Ex Ante Evaluation of the Economic Impact of Adopting Genomic Selection: The Case of Beef Cattle in Canada

by

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Abstract

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University of Guelph, 2014

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Professor John Cranfield

Feed efficiency is of great economic importance to the beef and cattle industry. Genomic selection can be adopted for the genetic improvement of feed efficiency in beef cattle. This study examines the economic impact of adopting genomic selection in Canadian beef industry. A multi-market equilibrium displacement model is developed to capture market and welfare effects of genomics adoption. Results show that Canadian cattle sector will benefit most significantly from genomic selection ($63.29 million), followed by the beef sector ($19.67 million), while the feed sector would be made worse off (-$1.17 million). Sensitivity analysis indicates that one more percent improvement in feed efficiency will lead to a $3.66 million increase in retail-level producer surplus change, a $11.79 million increase in farm-level producer surplus change and a $0.24 million decrease in feed-level producer surplus change. This study also identifies several parameters that are relatively important for the measurement of economic welfare changes.
Acknowledgement

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Chapter 1  Introduction

1.1 Background

Technological improvements in agriculture are of great importance because they may make contributions to relieve global issues such as food security. A considerable amount of research funds are spent each year by both private and public institutions to develop new technologies for agriculture. Research suggests that the process of the adoption of new technology may differ between agriculture and non-agriculture sectors. “Technology transfer in agriculture proceeds at a slow rate relative to many other industries because of its varied biological nature and because much agricultural production remains the province of millions of small-scale farmers world wide who are slow to adopt new technologies” (Phillips and Lu, 1987, p. 449). However, Phillips and Lu (1997) also pointed out that the pace of international transfer of agriculture technology has increased.

On the other hand, there is great uncertainty with respect to the economic impact of technological improvements in agriculture. A great amount of research has been conducted to reduce the uncertainty. Bieri et al (1972) made an attempt in their paper to explore the welfare effects of technological change in agriculture. They found that different models would lead to various conclusions about who gains and who loses from various types of technological change. The market effects of technology adoption are regarded as complicated because the impact of technology change may spill over into other markets (White and Araji, 1991).
Uncertainty in the welfare effect arising from technological improvements may decrease the relevant stakeholders’ confidence in developing or adopting new technology, especially those newly emerging technologies, such as biotechnology. Efforts have been undertaken by economic researchers to explain the economic impact of the adoption of such new technologies. McBride et al (2004) assess the financial impacts of adopting recombinant bovine somatotropin (rbST) in U.S. dairy farms. Their results suggest that many rbST users were possibly less profitable than nonusers.

As a newly emerging technology, genomic selection also presents many uncertainties. “Genomic selection is a form of marker-assisted selection in which genetic markers covering the whole genome are used so that all quantitative trait loci (QTL) are in linkage disequilibrium with at least one marker” (Goddard and Hayes, 2007, p.324). This approach may be adopted in the livestock sector, allowing producers to make breeding decisions that lead to specific objectives such as enhancing feed-efficiency and disease-resistance in livestock. The draft genome sequences of several important livestock animals in recent years have greatly accelerated the adoption of genomic selection in the livestock sector, such as chicken, hog and cattle industries.

In the cattle industry, with the dramatic reduction in genotyping cost, resulting from the rapidly changing technology and the sequencing of bovine genome (Elsik et al., 2009), genomic selection for some traits that are potentially important but expensive to measure has now become feasible. A typical example is the trait of feed efficiency, which is of great economic value under the pressure of increasing feed price around the world. Many recent studies have demonstrated the possibility of genomic improvement for feed efficiency in the cattle industry (Karisa et al., 2013; Lu et al., 2013; Grion et al., 2014).
Currently, genomic selection is more widely implemented amongst dairy cattle than beef cattle, and there are some promising results presented in the dairy cattle industry (Miller, 2010). More research efforts across countries and regions are required to promote the genomic selection for beef cattle. As one of the major beef producers in the world, Canada also plays an important role in the international research development of genomics adoption in beef cattle industry (Miller, 2010).

In Canada, the cattle and beef industry is a key component of the national agricultural sector. In 2012, there were 12.52 million cattle and calves, up 0.5% from the previous year, on 95,105 Canadian farms and ranches (source: AAFC, 2013). Farm cash receipts from the sale of cattle and calves in 2011 totalled $6.5 billion, accounting for 13% of total farm receipts in Canada (source: Statistics Canada, 2013). Beef production contributed approximately $25.96 billion to Canada’s economy in 2011, increasing 5.5% over 2010 (source: Statistics Canada, 2013). The domestic demand for beef products in Canada has been gradually declining over last two decades, as is shown in Figure 1.1. However, beef is still one of the most popular categories of meat in Canada. Table 1 presents the average household expenditure on four main categories of meat in Canada in 2011 and the expenditure on beef rank first among those categories of meat.
Table 1.1: Household Expenditure on Meat Products, Canada, 2011

<table>
<thead>
<tr>
<th>Geography</th>
<th>Overall Food</th>
<th>Beef</th>
<th>Pork</th>
<th>Chicken</th>
<th>Fish</th>
</tr>
</thead>
<tbody>
<tr>
<td>N.L.</td>
<td>7,671</td>
<td>304</td>
<td>162</td>
<td>257</td>
<td>61</td>
</tr>
<tr>
<td>P.E.I.</td>
<td>7,181</td>
<td>208</td>
<td>102</td>
<td>238</td>
<td>61</td>
</tr>
<tr>
<td>N.S.</td>
<td>7,557</td>
<td>219</td>
<td>137</td>
<td>201</td>
<td>83</td>
</tr>
<tr>
<td>N.B.</td>
<td>7,287</td>
<td>274</td>
<td>117</td>
<td>199</td>
<td>80</td>
</tr>
<tr>
<td>Que.</td>
<td>7,483</td>
<td>345</td>
<td>104</td>
<td>160</td>
<td>94</td>
</tr>
<tr>
<td>Ont.</td>
<td>7,832</td>
<td>248</td>
<td>96</td>
<td>212</td>
<td>121</td>
</tr>
<tr>
<td>Man.</td>
<td>7,234</td>
<td>240</td>
<td>112</td>
<td>212</td>
<td>52</td>
</tr>
<tr>
<td>Sask.</td>
<td>7,533</td>
<td>256</td>
<td>140</td>
<td>198</td>
<td>44</td>
</tr>
<tr>
<td>Alta.</td>
<td>8,512</td>
<td>300</td>
<td>124</td>
<td>188</td>
<td>108</td>
</tr>
<tr>
<td>B.C.</td>
<td>8,073</td>
<td>215</td>
<td>120</td>
<td>214</td>
<td>81</td>
</tr>
</tbody>
</table>

Source: Statistics Canada, Survey of household spending (SHS)

Figure 1.1: Average Consumption of Beef and Veal in Canada, 1980-2011

Source: Statistics Canada 2013
Currently, there are many Canadian researchers studying the technology and methods of adopting genomic selection in beef cattle production. However, limited research has been conducted with respect to the economic impact of adopting genomic selection in Canadian beef cattle industry, especially in terms of feed efficiency. In this thesis, an ex-ante evaluation will be conducted to evaluate the economic impact of adoption genomic selection for improved feed-efficiency in Canadian beef cattle industry.

1.2 Economic Problem

The economic problem facing the beef cattle industry in Canada is whether or not to use genomic selection to allow producers to make breeding decisions that lead to improved feed-efficiency in beef production. New technologies, such as genomic selection, can be used to select cattle that are more feed-efficient. However, knowing the advantages of new technologies is not enough to support producers’ decision on technological innovation. According to Pannell et al. (2006), there are several important influences on adoption of practices, economic benefit is one of them. In terms of the adoption of new technology, producers tend to concern about the consequent economic welfare change.

Genomic selection for more feed-efficient cattle may reduce the cost in beef cattle production, but if the corresponding price effects offset the cost reductions, then producers’ economic benefits may be affected. Therefore, an analysis of market outcome and economic welfare changes arising from adopting genomic selection in Canadian beef cattle production is needed for producers to make decision whether or not to use such technologies.
1.3 Economic Research Problem

The economic research problem addressed in this study is that economic welfare changes resulting from adopting genomic selection that allow producers to make breeding decisions that lead to improved feed-efficiency in Canadian beef production are unknown. First of all, the impact of genomic selection on feed-efficiency improvement is unclear. Currently there is no common conclusion about how much feed efficiency can be improved by genomic selection. Second, the relationship between feed-efficiency improvement and economic benefit is unclear, as it may vary across different countries, markets and sectors.

Addressing the research problem may enhance Canadian governments’ and beef producers’ understanding of welfare effects of genomic selection, and thus may affect the government and producers’ decision regarding technological innovation in the cattle and beef industry. Therefore, it is important to evaluate the economic welfare changes arising from the use of genomic selection.

1.4 Purpose and Objectives

The purpose of this study is to measure the economic welfare changes along the beef value chain in Canada arising from adopting genomic selection for feed-efficiency in beef cattle production.

The objectives of this study are:

1. To identity research gaps by reviewing the literature on (a) North American beef market, (b) Genomic-wide selection for the livestock, (c) Feed
efficiency in the beef cattle industry, (d) the equilibrium displacement model (EDM)

2. To develop a conceptual framework that can be used to anticipate the market and welfare effects of adopting genomic selection by modeling the North American beef market.

3. To construct an empirical framework that evaluates changes in the economic welfare of relevant stakeholders by applying the EDM approach.

4. To measure the market and welfare effects of adopting genomic selection by conducting an ex-ante evaluation using empirical models and collected data.

5. To provide market information and policy implications for beef producers to make decision on technological improvement by drawing conclusions from empirical results.

1.5 Outline of the Thesis

There are five chapters in this thesis. The first chapter provides the introduction to the thesis. It starts with presenting the background of the study and then identifies the economic problem and economic research problem. The purpose and objectives of this study are stated in this chapter. The second chapter presents the details of a conceptual framework for analyzing economic welfare changes arising from adopting genomic selection, and the market structure of North American beef industry is also illustrated in this chapter. In the following chapter an empirical framework for measuring economic welfare changes arising from adopting genomic selection in Canadian beef cattle industry, based on the EDM approach. The fourth chapter presents the data required for applying
the multi-market equilibrium displacement approach and the empirical results of market simulation. The final chapter provides policy implications based on the major findings. The limitations of this study and potential areas for future research will also be discussed in this chapter.
Chapter 2  Conceptual Framework

2.1 Introduction

The main purpose of this chapter is to develop a conceptual framework for the measurement of the economic welfare changes along the beef value chain arising from adopting genomic selection to enhance feed-efficiency in beef cattle production. Attention will be focused on the economic welfare of beef processors and cattle producers, who are the main economic agents in the beef production chain. Producer surplus is used as the primary proxy of economic welfare. Based on this conceptual framework, an empirical model will be developed to measure the changes in the producer surplus.

This chapter includes six sections. The next section briefly introduces the structure of beef and cattle markets, which can be vertically separated into a retail level and a farm level, and horizontally related between Canada and the U.S. In the second section, the production decision of cattle producers and beef processors is discussed at first, and then the technology adoption is incorporated and the economic welfare changes arising from cattle producers’ adoption of the technology are illustrated. In the third section, the induced economic welfare changes occurring to the input market (i.e. the feed grain market) as a result of technology adoption in the farm market (i.e. the cattle market) are further discussed. The fourth section discusses the impact of various technology spillovers on the size and distribution of benefit from the adoption of genomic technology. The fifth section illustrates that the welfare effects of genomics adoption may vary along with the length of run. The last section is a summary of this chapter.
2.2 Market Structure

2.2.1 Vertical Markets

In the conceptual framework, the beef marketing chain is broadly separated into a retail market and a farm market. The retail level refers to the market of beef products, while the farm level in this case refers to the market of fed cattle.

There are several sectors engaged in the production of beef products before they are sold in the retail markets. In North America, the beef production chain mainly consists of a processor sector, a feedlot sector and a cow-calf sector. Calves are produced in cow-calf operations and most of them will be sold to cattle feedlots after weaning. Young cattle will be matured in feedlots and then sold for slaughter. Some cow-calf operations also raise calves for one or two years and then sell them directly to slaughter.

According to Statistics Canada, there were approximately 84,160 farms and ranches engaged in cattle production in 2012. In contrast, there were only 20 federal slaughter plants (companies) in Canada in 2012, and the number of firms in this sector was generally declined in the last decade. The cattle feedlot sector in Canada is broadly regarded to be acting in a competitive manner. However, the role of Canadian beef processors in the cattle market and beef market is a controversial issue (Quagrainie et al., 2003; Rude et al., 2011).

In the development of the conceptual framework, the issue of the market power of Canadian beef processors is set aside, i.e. processors are assumed to be acting in a competitive manner in both the retail level and the farm level. The economic impact of
technology adoption on cattle producers and beef processors will be illustrated under the basic assumption that the retail market and farm market are both fully competitive.

As is shown in Figure 2.1, in the retail market beef processors face the primary demand from consumers for beef products, while in the farm market, cattle feedlots face the derived demand from beef processors for fed cattle. The marginal cost of cattle producers is translated into the primary supply curve in the farm market; the marginal cost of beef processors is called as the derived supply curve in the retail market.

(A) Canada  
(B) Trade  
(C) The U.S.

Figure 2.1: Market Structure
Given the international retail price of beef products, e.g. the price $P_R$ in Figure 2.1, the Canadian beef processor sector is willing to supply a certain quantity of beef products that equal to $QS_R$ in Panel A of Figure 2.1. In order to realize such an output level, the processing sector has to purchase a certain amount of cattle from the feedlot sector, which could be illustrated with the demand quantity $QD_F$ in the farm market.

2.2.2 Horizontal Markets

The beef and cattle markets in Canada and the U.S. are closely related (Young and Marsh, 1998; Miljkovic, 2008). For example, in 2012, Canada exported about 197,378 tonnes of beef and veal to the U.S.A, accounting for 72.8% of Canadian total beef and veal export (source: Statistics Canada 2013) and, simultaneously, 19% of beef and veal export (about 211,926 tonnes) from the U.S.A entered the Canadian market (source: United States Department of Agriculture).

Since exports to the U.S. account for a significant component of the economic wellbeing of the Canadian beef industry, it is important to take beef and cattle trade between Canada and the U.S. into consideration in the conceptual framework. For the convenience of addressing the research problem of this thesis, border measures and transportation costs with respect to beef and cattle trade between Canada and the U.S., as well as issues of exchange rates, are assumed away in the conceptual framework. In addition, the beef and cattle trade between Canada and other countries excluding the U.S. is neglected to focus the discussion.

Canada is generally regarded as an open economy that has enough trade volume to affect the price of beef and cattle in the North American market. As is shown in the top half of Panel A in Figure 2.1, for every level of beef retail price above the market
equilibrium in Canada (i.e. the intersection of domestic supply and demand curves), there is a corresponding quantity of excess supply of beef products. The excess supply of Canadian beef products needs to be transferred to the international trade market (i.e. the excess supply curve $ES_R$ in the top half of Panel B in Figure 2.1). In contrast, when the retail price is below the market equilibrium in the U.S. (as shown in the top half of Panel C of Figure 2.1), there will be excess demand for beef products, which has to be satisfied in the international beef market (i.e. the excess demand curve $ED_R$ in Panel B).

The beef trade market comes to equilibrium at the intersection of excess supply curve and excess demand curve (i.e. Point e in Panel B in Figure 2.1), where the quantity of excess supply of beef products from Canada will be equal to the quantity of excess demand from the U.S. The equilibrium price $P_R$ will be the common price faced by beef processors in both Canada and the U.S. Furthermore, in terms of the market for fed cattle, the situation is generally similar to the above discussion, as we can see from the bottom half of Figure 2.1.

### 2.3 Genomics Adoption and Economic Welfare

#### 2.3.1 Profit Maximization

As economic agents in the competitive markets, cattle producers are normally assumed to be acting to maximize their profits. Their optimization function can be expressed as follows:

$$Max_Q \Pi = P \cdot Q - C_i(W, Q_i, T)$$  \hspace{1cm} (2.1)

where $\Pi$ is the profit of i-th producer

$P$ is the price of cattle
\( Q_i \) is the output quantity of i-th producer

\( C_i \) is the cost function for i-th producer

\( W \) is the input price vector

\( T \) stands for the technology variable

Note that \( T \) is equal to zero when there is no adoption of new technology. For cattle producers, \( T \) will be different from zero after the adoption of genomic technology that leads to improved feed-efficiency in cattle.

Take the first order condition of equation (1) with respect to output quantity:

\[
\Pi_Q = P - MC_i(W, Q_i, T) = 0 \quad (2.2)
\]

\[
P = MC_i(W, Q_i, T) \quad (2.3)
\]

Equation (2.3) indicates that economic agents such as cattle producers, which act on the basis of profit maximization, will increase or decrease their output quantity until the marginal cost equals the output price. Consequently, the aggregated optimal output quantity for feedlot sector will be \( QS_F \), as is shown in the bottom half of Panel A of Figure 2.1.

As mentioned above, the beef-processing sector is assumed to be acting in a competitive manner in both the retail market and the farm market. Accordingly, the first order condition of the optimization function for the beef processing sector could be simply express as \( P=MC(Q) \), which indicates that beef processors will adjust their output quantity based on changes in the output price or/and their marginal cost. At the start, the aggregated optimal output quantity for processor sector will be \( QS_R \), as is shown in the top half of Panel A in Figure 2.1. When the market margin for beef processors is held constant, the changes in the marginal cost of cattle production will result in the changes
in the marginal cost of beef production, which means that the beef supply is affected by the cattle supply. Generally speaking, in the absence of new technology and given the output prices and output quantities in the retail and farm markets, the economic welfare (i.e. the producer surplus) of feedlot sector and of processor sector can be illustrated with the area of \( P_{ Cd } \) and \( P_{ Rab } \) in panel A of Figure 2.1, respectively.

### 2.3.2 Economic Welfare Changes

Genomic selection allows producers to make breeding decisions that lead to improved feed-efficiency in beef cattle production. The production cost of cattle feedlots that are involved in adopting such new technology will be directly affected. In the presence of technology adoption, the variable \( T \) in equation (1) is different from zero, and the marginal cost curve (i.e. the supply curve) for cattle producers is assumed to shift downwards. Correspondingly, the excess supply curve of Canadian cattle in the trade market will shift downwards, as is shown in Figure 2.2. The equilibrium price of fed cattle in the trade market, which is determined by the new excess supply and the unchanged excess demand, will fall from \( P_f \) to \( P'_f \). And the equilibrium quantity of cattle trade will increase from \( Q_{T_f} \) to \( Q'_T \). The Canadian feedlot sector acting on the basis of profit maximization will adjust their output quantity until the new marginal cost of fed cattle equals the new price of fed cattle, i.e., the quantity of fed cattle supplied increases from \( Q_{S_f} \) to \( Q'_{S_f} \).
Figure 2.2: The Economic Impact of Genomics Adoption
The beef sector is supposed to be affected by changes in price and quantity at the farm level. As a result, the derived supply curve in the retail market and the excess supply curve in the beef trade market are both supposed to shift downwards. Furthermore, the new equilibrium price of beef in the trade market is supposed to decline (from $P_R$ to $P_R'$), while the quantity of beef trade will increase (from $QT_R$ to $QT'_R$). And the quantity of beef supplied by the processors in the retail market will increase from $QS_R$ to $QS'_R$.

In the presence of technology adoption and given the changes in prices and quantities in both the farm market and the retail market, the economic welfare of cattle feedlot sector and of beef processor sector are increased by the area of $P'hij$ and $P'efg$ in panel A of Figure 2.2, respectively. Both feedlot sector and processor sector will benefit from the adoption of the genomic technology when the changes in producer surplus are greater than the fixed and sunk cost of technology adoption.

2.4 Feed Market

Canada is an important grain producer in the world and usually a net exporter in the international grain market. Grain is an important source of feed used in the cattle feedlot sector. Since the discussed genomic technology allows cattle feedlots to reduce the amount of feed fed to cattle, the economic welfare of feed producers will also be affected by the adoption of such new technology.

In the presence of the new technology, the demand curve in the feed market is supposed to shift downwards, as shown in Figure 2.3. The difference between feed supply and demand in Canada grows, which means the excess supply curve in the feed
trade market will shift downwards as well. As a result, the equilibrium price in the international feed market will decrease (from $P_w$ to $P'_w$) while the equilibrium quantity of trade will increase (from $QT$ to $QT'$). The economic welfare of Canadian feed producers declines by the area of $P_wabP'_w$ in Panel A of Figure 2.3. In other words, the Canadian feed sector will lose as a result of the adoption of genomic selection in beef cattle production.

(A) Canada  
(B) Trade  
(C) The R.O.W

Figure 2.3: The Economic Impact of Genomics Adoption on Feed Market

2.5 Technology Spillovers

The sections above discuss the economic impact of genomic technology adopted in Canadian beef industry. In general, the Canadian cattle feedlot sector and beef processor sector will benefit from the new technology while the feed sector will lose. However, if the genomic technology is adopted in the United States instead of Canada, the economic impact on Canadian feedlot sector and processor sector will be rather different.
When making a decision about whether or not to adopt the genomic technology, the Canadian beef industry not only needs to consider about the welfare effects of domestic technology adoption, but also has to take into account the shock caused by technology adoption in other countries such as the U.S. From this point of view, it is necessary to discuss the welfare effects of technology spillovers in the conceptual framework.

As is shown in Figure 2.4, the adoption of genomic technology in the U.S. is supposed to shift downwards the supply curves for cattle and beef in the U.S. markets, as well as the excess demand curves in the international markets (retail level and farm level). As there is no technology adoption in Canada, the Canadian cattle and beef markets are assumed to be constant and the excess supply curves in the international markets will be static. The equilibrium prices of cattle and beef in the trade markets will fall while the quantities of cattle and beef trade will increase. The economic welfare of Canadian cattle feedlot sector and beef processor sector will decrease by the area of \( P_c f P'_c \) and \( P_b a e P'_b \) respectively, as is shown in Panel A of Figure 2.4.

Furthermore, the welfare effects of genomics adoption could be more complicated when taking different types of technology spillovers into consideration. Suppose the genomic technology is adopted in the beef industries in more than one country, e.g. in both Canada and the U.S., the size and distribution of benefit from technological improvement may vary among countries due to different rates of technology investment and spread.
Figure 2.4: The Economic Impact of Genomics Adoption in the U.S.
2.6 Short Run Versus Long Run

Although unstated, the above sections discuss the welfare effects of genomics adoption on the basis of an underlying assumption that the genomic technology is adopted by the cattle feedlot sector collectively and immediately. However, this assumption hardly takes place in reality. The diffusion of technology adoption is a complicated process, ranging from months to decades. Evidences show that there could be different stages in the process of adoption (Rogers, 1983). Moreover, the speed of adoption may vary across firm sizes, regions and so on. According to Rogers (1983), there are basically five categories of adopters: innovators, early adopters, early majority, late majority and laggards. In general, the new technology will be adopted more widely as time goes, as is shown in Figure 2.5. At some point, the adoption ratio tends to decline again, since more new technology will be generated during the process of spread-out.

![Figure 2.5: Speed of Technology Adoption](image-url)
Genomic selection is supposed to gradually spread out in the beef cattle industry along with the length of run. Accordingly, welfare effects of genomic selection tend to be different between the short run and the long run. Figure 2.6 illustrates the short-run and long-run economic welfare changes arising from genomic selection.

![Figure 2.6: Welfare Effects in Short Run and Long Run](image)

As shown in Figure 2.6, the demand for fed cattle is held constant during the discussed period. The long-run supply of fed cattle is assumed to be more elastic than the short-run supply. Genomic selection is supposed to shift the long-run supply curve downwards to a greater extent than the short-run supply curve. In the short run, the economic welfare change in the feedlot sector arising from genomics adoption can be
illustrated with the area of abcd in Figure 2.6; in the long run, the economic welfare change equals the area of efgh. The long-run welfare effect of genomics adoption is regarded to be more significant than the short-run when the area of efgh exceeds that of abcd. Additionally, the difference between the long-run and short-run effects also depends on the elasticity of demand for fed cattle, i.e. the more elastic demand, the bigger difference. The situation in the beef processor sector is generally similar to the cattle feedlot sector.

2.7 Summary

The conceptual framework uses the producer surplus as a primary proxy of economic welfare. The feedlot sector and processor sector play an important role in the North American beef industry and they participate in the retail and farm markets to maximize their profit. Both sectors in Canada will benefit from the adoption of genomic selection in the Canadian beef cattle production, while the feed sector in Canada may lose. However, the situation may be different and complicated when take different types of technology spillovers into consideration. Furthermore, the welfare effects of genomics adoption tend to vary along with the length of run, due to different supply elasticity and varying speed of technology adoption.
Chapter 3  Empirical Framework

3.1 Introduction

This chapter is aimed to develop an empirical model for the measurement of economic welfare changes in the cattle feedlot sector and the beef processor sector arising from genomics adoption in cattle production. The model will be established step-by-step, starting from the simplest case of one single market, and then adding horizontal and vertical market structure. An equilibrium displacement model (EDM) approach will be used. The chapter includes five sections. The next section starts with a basic model illustrating the economic welfare changes arising from technological improvement in a closed economy. The second section applies the basic model to discuss genomic adoption in the Canadian cattle sector and takes the cattle trade between Canada and the U.S. into account. In the third section, the model is further developed to include the beef market. The fourth section includes the economic impact of genomics adoption in the cattle sector on domestic feed market. The last section is a summary of this chapter.

3.2 The Basic Model

Alston et al. (1995) discussed in detail about using equilibrium displacement model (EDM) to measure the effects of agricultural research. EDM approach is capable of estimating and comparing potential benefits from research and development, generic promotion investments and other policy changes (Mounter et al., 2008). Researchers from different countries have applied this approach in different sectors and markets, e.g. sheep, chicken and beef, to evaluate the research benefits (Zhao et al., 2000; Mounter et al.,
2008) or optimal advertising (Cranfield, 2002a; Cranfield, 2002b;). Brester et al (2004) used an equilibrium displacement model to estimate short-run and long-run changes in equilibrium prices and quantities of meat and livestock in the U.S. beef, pork and poultry sectors resulting from the implementation of country-of-origin labeling.

An EDM approach is also applied in this study. The empirical framework of this thesis will start with the basic model, which is used to simulate the welfare effects of technological improvement on cattle producers. To begin, assume initially a single market level in a closed economy that is fully competitive. As Figure 3.1 shows, the curve D denotes domestic demand for cattle, which is exclusively dependent on the cattle price. The demand curve is assumed to be static in this model. The curve S, which represents the initial supply of cattle in the market, is derived from the marginal cost for domestic cattle producers. The supply of cattle is assumed to be dependent on the cattle price, as well as the technology input, so that the economic impact of technological improvement can be taken into account. The cattle market comes to equilibrium when the quantity supplied equals the quantity demanded. In the presence of technological improvement, the marginal cost for cattle producers is supposed to decrease, which indicates that the supply of cattle will shift downwards from S to \( S' \). As a result, the equilibrium price of cattle will decline from \( P_0 \) to \( P_1 \), and the equilibrium quantity will increase from \( Q_0 \) to \( Q_1 \). Overall, producer surplus will increase by the area \( P_1bcd \).
The demand and supply in the cattle market of a closed economic can be expressed using the following basic model:

Demand: \( QD = f_1(P) \) \hspace{1cm} (3.1)

Supply: \( QS = f_2(P,T) \) \hspace{1cm} (3.2)

Equilibrium: \( QD = QS \) \hspace{1cm} (3.3)

where \( QD \) and \( QS \) denote the cattle demand and supply, respectively. \( P \) represents the cattle price in the market. \( T \) stands for a technology variable in cattle production, which behaves as the supply shifter in the model. \( T \) is equal to zero for the initial supply curve, \( S \), in Figure 3.1, indicating that there is no adoption of new technology. Equations (3.1) and (3.2) determine the domestic supply and demand of cattle in a closed economy. The
identity in equation (3.3) drives market clearing and hence discovery of the price of cattle in the closed economy.

An EDM approach is implemented here to illustrate linear approximations of the effects of exogenous changes in technology. Equations (3.1), (3.2) and (3.3) can be logarithmically differentiated and turned into the statements about elasticities as following:

\[ d \ln QD = \eta d \ln P \]  
(3.4)  

\[ d \ln QS = \epsilon_P d \ln P + \epsilon_T d \ln T \]  
(3.5)  

\[ d \ln QD = d \ln QS \]  
(3.6)

where \( \eta \) \( \leq 0 \) is the own-price elasticity of demand, \( \epsilon_P \) \( \geq 0 \) is the own-price elasticity of supply, and \( \epsilon_T \) \( \geq 0 \) is the elasticity of supply with respect to the technology variable.

To solve for equilibrium price in terms of the exogenous technology shock, substitute equations (3.4) and (3.5) into (3.6):

\[ \eta d \ln P = \epsilon_P d \ln P + \epsilon_T d \ln T \]

Solve for the logarithmically differential form of equilibrium price with respect to technology variable:

\[ d \ln P = \frac{\epsilon_T}{\eta - \epsilon_P} d \ln T = \lambda d \ln T \]  
(3.7)

where \( \lambda = \frac{\epsilon_T}{\eta - \epsilon_P} \) denotes the elasticity of equilibrium price with respect to the technology variable and is less than zero given \( \eta < 0, \epsilon_P > 0 \) and \( \epsilon_T > 0 \).

As mentioned above, under the assumption of a parallel technology-induced-shift in cattle supply, the cattle producers’ surplus will increase by the area of \( P_1bcd \) in Figure 3.1,
which consists of the area of $P_{1}ecd$ and the area of $bce$. Given the equilibrium prices and quantities before and after technology adoption, the change in producer surplus can be estimated with the following specification:

$$\Delta PS = (P_{1} - d)Q_{0} + \frac{1}{2}(P_{1} - d)(Q_{1} - Q_{0})$$

(3.8)

The above specification can be manipulated into an estimate of the change in producer surplus in terms of $d \ln P$ and $d \ln T$, as below:

$$\Delta PS = P_{0}Q_{0}(K + d \ln P)\left[1 + \frac{1}{2}(\varepsilon_{p}d \ln P + \varepsilon_{\tau}d \ln T)\right]$$

(3.9)

where $K = \frac{P_{0} - d}{P_{0}}$ denotes the vertical shift in supply function (or the proportional shift in initial price) arising from technology adoption (‘$d$’ stands for the price level at which beef producers are willing to maintain initial equilibrium supply quantity after technological changes, as shown in Figure 3.1). Note that $K$ is distinguished from $d \ln P$, as $K$ measures the proportional shift in initial price while $d \ln P = \frac{P_{1} - P_{0}}{P_{0}}$ stands for the percentage change in market equilibrium price. As shown in equation (3.7), $d \ln P$ is an endogenous variable dependent on $d \ln T$ (i.e. $d \ln P = \lambda d \ln T$). Similarly, $K$ is also an endogenous variable dependent on $d \ln T$. To solve for the relationship between $K$ and $d \ln T$, suppose the supply quantity to be constant after technology adoption, which can be written as following:

$$d \ln QS = 0 = \varepsilon_{\tau}(d \ln P)^{\ast} + \varepsilon_{\tau}d \ln T$$

(3.10)

where $(d \ln P)^{\ast}$ stands for vertical downward shift in supply function due to technology adoption. Solve equation (3.10):
Thus, the vertical shift in supply ($K$) can be expressed in terms of the technological variable ($d \ln T$):

$$K = -(d \ln P)^* \frac{\varepsilon_T}{\varepsilon_p} d \ln T$$

(3.12)

Substitute equations (3.7) and (3.12) into (3.9), the specification can be further turned into an estimate of the change in producer surplus in terms of:

$$\Delta PS = P_0Q_0 \left[ \frac{\varepsilon_T}{\varepsilon_p} + \lambda \right] d \ln T \left[ 1 + \frac{1}{2} (\varepsilon_p \lambda + \varepsilon_{\Pi}) d \ln T \right]$$

(3.13)

Equations (3.9) and (3.13) allow calculation of the change in producer surplus arising from technology adoption. With small transformations and adjustments, they can also be used to measure the economic welfare changes in the horizontally and vertically integrated North American beef markets.

### 3.3 Farm Market Modeling

As has been mentioned in the previous chapter, live cattle markets in Canada and the U.S. are closely related. Trade in live cattle between Canada and the U.S. accounts for a considerable part of their total export and import of live cattle. Canada is generally regarded as a net exporter in the North American live cattle market, while the U.S. is a net importer. The issues of transportation cost, border measures and exchange rates are assumed away in the conceptual framework, which means that cattle sectors in both countries are facing the same equilibrium price of cattle.
Figure 3.2 shows that, under the assumption of a parallel shift in supply and no technology spillovers, the adoption of genomic technology by Canadian cattle production is supposed to shift downward the excess supply of cattle, as discussed in the conceptual framework. Hence, the equilibrium price of cattle in North America will decrease. The quantity of domestic supply and demand in Canada will consequently change. Overall, the surplus of Canadian cattle producers will increase by the area \( P_f h i j \) in Figure 3.2.

(A) Canada

In the empirical framework, a price transmission equation is used to relate the price in Canada to the price in the U.S., and embodied in this equation are terms that reflect transportation cost, border measures and exchange rates are taken into account, which relaxes the assumption of a same equilibrium price in both countries. In the North American cattle market, the U.S. is usually regarded as a price leader, while Canada performs as a price follower. Therefore, the Canadian cattle price can be expressed as a function of the U.S cattle price. Cattle producers in Canada and the U.S. make their
supply decision based on the domestic cattle prices in Canada and the U.S., respectively. In addition, the technology variable is assumed to behave as a supply shifter for Canadian cattle producers.

The horizontally integrated North American cattle market can be modeled as following:

\[
\text{Demand: } QD^C_F = f_3(P^C_F) \tag{3.14}
\]
\[
QD^U_F = f_4(P^U_F) \tag{3.15}
\]
\[
\text{Supply: } QS^C_F = f_5(P^C_F, T) \tag{3.16}
\]
\[
QS^U_F = f_6(P^U_F) \tag{3.17}
\]
\[
\text{Equilibrium: } P^C_F = f_7(P^U_F) \tag{3.18}
\]
\[
QD^C_F + QD^U_F = QS^C_F + QS^U_F \tag{3.19}
\]

where QD and QS denote domestic demand and supply in each country, respectively. P stands for the equilibrium price in the North American cattle market. T is the technology variable. The superscripts C and U represent Canada and the U.S., respectively. The subscript F stands for the farm market, which has been explained in the previous chapter. Equations (3.14), (3.15), (3.16) and (3.17) determine the demand for and supply of cattle in Canada and the U.S. Equation (3.18) denotes the price linkage between Canadian cattle market and the U.S. cattle market. Equation (3.19) equates the sum of demand in each country to the sum of supply, which leads to the market clearing in North American cattle market.

Using the log differential rule, equations (3.14) to (3.19) can be turned into the following forms:
where $\eta_f \ (\leq 0)$ is the own-price elasticity of cattle demand. $\varepsilon_f \ (\geq 0)$ is the own-price elasticity of cattle supply. $\varepsilon_T \ (\geq 0)$ is the elasticity of cattle supply with respect to technology variable. $\psi_f$ is the elasticity of Canadian cattle price with respect to the U.S. cattle price. The constants ‘a’ and ‘b’ stand for the share of demand and supply, respectively.

Substitute equations (3.20) to (3.24) into equation (3.25):

$$a_f^C \eta_f^C \psi_f d \ln P_f^U + a_f^U \eta_f^U d \ln P_f^U = b_f^C (\varepsilon_f^C \psi_f d \ln P_f^U + \varepsilon_T d \ln T) + b_f^U \varepsilon_f^U d \ln P_f^U$$

Solve for the logarithmically differential form of the U.S. cattle price with respect to the technology change in Canadian cattle production:

$$d \ln P_f^U = \frac{b_f^C \varepsilon_f^C}{(a_f^C \eta_f^C \psi_f + a_f^U \eta_f^U) - (b_f^C \varepsilon_f^C \psi_f + b_f^U \varepsilon_f^U)} d \ln T = \lambda_f^U d \ln T \quad (3.26)$$

where $\lambda_f^U = \frac{b_f^C \varepsilon_f^C}{(a_f^C \eta_f^C \psi_f + a_f^U \eta_f^U) - (b_f^C \varepsilon_f^C \psi_f + b_f^U \varepsilon_f^U)}$ is the elasticity of the U.S. cattle price with respect to the technology change in Canadian cattle production. Substitute equation (3.26) into equation (3.24):

$$d \ln P_f^C = \psi_f d \ln P_f^U = \psi_f \lambda_f^U d \ln T = \lambda_f^C d \ln T \quad (3.27)$$
where $\lambda_C^C = \psi_\lambda \lambda_C^U$ is the elasticity of Canadian cattle price with respect to the technology change in Canadian cattle production.

The change in Canadian cattle producers’ surplus arising from genomics adoption can be estimated using the area of $P_i^hij$ in Figure 3.2:

$$\Delta PS_F^C = \text{area}[P_i^hij] + \text{area}[dhi] = (P_i^h - j)QS_F^0 + \frac{1}{2}(P_i^h - j)(QS_F^1 - QS_F^0)$$  \hfill (3.28)

Note that within the empirical framework, $P_F$ and $QS_F$ in equation (3.28) refer to Canadian cattle price and Canadian domestic supply of cattle, respectively. The above equation can be manipulated as below:

$$\Delta PS_F^C = P_F^0QS_F^0(K_F + d \ln P_F^C) \left[ 1 + \frac{1}{2}(\epsilon_C^C d \ln P_F^C + \epsilon_T^C d \ln T) \right]$$  \hfill (3.29)

where $K_F = \frac{P_F^0 - j}{P_F^0}$ stands for the vertical shift in Canadian domestic cattle supply arising from genomics adoption. Hold Canadian cattle supply to be constant after technology adoption:

$$d \ln QS_F^C = 0 = \epsilon_C^C(d \ln P_F^C)^* + \epsilon_T^C d \ln T$$  \hfill (3.30)

where $(d \ln P_F^C)^*$ stands for vertical downward shift in Canadian cattle supply function due to technology adoption. Thus, the vertical shift in cattle supply ($K_F$) can be expressed in terms of the technological variable ($d \ln T$):

$$K_F = -(d \ln P_F^C)^* = \frac{\epsilon_C^C}{\epsilon_T^C} d \ln T$$  \hfill (3.31)

Substitute equations (3.27) and (3.31) into (3.29):

$$\Delta PS_F^C = P_F^0QS_F^0 \left[ \frac{\epsilon_T^C}{\epsilon_F^C} + \lambda_F^C \right] d \ln T \left[ 1 + \frac{1}{2}(\epsilon_C^C \lambda_C^C + \epsilon_T^C) d \ln T \right]$$  \hfill (3.32)
Equations (3.29) and (3.32) can be used to measure the economic welfare change in Canadian cattle feedlot sector arising from the genomics adoption in Canadian cattle production when there is trade in live cattle.

### 3.4 Farm-Retail Markets Modeling

As discussed in the conceptual framework, the vertically integrated North American beef marketing chain consists of a retail level and a farm level, which represent the market of beef products and the market of fed cattle respectively. In the retail level, beef processors determine the supply of beef products and face the primary demand from consumers. In the farm level, cattle producers determine the supply of cattle and face the derived demand from beef processors.

Figure 3.3 shows that, under the assumption of fixed and constant size of market margin, the downward shift in Canadian domestic supply of fed cattle will result in a downward shift in Canadian domestic supply of beef products. As illustrated in the conceptual framework, the genomics adoption in Canadian cattle production is supposed to affect both the farm and retail markets. As a result of genomics adoption, Canadian cattle producers’ surplus will increase by the area of $P^1_{rfij}$ in Figure 3.3, while Canadian beef processors, acting as consumers of live cattle in the farm market, will benefit from the genomics adoption by the area of $P^0_{r}abP^1_{r}$ in Figure 3.3.
Figure 3.3: Welfare Effects in the North American Beef and Cattle Market
Within the empirical framework, the consumer demand for beef products in the retail market is assumed to be only dependent on domestic beef price. The beef supply in either country is the result of domestic cattle demand multiplied by the carcass weight of fed cattle. In the farm market, the derived demand for cattle depends on domestic cattle price and domestic beef price. Cattle producers in both countries determine the primary supply of cattle based on respective domestic cattle price. In addition, the technology variable is also a determinant for Canadian domestic cattle supply.

The horizontally and vertically integrated North American beef markets can be simplified as the following farm-retail model:

**Retail**

\[ QD^C_R = f_8(P^C_R) \] (3.33)

\[ QD^V_R = f_9(P^V_R) \] (3.34)

Supply: \[ QS^C_R = CW \times QD^C_F \] (3.35)

\[ QS^U_R = CW \times QD^U_F \] (3.36)

Equilibrium: \[ P^C_R = f_{10}(P^V_R) \] (3.37)

\[ QD^C_R + QD^V_R = QS^C_R + QS^U_R \] (3.38)

**Farm**

Demand: \[ QD^C_F = f_{11}(P^C_F, P^V_R) \] (3.39)

\[ QD^V_F = f_{12}(P^V_F, P^V_R) \] (3.40)

Supply: \[ QS^C_F = f_{13}(P^C_F, T) \] (3.41)

\[ QS^U_F = f_{14}(P^V_F) \] (3.42)

Equilibrium: \[ P^C_F = f_{15}(P^V_F) \] (3.43)

\[ QD^C_F + QD^V_F = QS^C_F + QS^U_F \] (3.44)
where CW stands for the carcass weight of fed cattle; the subscripts F and R denote the farm market and the retail market, respectively. Equations (3.33) to (3.36) determine the demand and supply in the retail market, while equations (3.39) to (3.42) refer to farm market. Equation (3.37) and (3.43) denote the price linkage between Canada and the U.S. in the retail level and the farm level, respectively. Equation (3.38) and (3.44) represent the market clearing in the retail level and the farm level, respectively.

The above model can be turned into the logarithmically differential form as following:

\[
\begin{align*}
\text{RETAIL} \\
&\begin{align*}
d\ln QD_R &= \alpha_R d\ln P_R \\
d\ln QD_U &= \alpha_U d\ln P_U \\
d\ln QS_R &= d\ln QD_F \\
d\ln QS_U &= d\ln QD_F \\
d\ln P_C &= \psi_R d\ln P_R \\
\end{align*} \\
&\begin{align*}
\alpha_R d\ln QD_R + \alpha_U d\ln QD_U &= b_R d\ln QS_R + b_U d\ln QS_U 
\end{align*}
\]

\[
\begin{align*}
\text{FARM} \\
&\begin{align*}
d\ln QD_F &= \eta_R d\ln P_F + \eta_C d\ln P_R \\
d\ln QD_U &= \eta_U d\ln P_F + \eta_R d\ln P_R \\
d\ln QS_F &= \epsilon_F d\ln P_F + \epsilon_C d\ln T \\
d\ln QS_U &= \epsilon_U d\ln P_F \\
d\ln P_F &= \psi_F d\ln P_F \\
\end{align*} \\
&\begin{align*}
a_C d\ln QD_F + a_U d\ln QD_U &= b_F d\ln QS_F + b_U 
\end{align*}
\]
where \( \eta (\leq 0) \) and \( \varepsilon (\geq 0) \) are the elasticities of cattle demand and supply, respectively. \( \alpha (\leq 0) \) is the elasticity of beef demand. \( \psi \) denotes the elasticity of Canadian price with respect to the U.S. price. The constants ‘a’ and ‘b’ stand for the share of demand and supply, respectively. The subscripts F and R stand for the farm market and the retail market respectively. The subscripts P and T denote the price variable and technology variable respectively. For example, \( \eta^C_F \) is the own-price elasticity of Canadian cattle demand, while \( \eta^C_R \) is the elasticity of Canadian cattle demand with respect to Canadian beef price; \( \varepsilon^C_F \) is the own-price elasticity of Canadian cattle supply, while \( \varepsilon^C_T \) is the elasticity of Canadian cattle supply with respect to technology.

Substitute equations (3.45) to (3.49) as well as (3.51) and (3.52) into equation (3.50):

\[
a^C_R \alpha^C_R \psi^R d \ln P^U_R + a^U_R \alpha^U_R d \ln P^U_R = b^C_R (\eta^C_F \psi^F d \ln P^U_F + \eta^C_R \psi^R d \ln P^U_R)
+b^U_R (\eta^U_F d \ln P^U_F + \eta^U_R d \ln P^U_R)
\]

Solve for the logarithmically differential form of the U.S. beef price with respect to the U.S. cattle price:

\[
d \ln P^U_F = \frac{b^C_R \eta^F \psi^F + b^U_R \eta^U_F}{(a^C_R \alpha^C_R \psi^R + a^U_R \alpha^U_R) - (b^C_R \eta^C_R \psi^R + b^U_R \eta^U_R)} d \ln P^U_R = \theta d \ln P^U_F \tag{3.57}
\]

where \( \theta = \frac{b^C_R \eta^F \psi^F + b^U_R \eta^U_F}{(a^C_R \alpha^C_R \psi^R + a^U_R \alpha^U_R) - (b^C_R \eta^C_R \psi^R + b^U_R \eta^U_R)} \) is the elasticity of the U.S. beef price with respect to the U.S. cattle price. Substitute equations (3.51) to (3.55) and equation (3.57) into equation (3.56):

\[
a^C_F (\eta^C_F \psi^F d \ln P^U_F + \eta^C_R \psi^R d \ln P^U_R) + a^U_F (\eta^U_F d \ln P^U_F + \eta^U_R d \ln P^U_R) =
+b^C_F (\varepsilon^C_F \psi^F d \ln P^U_F + \varepsilon^C_T d \ln T) + b^U_F \varepsilon^U_F d \ln P^U_F
\]
Solve for the logarithmically differential form of the U.S. cattle price with respect to the technological change in Canadian cattle production:

\[ d \ln P^U_F = \frac{b_F^C \epsilon^C_F}{a_F^r (\eta^C_F \psi^C_F + \eta^C_R \psi^C_R \theta)} + \frac{b_F^U \epsilon^U_F}{a_F^r (\eta^U_F \psi^U_F + \eta^U_R \psi^U_R \theta)} - (b_F^C \epsilon^C_F \psi^C_F + b_F^U \epsilon^U_F \psi^U_F) d \ln T = \lambda^U_F d \ln T \]  \hspace{1cm} (3.58)

where \( \lambda^U_F = \frac{b_F^C \epsilon^C_F}{a_F^r (\eta^C_F \psi^C_F + \eta^C_R \psi^C_R \theta)} + \frac{b_F^U \epsilon^U_F}{a_F^r (\eta^U_F \psi^U_F + \eta^U_R \psi^U_R \theta)} - (b_F^C \epsilon^C_F \psi^C_F + b_F^U \epsilon^U_F \psi^U_F) \) is the elasticity of the U.S. cattle price with respect to the technology change in Canadian cattle production.

Substitute equation (3.58) into equation (3.55):

\[ d \ln P^C_F = \psi^C_F d \ln P^U_F = \psi^C_F \lambda^U_F d \ln T = \lambda^C_F d \ln T \]  \hspace{1cm} (3.59)

where \( \lambda^C_F = \psi^C_F \lambda^U_F \) is the elasticity of Canadian cattle price with respect to the technology change in Canadian cattle production. Substitute equation (3.57) and (3.58) into equation (3.49):

\[ d \ln P^C_R = \psi^C_R d \ln P^U_R = \psi^C_R \theta d \ln P^U_R = \psi^C_R \theta \lambda^U_R d \ln T = \lambda^C_R d \ln T \]  \hspace{1cm} (3.60)

where \( \lambda^C_R = \psi^C_R \theta \lambda^U_R \) is the elasticity of Canadian beef price with respect to the technology change in Canadian cattle production.

The change in Canadian cattle producers’ surplus, and the change in Canadian beef processors’ surplus, as a result of genomics adoption in Canadian cattle production, can be estimated using the area \( P^i_F dj \) and the area \( P^0_F ab P^j_F \) in Figure 3.3, respectively.

\[ \Delta PS^C_F = \text{area}[P^i_F dj] + \text{area}[dhi] = (P^i_F - j)QS^0_F + \frac{1}{2}(P^i_F - j)(QS^i_F - QS^0_F) \]  \hspace{1cm} (3.61)

\[ \Delta PS^C_R = \Delta CS^C_F = \text{area}[P^0_F ae P^j_F] + \text{area}[abe] = (P^0_F - P^i_F)QD^0_F + \frac{1}{2}(P^0_F - P^i_F)(QD^i_F - QD^0_F) \]  \hspace{1cm} (3.62)
Note that within the empirical framework, $P_F$, $QS_F$ and $QD_F$ in equation (3.61) and (3.62) refer to Canadian domestic cattle price, supply and demand, respectively. The above two equations can be manipulated as below:

\[ \Delta PS_F^C = P_F^0 QS_F^0 (K_F + d \ln P_F^C) \left[ 1 + \frac{1}{2} (\varepsilon_F^C d \ln P_F^C + \varepsilon_F^C d \ln T) \right] \]  \hspace{1cm} (3.63)

\[ \Delta PS_R^C = P_F^0 QD_F^0 (-d \ln P_F^C) \left[ 1 + \frac{1}{2} (\eta_F^C d \ln P_F^C + \eta_R^C d \ln P_R^C) \right] \]  \hspace{1cm} (3.64)

where $K_F = \frac{P_F^0 - j}{P_F^0}$ stands for the vertical shift in Canadian domestic cattle supply. Hold Canadian cattle supply to be constant after technology adoption:

\[ d \ln QS_F^C = 0 = \varepsilon_F^C (d \ln P_F^C)^* + \varepsilon_F^C d \ln T \]  \hspace{1cm} (3.65)

where $(d \ln P_F^C)^*$ stands for the vertical downward shift in Canadian cattle supply function due to technology adoption. Thus, the vertical shift in cattle supply ($K_F$) can be expressed in terms of the technological variable $(d \ln T)$:

\[ K_F = -(d \ln P_F^C)^* = \frac{\varepsilon_F^C}{\varepsilon_F^C} d \ln T \]  \hspace{1cm} (3.66)

Substitute equations (3.59) and (3.66) into (3.63):

\[ \Delta PS_F^C = P_F^0 QS_F^0 \left[ \left( \frac{\varepsilon_F^C}{\varepsilon_F^C} + \lambda_F^C \right) d \ln T \right] \left[ 1 + \frac{1}{2} (\varepsilon_F^C \lambda_F^C + \varepsilon_F^C d \ln T) \right] \]  \hspace{1cm} (3.67)

Substitute equations (3.59) and (3.60) into (3.64):

\[ \Delta PS_R^C = P_F^0 QD_F^0 (-\lambda_F^C d \ln T) \left[ 1 + \frac{1}{2} (\eta_F^C \lambda_F^C + \eta_R^C \lambda_R^C) d \ln T \right] \]  \hspace{1cm} (3.68)
The economic welfare changes in Canadian cattle feedlot sector and beef processor sector arising from genomics adoption in Canadian cattle production can be estimated with equation (3.67) and equation (3.68), respectively.

### 3.5 Feed-Farm-Retail Markets Modeling

Feed plays an essential and important role in the production of fed cattle. Feed producers who determine the supply of feed products are facing the input demand from cattle producers for feed products. As is shown in Figure 3.4, the genomics adoption in Canadian cattle production will behave as a demand shifter in Canadian feed market, moving Canadian domestic demand for feed products from $D$ to $D'$. The equilibrium price of feed products in Canada declines from $P^0_{FD}$ to $P^1_{FD}$, and the quantity of domestic demand and supply in Canada will consequently decrease. Overall, the economic welfare change in Canadian feed sector can be illustrated with the area of $P^0_{FD}abP^1_{FD}$.

(A) Canada  
(B) Trade  
(C) The R.O.W

![Figure 3.4: Welfare Effects in the Feed Market](image-url)
Within the empirical framework, Canadian domestic demand for feed grains is generally determined by domestic feed price, as well as domestic price of intermediate products, such as fed cattle. Furthermore, in this thesis, Canadian domestic demand for feed grains is also dependent on the technology change in cattle production, in addition to the prices of feed and cattle. Canadian domestic supply of feed products is generally dependent on domestic feed price. In the rest of the world, both the feed supply and the feed demand are assumed to solely depend on the world feed price. In the farm market, Canadian domestic cattle supply is supposed to be dependent on Canadian domestic cattle price and domestic feed price, as well as the technology variable. The U.S. domestic cattle supply is dependent on the U.S. domestic cattle price, as well as the world feed price. The cattle demand in either Canada or the U.S. depends on domestic cattle price as well as domestic beef price. In the retail market, the beef supply in either country is the result of domestic cattle demand multiplied by the carcass weight of fed cattle, while the beef demand is assumed to be exclusively dependent on domestic beef price.

Based on the above discussion, the horizontally and vertically integrated feed-farm-retail markets can be simplified as the following model:

Demand: \( QD_R^C = f_{16}(P_R^C) \)  
\( QD_U^C = f_{17}(P_U^C) \)  

Supply: \( QS_R^C = CW \ast QD_F^C \)  
\( QS_U^C = CW \ast QD_F^U \)  

Equilibrium: \( P_R^C = f_{18}(P_R^U) \)  
\( QD_R^C + QD_U^C = QS_R^C + QS_U^C \)
where CW stands for the carcass weight of fed cattle; the subscripts FD, F and R denote the feed market, the farm market and the retail market, respectively; the superscript W denotes the world, and ROW stands for the rest of the world. Equations (3.69) to (3.72) determine the demand and supply in the retail market, while equations (3.75) to (3.78) refer to the farm market, and equations (3.81) to (3.84) are for the farm market. Equations (3.73) and (3.79) denote the price linkage between Canada and the U.S. in the retail level and the farm level respectively, while equation (3.85) stands for the linkage between Canadian feed price and the world feed price. Equation (3.74), (3.80) and (3.86) represent the market clearing in the retail level, the farm level and the feed market respectively.
The above model can be turned into the logarithmically differential form as following:

\[
d ln QD_R^C = \alpha_R^C d ln P_R^C \\
d ln QD_R^U = \alpha_R^U d ln P_R^U \\
d ln QS_R^C = d ln QD_F^C \\
d ln QS_R^U = d ln QD_F^U \\
d ln P_R^C = \psi_R d ln P_R^U \\
\]

\[
a_R^C d ln QD_R^C + a_R^U d ln QD_R^U = b_R^C d ln QS_R^C + b_R^U d ln QS_R^U \\
\]

\[
d ln QD_F^C = \eta_F^C d ln P_F^C + \eta_R^C d ln P_R^C \\
d ln QD_F^U = \eta_F^U d ln P_F^U + \eta_R^U d ln P_R^U \\
d ln QS_F^C = \epsilon_F^C d ln P_F^C + \epsilon_{FD}^C d ln P_{FD}^C + \epsilon_T^C d ln T \\
d ln QS_F^U = \epsilon_F^U d ln P_F^U + \epsilon_{FD}^U d ln P_{FD}^U \\
d ln P_F^C = \psi_T d ln P_F^U \\
\]

\[
a_F^C d ln QD_F^C + a_F^U d ln QD_F^U = b_F^C d ln QS_F^C + b_F^U d ln QS_F^U \\
\]

\[
d ln QD_{FD}^C = \gamma_{FD}^C d ln P_{FD}^C + \gamma_{FD}^U d ln P_{FD}^U + \gamma_T^C d ln T \]

\[
d ln QD_{FD}^{ROW} = \gamma_{FD}^{ROW} d ln P_{FD}^{ROW} \\
d ln QS_{FD}^C = \xi_{FD}^C d ln P_{FD}^C \\
d ln QS_{FD}^{ROW} = \xi_{FD}^{ROW} d ln P_{FD}^{ROW} \\
d ln P_{FD}^C = \psi_{FD} d ln P_{FD}^W \\
\]

\[
a_{FD}^C d ln QD_{FD}^C + a_{FD}^{ROW} d ln QD_{FD}^{ROW} = b_{FD}^C d ln QS_{FD}^C + b_{FD}^{ROW} d ln QS_{FD}^{ROW} \]

44
where $\eta$ ($\leq 0$) and $\varepsilon$ ($\geq 0$) are the elasticities of cattle demand and supply, respectively; 
$\alpha$ ($\leq 0$) is the elasticity of beef demand; $\gamma$ and $\xi$ are the elasticities of feed demand and supply, respectively; $\psi$ denotes the elasticity of Canadian price with respect to the U.S. 
price or the world price; the constants ‘$a$’ and ‘$b$’ stand for the share of demand and supply, respectively. Note that in the feed market, $a_{FD}^C + a_{FD}^{ROW} = b_{FD}^C + b_{FD}^{ROW} = 1$

Substitute equations (3.87) to (3.91) as well as (3.93) and (3.94) into equation (3.92):

$$a_R^C \alpha_R^C \psi_R^d \ln P_R^U + a_R^U \alpha_R^U \ln P_R^U = b_R^C (\eta_R^C \psi_R^d \ln P_R^U + \eta_R^U \psi_R^d \ln P_R^U)$$

$$+ b_R^U (\eta_R^U d \ln P_R^U + \eta_R^d d \ln P_R^U)$$

Solve for the logarithmically differential form of the U.S. beef price with respect to the U.S. cattle price:

$$d \ln P_R^U = \frac{b_R^C \eta_R^C \psi_R^d + b_R^U \eta_R^U}{(a_R^C \alpha_R^C \psi_R^d + a_R^U \alpha_R^U) - (b_R^C \eta_R^C \psi_R^d + b_R^U \eta_R^U)} d \ln P_R^U = \theta d \ln P_F^U$$

(3.105)

where $\theta = \frac{b_R^C \eta_R^C \psi_R^d + b_R^U \eta_R^U}{(a_R^C \alpha_R^C \psi_R^d + a_R^U \alpha_R^U) - (b_R^C \eta_R^C \psi_R^d + b_R^U \eta_R^U)}$ is the elasticity of the U.S. beef price 
with respect to the U.S. cattle price. Substitute equations (3.93) to (3.97) as well as 
equations (3.103) and (3.105) into equation (3.98):

$$a_R^C (\eta_R^C \psi_R^d d \ln P_F^U + \eta_R^U \psi_R^d \theta d \ln P_F^U) + a_R^U (\eta_R^U d \ln P_F^U + \eta_R^d \theta d \ln P_F^U) =$$

$$b_R^C (\varepsilon_R^C \psi_R^d d \ln P_F^U + \varepsilon_R^U \psi_R^d d \ln P_F^U + \varepsilon_R^C d \ln T) + b_R^U (\varepsilon_R^U d \ln P_F^U + \varepsilon_R^U d \ln P_F^U + \varepsilon_R^U d \ln T)$$

which could be rewritten as below:

$$[a_R^C (\eta_R^C \psi_R^d + \eta_R^U \psi_R^d \theta) + a_R^U (\eta_R^U + \eta_R^d \theta) - b_R^C \psi_R^d - b_R^U \psi_R^d] \ln P_F^U =$$

$$(b_R^C \varepsilon_R^C \psi_R^d + b_R^U \varepsilon_R^U \psi_R^d) d \ln P_F^U + b_R^C \varepsilon_R^C d \ln T$$

(3.106)

Substitute equation (3.97) and equations (3.99) to (3.103) into equation (3.104):
which could be rewritten as below:

\[
\begin{align*}
 a_C^{FD} (\gamma^C_{FD} \psi_{FD} d \ln P^W_{FD} + \gamma^C_{F} \psi_{F} d \ln P^U_{F} + \gamma^C_{I} d \ln T) + a_{FD}^{ROW} \gamma_{FD}^{ROW} d \ln P^W_{FD} = \\
 b_C^{FD} \xi^C_{FD} \psi_{FD} d \ln P^W_{FD} + b_{FD}^{ROW} \xi_{FD}^{ROW} d \ln P^W_{FD}
\end{align*}
\]

Solve simultaneous equations (3.106) and (3.107), for \( d \ln P^U_{F} \) and \( d \ln P^W_{FD} \) with respect to \( d \ln T \), respectively:

\[
\begin{align*}
 d \ln P^U_{F} &= \lambda^U_{F} d \ln T \quad (3.108) \\
 d \ln P^W_{FD} &= \lambda^W_{FD} d \ln T \quad (3.109)
\end{align*}
\]

where \( \lambda^U_{F} \) is the elasticity of the U.S. cattle price with respect to the technology change in Canadian cattle production, and \( \lambda^W_{FD} \) is the elasticity of the world feed price with respect to the technology change in Canadian cattle production. Substitute equation (3.108) into (3.97), and equation (3.109) into (3.103), respectively:

\[
\begin{align*}
 d \ln P^C_{F} &= \psi_F d \ln P^U_{F} = \psi_F \lambda^U_{F} d \ln T = \lambda^C_{F} d \ln T \quad (3.110) \\
 d \ln P^C_{FD} &= \psi_{FD} d \ln P^W_{FD} = \psi_{FD} \lambda^W_{FD} d \ln T = \lambda^C_{FD} d \ln T \quad (3.111)
\end{align*}
\]

where \( \lambda^C_{F} \) is the elasticity of Canadian cattle price with respect to the technology change in Canadian cattle production, and \( \lambda^C_{FD} \) is the elasticity of Canadian feed price with respect to the technology change in Canadian cattle production. Substitute equation (3.105) and equation (3.108) into equation (3.91):

\[
\begin{align*}
 d \ln P^C_{R} = \psi \theta d \ln P^C_{R} = \psi \theta d \ln P^U_{F} = \psi \theta \lambda^U_{F} d \ln T = \lambda^C_{R} d \ln T \quad (3.112)
\end{align*}
\]
where $\lambda^C_r$ is the elasticity of Canadian beef price with respect to the technology change in Canadian cattle production.

The changes in Canadian cattle producers’ and beef processors’ surplus, arising from the genomics adoption in Canadian cattle production, can be estimated using the areas $P_{Fij}^1$ and $P_{F}^0 abP_{F}^1$ in Figure 3.3, respectively. Meanwhile, Canadian feed producers’ surplus will decrease by the area of $P_{FD}^0 abP_{FD}^1$ in Figure 3.4:

\[ \Delta PS_F = \text{area} [P_{F}^1 dij] + \text{area} [dhi] = (P_F^1 - j)QS_F^0 + \frac{1}{2} (P_F^1 - j)(QS_F^1 - QS_F^0) \]

\[ \Delta PS_R^C = \Delta CS_F^C = \text{area} [P_{F}^0aeP_{F}^1] + \text{area} [abe] = (P_F^0 - P_F^1)QD_F^0 + \frac{1}{2} (P_F^0 - P_F^1)(QD_F^1 - QD_F^0) \]

\[ -\Delta PS_{FD} = \text{area} [P_{FD}^0 acP_{FD}^1] - \text{area} [abc] = (P_{FD}^0 - P_{FD}^1)QS_{FD}^0 - \frac{1}{2} (P_{FD}^0 - P_{FD}^1)(QS_{FD}^0 - QS_{FD}^1) \]

Note that within the empirical framework, $P_F$ and $P_{FD}$ in the above three equations refer to Canadian domestic cattle price and feed price, respectively; $QS_F$, $QD_F$ and $QS_{FD}$ refer to Canadian domestic cattle supply, cattle demand and feed supply, respectively. The above three equations can be manipulated as below:

\[ \Delta PS_F^C = P_F^0 QS_F^0 (K_F + d \ln P_F^C) \left[ 1 + \frac{1}{2} (\varepsilon_p^C d \ln P_F^C + \varepsilon_T^C d \ln P_{FD}^C + \varepsilon_T^C d \ln T) \right] \]  

(3.113)

\[ \Delta PS_R^C = P_F^0 QD_F^0 (-d \ln P_F^C) \left[ 1 + \frac{1}{2} (\eta_p^C d \ln P_F^C + \eta_r^C d \ln P_R^C) \right] \]  

(3.114)

\[ \Delta PS_{FD}^C = P_{FD}^0 QS_{FD}^0 d \ln P_{FD}^C (1 + \frac{1}{2} \xi_{FD}^C d \ln P_{FD}^C) \]  

(3.115)

where $K_F = \frac{P_F^0 - j}{P_F^0}$ stands for the vertical shift in Canadian domestic cattle supply. Hold Canadian cattle supply to be constant after technology adoption:
\[
d\ln QS^C_F = 0 = \varepsilon^C_F (d\ln P^C_F) + \varepsilon^C_{FD} d\ln P^C_{FD} + \varepsilon^C_T d\ln T \tag{3.116}
\]

where \((d\ln P^C_F)^*\) stands for the vertical downward shift in Canadian cattle supply function due to technology adoption. Thus, the vertical shift in cattle supply \((K_F)\) can be expressed in terms of the technological variable \((d\ln T)\):

\[
K_F = -(d\ln P^C_F)^* = \frac{\varepsilon^C_{FD}}{\varepsilon^C_F} d\ln P^C_{FD} + \frac{\varepsilon^C_T}{\varepsilon^C_F} d\ln T = (\frac{\lambda^C_{FD}\varepsilon^C_{FD}}{\varepsilon^C_F} + \varepsilon^C_T) d\ln T \tag{3.117}
\]

Substitute equations (3.110), (3.111) and (3.117) into (3.113):

\[
\Delta PS^C_F = P^0_F QS^0_F \left[ \frac{\lambda^C_{FD}\varepsilon^C_{FD}}{\varepsilon^C_F} + \frac{\varepsilon^C_T}{\varepsilon^C_F} + \lambda^C_F \right] d\ln T \left[ 1 + \frac{1}{2} (\varepsilon^C_F \lambda^C_F + \varepsilon^C_{FD} \lambda^C_{FD} + \varepsilon^C_T) d\ln T \right] \tag{3.118}
\]

Substitute equations (3.110) and (3.112) into (3.114):

\[
\Delta PS^C_R = P^0_R QS^0_R (-\lambda^C_T d\ln T) \left[ 1 + \frac{1}{2} (\eta^C_F \lambda^C_F + \eta^C_R \lambda^C_R) d\ln T \right] \tag{3.119}
\]

Substitute equations (3.111) into equation (3.117):

\[
\Delta PS^C_{FD} = P^0_{FD} QS^0_{FD} \lambda^C_{FD} d\ln T (1 + \frac{1}{2} \varepsilon^C_{FD} \lambda^C_{FD} d\ln T) \tag{3.120}
\]

The economic welfare changes in Canadian cattle feedlot sector, beef processor sector and feed sector, which arise from the genomics adoption in Canadian cattle production, can be estimated with equation (3.118), (3.119) and (3.120), respectively.

### 3.6 Summary

A multi-market equilibrium displacement model is developed step by step in this chapter, starting with the most basic model, which refer to the technology change in a close economy. The second model denotes the North American cattle market and takes the trade between Canada and the U.S. into consideration. The retail level (beef market)
is incorporated in the third model. The last model includes the retail, farm and feed level, denoting the beef, cattle and feed grain market. Equations established in the feed-farm-retail model can be used to capture market and welfare changes arising from adopting genomic selection in Canadian beef production.

Table 3.1: Summary of Notation

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>QD: Demand</td>
<td>$\alpha$: The elasticity of beef demand</td>
</tr>
<tr>
<td>QS: Supply</td>
<td>$\beta$: The elasticity of beef supply</td>
</tr>
<tr>
<td>P: Price</td>
<td>$\eta$: The elasticity of cattle demand</td>
</tr>
<tr>
<td>T: Technology</td>
<td>$\varepsilon$: The elasticity of cattle supply</td>
</tr>
<tr>
<td>PS: Producer surplus</td>
<td>$\gamma$: The elasticity of feed demand</td>
</tr>
<tr>
<td>K: The proportional supply shift</td>
<td>$\xi$: The elasticity of feed supply</td>
</tr>
<tr>
<td>R: Retail</td>
<td>$\psi$: The elasticity of Canadian price with respect to the U.S. (or world) price</td>
</tr>
<tr>
<td>F: Farm</td>
<td>$\theta$: The elasticity of the U.S beef price with respect to the U.S. cattle price</td>
</tr>
<tr>
<td>FD: Feed</td>
<td>$\lambda$: The elasticity of price with respect to the technology change</td>
</tr>
<tr>
<td>C: Canada</td>
<td></td>
</tr>
<tr>
<td>U: The U.S.</td>
<td></td>
</tr>
<tr>
<td>W: World</td>
<td></td>
</tr>
<tr>
<td>ROW: The rest of the world</td>
<td></td>
</tr>
<tr>
<td>a: The share of demand</td>
<td></td>
</tr>
<tr>
<td>b: The share of supply</td>
<td></td>
</tr>
</tbody>
</table>
Chapter 4  Results

4.1 Introduction

In the last chapter, a multi-market equilibrium displacement model was developed to evaluate the economic impact of adopting genomic selection for feed efficiency in Canadian beef production and the feed grain sector. This chapter provides the results of a baseline simulation as well as the sensitivity analysis of welfare measurement. Five sections are included in this chapter. The next section briefly reviews existing research on feed efficiency in the beef cattle industry. The second section presents parameters values and data used for baseline simulation. The third section provides results of the baseline simulation. In the fourth section, the sensitivity of economic welfare changes to technology shocks and individual parameters is analyzed. The last section is a summary of this chapter.

4.2 Research on Feed Efficiency

4.2.1 Definition of Feed Efficiency

Efficiency may be regarded as the ratio of output to input. Feed efficiency in livestock refers to the relative ability of livestock to turn feed intake into body mass or other output such as milk or eggs. In the beef cattle industry, feed cost generally accounts for about two third of total beef production cost, second only to the fixed cost. Approximately 75% of feed cost is associated with the maintenance of breeding cows. This implies that feed efficiency is a trait of great economic importance to the beef
industry. Improvement in feed efficiency will help to reduce feed cost in beef production and result into a significant economic effect. Reduction in the feed used by the beef industry will also contribute to improving global food security. Furthermore, the importance of feed efficiency is also enhanced by the upward trend in feed price over past few years, as is shown in Figure 4.1.

![Figure 4.1: Canadian Feed Grain Price, 2004-2013](image)

4.2.2 Measures of Feed Efficiency

The most common and simplest way to measure feed efficiency could be feed to gain ratio (F: G), which may also known as feed conversion ratio (FCR). It is defined as feed intake (FI) per unit weight gain. Usually, dry matter intake (DMI) is used to measure feed intake, as the water content may vary across different feed grains. Therefore feed conversion ratio is also known as DMI to gain ratio. There has been a huge improvement
in feed conversion ratio for beef cattle over the past half century, from 10:1 in the 1950s to 6:1 nowadays. However, feed conversion ratio amongst beef cattle is still relatively low, compared to the ratio in the chicken sector (2:1) and the hog sector (3:1). Although feed conversion ratio is a convenient way to measure feed efficiency of beef cattle, it is not an appropriate index for the selection of more feed-efficient beef cattle, because FCR fails to identify the portions of feed intake used for maintenance and growth. Using feed conversion ratio to select cattle may lead to undesired side effects, such as increased cow mature size and increased feed cost for cow herd.

Another commonly used term to measure feed efficiency is residual feed intake (RFI), also known as net feed intake (NFI). The concept of residual feed intake was first put forward by Koch et al. (1963), who suggested that feed efficiency may be computed as a function of feed consumed, gain in body weight and time. They recognized that variations in measured efficiency were affected by the variations in maintenance requirements, differences in composition of gain and differences in feed consumption. To effectively measure feed efficiency, Koch et al. (1963) partitioned feed intake into two parts: one part is the expected feed intake for the given level of production and the other part is the residual portion, which is actually the measure of efficiency in their paper. Therefore, residual feed intake is defined as the difference between actual feed intake and expected feed intake based on animals’ size, body gain and composition over a specific period. Simply speaking, efficient animals have lower (negative) RFI values. In addition to feed conversion ratio and residual feed intake, there are several other measures of feed efficiency being used, such as average daily gain (ADG), residual average daily gain (RADG) and adjusted dry matter intake (Adj. DMI). Archer et al. (1999) discussed
different indices that have been used to express aspects of efficiency on cattle over certain periods of the production cycle. Arthur and Herd (2008) summarized several commonly used traits of growth and feed efficiency, as presented in Table 4.1.

Table 4.1: Several Growth and Feed Efficiency Traits

<table>
<thead>
<tr>
<th>Trait name</th>
<th>Abbr.</th>
<th>Definition</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Live weight</td>
<td>LWT</td>
<td>Weight (wt) at a specified age</td>
<td></td>
</tr>
<tr>
<td>Average daily gain</td>
<td>ADG</td>
<td>Wt gain per day</td>
<td>Regression coefficient from the regression of weight on time (days)</td>
</tr>
<tr>
<td>Relative growth rate</td>
<td>RGR</td>
<td>Growth relative to instantaneous size. Exp. in Arthur et al. (2008) as percentage of change in LWT per day</td>
<td>100 * (log end wt - log start wt) ÷ days on test (Fitzhugh &amp; Taylor, 1971)</td>
</tr>
<tr>
<td>Kleiber ratio</td>
<td>KR</td>
<td>Wt gain per unit metabolic body wt</td>
<td>ADG ÷ average test period LWT0.75</td>
</tr>
<tr>
<td>Feed intake</td>
<td>FI</td>
<td>Feed intake per day</td>
<td></td>
</tr>
<tr>
<td>Feed conversion ratio</td>
<td>FCR</td>
<td>FI per unit wt gain</td>
<td>FI ÷ ADG</td>
</tr>
<tr>
<td>Partial efficiency of growth</td>
<td>PEG</td>
<td>Efficiency of wt gain net of maintenance feed (Fm) requirements</td>
<td>ADG ÷ (FI - Fm), where Fm was obtained by formulas from feeding standards</td>
</tr>
<tr>
<td>Residual feed intake (by Feeding Standards formulae)</td>
<td>RFI$\text{fsf}$</td>
<td>FI net of the expected feed requirements for maintenance and growth, with the expected feed requirements (expFI) obtained from feeding standards formula</td>
<td>FI - expFI, where expFI was obtained by formulas from feeding standards</td>
</tr>
<tr>
<td>Residual feed intake (by Regression)</td>
<td>RFI$\text{reg}$</td>
<td>FI net of the expected feed requirements for maintenance and growth, with expFI obtained by regression</td>
<td>FI - expFI, where expFI was obtained by the regression of FI on average test period LWT0.75 and ADG</td>
</tr>
</tbody>
</table>

Source: Arthur et al., 2008
4.2.3 Genetic Improvement of Feed Efficiency

Compared to non-genetic methods of improving feed efficiency (e.g. diet management and growth promotants), genetic improvement of feed efficiency has the advantage of being cumulative and maintained without further input cost after initial cost of selection for superior breeding stock (Herd et al., 1997). A considerable amount of research has been conducted with respect to genetic improvement of feed efficiency in beef cattle. Koch et al. (1963) suggested that selecting for feed efficiency would improve feed efficiency in beef cattle and lead to increased daily gain, without affecting feed consumption. The study by Herd et al. (2003) indicated that selection for post-weaning RFI had the potential to decrease feed intake and improve feed efficiency of growing animals and mature animals. Considerable variation has been observed in both residual metabolizable energy consumption and residual dry matter consumption, and it might to some degree be attributed to genetic variation (Liu et al., 2000). Furthermore, researchers (Nieuwhof et al. 1992; Arthur et al., 1996; Archer et al. 1998; Arthur et al, 1999; Herd and Bishop, 2000; Arthur et al, 2001) have also examined the relationship between feed efficiency and other traits of beef cattle, such as growth, body composition and cow performance.

Research institutions from different countries, including Beef Cattle Research Council (BCRC) in Canada, New South Wales (NSW) Agricultural Research Centre and Beef Corporative Research Center (CRC) in Australia, have made great contributions to genetic improvement of feed efficiency in beef cattle, and led to significant economic benefit to the beef industry. According to the research by NSW Agricultural Research Center (Richardson et al., 1998), steers selected for lower RFI would have lower DMI
over the test (9.22 ± 0.18 kg/day in the lower RFI line versus 9.78 ± 0.16 kg/day in the lower RFI line), lower RFI (-0.20 ± 0.11 versus 0.17 ± 0.232 kg DM/day) and lower F: G (6.97 ± 0.23 versus 7.60 ± 0.232 kg/kg). Another study in Australia (Arthur et al., 2001) found that after two generations of selection for lower RFI, steers and heifers with similar weight and performance would consume 11% less feed compared to their randomly mated contemporary groups. Exton et al. (2000) suggested that investment in bulls that are genetically superior for net feed efficiency would result in an annual profit of AUD 6.95 per cow for a base enterprise (100-cow herd) and a initial saving in the feed cost of AUD 8.08 per head (which increased to AUD 35 per head after 25 years) in the feedlot. A study in Alberta, Canada (Liu et al., 2000) indicated that the most efficient bull might save as much as CAD 58.32 compared to the least efficient bulls. Other researchers in Alberta (Okine et al., 2004) suggested that 5% increase in feed efficiency would lead to a saving of CAD 18/head in steers, based on the calculation presented in Table 4.2. BCRC in Canada concluded that selection for low RFI would improve feed to gain ratio by 10% to 15% and reduce feed costs by CAD 0.07 to 0.10 /head/day for feeders and CAD 0.11 to 0.12 /head/day for cows (source: BCRC website, 2014).
Table 4.2: Simulated Cost and Saving for Steers

<table>
<thead>
<tr>
<th></th>
<th>Actual Data (200 days)</th>
<th>Calculated 5% Increase in Feed Efficiency (200 days)</th>
<th>Calculated 5% Increase in Weight Gain (191 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Intake (kg/day)</td>
<td>9.45</td>
<td>8.98</td>
<td>9.91</td>
</tr>
<tr>
<td>Feed efficiency (kg/kg gain)</td>
<td>6.08</td>
<td>5.78</td>
<td>6.08</td>
</tr>
<tr>
<td>Gain (kg/day)</td>
<td>1.55</td>
<td>1.55</td>
<td>1.63</td>
</tr>
<tr>
<td>Feed ($/ kg gain)</td>
<td>1.13</td>
<td>1.07</td>
<td>1.13</td>
</tr>
<tr>
<td>Feed cost ($ for total gain/day)</td>
<td>1.75</td>
<td>1.66</td>
<td>1.84</td>
</tr>
<tr>
<td>Total feed costs</td>
<td>$350</td>
<td>$332</td>
<td>$352</td>
</tr>
<tr>
<td>Total costs including yardage ($0.37/day)</td>
<td>$424</td>
<td>$406</td>
<td>$422</td>
</tr>
<tr>
<td>Savings for 200 days @$0.186/kg feed</td>
<td>—</td>
<td>$18 per head</td>
<td>$2 per head</td>
</tr>
</tbody>
</table>

Source: Okine et al., 2004

4.2.4 Genomic Selection for Feed Efficiency

Genomic selection was first described by Meuwissen et al. (2001). Over the past few years, rapidly changing technologies and drastically reduced genotyping cost make genomic selection for feed efficiency in beef cattle more feasible. As a new tool for genetic improvement of feed efficiency, genomic selection allows for increased selection accuracy, decreased generation interval and increase selection intensity (Miller, 2010). Shortening generation intervals as much as reproductive technology allow will help to maximize the advantage of genomic selection (Goddard and Hayes, 2007). Applications of genomic selection in the design and implementation of livestock breeding programs may promise gains across the value chain (Eggen 2012). Currently, the most appropriate way to apply genomic selection in the genetic improvement programs is to associate
genomic information with animal genetic valuation, e.g. estimated breeding values (EBV) (Miller, 2010). Researchers have already been working on the accuracy of genomic breeding values (GBV) in recent years (Meuwissen and Goddard, 2010; Bolormaa et al, 2013; Chen et al., 2013; Saatchi et al., 2013). To effectively implement genomic selection for feed efficiency in beef cattle, an overwhelming size of reference cattle population is required and therefore international collaboration is very necessary (Miller, 2010). Efforts have been undertaken to implement genomic selection by organizations across countries, e.g. USDA Agricultural Research Service (ARS) in the U.S., Ontario Ministry of Agricultural, Food and Rural Affairs (OMAFRA), University of Guelph, University of Alberta in Canada and Beef Corporative Research Center (CRC) in Australia, promising an accelerated genetic improvement of feed efficiency in beef cattle.

4.3 Data Summary

To evaluate the economic impact of adopting genomic selection in Canadian beef production, a full set of data are collected, on the basis of the multi-market equilibrium displacement model developed in previous chapter. Table 4.3 presents a single set of parameters and data that is necessary for market simulation. Generally, those parameters and data fall into three categories.
<table>
<thead>
<tr>
<th>Elasticity/Data</th>
<th>Symbol</th>
<th>Value</th>
<th>Canada</th>
<th>U.S/R.O.W.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RETAIL MARKET:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Own-price demand elasticity</td>
<td>( \alpha_R )</td>
<td>-0.289&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-0.196&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Elasticity of price linkage</td>
<td>( \psi_R )</td>
<td>1.002&lt;sup&gt;a&lt;/sup&gt;</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Demand share</td>
<td>( a_R )</td>
<td>7.53%</td>
<td>92.47%</td>
<td></td>
</tr>
<tr>
<td>Supply share</td>
<td>( b_R )</td>
<td>9.82%</td>
<td>90.18%</td>
<td></td>
</tr>
<tr>
<td><strong>FARM MARKET:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Own-price demand elasticity</td>
<td>( \eta_F )</td>
<td>-0.207&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-0.209&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Elasticity of demand with respect to retail price</td>
<td>( \eta_R )</td>
<td>0.137&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.323&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Own-price supply elasticity</td>
<td>( \varepsilon_F )</td>
<td>0.431&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.061&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Elasticity of supply with respect to feed price</td>
<td>( \varepsilon_{FD} )</td>
<td>-0.101&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-0.035&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Technology-induced supply shift</td>
<td>( \varepsilon_T d\ln T )</td>
<td>0.01</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Elasticity of price linkage</td>
<td>( \psi_F )</td>
<td>0.931&lt;sup&gt;a&lt;/sup&gt;</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Demand share</td>
<td>( a_F )</td>
<td>10.02%</td>
<td>89.98%</td>
<td></td>
</tr>
<tr>
<td>Supply share</td>
<td>( b_F )</td>
<td>12.66%</td>
<td>87.34%</td>
<td></td>
</tr>
<tr>
<td>Avg. cattle value (CAD/head)</td>
<td>( P^0_F )</td>
<td>1190.09</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Avg. cattle supply (head)</td>
<td>( QS^F_0 )</td>
<td>4,348,611</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Proportional shift in farm price</td>
<td>( K_F )</td>
<td>0.0163</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td><strong>FEED MARKET:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Own-price demand elasticity</td>
<td>( \gamma_{FD} )</td>
<td>-0.554&lt;sup&gt;d&lt;/sup&gt;</td>
<td>-0.268&lt;sup&gt;e&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Elasticity of demand with respect to farm price</td>
<td>( \gamma_F )</td>
<td>-0.198&lt;sup&gt;d&lt;/sup&gt;</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Technology-induced demand shift</td>
<td>( \gamma_T d\ln T )</td>
<td>-0.0163</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Own-price supply elasticity</td>
<td>( \xi_{FD} )</td>
<td>0.27&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>Elasticity of price linkage</td>
<td>( \psi_{FD} )</td>
<td>1.0</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Demand share</td>
<td>( a_{FD} )</td>
<td>2.04%</td>
<td>97.96%</td>
<td></td>
</tr>
<tr>
<td>Supply share</td>
<td>( b_{FD} )</td>
<td>2.54%</td>
<td>97.46%</td>
<td></td>
</tr>
<tr>
<td>Avg. feed grain price (CAD/tonne)</td>
<td>( P^0_{FD} )</td>
<td>172.05</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Avg. feed grain supply (000 tonnes)</td>
<td>( QS^0_{FD} )</td>
<td>25,117</td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Cranfield and Goddard, 1999; <sup>b</sup> Cranfield, 2010; <sup>c</sup> Buhr and Kim, 1997; <sup>d</sup> Richards and Patterson, 2003; <sup>e</sup> USDA, 2005; <sup>f</sup> Choi and Helmberger, 1993
4.3.1 Type One: Market Statistics

The first type of data refers to the original market prices and supply quantities in Canada, as well as the market shares of Canada and the U.S. (or the rest of the world). The values for these parameters are basically calculated based on the data collected from Statistic Canada and United States Department of Agriculture (USDA), mostly covering the period from 2004 to 2012.

As shown in Table 4.3, in the retail level, beef demand in Canada accounts for about 7.53% of total North American beef market, while U.S beef demand makes up the rest 92.47%. Meanwhile, the beef products from Canada occupies around 9.82% of total beef supply in North America, compared to the rest 90.18% from the U.S.

In the farm level, Canada’s shares in cattle demand and supply are 10.02% and 12.66% respectively while the shares of the U.S. are 89.98% and 87.34% respectively. In Canada, the average live cattle price (over the period from 2005 to 2013) was $1190.09 per head, and the average annual cattle supply was about 4.3 million heads.

In the feed level, data for five main types of coarse grains, including corn, barley, oats, rye and mixed grains, are collected and calculated. Results show that, in the feed grain market, Canada accounts for 2.04% and 2.54% in global feed demand and supply respectively while the rest of the world contribute 97.96% and 97.46% to global feed demand and supply respectively. In Canada, the average feed grain price over the sample period (2004 to 2012) was $172.05 per tonne, and the average feed grain supply was about 25.12 million tonnes.

Generally speaking, in North American beef industry, the estimated share of Canada in supply exceeds the country’s share in demand, which indicates that Canada is a net
exporter while the U.S. is a net importer in both retail and farm levels. Furthermore, the estimated shares of Canada in the global feed grain market show that Canada is also a net feed grain exporter in the world. These findings are consistent with the assumption in the conceptual framework.

4.3.2 Type Two: Technology Shock

The second type of parameters and data are related to the technological shock, including technology-induced supply and demand shifts (i.e. $\epsilon_t d\ln T$ and $\gamma_t d\ln T$), as well as the proportional shifts in cattle price (i.e. $K_F$). In the vertically integrated North American beef industry model, adoption of genomic-based testing is captured as a shift in Canadian cattle supply and feed grain demand, which are respectively symbolized by $\epsilon_t d\ln T$ and $\gamma_t d\ln T$, as shown in Table 4.3. It is worthwhile to mention that technology-induced supply and demand shifts are different from percentage changes in equilibrium supply and demand quantities ($d\ln QS$ and $d\ln QD$), since the former notation denotes the direct shock to cattle production or feed grain demand caused by genomics adoption, excluding the effects of market response. Usually technology-induced supply and demand shifts are supposed to be either offset or enhanced by the effects of changes in market prices. Similarly, the proportional shift in Canadian cattle price ($K_F$) are different from the percentage change in Canadian cattle price ($d\ln P^C_F$), as $d\ln P^C_F$ is defined as

$$\frac{P^1_F - P^0_F}{P^0_F}$$

while $K_F = \frac{P^0_F - j}{P^0_F}$, where “j” stands for the price level at which Canadian cattle producers are willing to maintain initial equilibrium supply quantity after technological improvement.
As discussed in Section 4.2.3, BCRC’s research suggested that genetic improvement of feed efficiency would reduce feed costs by CAD 0.07 to 0.10 /head/day for feeders and CAD 0.11 to 0.12 /head/day for cows, which can be translated as a saving of CAD 14 to 20 for feeders and CAD 22 to 24 for cows, over a 200-day feeding period. These estimates are consistent with the study by Okine et al. (2004), who suggested a saving of CAD 18/head in steers over a 200-day feeding period. According to these findings, the reduction in the cost of beef cattle production arising from genomic selection for feed efficiency is assumed to be CAD 20/head in this thesis. Consequently, the proportional shift in Canadian cattle price, i.e. \( K_F \) is equal to 0.0168 (CAD 20/head ÷ CAD 1190.09/head). According to Okine et al. (2004), 5% improvement in feed efficiency will reduce feed intake by 0.47kg/day (9.45kg/day - 8.98kg/day), which indicates that the feed consumed by cattle over a 200-day feeding period may decrease by about 94kg (0.47kg/day*200 days). The average annual supply of cattle in Canada over the period from 2004 to 2012 is about 4,348,611 heads. Therefore, the annual feed grains consumed by Canadian beef cattle may decrease by about 408.77 million kg, which indicates that the technology-induced feed demand shift (i.e. \( \gamma_T d \ln T \)) is approximately -0.0163 (-408.77 million kg ÷ 25,117 million kg). Lastly, the technology-induced cattle supply shift (i.e. \( \varepsilon_T d \ln T \)) can be calculated using Equation 3.117 (as presented in the previous chapter) and running simulation on TSP 5.1 programs. According to the estimation result, \( \varepsilon_T d \ln T \) is approximately 0.0072.
4.3.3 Type Three: Elasticity

The last type of parameters and data include the elasticity of demand, supply and price linkage in three market levels. Values for these parameters are mostly collected from previous studies. In terms of North American beef and cattle markets (i.e. the retail and farm levels), the values for elasticity are mostly from the paper by Cranfield and Goddard (1999) and the report by Cranfield (2010), except for the parameter $\eta^U_R$ (elasticity of U.S. cattle demand with respect to retail price), which is collected from the paper by Buhr and Kim (1997). Table 4.3 shows that, in Canada, the values for own-price beef demand elasticity ($\alpha^C_R$) and own-price cattle demand elasticity ($\eta^C_F$) are -0.289 and -0.207 respectively. The corresponding values for U.S. are -0.196 and -0.209 respectively. The elasticity of cattle demand with respect to beef retail price ($\eta^C_R$) is estimated to be 0.137 in Cranfield 2010; however, the corresponding value for the U.S. is not available in that report. According to Buhr and Kim (1997), the elasticity of U.S. total cattle slaughter with respect to the price of beef production is about 0.323, which is adopted as the value for $\eta^U_R$ (the elasticity of cattle demand with respect to beef retail price in U.S.) in this thesis. On the other hand, the values for the own-price cattle supply elasticity in Canada and the U.S. ($\epsilon^C_F$ and $\epsilon^U_F$) are 0.431 and 0.061 respectively (Cranfield and Goddard, 1999), while the elasticity of cattle supply with respect to feed price in these two countries ($\epsilon^C_{FD}$ and $\epsilon^U_{FD}$) are estimated to be -0.101 and -0.035 respectively (Cranfield 2010). Moreover, in the retail level and farm level, the elasticity of Canadian price with respect to U.S. price ($\psi_R$ and $\psi_F$) are 1.002 and 0.931, respectively (Cranfield and Goddard, 1999).
In terms of the feed grain market, the own-price elasticity for feed grain demand in Canada \( (\gamma_{FD}^C) \) equals -0.554, which is from the paper by Richards and Patterson (2003). The corresponding value for the world \( (\gamma_{FD}^W) \), -0.268, is drawn from the average value of the own-price cereal demand elasticity in 144 countries (or regions) estimated by United States Department of Agriculture (USDA, 2005). The elasticity of feed grain demand with respect to cattle price in Canada \( (\gamma_{F}^C) \) is not available for this time being; therefore, the value for the elasticity of grain and cereal demand with respect to meat price from Richards and Patterson (2003) is used in its place (i.e. -0.198). On the supply side, Choi and Helmberger (1993) estimated the own-price elasticity of corn supply in U.S. to be 0.27, which is adopted as the value for the own-price elasticity of grain supply in Canada \( (\xi_{FD}^C) \). The corresponding value for the world is assumed to be 0.9 in this study, which indicates the assumption of an inelastic grain supply in the whole world. Furthermore, the elasticity of Canadian price with respect to the world price in the feed grain market is currently set to be 1.0 in this thesis, based on the corresponding values for the retail and farm levels (1.002 and 0.931).

### 4.4 Baseline Simulation

#### 4.4.1 Simulation Techniques

In the baseline simulation, the North American beef industry and feed grain sector are modeled using TSP 5.1, based on the empirical framework developed in previous chapter. A complete set of formulas and identities, which consist of various endogenous
variables and parameters, are built on TSP program to capture the supply, demand and equilibrium in multi-market levels.

Generally speaking, genomic adoption \((d \ln T)\) is incorporated as the most important exogenous variable in the model, while the changes in demand \((d \ln QD)\), supply \((d \ln QS)\), equilibrium prices \((d \ln P)\) and producer surplus \((\Delta PS)\) in all three levels (retail, farm and feed) are endogenous variables dependent on \(d \ln T\). The measurements of these endogenous variables are not only dependent on the magnitude of technological change, but also affected by the values of parameters such as supply and demand elasticity.

To be specific, there are 21 endogenous variables to be measured in the baseline simulation using TSP, including changes in demand \((d \ln QD^C_R, d \ln QD^U_R, d \ln QD^C_F, d \ln QD^U_F, d \ln QD^C_{FD}, d \ln QD^U_{FD})\), changes in supply \((d \ln QS^C_R, d \ln QS^U_R, d \ln QS^C_F, d \ln QS^U_F, d \ln QS^C_{FD}, d \ln QS^U_{FD})\), changes in prices \((d \ln P^C_R, d \ln P^U_R, d \ln P^C_F, d \ln P^U_F, d \ln P^C_{FD}, d \ln P^U_{FD})\) and changes in Canada’s producer surplus \((\Delta PS^C_R, \Delta PS^C_F, \Delta PS^C_{FD})\). On the other hand, \(K_F, \varepsilon_T d \ln T\) and \(\gamma_T d \ln T\) are used as main exogenous variables in the market simulation, respectively denoting vertical shifts in Canadian cattle price, cattle supply and feed grain demand arising from the adoption of genomic selection. Moreover, there are a total of 18 parameters in the set of formulas and identities, denoting different elasticity in the retail level \((\alpha^C_R, \alpha^U_R, \psi_R)\), the farm level \((\eta^C_F, \eta^U_F, \eta^C_R, \eta^U_R, \varepsilon^C_F, \varepsilon^U_F, \varepsilon^C_{FD}, \varepsilon^U_{FD}, \psi_F)\) and the feed level \((\gamma^C_{FD}, \gamma^U_{FD}, \chi^C_F, \chi^U_F, \xi^C_{FD}, \xi^U_{FD}, \psi_{FD})\). Lastly, the market shares of countries, original market prices and supply quantities in Canada generally play the role of constants in the model.
Based on the model specified above and the set of data presented in Table 4.3, a baseline simulation is conducted using TSP program, and results are summarized in Table 4.4. These results show the economic impact of adopting genomic selection in Canada beef production, which can be broadly separated into two aspects: market effects and welfare effects.

4.4.1 Market Effects

In the baseline simulation, it is estimated that genomics adoption will cause a shift of 0.72% in Canadian cattle supply and -1.63% in Canadian feed grain demand. Table 4.4 shows that, in the presentation of given technological changes, the market prices in all three levels will decline. Specifically, the cattle prices will decline most significantly, ranging from -0.46% (Canada) to -0.49% (the U.S.). The U.S. cattle price decline more than Canada, which indicates that the U.S. cattle producers are probably facing more pressure as a result of genomics adoption in Canada. The changes in beef retail prices in these two countries are close to each other, both declining by approximately 0.20%. By comparing the changes in beef price and cattle price, it can be broadly concluded that the market margin between North American beef sector and cattle sector is supposed to expand with the adoption of genomic selection. Furthermore, simulation results show that in the feed grain market, the price will fall just slightly (no more than 0.03%) in Canada and the rest of the world. The change in feed price is relatively small because Canada only occupies a relatively small share in the global feed grain market.

A lower cattle price is supposed to increase the quantity of cattle demand while reduce the quantity of cattle supply. Table 4.4 shows that the cattle demand will increase by 0.07% in Canada and 0.04% in the U.S. On the other hand, the U.S. cattle supply falls
by -0.03% along with price change, while Canadian cattle supply increase by 0.53% against price change. The change in Canadian cattle supply indicates that the effect of cost reduction in Canadian cattle sector resulting from genomics adoption exceeds the corresponding price effects. In the retail level, beef demand increases by 0.06% in Canada and 0.04% in the U.S., which is consistent with changes in beef price. It is worth mentioning that the percentage change in beef supply in each country is exactly the same as the percentage change in cattle demand of that country (as discussed in the empirical framework, the beef supply is a function of cattle demand multiplied by carcass weight, which indicates that the percentage changes in beef supply will be the same with cattle demand). Finally, in the feed grain market, the demand increases slightly (0.007%) in the rest of the world (due to a lower price) but decreases in Canada, which indicates that the genomics selection leads to improved feed efficiency and reduced input demand in Canadian cattle sector. Moreover, simulation results show that the feed supply in both Canada and the rest of the world will decline, as expected in the conceptual framework.
Table 4.4: Market and Welfare Effects of Genomic Adoption

<table>
<thead>
<tr>
<th>Markets</th>
<th>Regions</th>
<th>Canada</th>
<th>U.S. (or R.O.W.)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Retail</strong></td>
<td>Demand (%)</td>
<td>0.0585</td>
<td>0.0396</td>
</tr>
<tr>
<td></td>
<td>Supply (%)</td>
<td>0.0675</td>
<td>0.0381</td>
</tr>
<tr>
<td></td>
<td>Price (%)</td>
<td>-0.2023</td>
<td>-0.2019</td>
</tr>
<tr>
<td></td>
<td>Producer Surplus Change</td>
<td>$19.67 million</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Farm</strong></td>
<td>Demand (%)</td>
<td>0.0675</td>
<td>0.0381</td>
</tr>
<tr>
<td></td>
<td>Supply (%)</td>
<td>0.5257</td>
<td>-0.0292</td>
</tr>
<tr>
<td></td>
<td>Price (%)</td>
<td>-0.4602</td>
<td>-0.4943</td>
</tr>
<tr>
<td></td>
<td>Producer Surplus Change</td>
<td>$63.29 million</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Feed</strong></td>
<td>Demand (%)</td>
<td>-1.5239</td>
<td>0.0072</td>
</tr>
<tr>
<td></td>
<td>Supply (%)</td>
<td>-0.0073</td>
<td>-0.0244</td>
</tr>
<tr>
<td></td>
<td>Price (%)</td>
<td>-0.0271</td>
<td>-0.0271</td>
</tr>
<tr>
<td></td>
<td>Producer Surplus Change</td>
<td>$-1.17 million</td>
<td>N/A</td>
</tr>
</tbody>
</table>

4.4.2 Welfare Effects

Alston et al. (1995) presented an equilibrium framework for analyzing changes in economic welfare arising from technological improvements. In this thesis, the welfare effects of adopting genomic selection for feed efficiency in Canadian beef production are measured using the multi-market equilibrium displacement framework. As shown in the second chapter (the conceptual framework), it is assumed that the adoption of genomic selection will lead to a parallel shift in cattle supply, feed demand, followed by a parallel shift in beef supply. Within the context of my conceptual framework, the producer
surplus changes in Canada can be illustrated using the coloured areas in Figure 2.2 and Figure 2.3.

The producer surplus change in Canada can be empirically measured using equations (3.113), (3.114) and (3.115), which are developed in section 3.5 (the feed-farm-retail model):

\[
\Delta P_{FS}^C = P_F^0 Q_S^0 (K_F + d \ln P_F^C) \left[ 1 + \frac{1}{2} (\varepsilon_F^C d \ln P_F^C + \varepsilon_{FD}^C d \ln P_{FD}^C + \varepsilon_{RT}^C d \ln T) \right]
\]

\[
\Delta P_{SR}^C = P_F^0 Q_D^0 (-d \ln P_F^C) \left[ 1 + \frac{1}{2} (\eta_F^C d \ln P_F^C + \eta_R^C d \ln P_R^C) \right]
\]

\[
\Delta P_{FD}^C = P_{FD}^0 Q_S^0 d \ln P_{FD}^C (1 + \frac{1}{2} \xi_{FD}^C d \ln P_{FD}^C)
\]

where \( \Delta P_{SR}^C, \Delta P_{FS}^C \) and \( \Delta P_{FD}^C \) are three endogenous variables standing for producer surplus changes in Canadian beef sector, cattle sector and feed sector respectively. The required parameters and data in these three equations are presented in Table 4.3 and 4.4.

Simulation results show that, when assuming a technological shock of 0.72% in Canadian cattle supply and -1.63% in Canadian feed demand, the economic welfare of Canadian cattle sector will increase most significantly (by $63.29 million), followed by the beef sector ($19.67 million), while feed sector would made worse off (-$1.17 million). It is interesting to find out that the post-farm gate Canadian beef sector gains significant benefit from the genomics adoption in cattle, which maybe explained by the increased market margin between Canadian beef sector and cattle sector after technological changes. The relatively small amount of welfare change in Canadian feed sector is consistent with expectation, due to the small share of Canada in global feed grain market.
4.5 Sensitivity Analysis

4.5.1 Sensitivity to Technology Shock

In last section, the economic impact of adopting genomic selection in Canadian beef production is simulated on TSP program, using parameter values from previous studies and an estimated technological shock of 0.72% increase in cattle supply and 1.63% decrease in feed grain demand. Simulation results provide a perspective of market and welfare effects on North American beef industry and Canadian feed sector resulting from genomics adoption. However, as mentioned before, the measurements of those endogenous variables are affected by both technology variables (i.e. technology shock) and values of parameters.

In the baseline simulation, the technology shock, including technology-induced supply and demand shifts (i.e. $\epsilon_T d \ln T$ and $\gamma_T d \ln T$), as well as the proportional shift in cattle price (i.e. $K_p$), are estimated based on the research by Okine et al. (2004) and BCRC. A 5% improvement in feed efficiency is assumed in Okine et al. (2004) and supposed to reduce feed intake by 0.47 kg/head/day. Following their framework, a 1% improvement in feed efficiency is estimated to reduce feed intake by 0.09 kg/head/day while a 10% improvement will reduce feed intake by 0.94 kg/head/day. Table 4.5 presents the savings for steers over 200-day feeding period with different improvements in feed efficiency.
Table 4.5: Estimated Savings for Steers: Three Scenarios

<table>
<thead>
<tr>
<th></th>
<th>Actual Data</th>
<th>1% Improvement in Feed Efficiency</th>
<th>5% Improvement in Feed Efficiency</th>
<th>10% Improvement in Feed Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Intake (kg/day)</td>
<td>9.45</td>
<td>9.36</td>
<td>8.98</td>
<td>8.51</td>
</tr>
<tr>
<td>Feed efficiency (kg/kg gain)</td>
<td>6.08</td>
<td>6.02</td>
<td>5.78</td>
<td>5.47</td>
</tr>
<tr>
<td>Gain (kg/day)</td>
<td>1.55</td>
<td>1.55</td>
<td>1.55</td>
<td>1.55</td>
</tr>
<tr>
<td>Feed ($/ kg gain)</td>
<td>1.13</td>
<td>1.12</td>
<td>1.07</td>
<td>1.02</td>
</tr>
<tr>
<td>Feed cost ($ for total gain/day)</td>
<td>1.75</td>
<td>1.73</td>
<td>1.66</td>
<td>1.58</td>
</tr>
<tr>
<td>Total feed costs</td>
<td>$350</td>
<td>$346</td>
<td>$332</td>
<td>$316</td>
</tr>
<tr>
<td>Total costs including yardage ($0.37/day)</td>
<td>$424</td>
<td>$420</td>
<td>$406</td>
<td>$390</td>
</tr>
<tr>
<td>Savings for 200 days @ $0.186/kg feed</td>
<td>___</td>
<td>$4 per head</td>
<td>$18 per head</td>
<td>$34 per head</td>
</tr>
</tbody>
</table>

Based on the above estimation, the technology-induced feed demand shifts (i.e. $\gamma_T \cdot d\ln T$) arising from 1%, 5% and 10% improvements in feed efficiency are calculated to be about -0.0031 (-0.09 kg/head/day * 200 days * 4,348,611 heads ÷ 25,117 million kg), -0.0163 (-0.47 kg/head/day * 200 days * 4,348,611 heads ÷ 25,117 million kg) and -0.0325 (-0.94 kg/head/day * 200 days * 4,348,611 heads ÷ 25,117 million kg) respectively.

To be consistent with Section 4.3.2, cost savings in above three scenarios are adjusted to be CAD 4.4/head, CAD 20/head and CAD 37.8/head respectively. Therefore, the proportional shifts in Canadian cattle price (i.e. $K_F$) in these three scenarios are estimated to be 0.0037 (CAD 4.4/head ÷ CAD 1190.09/head), 0.0168 (CAD 20/head ÷ CAD 1190.09/head) and 0.0318 (CAD 37.8/head ÷ CAD 1190.09/head) respectively.

Lastly, the technology-induced cattle supply shifts (i.e. $\varepsilon_T d\ln T$) in these three scenarios...
are estimated to be 0.0016, 0.0072 and 0.0137 respectively, by using Equation 3.117 and running simulation on TSP 5.1 programs. The producer surplus changes in these three scenarios are calculated respectively based on the technology shocks estimated above. Results are presented in Table 4.6. Generally speaking, one more percent improvement in feed efficiency is supposed to lead to a $3.66 million increase in retail-level producer surplus change, a $11.79 million increase in farm-level producer surplus change and a $0.24 million decrease in feed-level producer surplus change.

Table 4.6: Technology shocks and PS Changes: Three Scenarios

<table>
<thead>
<tr>
<th>Response</th>
<th>Scenarios</th>
<th>Improvement in Feed Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1%</td>
</tr>
<tr>
<td>Technology Shock %</td>
<td>$K_F$</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td>$\epsilon_T d \ln T$</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td>$\gamma_T d \ln T$</td>
<td>-0.31</td>
</tr>
<tr>
<td>PS Changes (million CAD)</td>
<td>$\Delta P_{SR}$</td>
<td>4.33</td>
</tr>
<tr>
<td></td>
<td>$\Delta P_{SF}$</td>
<td>13.92</td>
</tr>
<tr>
<td></td>
<td>$\Delta P_{FD}$</td>
<td>-0.22</td>
</tr>
</tbody>
</table>

4.5.2 Sensitivity to Parameters

4.5.2.1 Parameter Distributions

In addition to the technology shocks, the values of parameters also play an important role in measuring For a specific parameter, such as the own-price cattle
demand elasticity, the estimated value is likely to vary across studies. Therefore, the results of simulation are supposed to be changeable based on different data sources.

Zhao et al. (2000) examined the probability distributions of economic surplus changes arising from technological changes in Australian wool industry, by specifying the subjective probability distributions for individual parameters. Following their framework, a Monte Carlo simulation, with 10,000 draws for each parameter presented in the feed-farm-retail model, is conducted to examine the probability distributions of producer surplus changes arising from genomics adoption in Canadian beef production. The distributions for individual parameters are specified as below:

\[
\begin{align*}
\text{ALPHARC (i.e. } \alpha_R^C) & \sim N(-0.289, 0.0289^2) \\
\text{ALPHARU (i.e. } \alpha_R^U) & \sim N(-0.196, 0.0196^2) \\
\text{PSIR (i.e. } \psi_R) & \sim N(1.002, 0.1002^2) \\
\text{ETAFC (i.e. } \eta_F^C) & \sim N(-0.207, 0.0207^2) \\
\text{ETAFU (i.e. } \eta_F^U) & \sim N(-0.209, 0.0209^2) \\
\text{ETARC (i.e. } \eta_R^C) & \sim N(0.137, 0.0137^2) \\
\text{ETARU (i.e. } \eta_R^U) & \sim N(0.323, 0.0323^2) \\
\text{EPSFC (i.e. } \epsilon_F^C) & \sim N(0.431, 0.0431^2) \\
\text{EPSFU (i.e. } \epsilon_F^U) & \sim N(0.061, 0.0061^2) \\
\text{EPSGC (i.e. } \epsilon_{FD}^C) & \sim N(-0.101, 0.0101^2) \\
\text{EPSGU (i.e. } \epsilon_{FD}^U) & \sim N(-0.035, 0.0035^2) \\
\text{PSIF (i.e. } \psi_F) & \sim N(0.931, 0.0931^2) \\
\text{GAMGC (i.e. } \gamma_{FD}^C) & \sim N(-0.554, 0.0554^2)
\end{align*}
\]
GAMGW (i.e. $\gamma_{FD}^W$) $\sim$ N (-0.268, 0.0268$^2$)  (4.14)

GAMFC (i.e. $\gamma_{F}^C$) $\sim$ N (-0.198, 0.0198$^2$)  (4.15)

XIGC (i.e. $\xi_{FD}^C$) $\sim$ N (0.27, 0.027$^2$)  (4.16)

XIGW (i.e. $\xi_{FD}^W$) $\sim$ N (0.9, 0.09$^2$)  (4.17)

PSIG (i.e. $\psi_{FD}$) $\sim$ N (1.0, 0.1$^2$)  (4.18)

The mean value ($\mu$) for the probability distribution of each individual parameter is drawn from the corresponding value in Table 4.3, and the standard deviation ($\sigma$) is set to be 10% of the parameter’s mean value. Using TSP program, 10,000 sets of parameter values are independently randomized on the basis of distributions in equations 4.1 to 4.18.

### 4.5.2.2 Distributions of Endogenous Variables

Holding the exogenous variables $\epsilon_T d \ln T$ (vertical shifts in Canadian cattle supply) and $\gamma_T d \ln T$ (vertical shifts in Canadian feed demand) to be 0.72% and -1.63% respectively, the feed-farm-retail model is simulated 10,000 times on TSP, using 10,000 sets of parameter values sampled as above. Simulation generates 10,000 estimates for each individual endogenous variable in the model. Table 4.7 provides a summary of the statistics for estimation results.

Table 4.7 provides the mean values for endogenous variable distributions, given 10,000 sets of parameter values. The differences between the mean values and the baseline results are very small, which is consistent with the finding in Zhao et al.’s paper (2000). Specifically, given the probability distributions of parameter values, the measurements of welfare changes ($\Delta PS_{R}^C, \Delta PS_{F}^C$ and $\Delta PS_{FD}^C$) will be distributed with
respective mean value of 19.65 million, 63.32 million and -1.18 million, as illustrated in
Figure 4.2 to 4.4.

Table 4.7: Summary Statistics of Endogenous Variables

<table>
<thead>
<tr>
<th>Endogenous Var.</th>
<th>Baseline</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d \ln P_R^C$ (%)</td>
<td>-0.2023</td>
<td>-0.2028</td>
<td>0.0303</td>
<td>-0.3370</td>
<td>-0.1083</td>
</tr>
<tr>
<td>$d \ln P_R^U$ (%)</td>
<td>-0.2019</td>
<td>-0.2025</td>
<td>0.0239</td>
<td>-0.3220</td>
<td>-0.1263</td>
</tr>
<tr>
<td>$d \ln QD_R^C$ (%)</td>
<td>0.0585</td>
<td>0.0586</td>
<td>0.0103</td>
<td>0.0296</td>
<td>0.1082</td>
</tr>
<tr>
<td>$d \ln QD_R^U$ (%)</td>
<td>0.0396</td>
<td>0.0395</td>
<td>0.0044</td>
<td>0.0257</td>
<td>0.0591</td>
</tr>
<tr>
<td>$d \ln QS_R^C$ (%)</td>
<td>0.0675</td>
<td>0.0673</td>
<td>0.0146</td>
<td>0.0166</td>
<td>0.1243</td>
</tr>
<tr>
<td>$d \ln QS_R^U$ (%)</td>
<td>0.0381</td>
<td>0.0380</td>
<td>0.0052</td>
<td>0.0210</td>
<td>0.0591</td>
</tr>
<tr>
<td>$d \ln P_F^C$ (%)</td>
<td>-0.4602</td>
<td>-0.4598</td>
<td>0.0533</td>
<td>-0.6792</td>
<td>-0.2567</td>
</tr>
<tr>
<td>$d \ln P_F^U$ (%)</td>
<td>-0.4943</td>
<td>-0.4957</td>
<td>0.0491</td>
<td>-0.7087</td>
<td>-0.3177</td>
</tr>
<tr>
<td>$d \ln QD_F^C$ (%)</td>
<td>0.0675</td>
<td>0.0673</td>
<td>0.0146</td>
<td>0.0166</td>
<td>0.1243</td>
</tr>
<tr>
<td>$d \ln QD_F^U$ (%)</td>
<td>0.0381</td>
<td>0.0380</td>
<td>0.0052</td>
<td>0.0210</td>
<td>0.0591</td>
</tr>
<tr>
<td>$d \ln QS_F^C$ (%)</td>
<td>0.5257</td>
<td>0.5249</td>
<td>0.0430</td>
<td>0.3581</td>
<td>0.7086</td>
</tr>
<tr>
<td>$d \ln QS_F^U$ (%)</td>
<td>-0.0292</td>
<td>-0.0292</td>
<td>0.0036</td>
<td>-0.0470</td>
<td>-0.0173</td>
</tr>
<tr>
<td>$d \ln P_{FD}^C$ (%)</td>
<td>-0.0271</td>
<td>-0.0273</td>
<td>0.0035</td>
<td>-0.0480</td>
<td>-0.0158</td>
</tr>
<tr>
<td>$d \ln P_{FD}^U$ (%)</td>
<td>-0.0271</td>
<td>-0.0273</td>
<td>0.0022</td>
<td>-0.0390</td>
<td>-0.0210</td>
</tr>
<tr>
<td>$d \ln QD_{FD}^C$ (%)</td>
<td>-1.5239</td>
<td>-1.5238</td>
<td>0.0142</td>
<td>-1.5708</td>
<td>-1.4554</td>
</tr>
<tr>
<td>$d \ln QD_{FD}^U$ (%)</td>
<td>0.0072</td>
<td>0.0073</td>
<td>0.0008</td>
<td>0.0046</td>
<td>0.0108</td>
</tr>
<tr>
<td>$d \ln QS_{FD}^C$ (%)</td>
<td>-0.0073</td>
<td>-0.0074</td>
<td>0.0012</td>
<td>-0.0140</td>
<td>-0.0040</td>
</tr>
<tr>
<td>$d \ln QS_{FD}^U$ (%)</td>
<td>-0.0244</td>
<td>-0.0244</td>
<td>0.0009</td>
<td>-0.0275</td>
<td>-0.0205</td>
</tr>
<tr>
<td>$\Delta PS^C_R$ (000,000)</td>
<td>19.6712</td>
<td>19.6532</td>
<td>2.2791</td>
<td>10.9720</td>
<td>29.0387</td>
</tr>
<tr>
<td>$\Delta PS^C_F$ (000,000)</td>
<td>63.2935</td>
<td>63.3151</td>
<td>2.7624</td>
<td>51.9388</td>
<td>73.8497</td>
</tr>
<tr>
<td>$\Delta PS^C_{FD}$ (000,000)</td>
<td>-1.1716</td>
<td>-1.1799</td>
<td>0.1509</td>
<td>-2.0721</td>
<td>-0.6829</td>
</tr>
</tbody>
</table>

Note: “Baseline” column lists estimates of endogenous variables in the baseline simulation
Figure 4.2: Distribution of Retail Producer Surplus Change

Figure 4.3: Distribution of Farm Producer Surplus Change
As discussed before, the measurements of producer surplus changes are affected by both the exogenous variable (i.e. technological changes) and values for parameters in the model. Holding the exogenous variables to be fixed in this study, the relationship between the measurements of producer surplus changes and the different sets of parameter values can be defined as below:

$$\Delta P_{Si} = f(\omega_1, \omega_2, \ldots, \omega_j, \ldots, \omega_{18})$$  \hspace{1cm} (4.19)

where $\Delta P_{Si}$ stands for a particular measurement of producer surplus changes. $\omega_j$ denotes one of the 18 parameters in the feed-farm-retail model. The results of each welfare measurement from last section are regressed over 10,000 sets of parameter values using
TSP program, to capture the response of welfare changes to individual parameters. Regression results are summarized in Table 4.8.

Table 4.8: Summary of Regression Results

<table>
<thead>
<tr>
<th>Variable</th>
<th>Elasticity</th>
<th>$\Delta PS_R^C$ Coef.</th>
<th>$\Delta PS_F^C$ Coef.</th>
<th>$\Delta PS_{FD}^C$ Coef.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALPHARC</td>
<td>Own price beef demand w.r.t. beef price, CAN</td>
<td>0.589***</td>
<td>-17.212***</td>
<td>0.262***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(7.824)</td>
<td>(-27.440)</td>
<td>(22.533)</td>
</tr>
<tr>
<td>ALPHARU</td>
<td>Own price beef demand elasticity, US</td>
<td>21.814***</td>
<td>-52.171***</td>
<td>0.470***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(196.803.)</td>
<td>(-56.494)</td>
<td>(27.508)</td>
</tr>
<tr>
<td>PSIR</td>
<td>Elasticity of price linkage, RETAIL</td>
<td>0.050**</td>
<td>4.705***</td>
<td>-0.071***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.318)</td>
<td>(25.951)</td>
<td>(-21.202)</td>
</tr>
<tr>
<td>ETAFC</td>
<td>Own price cattle demand elasticity, CAN</td>
<td>2.088***</td>
<td>-27.789***</td>
<td>0.401***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(20.087)</td>
<td>(-32.086)</td>
<td>(25.010)</td>
</tr>
<tr>
<td>ETAFU</td>
<td>Own price cattle demand elasticity, US</td>
<td>35.956***</td>
<td>-67.025***</td>
<td>0.485***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(344.370)</td>
<td>(-77.050)</td>
<td>(30.100)</td>
</tr>
<tr>
<td>ETARC</td>
<td>Elasticity of cattle demand w.r.t. beef price, CAN</td>
<td>4.453***</td>
<td>28.506***</td>
<td>-0.526***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(28.065)</td>
<td>(21.564)</td>
<td>(-21.488)</td>
</tr>
<tr>
<td>ETARU</td>
<td>Elasticity of cattle demand w.r.t. beef price, U.S.</td>
<td>16.523***</td>
<td>-5.648***</td>
<td>-0.162***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(246.896)</td>
<td>(-10.130)</td>
<td>(-15.723)</td>
</tr>
<tr>
<td>EPSFC</td>
<td>Own price cattle supply elasticity, CAN</td>
<td>33.633***</td>
<td>-29.564***</td>
<td>-0.054***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(670.595)</td>
<td>(-70.752)</td>
<td>(-6.958)</td>
</tr>
<tr>
<td>EPSFU</td>
<td>Own price cattle supply elasticity, US</td>
<td>-85.733***</td>
<td>185.837***</td>
<td>-1.588***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-235.729)</td>
<td>(61.331)</td>
<td>(-28.308)</td>
</tr>
<tr>
<td>EPSGC</td>
<td>Elasticity of cattle supply w.r.t. feed price, CAN</td>
<td>-3.578***</td>
<td>-40.553***</td>
<td>0.686***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-16.711)</td>
<td>(-22.734)</td>
<td>(20.770)</td>
</tr>
<tr>
<td>EPSGU</td>
<td>Elasticity of cattle supply w.r.t. feed price, US</td>
<td>-15.385***</td>
<td>-118.031***</td>
<td>2.039***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-24.595)</td>
<td>(-22.648)</td>
<td>(21.139)</td>
</tr>
<tr>
<td>PSIF</td>
<td>Elasticity of price linkage, FARM</td>
<td>14.903***</td>
<td>-13.072***</td>
<td>-0.026***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(637.472)</td>
<td>(-67.112)</td>
<td>(-7.317)</td>
</tr>
<tr>
<td>GAMGC</td>
<td>Own price feed demand elasticity, CAN</td>
<td>-0.622***</td>
<td>-7.979***</td>
<td>0.107***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-15.805)</td>
<td>(-24.338)</td>
<td>(17.686)</td>
</tr>
<tr>
<td>GAMGW</td>
<td>Own price feed demand elasticity, WORLD</td>
<td>-1.151***</td>
<td>-16.637***</td>
<td>-0.733***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-14.351)</td>
<td>(-24.908)</td>
<td>(-59.281)</td>
</tr>
<tr>
<td>GAMFC</td>
<td>Elasticity of feed demand w.r.t. beef price, CAN</td>
<td>-1.699***</td>
<td>-21.223***</td>
<td>0.005*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-15.408)</td>
<td>(-23.106)</td>
<td>(0.292)</td>
</tr>
<tr>
<td>XIGC</td>
<td>Own price feed supply elasticity, CAN</td>
<td>1.301***</td>
<td>16.068***</td>
<td>-0.247***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(16.166)</td>
<td>(23.972)</td>
<td>(-19.921)</td>
</tr>
<tr>
<td>XIGW</td>
<td>Own price feed supply elasticity, WORLD</td>
<td>0.279***</td>
<td>5.293***</td>
<td>0.921***</td>
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<tr>
<td></td>
<td></td>
<td>(11.678)</td>
<td>(26.583)</td>
<td>(249.763)</td>
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<td>PSIG</td>
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<td>4.702***</td>
<td>-1.243***</td>
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<tr>
<td></td>
<td></td>
<td>(18.892)</td>
<td>(26.073)</td>
<td>(-372.402)</td>
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Adj. $R^2$ = 0.990606 0.649136 0.949386

Note: *** denotes significance at the 1% significance level; ** denotes significance at the 5% significance level; * denotes significance at the 10% significance level; Values in parentheses are t-statistics.
As shown in Table 4.8, the estimated coefficients of variables (i.e. parameters in the feed-farm-retail model) across all three welfare measurements are very large. This is because those producer surplus changes are usually stated in million dollars, while values for parameters are relatively small. Figure 4.5 to 4.7 is provided below to compare the relative importance of each individual parameter across measurements of welfare changes.

Figure 4.5: Estimated Coefficients (000,000) for Retail PS Change
Figure 4.6: Estimated Coefficients (000,000) for Farm PS Change

Figure 4.7: Estimated Coefficients (000,000) for Feed PS Change
4.5.2.4 Sensitivity Elasticity

The coefficients of parameters for each measurement of welfare change broadly reflect the impact of parameter values on producer surplus changes. To further explore the relationship between producer surplus changes and parameters of the model, the sensitivity elasticity of a particular welfare change with respect to each individual parameter is defined as below:

\[
\rho_{ij} = \frac{\frac{\partial(\Delta PS_i)}{\partial \omega_j} \times \bar{\omega}_j}{\Delta \bar{PS}_i} \quad (4.20)
\]

where \( \rho_{ij} \) is the sensitivity elasticity of \( \Delta PS_i \) with respect to \( \omega_j \); \( \Delta PS_i \) stands for a particular measurement of producer surplus changes; \( \omega_j \) denotes one of the 18 parameters in the feed-farm-retail model; \( \bar{\omega}_j \) is mean value for a specific parameter, which is specified in equations (4.1) to (4.18); \( \Delta \bar{PS}_i \) is the mean value for a particular welfare change, which is presented in Table 4.5; Moreover, \( \frac{\partial(\Delta PS_i)}{\partial \omega_j} \) denotes the coefficient of \( \omega_j \) for \( \Delta PS_i \), which can be found in Table 4.6.

Based on equation (4.20), and using the data stated above, the sensitivity elasticity of welfare changes with respect to individual parameters are calculated and summarized in Table 4.9. Also, Figure 4.8 is provided in order to clearly compare the sensitivity elasticity across measurements of welfare changes in different market levels.
Table 4.9: Summary of Sensitivity Elasticity

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Figure 4.8: Sensitivity Elasticity of Producer Surplus Changes

In Figure 4.8, series Retail, Farm and Feed stand for the sensitivity elasticity of $\Delta PS^C_R$, $\Delta PS^C_F$ and $\Delta PS^C_{FD}$ with respect to individual parameters. The numbers of parameters can be found in Table 4.7. From Table 4.9 and Figure 4.8, it is interesting to find that the welfare change in Canadian cattle sector is most sensitive to $\eta^U_F$ (own-price cattle demand elasticity in the U.S.): 1% increase in $\eta^U_F$ is supposed to increase $\Delta PS^C_F$ by 0.22%. This is probably because Canada exports a considerable amount of cattle to the U.S., which is the biggest importer of Canadian live cattle. Therefore the own-price cattle demand elasticity in the U.S. would matter to the Canadian cattle producers’ surplus. The other relatively important parameters for the welfare change in Canadian cattle sector
include, $\epsilon_F^C$ (own-price cattle supply elasticity in Canada), $\psi_F$ (the elasticity of Canadian cattle price with respect to the U.S. cattle price), $\epsilon_F^U$ (own-price cattle supply elasticity in the U.S.), and $\alpha_R^U$ (own-price beef demand elasticity in the U.S.). For the welfare change in Canadian beef sector, the most important parameters include $\epsilon_F^C$ (sensitivity: 0.7376), $\psi_F$ (sensitivity: 0.7060), $\psi_R$ (the elasticity of Canadian beef price with respect to the U.S. beef price), $\eta_F^U$ (sensitivity: -0.3824), $\eta_R^U$ (the elasticity of cattle demand with respect to beef price in the U.S.) (sensitivity: 0.2715) and $\alpha_R^U$ (sensitivity: -0.2176). Generally speaking, $\epsilon_F^C$ (own-price cattle supply elasticity in Canada), $\psi_F$ (the elasticity of Canadian cattle price with respect to the U.S. cattle price) and $\eta_F^U$ (own-price cattle demand elasticity in the U.S.), are three most important parameters in measuring welfare changes for Canadian beef and cattle producers. This is probably because that the beef markets in Canada and the U.S are highly integrated, and meanwhile U.S. accounts for a major share in the North American beef market.

In terms of Canadian feed sector, the producer surplus change is most sensitive to $\psi_{FD}$ (the elasticity of Canadian feed price with respect to the world feed price), $\xi_F^W$ (own-price feed supply elasticity in the world) and $\gamma_F^W$ (own-price feed demand elasticity in the world). Again, this may be explained by the respective market shares of Canada and the rest of the world in the global feed market. Based on the sensitivity analysis, in order to provide a reasonable evaluation of economic welfare changes resulting from genomics adoption, more research efforts should be expanded to be certain about those relatively important parameters.
4.6 Summary

This chapter starts with an introduction of existing research on feed efficiency and discussion about the potential of adopting genomic selection for feed efficiency in beef cattle. The second section presents the parameters and data required in the feed-farm-retail model. A baseline simulation is conducted in the third section and simulation result is consistent with the expectation in the conceptual framework. The fourth section analyzes the sensitivity of welfare changes with respect to technology shocks and individual parameters. Results illustrate the marginal effect of improvement in efficiency on welfare changes and also help to identify the relatively important parameters in measuring welfare changes arising from adopting genomic selection.
Chapter 5 Conclusions

5.1 Introduction

Rapidly changing technologies and drastically reduced genotyping cost make adopting genomic selection in livestock sector more feasible. Genomic information can be used to achieve particular outcome, such as genetic improvement of feed efficiency in the beef cattle. Cows and bulls that are genetically superior for feed efficiency can be selected for breeding, thus their progeny is expected to have relatively higher feed efficiency. The upward trend in global feed price makes feed efficiency more valuable than before, and encourages more research efforts in genomic selection for feed efficiency. However, the potential economic welfare changes resulting from genomic selection in the beef production is currently unknown, making it more difficult for Canadian beef producers to make decision about adopting genomic selection. The production cost may fall with improved feed efficiency, but if the corresponding price effects offset the cost reductions, then producers’ economic benefit may be affected. To address this problem, an ex-ante evaluation is conducted in this thesis with respect to the economic impact of adopting genomic selection in Canadian beef production. Five chapters are included in this study. The first chapter presents the background, research problem, purpose and objectives. Conceptual and Frameworks are developed in the following two chapters. The fourth chapter provides results and the final chapter is a conclusion of the study.
The rest of the final chapter is organized as follows: the next section summarizes the key findings of this study; the third section discusses limitations while the last section provides suggestion for future research.

5.2 Summary of Findings

As a new tool for genetic improvement of feed efficiency in beef cattle, genomic selection shows advantages in increased selection accuracy, decreased generation interval and increase selection intensity. However, the effects of genomic adoption on feed efficiency are currently unclear. Research in Australia and Canada have suggested that selection for lower residual feed intake (more efficient cattle) led to 10% to 12% decrease in feed intake and 9% to 15% improvement in feed to grain ratio. It is assumed in this thesis that genomic selection can achieve similar effects. Based on existing research, the proportional shift in cattle price is estimated to be 1.68%. Technology-induced shifts in cattle supply and feed demand in Canada are estimated to be 0.72% and 1.63%.

Using estimated technology shocks and collected market data, the baseline simulation is conducted and results shows that cattle prices are most significantly affected by adopting genomic selection (-0.46% in Canada and -0.49% in the U.S.). The market margin between the beef and cattle sectors would probably expand after genomic adoption. In terms of economic welfare, Canadian cattle sector will increase most significantly (by $63.29 million), followed by the beef sector ($19.67 million), while feed sector would made worse off ($1.17 million).

Following the baseline simulation, a sensitivity analysis is undertaken to examine the impact of technology shocks on welfare changes. Results show that one more percent
improvement in feed efficiency is supposed to lead to a $3.66 million increase in retail-level producer surplus change, a $11.79 million increase in farm-level producer surplus change and a $0.24 million decrease in feed-level producer surplus change. Moreover, the sensitivity of welfare changes to individual parameters is also analyzed. The Monte Carlo simulation with 10,000 draws of parameters shows that the differences between mean values of variables (from Monte Carlo simulation) and baseline simulations are very small. The result of calculating sensitivity elasticity shows that \( \varepsilon^C_f \) (own-price cattle supply elasticity in Canada), \( \psi_f \) (the elasticity of Canadian cattle price with respect to the U.S. cattle price) and \( \eta^U_f \) (own-price cattle demand elasticity in the U.S.), are three most important parameters in measuring welfare changes for Canadian beef and cattle producers, which is probably because that the beef markets in Canada and the U.S are highly integrated, and meanwhile U.S. accounts for a major share in the North American beef market.

5.3 Implications

As demonstrated in the baseline simulation, when assuming a technological shock of 0.72% in Canadian cattle supply and -1.63% in Canadian feed demand (arising from 5% improvement in feed efficiency), the economic welfare of Canadian cattle sector will increase most significantly ($63.29 million), followed by the beef sector ($19.67 million), while the feed sector would made worse off (-$1.17 million). Therefore, the total economic benefit for Canadian beef industry and feed sector arising from genomic selection for feed efficiency is equals to $81.39 million, which suggests that adopting genomic selection is profitable for Canadian beef industry. As mentioned in Chapter 1,
the economic problem facing the beef cattle industry in Canada is whether or not to use genomic selection to allow producers to make breeding decisions that lead to improved feed-efficiency in beef production. The findings of this study provide implications for this economic problem and encourage Canadian beef industry to make more efforts in developing the genomic selection for feed efficiency.

Equally important, the findings of this study may provide implications for the distribution of benefit arising from genomic selection between the feedlot sector and the cow-calf sector in Canada. As illustrated in the conceptual framework and empirical framework, to simplify the model, the cow-calf sector is not distinguished from the feedlot sector within the farm level of North American beef industry. However, the cow-calf plays a vital role in the adoption of genomic selection and therefore is entitled to the economic benefit arising from adopting genomic selection. According to the baseline simulation, the economic welfare in the farm level in Canada will increase by $63.29 million due to the adoption of genomic selection for feed efficiency, which indicates that the average economic benefit for Canadian cattle sector resulting from genomic selection is about $14.55/head ($63.29 million ÷ 4,348,611 heads). This provides an upper bound for the average benefit that can be distributed to Canadian cow-calf sector. Simply speaking, we can assume that Canadian feedlot sector is willing to pay the cow-calf sector a premium that is no more than $14.55/head for the cattle that is genetically superior in feed efficiency.
5.4 Limitations

Several limitations exist in this study. The first limitation is related to the equilibrium displacement model (EDM). A multi-market equilibrium framework is used in this study, and the shifts in Canadian cattle supply and feed demand due to genomic adoption are assumed to be parallel. This makes the measurement of economic welfare much easier, but is usually deviating from the reality.

Second, three market levels are discussed in this study, including the retail level, the farm level and the feed level. The farm level actually consists of the feedlot sector as well as the cow-calf sector. This assumption greatly reduces the difficulty in modeling North American beef Industry and feed grain sector and make it more feasible to evaluate the welfare changes arising from genomic selection. However, cattle on the cow-calf operations are usually fed differently from cattle on the feeding operations, which indicate that economic impact of adopting genomic selection tends to be different between the cow-calf sector and feedlot sector.

Third, in the empirical framework and baseline simulation, it is assumed that genomic selection only takes place in Canada, while the U.S. beef producers are indifferent to this new technology. This assumption helps to simplify the economic analysis of technology adoption, but it ignores the potential effects of technology spillovers. As shown in the conceptual framework, the economic welfare changes in Canadian beef industry could be significantly different with the presentation of technology spillovers in the U.S.

Lastly, this study only measures Canadian producers’ surplus changes arising from genomic adoption. The producer surplus changes in the U.S. (or the rest of the world) are
not taken into consideration. In fact, measuring and comparing the economic welfare changes in both countries (or regions) will help to understand the entire welfare effects of genomic selection.

### 5.4 Areas for Future Research

The contribution of genomic selection to the genetic improvement of feed efficiency is currently unclear. More research should be conducted to find out how significantly feed efficiency will be improved with the adoption of genomic selection. Also, to effectively evaluate the economic welfare changes arising from adopting genomic selection, it requires a better understanding of the relationship between improvement in feed efficiency and the beef production cost.

Based on the sensitivity analysis, the measurement of economic welfare changes in North American beef industry (i.e. the retail-farm-feed model) are sensitive to several parameters, including $\epsilon^C_r$ (own-price cattle supply elasticity in Canada), $\psi_r$ (the elasticity of Canadian cattle price with respect to the U.S. cattle price) and $\eta^U_r$ (own-price cattle demand elasticity in the U.S.). Therefore, the analysis or estimate of those relatively important elasticities is needed in order to measure economic welfare changes more accurately in the future.

Furthermore, the effects of technology spillovers in the U.S. should be analyzed in future research, and the economic welfare changes in the U.S. (or the rest of the world) should also be calculated to understand the entire welfare effects of genomic selection and provide better policy implications. Market data for the U.S. (or the rest of the world) needs to be collected, including average prices, demand and supply.
Bibliography


Appendix 1  TSP Results of Baseline Simulation

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TSP Version 5.0
(12/18/07) TSP/GiveWin 15MB
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In case of questions or problems, see your local TSP consultant or send a description of the problem and the associated TSP output to:
TSP International
P.O. Box 61015
Palo Alto, CA 94306
USA

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46 \\
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48 \text{FRML EQSFC ESFC} = \text{EPSFC} \times \text{EPFC} + \text{EPSGC} \times \text{EPGC} + \text{EPSTCETC}; \quad \text{FARM SUPPLY IN CANADA} \\
49 \text{FRML EQSFU ESFU} = \text{EPSFU} \times \text{EPFU} + \text{EPSGW} \times \text{EPGW}; \quad \text{FARM SUPPLY IN U.S.} \\
50 \text{FRML PLF EPFC} = \text{PSIF} \times \text{EPFU}; \quad \text{PRICE LINKAGE IN FARM LEVEL} \\
51 \text{IDENT MKCF EDFC} = (\text{BFC} \times \text{ESFC} + \text{BFU} \times \text{ESFU} - \text{AFU} \times \text{EDFU}) / \text{AFC}; \quad \text{MARKET CLEARING IN FARM LEVEL} \\
52 \\
52 \text{FRML EQDGC EDGC} = \text{GAMGC} \times \text{EPGC} + \text{GAMFC} \times \text{EPFC} + \text{GAMTCETC}; \quad \text{GRAIN DEMAND IN CANADA} \\
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56 \text{FRML PLG EPGC} = \text{PSIG} \times \text{EPGW}; \quad \text{PRICE LINKAGE IN GRAIN MARKET} \\
57 \text{IDENT MKCG EDCG} = (\text{BGC} \times \text{ESGC} + \text{BGW} \times \text{ESGW} - \text{AGW} \times \text{EDGW}) / \text{AGC}; \quad \text{MARKET CLEARING} \\
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<td>0.00067548</td>
<td>0.00038101</td>
<td>-0.0046020</td>
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</tbody>
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<th>EDFC</th>
<th>EDFU</th>
<th>ESFC</th>
<th>ESFU</th>
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<td>0.0052573</td>
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<th>EPGW</th>
<th>EDGC</th>
<th>EDGW</th>
<th>ESGC</th>
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<td>-0.00027113</td>
<td>-0.015239</td>
<td>0.000072662</td>
<td>-0.000073204</td>
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<td>0.0072134</td>
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END OF OUTPUT.

**MEMORY USAGE: ITEM: DATA ARRAY TOTAL MEMORY**

<table>
<thead>
<tr>
<th>UNITS: (4-BYTE WORDS) (MEGABYTES)</th>
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</thead>
<tbody>
<tr>
<td>MEMORY ALLOCATED : 3250000 15.0</td>
</tr>
<tr>
<td>MEMORY ACTUALLY REQUIRED : 7168 2.1</td>
</tr>
<tr>
<td>CURRENT VARIABLE STORAGE : 3869</td>
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</table>