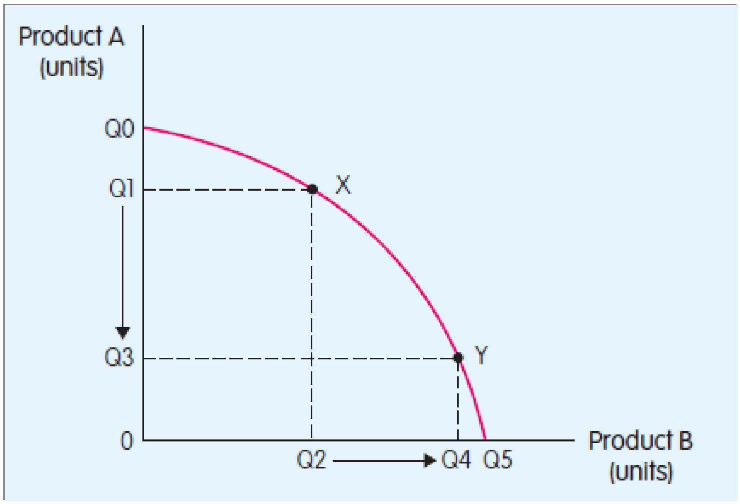

Figure 7: Production Possibility Frontier

Source: Adapted from Nicholson (1995, p.15)

In economics, the production possibility frontier (PPF) is a graph (Figure 7) representing the alternative combination of two outputs (goods or services) that can be efficiently produced during a specified period of time with a fixed quantity of inputs.

The PPF shows the maximum amount of one commodity that can be obtained for any specified production level of the other commodity, given the society's technology and the amount of factors of production available (Nicholson, 1995). All points inside the frontier are feasible but productively inefficient. With the same amount of inputs, more of one or both outputs could be produced. All points outside the curve are unfeasible with the given resources and thus, unattainable in the short run (McCoy, 2003).

To increase the quantity of one good produced, production of the other good must be sacrificed. The PPF can be used to predict how much of the production of one commodity must be sacrificed for a given increase in production of the other commodity and the shape of PPF is usually expected to be concave (bowed-outward)(Lipsey, 2002).

The slope of the production possibility frontier (PPF) at any given point is called the marginal rate of transformation (MRT). It describes numerically the rate at which output of one good can be transformed (by re-allocation of production resources) into output of the other. It is also called the (marginal) "opportunity cost" of a commodity; that is, it is the opportunity cost of *X* in terms of *Y* at the margin (Nicholson, 1995).

Assuming that the supply of the economy's factors of production is constant, growing more by-products requires resources to be redirected from growing more human products.

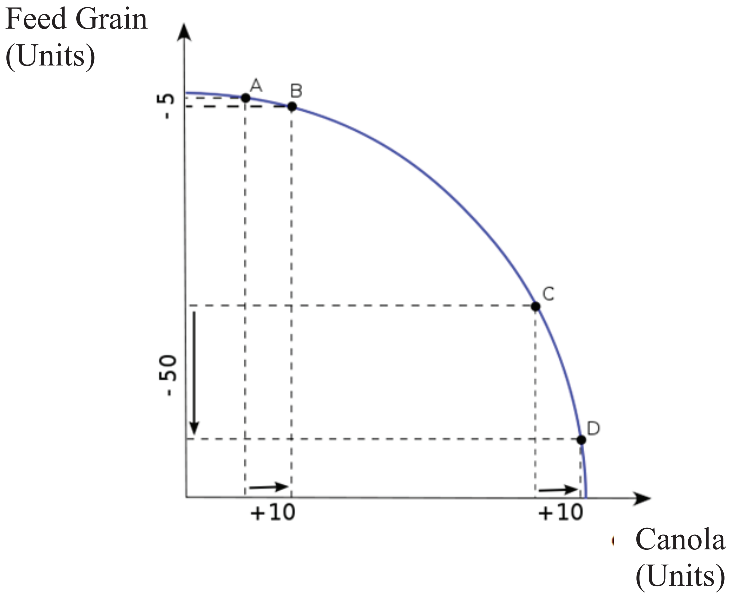

Figure 8: Transferring Resources out of Producing Feed Grain into Producing Canola

Source: Adapted from Barthwal (2007, p.31)

Generally, the PPF curve is concave from the origin, which demonstrates increasing opportunity costs (Figure 8). It represents a disparity in the factor intensities and technologies of the two production sectors. As an economy specializes more and more in one product, the opportunity cost of producing that product increases as greater resources are used less efficiently for its production. For example, with increasing production of canola, more growers of feed grain farms would move to production of canola. At first, the least efficient feed grain grower will transferred to plant more canola; moving these growers will have little impact on the marginal opportunity cost of canola. The loss in feed grain production will be 5 units if canola production is to be increased by 10 units (moving from point A to point B in Figure 8). However, the marginal opportunity cost of canola increases as production of canola increases forward the horizontal intercept of the

PPF. Marginal cost of canola increases because less and less efficient canola growers switch from feed grain where they are more efficient into canola, where they are less efficient. When moving from Point C to Point D, with an increase of 10 units of canola production, a greater loss of 50 units in wheat production would result (Barthwal, 2007).

In order to study the output substitution, two models, one that includes a revenue function and one that includes an output-oriented distance function, will be used. The distance function is called as the "primal approach" as it develops a set of primal factor demands and Morishima substitution elasticities (Coelli et al., 2006; Karagiannis et al., 2004; Kumbhakar and Tsionas, 2005). The revenue function develops a set of dual factor supplies and Morishima substitution elasticities, which will be called the "dual approach" (e.g. Clark and Youngblood, 1992). The information contained in the two models is identical as one model is dual to the other. Given either of the two functions, the other function can be derived (Deaton, 1979).

3.2 Distance and revenue functions[1]

3.2.1 Output distance function

The distance function is useful in describing the technology as it can measure the efficiency and productivity of technology. Coelli et al. (1998, p.47) stated that "the distance function is highly related to the production possibility frontier[2], and it can be

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[1] This section draws heavily on the economic literature concerning revenue and distance functions, especially work by Coelli et. al.(1998, p.44-48).

[2] The same concept used to describe macroeconomic trade offs can be used to capture important elements of a firm's decisions about trade offs. At this point, we introduce the PPF as a device that can be applied to a firm.

used to demonstrate a multi-input, multi-output production technology without the need to specify a behavioural objective (e.g. cost-minimization or profit-maximization)." A maximal proportional expansion of the output vector is considered for the output distance function, based on the condition that a specific input vector has been given (Coelli et al. , 1998).

According to Bjorndal et.al. (2002, p.5) , "given the existence of a production possibility frontier, the distance that any producer is away from the frontier is a function of the set of inputs used, **x**, and the levels of outputs produced, **y**. " For the output function, this can be expressed as:

$$D_0(\mathbf{x}, \mathbf{y}) = \min \{\theta \mathbf{:}\ (\mathbf{y}/\theta) \in P(\mathbf{x})\}, \text{(Coelli et. al.,1998; p.47).}$$

D_0 (**x, y**) is the distance from the firm's output set to the frontier. θ is the corresponding level of efficiency and it measures the proportional (radial) expansion of the output vector that brings the firm to the efficient frontier. Grosskoph et al., (1995, p.577) said, "The output distance function seeks the largest proportional increase in the observed output vector possible, given that the expanded vector ($\mathbf{y}/\theta$) is still an element of the original output set." If the firm is fully efficient, the output vector would be on the frontier with θ equal to one. On the other hand, if the firm is inefficient, then θ would be less than one (Shephard, 1970). Moreover, according to Coelli et al. (1998), the restricted output distance function has the following properties: 1) non-decreasing in outputs and non-increasing in inputs; 2) linearly homogeneous in outputs; and 3) quasi-convex in inputs and convex in outputs.

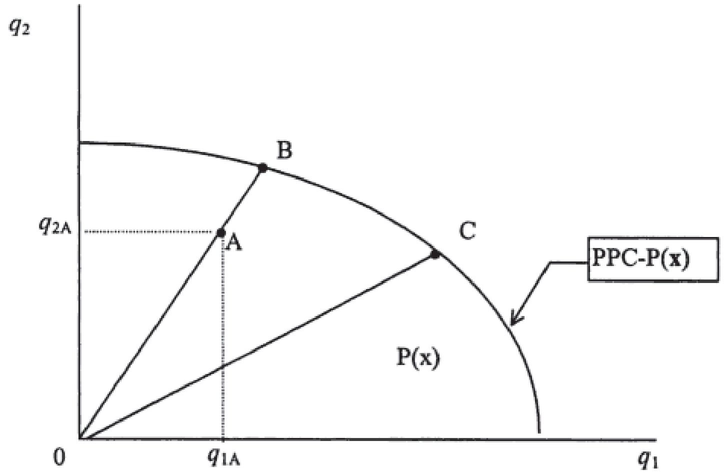

Figure 9: Output Distance Function and Production Possibility Set

Source: Coelli et al. (1998, p.48)

In the two outputs case, q_1 and q_2 are produced by using the input vector **x**. For a given input vector **x**, we can demonstrate the production technology on a two dimensional diagram in Figure 9. The firm's production possibility set, P(**x**), is the area bounded by the production possibility frontier, PPC-P(**x**), and the q_1 and q_2 axes (Coelli et al., 1998). At Point A, the firm is using input level x to produce the outputs of q_{1A} and q_{2A} and its value of the distance function θ is equal to OA/OB. Points B and C are observed on the production possibility surface which means their values of distance functions are equal to one.

3.2.2 Revenue function

In economics, the revenue function is studied to determine the maximum revenue that can be obtained from a given input vector **x**. For a multiple-input and multiple-output firm, the revenue maximization problem can be explained as:

$r(\mathbf{p},\mathbf{x}) = \max \mathbf{p}'\mathbf{y}$ such that $T(\mathbf{y},\mathbf{x}) = 0$, (Coelli et. al.,1998; p.31).

where $\boldsymbol{p} = (p_1, p_2, \ldots, p_i)'$ is a vector of output prices which are not affected by the firms' behaviors (i.e., it is perfectly competitive in output markets). Moreover, according to Coelli et al. (1998, p.31), the revenue function has the following properties: 1) Non-negativity in r; 2) Non-decreasing in output prices and input quantities; 3) Linearly homogeneous in r; and 4) Convex in output prices.

In economics, revenue function is studied when determining the maximum revenue that can be obtained from a given input vector **x**.

In two output scenario:

$$TR = p_1y_1+p_2y_2$$

TR: Total revenue

y: Output of crops

x: Quantities of Inputs (e.g. labor and land)

When revenue is maximized, the slope of the revenue function is equal to the slope of the PPF (Figure 10)

$$TR_{\text{slope}} = -p_2/p_1 = \text{PPF}_{\text{slope}}$$

Therefore, we can estimate the PPF curve through the revenue function under the assumptions that revenue is maximized and inputs are fixed.

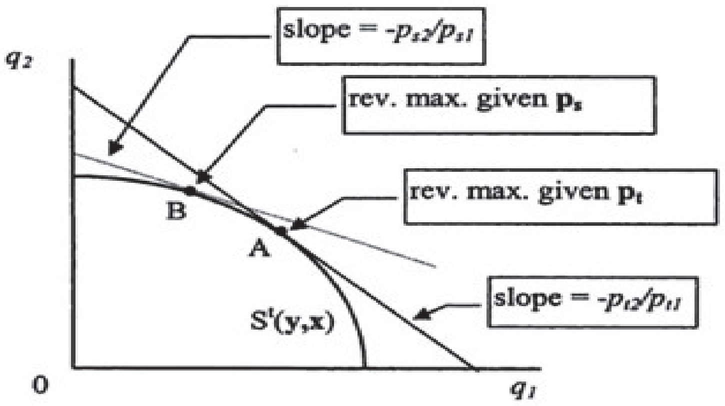

Figure 10: The Production Possibility Frontier and Revenue Maximisation

Source: Coelli et al. (1998, p.46)

3.3 The elasticities of substitution[3]

3.3.1 The development of elasticity of substitution

According to Mundra and Russell (2010, p.1), it was said that “Hicks (1932) introduced the elasticity of substitution as a tool for studying the capital and labor income shares in a growing economy with a constant-returns-to-scale technology and neutral technological change. The elasticity was defined as the logarithmic derivative of the capital/labor ratio with respect to the technical rate of substitution of labor for capital.” Mundra and Russell (2010) demonstrated that with higher elasticity, it is easier to substitute one input for the other and there is less degree of “curvature” of the isoquant.

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[3] This section draws heavily on the economic literature concerning elasticities of substitution, especially work by Mundra and Russell (2004), and Blackorby and Russell (1989).

Compared to the one generalization for the Hicksian two-variable elasticity of substitution, Allen and Hicks (1934) introduced two generalizations of original elasticity concept for the study of multi-inputs (more than two inputs). The first one is called the Hicks' elasticity of substitution (HES). HES is defined by applying the two-input formula to each pair of inputs, holding constant all other input quantities (as well as output). Blackorby and Russell (1989) argued that HES does not explain the comparative statics of factor shares as it does not allow for optimal adjustment of all inputs to a change in a price ratio. This inadequacy was rectified by the other generalization, which is called the "partial elasticity of substitution" by Allen. The partial elasticity of substitution was introduced by Allen and Hicks, and more thoroughly investigated by Allen (1938) and Hirofumi Uzawa (1962); it was therefore called the Allen elasticity of substitution (AES) (or Allen/Uzawa elasticity). This concept has been a standard statistic reported in empirical studies of production and consumption.

Mundra and Russell (2004, p.2) stated that "when one advances to more than two inputs, the measurement of the effect of changes in quantity ratios on price ratios is not a simple inverse of the effect of changes in price ratios on quantity ratios." It was argued in the paper that for more than two commodities, different elasticity of substitution concepts should be applied for solving the various questions about substitutability among commodities. Direct elasticities should be used to evaluate the effects of price changes while dual elasticities can be used to access the effects of quantity changes.

Although the Allen/Uzawa elasticity of substitution (or Antonelli elasticity of complementarity) was originally developed in terms of cost function (or input distance function) for the study of input substitution (with output held constant), Bjorndal et.al. (2004) did apply this concept for the study of the output substitution in multi-species trawl fisheries by estimating the Antonelli elasticity from the output distance function.

The Antonelli elasticity of complementarity between output y_i and y_j (in terms of the distance function D) is given by[4]:

$$\sigma_{ij}^{A}(x,y)=\frac{D\dfrac{\partial^2 D}{\partial y_i \partial y_j}}{\dfrac{\partial D}{\partial y_i}\dfrac{\partial D}{\partial y_j}}=\frac{D(x,y)D_{ij}(x,y)}{D_i(x,y)D_j(x,y)} \tag{1}$$

Similarly, the Allen/Uzawa partial elasticity of substitution can be calculated from the revenue function as[5]:

$$\sigma_{ij}^{A}(x,p)=\frac{R\dfrac{\partial^2 R}{\partial p_i \partial p_j}}{\dfrac{\partial R}{\partial p_i}\dfrac{\partial R}{\partial p_j}}=\frac{R(x,p)R_{ij}(x,p)}{R_i(x,p)R_j(x,p)} \tag{2}$$

where subscripts indicate partial derivatives, R is total revenue, and p_i is the price of i^{th} output. Using Shephard's Lemma (Shephard R.W., 1953),

$$y_i = R_i(x,p)$$

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[4], [5] Equation (1) and (2) are excerpted from Clark et.al. (2009, p.3-4), but we study revenue function instead of cost function in this paper.

where y_i is the optimal quantity of i^{th} output, $\boldsymbol{x}$ is input quantity, and $\boldsymbol{p}$ is the vector of output prices. This can be written:

$$\sigma_{ij}^{A}(x,p) = \frac{\varepsilon_{ij}(x,p)}{S_j(x,p)}$$

where $\varepsilon_{ij}(x,p)$ is the (constant-output) cross-price elasticity of demand and $S_j(x,p) = p_j R_j(x,p)/R(x,p)$ is the share of the j^{th} output in total revenue ((Allen,1934) and (Uzawa,1962)). Mundra et. al. (2004, p.8) said "if $\sigma_{ij}^{A}(x,p) > 0$ (that is, if increasing the j^{th} price increases the optimal quantity of output i), it can be said that output i and j are direct Allen-Uzawa complements; if $\sigma_{ij}^{A}(x,p) < 0$, they are direct Allen-Uzawa substitutes".

3.3.2 Morishima elasticity of substitution

Blackorby and Russell (1989) also argued that AES is totally uninformative as it would not preserve any of the significant properties of the Hicksian notion when it is reduced to a two-dimensional case. They concluded that AES can not assess the substitution, reveal any information about relative factor shares, or be interpreted as a logarithmic derivative of quantity ratios to marginal rates of substitution. An alternative concept which does preserve the salient characteristics of the original Hicksian concept is called the "Morishima elasticity of substitution (MES)". It was originally introduced by Morishima (1967) in a note written in Japanese and fortunately, discovered by Blackorby and Russell in 1975 (Blackorby and Russell, 1989). Blackorby and Russell (1989) illustrated that the Morishima elasticity takes care of all changes of the optimal quantity ratio in response to the changes of price ratio. It is a measure of curvature and a sufficient statistic for assessing (quantitatively as well as qualitatively) the effects of change in price or quantity ratios on relative factor shares. In addition, MES can be interpreted as a logarithmic derivative of a quantity ratio with respect to a marginal rate of substitution or a price ratio.

A study by Grosskopf (1995b) calculated Morishima elasticities of substitution for estimating the output substitutability of hospital services. The Morishima elasticity of substitution between output y_i and y_j (in terms of the Distance function D) is given by[6]:

$$\sigma_{ij}^{M}(x,y)=\frac{y_i D_{ij}(x,y)}{D_j(x,y)}-\frac{y_i D_{ii}(x,y)}{D_i(x,y)}=\varepsilon_{ji}(x,y)-\varepsilon_{ii}(x,y)$$

Similarly, the Morishima elasticity of substitution can be calculated from the revenue function as[7]:

$$\sigma_{ij}^{M}(x,p)=\frac{p_i R_{ij}(x,p)}{R_j(x,p)}-\frac{p_i R_{ii}(x,p)}{R_i(x,p)}=\varepsilon_{ji}(x,p)-\varepsilon_{ii}(x,p)$$

In other words, the corresponding Morishima elasticity of substitution between outputs y_i and y_j is found by subtracting the diagonal element, A_{ij}, from each element of the j^{th} row of the elasticity of substitution matrix whose elements are given by Equations (Eq.) (1) and (2) (i=1,...k and j=1,...k). Mundra et. al. (2004, p.8) stated that, "if $\sigma_{ij}^{M}(x,p)>0$ (that is, if increasing the jth price increases the optimal quantity of output i relative to the optimal quantity of output j), the output i is a direct Morishima complement for output j; if $\sigma_{ij}^{M}(x,p)<0$, output j is a direct Morishima substitute to output i". Gordon et. al.

[6, 7] Equations are excerpted from Mundra and Russell (2004, p.8-10).

(1993) obtained the Morishima elasticity from revenue function for testing the output substitution possibilities in Cod Fish Processing in Norway.

CHAPTER 4 Model Specification

In this chapter, both distance and revenue functions are specified in the transcendental logarithmic (TL) functional form with the multi-output variables and single input variable. The derivation of the Morishima Elasticities from the dual models is explained.

4.1 The output distance function

In order to estimate the distance from the frontier, both the frontier and the relationship between inputs and outputs must be estimated. This requires some forms of multi-output production function P(***x***) to be specified. The translog production function is the most common functional form applied, which does not impose restrictive assumptions on substitutability between outputs (Bjorndal et al., 2002).

The translog distance function with i ($i=1,2,\ldots,k$) outputs quantities (y_i) and one aggregate input (x) quantity can be represented by[8]:

$$\ln D = \alpha_0 + \sum_{i=1}^{k+1} \alpha_i \ln y_i^* + \frac{1}{2} \sum_{i=1}^{k+1} \sum_{j=1}^{k+1} \alpha_{ij} \ln y_i^* \ln y_j^* \tag{3}$$

where lnD is the natural logarithm of the distance function, $\ln y_i^* = \{\ln y_1, \ln y_2, \ldots, \ln y_k, \ln x\}$ is either the natural logarithms of an output or input quantity and α's are parameters. ***y*** is defined as a vector that includes $\{y_1, y_2, \ldots, y_k\}$, ***x*** is the aggregate input quantity. To introduce only one aggregate variable for input rather than several input variables can avoid losing too many degrees of freedom as more degrees of freedom would be lost with more variables to be introduced into the model (Clark, et.al., 2009).

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[8] Equation (3) is excerpted from Clark et.al. (2009, p.3).

Properties of the distance function include: 1) homogeneous of degree 1 in ***y***; 2) convex in ***y*,** and; 3) non-increasing in *x*, and; 4) symmetric in ***y*** (Deaton, 1979).

As the distance function is homogeneous of degree 1 in ***y*** and symmetric in ***y***[9]**:**

$$\sum_{i=1}^{k}\alpha_i = 1,\ \sum_{j=1}^{k}\alpha_{ij} = 0 \ \text{ and } \ \alpha_{ij} = \alpha_{ji}$$

$$i/j = \text{Outputs}$$

The output-oriented distance function:

$$\mathrm{D} = \mathrm{e}^{(\alpha_0 + \sum_{i=1}^{k+1}\alpha_i \ln y_i^* + \frac{1}{2}\sum_{i=1}^{k+1}\sum_{j=1}^{k+1}\alpha_{ij} \ln y_i^* \ln y_j^*)}$$

$$\frac{\partial D}{\partial y_i} = \frac{D}{y_i}\left[\alpha_i + \sum_{j}^{k}\alpha_{ij}\ln y_i + \alpha_{ik+1}\ln x\right] \qquad (4)$$

where $\mathrm{D} = p_1 y_1/\mathrm{R} + p_2 y_2/\mathrm{R} + \ldots p_i y_i/\mathrm{R}$, p_i is the price value of output *i*, y_i is the output of i^{th} crop, and *R* is the total revenue of all crops (Shephard, 1970).

$$\frac{\partial D}{\partial y_i} = \frac{p_i}{R} \qquad (5)$$

Thus, from Eq. (4) and (5), it can be seen that：

$$\frac{p_i}{R} = \frac{D}{y_i}\left[\alpha_i + \sum_{j}^{k}\alpha_{ij}\ln y_i + \alpha_{ik+1}\ln x\right]$$

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[9] Equations are excerpted from Clark et.al. (2009, p.3).

It is assumed that the firm is fully efficient, D(x, y) = $\theta = 1$， then

$$\frac{p_i y_i}{R} = \left[\alpha_i + \sum_j^k \alpha_{ij} \ln y_i + \alpha_{ik+1} \ln x \right] \tag{6}$$

The differentiation of Eq. (3) with respect to lny_i results in the following:

$$\frac{\partial \ln D}{\partial \ln y_i} = \left[\alpha_i + \sum_j^k \alpha_{ij} \ln y_i + \alpha_{ik+1} \ln x \right]. \tag{7}$$

From the Eq. (6) and (7), we obtain

$$\frac{\partial \ln D}{\partial \ln y_i} = \frac{p_i y_i}{R} = \mathrm{S}_i$$

$$S_i = \left[\alpha_i + \sum_j^k \alpha_{ij} \ln y_i + \alpha_{ik+1} \ln x \right] \tag{8}$$

where S_i = $p_i y_i / R$ is the share of total revenue, p_i is the price of output i, and R is total revenue, $R = \Sigma p_i y_i$ (Deaton, 1979). The set of i share equations resulting from differentiating Eq. (3) by each output lny_i is called the primal system of share equations. Also, the Antonelli partial elasticity of complementarity, ρ_{ij}, between output y_i and output y_j is given by[10]:

$$\rho_{ij} = \frac{D \dfrac{\partial^2 D}{\partial y_i \partial y_j}}{\dfrac{\partial D}{\partial y_i} \dfrac{\partial D}{\partial y_j}} \tag{9}$$

The corresponding Morishima elasticity of complementarity (Blackorbyand Russell, 1989 and Morishima, 1967) between outputs y_i and y_j is found by subtracting the share

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[10] Equation is excerpted from Clark et.al. (2009, p.3).

weighted diagonal element, $s_i\rho_{ii}$, from the share weighted element of the *j*th row, $s_j\rho_{ij}$, of the elasticity of substitution matrix whose elements are given by Eq. (9) ($i=1,\ldots, k$ and $j=1,\ldots, k$) (e.g. Clark et.al., 2009).

4.2 The revenue function

Consider a translog revenue function of *i* output prices (p_i, $i=1,2,\ldots,k$) and one aggregate input quantity (x)[11]:

$$\ln R = \beta_0 + \sum_{i=1}^{k+1} \beta_i \ln p_i^* + \frac{1}{2}\sum_{i=1}^{k+1} \sum_{j=1}^{k+1} \beta_{ij} \ln p_i^* \ln p_j^* \tag{10}$$

The *lnR* is the natural logarithm of the revenue function. The $\ln p_i^*$ $=\{lnp_1, lnp_2, \ldots, lnp_{k,}, lnx\}$ is a vector of natural logarithms of output prices and input quantity. ***p*** is defined as a vector that includes $\{p_1, p_2, \ldots, p_k\}$ and β's are parameters. The aggregate input quantity (x) is also applied to avoid losing too many degrees of freedom from multi-inputs.

Properties of the revenue function include: 1) homogeneous of degree 1 in ***p***; 2) convex in ***p***, and; 3) non-decreasing in *x*, and; 4) symmetric in ***p*** (Deaton, 1979).

As the revenue function is homogeneous of degree 1 in ***p*** and symmetric in ***p***[12]**:**

$$\sum_{i=1}^{k} \beta_i = 1, \quad \sum_{j=1}^{k} \beta_{ij} = 0 \text{ and } \beta_{ij} = \beta_{ji}$$

[11,12] Equations are adapted from Clark et.al. (2009, p.4), we study revenue function in this paper instead of cost function, which was studied in Clark's paper.

Differentiation of Eq.(10) with respect to *lnp*$_i$ results in the following equation:

$$S_{\text{i}} = \left[\beta_i + \sum_j^k \beta_{ij} \ln p_i + \beta_{ik+1} \ln x \right] = \frac{p_i y_i}{TR}, \tag{11}$$

i/j: crops,
1= $S_1+S_2+\ldots S_i$

where $S_i = p_i y_i / TR$ is the share of total revenue, p_i is the price of output *i*, and *TR* is total revenue of all crops, $TR = \Sigma p_i y_i$ (Deaton, 1979). The set of *i* share equations results from differentiating Eq. (10) by each output p_i will be called the primal system of share equations.

Also, the Allen/Uzawa partial elasticity of substitution, σ_{ij}, between output y_i and y_j is given by[13]:

$$\sigma_{ij}^{A} = \frac{R \dfrac{\partial^2 R}{\partial p_i \partial p_j}}{\dfrac{\partial R}{\partial p_i} \dfrac{\partial R}{\partial p_j}} \tag{12}$$

The corresponding Morishima elasticity of complementarity (Blackorby and Russell, 1989 and Morishima, 1967) between outputs y_i and y_j is found by subtracting the share weighted diagonal element, $s_i\sigma_{ii}$, from the share weighted element of the *j*th row, $s_j\sigma_{ij}$, of the elasticity of substitution matrix whose elements are given by Eq. (12) (*i=1,..., k* and *j=1,..., k*) (e.g. Clark et.al., 2009).

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[13] Equation is adapted from Clark et.al. (2009, p.4), we study revenue function in this paper instead of cost function, which was studied in Clark's paper.

CHAPTER 5 Econometric Issues

The non-stationary approach is applied in this paper because it not only allows for the estimation of long-run elasticity from the models, but also allows variables to be weakly endogeneous in the system and still generates a consistent set of parameter estimates. This is in contrast to models using stationary time series data within which both short-run and long-run parameters can easily be confounded and lead to some difficulties in the parameter estimations (Clark et.al., 2009). Also, stationary regressors with weak endogeneity would require an appropriate set of instruments to achieve parameter consistency, but it is not easy to find these instruments as both prices and quantities are endogenous (Coelli et al., 2008). The non-stationarity is tested by using the Augmented Dickey-Fuller (ADF) test developed by Dickey and Fuller, which is conducted by testing the null hypothesis that the time series contains one unit root (Mantalos and Karagrigorious, 2012).

As the data on both prices and quantities are available, share equations from both distance and revenue functions can be simultaneously estimated, using the assumption that all data are non-stationary (Clark et.al., 2009). The translog distance function (Eq.(3)) is called the "primal" approach and the translog revenue function (Eq.(10)) is called the "dual" approach. The distance and revenue functions are dual to one another, so the information contained in one function is identical to the other (Deaton, 1979).

Mundlak (1996) argued that simultaneous estimation is preferred to separate estimation as it utilizes full information and therefore leads to statistical efficiency of estimates. It also allows additional restrictions implied by the primal and dual models to be imposed and tested. Clark et.al. (2009, p.5) said “the major advantage of full system estimation is the consideration of additional correlations among equations. These are considerable under cointegration since autoregressive (own equation as well as cross equation) error structures are considered in the estimation. This implies that substantial short-run dynamics are accounted for in estimation. Significance of any of these error structures will result in improved estimates combining cointegration techniques with simltaneous primal dual estimation.”

Moreover, the estimated parameters are robust to endogeneity assumptions when equations are cointegrated (Pesarsan and Shin, 2002). From previous studies, all variables are considered to be endogeneous in cointegrated systems that developed from vector autoregressions (VARs), but the asymptotically efficient estimators derived from cointegrating systems (such as OLS(Engle and Granger, 1987) and MLE by (Johanse, (1991)) would still be consistent (Pesaran and Shin, 2002). In this paper, parameters are estimated from the long-run structural modeling developed by Pesaran and Shin (2002)), which is based on the Johansen’s Maximum Likelihood Estimation.

CHAPTER 6 Data

This project uses time series data of Canadian Prairies, which includes the three provinces of Manitoba, Alberta, and Saskatchewan from 1971 to 2007. The reason for not considering the earlier data is that the shares of canola in the prairie region of Canada before 1971 were low which may lead to some difficulties of estimation.

All data used in the empirical analysis is assembled from the Statistics Canada, and with the price indices normalized to 100% for 2007. The data include: 1) the expense and price index of total aggregate input, through which the aggregate quantity for input can be calculated. The reason to use the aggregated input variable instead of the individual input variables is that more variables entered into the model would cause more degrees of freedom to be lost; thus, less information would be used for estimating the reliable coefficients. 2) The data also include total revenues, unit values, quantities of crops and farm product price index. The crops being studied include: (a) the biofuel crops of wheat and canola, wheat for bioethanol production and canola for biodiesel production; (b) food crops of feed grain (barley, oat and rye), which are used for feeding livestock and producing meat for human consumption.

CHAPTER 7 Results

As the non non-stationary approach is applied in this paper for studying the long-run elasticity within the crops, the non-stationary of data is firstly tested by using the Augmented Dickey-Fuller (ADF) test with its results presented in the first subsection of this chapter. The remaining parts of this chapter reveal the empirical results for Elasticities for each crop and the Morishima Elasticities of substitution between the biofuels crops and food crops in the prairie region of Canada. The estimates for the parameters of dual models are presented in the Appendix (Table A.1 to Table A.4).

7.1 Dickey-Fuller tests

Table 1 presents the results for Dickey-Fuller (DF) unit root test on the data. If the tested statistic is greater than the critical value, the unit root is not rejected and the data is non-stationary. Most of the data (bold words) from the DF test with intercept are non-stationary at a 1% level of significance, while prices are more likely to be stationary.

Table 1: Augmented Dickey Fuller Tests on data (1971-2007)

Alberta						
Wheat	**-3.23**	**-3.21**	**-3.38**	-4.93	**-3.85**	**-3.18**
	(0)	(0)	(0)	(1)	(0)	(0)
Feed Grain	-4.26	-3.93	**-2.20**	-4.24	-4.16	**-2.98**
	(0)	(0)	(3)	(0)	(0)	(0)
Canola	-4.57	**-1.53**	**-1.16**	-4.79	**-3.73**	-5.67
	(1)	(0)	(2)	(1)	(0)	(1)
Input		-11.79			-36.76	
		(0)			(0)	
Saskatchewan						
Wheat	**-3.15**	**-3.08**	**-1.16**	-4.80	**-3.42**	**-3.25**
	(0)	(0)	(0)	(1)	(0)	(0)
Feed Grain	-5.66	**-3.48**	**-3.49**	-5.59	-4.32	**-3.64**
	(0)	(0)	(0)	(0)	(0)	(0)
Canola	-5.34	**-1.22**	**-0.90**	-5.33	-4.74	-4.60
	(1)	(0)	(2)	(1)	(0)	(0)
Input		-4.28			**-1.78**	
		(0)			(0)	
	Deterministic Variables included in Dickey Fuller Regression					
	Intercept			**Intercept, trend**		
Manitoba	**Price**	**Quantity**	**Share**	**Price**	**Quantity**	**Share**
Wheat	**-2.47**	**-3.00**	**-0.89**	-4.72	**-3.25**	**-1.91**
	(0)	(0)	(0)	(0)	(0)	(0)
Feed Grain	-5.08	-5.34	**-3.01**	-4.95	-5.35	**-2.04**
	(1)	(2)	(2)	(1)	(0)	(2)
Canola	-4.90	**-1.12**	**-0.24**	-5.17	-4.49	-4.21
	(1)	(2)	(2)	(1)	(0)	(1)
Input		-3.80			**-3.01**	
		(0)			(0)	

Value in parentheses is number of lagged first differences included in Dickey-Fuller regression. Critical values for Dickey-Fuller test (1%, 5%, n=50): **-3.58**,-2.93 (constant); **-4.15**,-3.50 (constant, trend). Source of critical values: Fuller (1976), p.373.

7.2 The elasticities of substitution from revenue function (dual model)

Table 2: Elasticity and Morishima Elasticity of Substitution Matrix for Canadian Prairies

Dual Model – Manitoba			
Elasticity Matrix			
	Price		
Quantity	Wheat	Feed Grain	Canola
Wheat	**0.98**	-1.20	-0.08
Feed Grain	-2.02	**3.24**	-0.27
Canola	-0.27	-0.53	**1.54**
Morishima Elasticity of Substitution Matrix			
	Price		
Quantity	Wheat	Feed Grain	Canola
Wheat	0.00	-2.18	**-1.06**
Feed Grain	**-5.26**	0.00	**-3.50**
Canola	**-1.81**	-2.07	0.00
Dual Model – Alberta			
Elasticity Matrix			
	Price		
Quantity	Wheat	Feed Grain	Canola
Wheat	**1.08**	-1.13	0.07
Feed Grain	-1.08	**1.88**	-0.59
Canola	0.13	-1.21	**1.17**
Morishima Elasticity of Substitution Matrix			
	Price		
Quantity	Wheat	Feed Grain	Canola
Wheat	0.00	-2.21	**-1.01**
Feed Grain	**-2.96**	0.00	**-2.46**
Canola	**-1.04**	-2.38	0.00
Dual Model – Saskatchewan			
Elasticity Matrix			
	Price		
Quantity	Wheat	Feed Grain	Canola
Wheat	**4.73**	-1.10	-0.45
Feed Grain	-2.08	**2.54**	0.39
Canola	-1.38	0.64	**4.26**
Morishima Elasticity of Substitution Matrix			
	Price		
Quantity	Wheat	Feed Grain	Canola
Wheat	0.00	-5.83	**-5.18**
Feed Grain	**-4.61**	0.00	**-2.14**
Canola	**-5.64**	-3.62	0.00

Table 2 demonstrates the elasticities of substitution for the three provinces in the prairie region of Canada (Manitoba, Alberta and Saskatchewan), which are estimated from the dual model of revenue function (Eq. (10)). Two sets of elasticities are tabulated for the revenue function: Elasticity and Morishima Elasticity.

All the diagonal elements in Elasticity Matrix are positive. The increase of i^{th} price will lead to the increase of the optimal quantity of output i. Thus, the law of supply is satisfied as these diagonal elements represent their own elasticities of complementarity.

The Morishima elasticities are proceeded from Elasticity Matrix by eliminating the own elasticities of complementarity. All estimates except for diagonal elements are negative (Table 2), which indicates that all outputs are net price-substititutes. In other words, if the price of i^{th} output increases, the optimal quantity of output j supplied relative to the optimal quantity of output i supplied will decrease. This is an expected result as the increase of price of i^{th} crop causes its own supply increase as the law of supply. Also from the PPF theory, increasing the quantity of one good (i^{th} crop) produced, production of other goods (j^{th} crop) must be sacrificed. Therefore, the increase of the price of i^{th} crop leads to the decrease of quantity of j^{th} crop. Thus, all Morishima cross-elasticities are expected to be negative.

In addition, all of the Morishima cross-elasticities are larger than 1 in the absolute value, and the biggest one has reached -5.64 (canola for wheat in Saskatchewan), which indicates that a 1-percent decrease in the price of wheat would increase the quantity ratio of canola to wheat by 5.64 percent. The highly elastic of substitutes between food crop (feed grain) and biofuels crops (wheat and canola) indicate that a small adjustment in the price of biofuels crops would highly affect the optimal quantities of other food crops supplied. For example, a really small amount of increase in the price of canola or wheat would highly decrease the optimal quantity of feed grains supplied relative to other crops. Also, a small decrease of feed grains price would increase optimal quantity of canola and wheat supplied relative to other crops.

From the Elasticity Matrix for Manitoba, the own-price substitution of feed grain is highly elastic with the elasticity value of 3.24, which indicates that a 1-percent increase in the price of canola would increase its supply by 3.24 percent. However, the own-price substitutions are mildly elastic for canola (1.54) and even inelastic (0.98) for wheat. In Alberta, the own-price substitutions for all three crops are shown to be mildly elastic. However, both of the own-price substitutions for biofuel crops in Saskatchewan are highly elastic (4.73 for wheat and 4.26 for canola), which indicates that Saskatchewan has the most potential for producing biodiesel and bioethanol within the three provinces.

To produce bioethanol using wheat, more resources must be invested into wheat production. From the Morishima elasticity Matrix, canola and feed grains are all elastic substitutes for wheat in the three provinces; they can be easily substituted with wheat production. Focusing on the first column of the Morishima elasticity matrix, it can be seen that the cross-price substitutions of feed grain and canola for wheat are -5.26 and -1.81 in Manitoba, -2.96 and -1.04 in Alberta. This indicates that canola is a mildly elastic substitute for wheat but feed grain is a highly elastic substitute for wheat in Manitoba and Alberta. To produce bioethanol by using wheat crop would have much more impact on the meat market (or feedgrain) than canola oil market (or canola). However, both canola and feed grain are shown to be highly elastic substitute for wheat in Saskatchewan with the cross price substitutute of -4.61 and -5.64 respectively. Contrary to the other two provinces, producing bioethanol in Saskatchewan would have a smaller impact on the meat market than the canola oil market.

If government policy mandates a slight increase in the wheat price in Saskatchewan, the quantity of wheat supplied would be substantially increased, as wheat has the large own-price elasticity of 4.73 (see Elasticity Matrix in Table 2).[14] However, this would lead to a large decrease in the optimal production of feed grain supplied as feedgrain has a high cross price-substitution elasticity for the wheat (-4.61), and then the price of meat might be significantly increased. As the majority of meat consumers are well off, a high increase in the meat price can lead to a progressive economic situation as rich people would be less well off – the increase in price affects rich people more than poor people. Raising the wheat price could even cause a larger decrease in the optimal production of canola as canola has the higher cross price-substitution elasticity than the wheat (-5.64). Similarly, the decrease of canola production might also increase the prices of canola by-products, such as vegetable oil and meat. Then, this would negatively affect poor people as well as the rich people.

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[14] The province of Saskatchewan is not large enough to influence world's prices. The argument here is that the supply of wheat is price elastic.

To produce biodiesel by increasing the canola quantity supplied, it is necessary to invest more resources into the canola production. From the results, both wheat and feed grains are elastic substitutes for canola, so they can be easily substituted by the canola production. Focusing on the third column of the Morishima elasticity substitution matrix, it is apparent that the cross price-substitutions of wheat for canola are both smaller than the cross price-substitutions of feedgrain for canola in both provinces of Manitoba and Alberta. Therefore, to produce biodiesel by using canola might have much more impact on the meat market (or feedgrain) than on the bread market (or wheat). However, both wheat and feed grain are shown to be highly elastic substitutes for wheat in Saskatchewan with the cross price substitutute of -5.18 and -2.14, respectively. Unlike the other two provinces, producing bioethanol in Saskatchewan might have a smaller impact on the meat market than on the bread market.

The Elasticity Matrix shows the own price elasticity of canola in Saskatchewan is 4.26, which means that an increase in the canola price would highly increase its own production. If government policy mandates a slight increase in the canola price, the optimal quantity of canola supplied would increase significantly and substantial input resources would need to be removed from feed grains or wheat. The decreased productions of feed grains and wheat might lead to the prices of meat and bread increasing, with more increase in the bread's price. Also, as the residuals of canola are resources for feedstock, the actual impacts of biodiesel production on the meat market would be smaller than the estimates.

7.3 The elasticities of complementarity from distance function (primal model)

Table 3: Elasticity and Morishima Elasticity of Complementarity Matrix for Canadian Prairies

Primal Model – Manitoba			
Elasticity Matrix			
Price	Quantity		
	Wheat	Feed Grain	Canola
Wheat	**1.28**	-0.89	-0.27
Feed Grain	-1.50	**1.86**	-0.22
Canola	-0.90	-0.43	**4.47**
Morishima Elasticity of Complementarity Matrix			
Price	Quantity		
	Wheat	Feed Grain	Canola
Wheat	0.00	-2.17	**-1.55**
Feed Grain	**-3.37**	0.00	**-2.08**
Canola	**-5.37**	-4.91	0.00
Primal Model – Alberta			
Elasticity Matrix			
Price	Quantity		
	Wheat	Feed Grain	Canola
Wheat	**3.26**	-1.03	0.09
Feed Grain	-0.99	**2.00**	-0.64
Canola	0.17	-1.31	**1.27**
Morishima Elasticity of Complementarity Matrix			
Price	Quantity		
	Wheat	Feed Grain	Canola
Wheat	0.00	-4.29	**-3.17**
Feed Grain	**-2.99**	0.00	**-2.64**
Canola	**-1.10**	-2.58	0.00
Primal Model – Saskatchewan			
Elasticity Matrix			
Price	Quantity		
	Wheat	Feed Grain	Canola
Wheat	**1.42**	-0.86	-0.40
Feed Grain	-1.62	**1.97**	0.13
Canola	-1.22	0.22	**1.98**
Morishima Elasticity of Complementarity Matrix			
Price	Quantity		
	Wheat	Feed Grain	Canola
Wheat	0.00	-2.27	**-1.81**
Feed Grain	**-3.59**	0.00	**-1.84**
Canola	**-3.20**	-1.76	0.00

Table 3 demonstrates the elasticities of complementarity for the three provinces in the prairie region of Canada (Manitoba, Alberta and Saskatchewan), which are estimated from the primal model of distance function (Eq. 3). Two sets of elasticities are tabulated for the revenue function: Elasticity and Morishima Elasticity.

In the case of the primal model, all the diagonal elements in the Elasticity matrix from the table above are positive, indicating that the law of supply is also satisfied. All estimates except for diagonal elements in the Morishima elasticity of complementarity Matrix are negative, indicating that all outputs are net substititutes, which is consistent with the results from the dual model.

All of the Morishima elasticities are larger than 1 in the absolute value, which is also consistent with the results from the dual model. The large elasticity of complementarity between feed grain and biofuel crops (wheat and canola) indicates that biofuels are elastic substitutions for feed grain. A slight adjustment in the quantity of biofuels crops would highly affect the prices of feed grains relative to biofuel crops. In other words, a small increase of quantities of canola and wheat would decrease the optimal price of feed grain relative to biofuel crops.

If government policy mandates a slight increase in the wheat and canola productions, the price of feed grain would significantly drop, according to the discussion above. However, this would lead to a large decrease in the optimal production of feed grain supplied, as its elastic own-price substitution (see Elasticity Matrix in Table 3). As the quantity of supplied feedgrain for livestocks decreases, the price of meat might be significantly increased.

From the Morishima matrix, the cross substitutes between canola and wheat are quite elastic, which indicates that a small increase in the quantity of one of them would decrease the price of the other. For example, when the quantity of wheat increases, the price of canola relative to wheat would decrease. The decline price of canola might lead to its supplied quantity decrease and the prices of canola oil and meat might go up.

CHAPTER 8 Conclusion

In this study, simultaneous estimation for revenue function and distance function has been conducted for Canadian Prairies, including three provinces of Manitoba, Alberta and Saskatchewan. Three provinces are separately estimated, through which we can observe different estimates from each province. The results from the primal model (distance function) are consistent with those from the dual model (revenue function). Over-identifying restrictions of symmetry and homogeneity restrictions are not rejected for both models at the lag length of one.

All estimated elasticities and Morishima elasticities of substitution from the dual model and the primal model show that all outputs are net price-substitutes and net substitutes for Canadian Prairies. The negative and large Morishima elasticity estimates show that all substitutions among biofuels crops and feed grain are elastic, and there are long run substitutions within the biofuel crops and also between the biofuels crops and feed grain. Due to the large elasticities, an increase in the production of one biofuel crop might highly increase the prices of other crops, through which the food price might go up, especially for the meat.

According to the discussions in the previous chapter, Saskatchewan has the most potential for producing both biodiesel and bioethanol within the three provinces. To produce bioethanol and biodiesel in Saskatchewan would have less impact on the meat market than on the canola oil market and bread market, respectively. However, producing bioethanol and biodiesel in Manitoba and Alberta would have less impact on the canola oil market and bread market than on the meat market.

In order to preserve the degrees of freedom during the estimation, data from three provinces were combined for the estimation with the assumption that the long-run technologies are same for each province of Canadian Prairies. However, the aggregated estimation has resulted in unrealistic high elasticities (see Tables A.5 and A.6 in Appendix). Two provincial dummy variables (one for Manitoba and the other for Alberta) were added but they were not sufficient for capturing the technology differences within the provinces.

This project studied the impacts that biofuels production would have on the food industry in the prairie region of Canada. It is expected that this research will help governments assess the merits of forthcoming biofuels policy strategies. However, there are several improvements which can be made for this paper. First, some of the data are shown to be stationary through the Augmented Dickey Fuller Test (Table1), which contradicts the assumption that all data are non-stationary time series. One reason might be that the introduced unit value of crops is not an appropriate price index as it does not consider the heterogeneous qualities of crops. In a future study, prices of different grades for each crop could be corrected to generate an aggregated price index which is a more accurate price as it is properly adjusted for the quality variation. Second, there were thirteen variables selected for each model but only 37 observations for each variable were obtained. The sample size was too small and too many degrees of freedom were lost. One solution is to use separate estimation for the distance function and revenue function instead of simultaneous estimation, through which the number of variables would be reduced to ten. However, separate estimation would only utilize limited information and it is less efficient than simultaneous estimation (Clark, et.al., 2009).

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Appendix

Table A.1: Descriptive statistics of employed variables for Western Canada (1971-2007, 2007=1.00)

	Manitoba		Alberta		Saskatchewan	
Shares	Mean	Stand. Deviation	Mean	Stand. Deviation	Mean	Stand. Deviation
Wheat	0.530	0.090	0.392	0.048	0.539	0.134
Feed Grain	0.314	0.087	0.410	0.089	0.285	0.079
Canola	0.157	0.098	0.199	0.077	0.175	0.090
Prices						
Wheat	1.480	0.292	1.042	0.181	0.669	0.127
Feed Grain	0.933	0.156	0.856	0.144	0.797	0.257
Canola	1.065	0.150	1.060	0.143	0.847	0.122
Quantities						
Wheat	1.065	0.331	0.954	0.273	1.729	0.484
Feed Grain	0.951	0.206	1.156	0.190	0.772	0.192
Canola	0.443	0.300	0.487	0.258	0.455	0.268
Total input quantity	0.707	0.193	0.699	0.214	0.822	0.170

Source: Statistics Canada, CANSIM database and own calculations.

Parameters from Provincial Estimation for Canadian Prairies:

Table A.2: Manitoba Share Equations Estimate (1971-2007)

Regressor Natural logarithm of	**Share – (Distance Function)**		
	Wheat	Feed Grain	Canola
Wheat Quantity	**0.3157**	**-0.2882**	**-0.0275**
	(4.38)	(-2.08)	(-0.98)
Feed Grain Quantity	**-0.2882**	**0.2996**	**-0.0114**
	(-2.08)	(0.83)	(-0.99)
Canola Quantity	**-0.0275**	**-0.0114**	**0.0389**
	(-0.98)	(-0.99)	(0.95)
Aggregate Input Quantity	**0.03616**	**-0.2168**	**-0.1448**
	(0.07)	(-2.81)	(-0.32)
Intercept	**0.8832**	**0.1636**	**-0.0468**
	(3.05)	(2.70)	(-1.71)
Trend	**-0.0151**	**0.0056**	**0.0095**
	(-2.78)	(0.87)	(1.91)
Regressor Natural logarithm of	**Share (Revenue Function)**		
	Wheat	Feed Grain	Canola
Wheat Price	**0.4014**	**-0.4246**	**0.0232**
	(4.62)	(-4.22)	(2.79)
Feed Grain Price	**-0.4246**	**0.4394**	**-0.0149**
	(-4.91)	(3.72)	(-1.43)
Canola Price	**0.0232**	**-0.0149**	**-0.0083**
	(2.79)	(-1.43)	(-1.03)
Aggregate Input Quantity	**-0.1043**	**0.2567**	**-0.1523**
	(3.78)	(3.00)	(-0.96)
Intercept	**0.3383**	**0.8228**	**-0.1610**
	(4.08)	(2.35)	(-0.98)
Trend	**0.0021**	**-0.0139**	**0.0118**
	(4.18)	(-1.23)	(3.08)

Notes to table: Asymptotic t-values are in parentheses. T-values are determined by calculating the likelihood ratio statistic (denoted l) of the restriction $\beta_i=0$ on individual parameters using the likelihood function with symmetry and homogeneity imposed as the unrestricted likelihood function. Estimates of t-values for parameters (denoted $se(\beta_i)$) are calculated using the formula $t(\beta_i)=\sqrt{l}$.

Table A.3: Alberta Share Equations Estimate (1971-2007)

Regressor Natural logarithm of	**Share – (Distance Function)**		
	Wheat	Feed Grain	Canola
Wheat Quantity	**0.2042**	**-0.3167**	**0.1125**
	(3.34)	(-2.78)	(5.12)
Feed Grain Quantity	**-0.3167**	**0.4910**	**-0.1743**
	(-2.79)	(2.78)	(-1.46)
Canola Quantity	**0.1125**	**-0.1743**	**0.0618**
	(5.12)	(-1.46)	(5.36)
Aggregate Input Quantity	**0.1347**	**0.0237**	**-0.1584**
	(1.02)	(0.55)	(-2.60)
Intercept	**0.8399**	**-0.0028**	**0.1629**
	(3.85)	(0.97)	(3.27)
Trend	**-0.0131**	**0.0097**	**0.0034**
	(-4.54)	(3.21)	(1.97)
Regressor Natural logarithm of	**Share (Revenue Function)**		
	Wheat	Feed Grain	Canola
Wheat Price	**0.1810**	**-0.2804**	**0.0994**
	(2.00)	(-2.13)	(4.14)
Feed Grain Price	**-0.2804**	**0.4346**	**-0.1542**
	(-3.34)	(1.47)	(-3.41)
Canola Price	**0.0994**	**-0.1542**	**0.0548**
	(4.14)	(-3.41)	(3.54)
Aggregate Input Quantity	**0.2131**	**-0.0980**	**-0.1151**
	(3.93)	(-3.31)	(-4.85)
Intercept	**0.4635**	**0.5804**	**-0.0439**
	(1.78)	(2.53)	(-2.69)
Trend	**-0.0026**	**-0.0065**	**0.0092**
	(-4.23)	(-2.30)	(1.54)

Notes to table: asymptotic t-values are in parentheses. T-values are determined by calculating the likelihood ratio statistic (denoted l) of the restriction $\beta_i=0$ on individual parameters using the likelihood function with symmetry and homogeneity imposed as the unrestricted likelihood function. Estimates of t-values for parameters (denoted $se(\beta_i)$) are calculated using the formula $t(\beta_i)=\sqrt{l}$.

Table A.4: Saskatchewan Share Equations Estimate (1971-2007)

Regressor Natural logarithm of	**Share – (Distance Function)**		
	Wheat	Feed Grain	Canola
Wheat Quantity	**0.3625**	**-0.2829**	**-0.0796**
	(6.33)	(-5.36)	(-2.45)
Feed Grain Quantity	**-0.2829**	**0.2308**	**0.0521**
	(-5.36)	(0.49)	(3.72)
Canola Quantity	**-0.0796**	**0.0521**	**0.0275**
	(-2.45)	(3.71)	(3.76)
Aggregate Input Quantity	**-0.1157**	**0.0193**	**0.0964**
	(-3.19)	(3.54)	(2.53)
Intercept	**0.0946**	**0.7029**	**0.2025**
	(3.39)	(5.59)	(3.88)
Trend	**0.0039**	**-0.0074**	**0.0035**
	(3.00)	(-4.17)	(2.16)

Regressor Natural logarithm of	**Share (Revenue Function)**		
	Wheat	Feed Grain	Canola
Wheat Price	**0.5982**	**-0.4732**	**-0.1249**
	(4.01)	(-5.80)	(-2.71)
Feed Grain Price	**-0.4732**	**0.3766**	**0.0967**
	(-4.40)	(6.10)	(3.38)
Canola Price	**-0.1249**	**0.0967**	**0.0282**
	(-2.71)	(3.39)	(5.58)
Aggregate Input Quantity	**0.1800**	**-0.2244**	**0.0443**
	(5.41)	(-5.06)	(5.90)
Intercept	**0.9114**	**0.0719**	**0.0167**
	(6.87)	(5.62)	(5.72)
Trend	**-0.0112**	**0.0041**	**0.0072**
	(-6.47)	(5.53)	(4.62)

Notes to table: asymptotic t-values are in parentheses. T-values are determined by calculating the likelihood ratio statistic (denoted l) of the restriction $\beta_i=0$ on individual parameters using the likelihood function with symmetry and homogeneity imposed as the unrestricted likelihood function. Estimates of t-values for parameters (denoted $se(\beta_i)$) are calculated using the formula $t(\beta_i)=\sqrt{l}$.

Elasticities and Morishima Elasticities from the Aggregate Estimation for the Prairie Region of Canada:

Table A.5: Elasticity and Morishima Elasticity of Substitution Matrix for Canadian Prairies

Dual Model			
Elasticity Matrix			
	Price		
Quantity	Feed Grain	Canola	Wheat
Feed Grain	**89.60**	-0.05	-3.30
Canola	-0.08	**1.06**	-1.52
Wheat	-1.74	-0.49	**33.84**
Morishima Elasticity of Substitution Matrix			
	Price		
Quantity	Feed Grain	Canola	Wheat
Feed Grain	0.00	**-89.64**	**-92.89**
Canola	-1.13	0.00	**-2.58**
Wheat	-35.58	**-34.34**	0.00

Table A.6: Antonelli and Morishima Elasticity of Complementarity Matrix for Canadian Prairies

Primal Model			
Elasticity Matrix			
	Quantity		
Price	Feed Grain	Canola	Wheat
Feed Grain	**1.44**	-0.09	-1.37
Canola	-0.15	**1.08**	-0.70
Wheat	-0.72	-0.23	**1.24**
Morishima Elasticity of Complementarity Matrix			
	Quantity		
Price	Feed Grain	Canola	Wheat
Feed Grain	0.00	**-1.53**	**-2.81**
Canola	-1.23	0.00	**-1.78**
Wheat	-1.97	**-1.47**	0.00