AN ECONOMIC ANALYSIS OF GENE MARKER ASSISTED SEEDSTOCK SELECTION IN BEEF CATTLE

by

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE STUDIES

(Agricultural Economics)

THE UNIVERSITY OF BRITISH COLUMBIA

October 2006

ABSTRACT

This study analyzes the economic impact of a recent gene marker innovation for seedstock selection in beef cattle. Gene markers are being developed for many beef cattle attributes; this study focused on the tenderness quality of beef using two categories: tender and tough. The study begins by describing conventional procedures for seedstock selection, the science which underlies selection by gene markers and other non-genetic procedures currently being used to improve beef tenderness. After describing the commercialization of the gene marker innovation, a stylized model of a beef supply chain is constructed. The supply chain consists of a representative consumer, a producer/processor group and a monopolist supplier of the patented technology. Welfare changes resulting from the adoption of the innovation were simulated using four sets of demand elasticity data from literatures.

An important focus of this research is determining how the economic surplus from the innovation will be shared by consumers, producers and the gene marker monopolist. The consumer and gene marker monopolist benefit from the technology unless the marginal and fixed cost variables (not estimated in this study) of the monopolist, are excessively high. Producer surplus was simulated as positive with three of the four elasticity data sets. The share of surplus capture by producers is generally low relative to the gains captured by consumers and the gene marker monopolist. Comparative static analysis reveal that the benefit from the innovation varies across breeds, being higher for breeds in which the favorable form of the marker gene is more likely to be present.

Despite the apparent benefits of the innovation for beef supply chain participants, reported interviews with industry scientists reveal that markers should not be viewed as a replacement for conventional selection techniques. Indeed, selecting seedstock on the basis of a small number of available markers is not likely to produce the benefits that are currently being promised by life science companies. Consequently, this study recommends that the innovation be incorporated into existing seedstock selection practices. Much more analysis is needed to understand the full economic impact of gene markers for beef tenderness and for other beef quality attributes.

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ACKNOWLEDGEMENTS

I owe a great deal of appreciation to my thesis supervisor Professor James Vercammen as well as my co-supervisor Professor Kathy Baylis. This piece of work would definitely have been impossible for me without their guidance, criticisms, and suggestions. I also must express my gratitude to professors Murray Fulton, Sumeet Gulati and Jean-Etienne de Bettignies for their comments. I specifically wish to thank Professor Timothy Beatty for his constant empathy, advice, and encouragement while I struggled to complete my masters program. I will never forget the supportive roles and friendliness of professors Rick Barichello and Kelleen Wiseman both of whom I had the opportunity to work with in the course of my program. I must not fail to acknowledge the funding I enjoyed from the Food and Resource Economics Group of UBC. It would have been practically impossible for me to begin and complete the masters program as an international student, without their full financial support which saw me through the entire duration of the program. Also worthy of appreciation is the financial support I enjoyed from the Canadian Agricultural Innovation Research Network (CAIRN) as well as the role of the National Beef Industry Development Fund (NBIDF) which provided the full funding for this research. Many thanks also to the industry experts and scientists who were interviewed in the course of this research.

I am most proud of my wife Otibhor and other members of my family, for their unfaltering support, love and encouragement.

1. INTRODUCTION

1.1) BACKGROUND

In July 2000, a new technology was introduced for use in the cattle industry. Developed out of a pre existing knowledge regarding the structure and arrangement of genes (Genomics) in the cattle, this technology was either to change the way we farm cattle, or at least to demand careful attention and consideration by farmers. The innovation was the first of many of such that were to come afterwards, all based on the same scientific principles yet directed at different qualities in the beef we eat. This innovation was called GeneStar Marbling, with the word “gene” suggesting that it has to do with the cattle genes: - the very biological factors in the animal which determines its characteristics and indeed its end carcass quality. GeneStar Marbling was targeted specifically at the marbling quality in beef. The technology was to be used in testing and determining an animal’s potential to sire calves with good marbling quality which has been found to be associated with juiciness and flavor in beef cuts.

This innovation as well as many others in its class that have been developed and introduced up till date have all come to be regarded with a general name:- Gene Markers. Markers have been developed for quite a hand full of the at least 30,000 genes in cattle each of which is associated with a specific animal characteristic. Additionally, research is ongoing towards the development of similar technologies for insect resistance, feeding efficiency and retail beef yield in the cattle (Harris 2002; Evans and Buchanan 2004). By

and large, life sciences companies are currently very busy churning out a variety of markers for traits ranging from fur color, to milk yield. Be that as it may, two groups of markers have over the past five years become very popular in the beef industry:-those that test for the marbling and tenderness genes in the cattle.

The much concern over these two qualities in live cattle is a direct consequence of the increased demand that have been associated with beef of higher marbling and tenderness attributes. From the consumer perspective, the most important quality attribute in beef is its palatability and this attribute has been directly associated with the marbling and tenderness qualities in the beef steak. In a 1998 survey of shoppers at grocery shops in the United States, Lusk et al (1999) found that with complete information regarding tenderness levels of available beef packs, 90 percent of the consumers preferred the tender steak and 51 percent were willing to pay an average premium of $1.84/lb to obtain the tender steak, rather than the tough steak. In recognition of the importance of beef quality as a determinant of demand for the product, the farmer faces an immediate challenge of recruiting into the supply chain, only those bulls and cows with higher potential for producing calves that would end up with good quality carcasses. Interestingly, the inventors of gene markers have hailed it to be a cutting edge technology for predicting this potential among would-be breeding stock.

1.2) PROBLEM STATEMENT

While seeking to assist farmers in their prediction of animals with high potential for carcass quality, the gene marker innovation has apparently created a lot of debate and

raised questions regarding its value and practicality. This pessimistic attitude is particularly higher with regards to the marbling quality for which there already existed a conventional seedstock selection technique. For a long time, breeders have used the technique known as Expected Progeny Differences (EPD), to discriminate between candidate bulls and cows for breeding purpose. Based on a mathematical equation that uses measurements on the candidate animals, their progenies, as well as their relatives, the EPD technique has been in use in predicting animals with the highest potential for producing calves of the desired marbling quality. The technique has also been in use for several other traits including carcass weight and retail beef yield. However, an obvious shortcoming of this technique has been the impossibility of executing it for the tenderness trait. Hence up until the discovery of tenderness gene markers, the beef industry has been without a genetic selection tool for tenderness.

Today as life science companies as well as universities are actively engage in the discovery of new gene-markers for tenderness, marbling as well as other traits in the cattle, they also engaged in widespread campaigns which portray these markers as highly accurate test of an animal's ability to sire good quality progeny. This view point is at variance with that of scholars who claim that these marker tests have been developed for only a handful of the many genes that affect quality characteristics and hence are not completely informative enough as to guarantee full reliability. They emphasize that an animal's trait is affected by the interaction among a few major genes as well as several other minor genes, that the marker tests have only been developed for some major genes, and that selection based on gene marker information alone cannot be 100% reliable until

all the major and minor genes affecting a trait have been completely identified and "marked" (Kinghorn, 2005; Gordon, 2001). Additionally, it is believed that the final quality of an animal or its product is not completely due to it genetic endowment but rather partially due to management factors such as nutrition, housing and disease control (Gordon, 2001). These view points imply that gene markers as we have them today would still not guarantee a perfect prediction regarding the end product quality of animals on the supply chain. Against this background, farmers are skeptical as to the cost effectiveness of the technology in selecting for the marbling trait for which conventional EPD technique already exists. In the January 2005 Issue of *the Register*, a publication of the American Simmental Association, Dr. Wade Shafer, the association's Director of Performance Programs comments:

> "…I don't mean to imply that genomic technology doesn't have a place in cattle breeding. It assuredly does. I do feel, however, that there is a counterproductive whirl that surrounds it. This is understandable, as new technologies tend to whip up frenzy. …… At high EPD accuracies, DNA (gene marker) information contributes little or nothing to the estimate of a sire's genetic level-we already know what it is."

Be that as it may, it is a widely held opinion that gene markers could be of benefit to the industry with regards to the tenderness quality for which a practical seedstock selection criteria did not exist. Additionally, proposals have been made to incorporate gene marker information into existing EPDs in selecting for traits for which EPDs already exists (Sundstrom, 2004). Against this background, researchers from four US universities (Cornell, Iowa, Colorado and Georgia) formed the National Beef Cattle Evaluation Consortium in July 2001 with the primary aim of melding gene marker information into the EPD equation. As an alternative to melding the information into a single equation, the industry is also contemplating the option of a two-stage seedstock screening with the

firsts stage relying on gene marker tests and the last stage, using EPDs. Granted that the marker-enhanced selection process is expected to be more reliable than the conventional selection method, several questions come to mind. First; to what extent will incorporating gene marker information into the selection process, increase the efficacy of seedstock selection? Second; how will this increased efficacy transform into increased availability of high quality beef in the market place? Third; given a new set of marker-induced costs, quality-induced demand, and market structure, how will individual participants at each level of the supply chain react to the marginal increases in the probabilities of achieving the desired product quality? And fourth; how will these changes impact on equilibrium prices, quantities and profits along the supply chain. While the first 2 questions demand an expert scientific opinion, the last two underscore the need for economic analysis.

1.3) OBJECTIVES OF RESEARCH

The objectives of this research therefore, are

i) to review scientific literatures on gene markers with a view to understanding the basic biological science behind the innovation,

ii) to interview industry experts / scientists and source relevant data on the technology and its application in the beef industry,

iii) to review news articles and obtain relevant information about the commercialization of the innovation within the beef industry,

iv) to construct a theoretical model of the beef supply chain with a view to analyzing the innovation’s impact on beef producers,

v) to simulate changes in the beef industry's surpluses that would result from the introduction of the innovation,

vi) to identify possible problems in the implementation of the technology in the beef industry and

vii) to make relevant recommendations to beef producers.

1.4) OUTLINE OF REPORT

This chapter has provided some background information regarding the innovation and potential application of gene markers in the beef industry. Chapter 2 presents some detailed scientific perspectives of seedstock selection techniques and other techniques for enhancing product quality in the beef industry. Chapter 3 explores the commercialization of gene markers as a seedstock selection technique in the beef industry. Chapter 4 reviews relevant economic literatures and presents a theoretical model for analyzing the economic impact of the innovation on the beef industry. Chapter 5 presents results from simulations and evaluates the effects of exogenous variable changes on the results. Finally, chapter 6 draws conclusions from the research findings and makes specific recommendations to beef producers.

2. COMPETING TECHNOLOGIES FOR ENHANCING BEEF QUALITY

This chapter provides a detailed exploration of the application of the gene marker technology in enhancing beef quality traits. The technology's use is discussed within the context of already existing technologies for achieving the same purpose. The discussion enables comparison among the alternative methods while explaining the basic biological science behind the gene marker technology.

2.1) SEEDSTOCK SELECTION TECHNIQUES

In the selection of animals into the breeding stock, farmers are more concerned with the genetic value of the animal rather than its phenotypic value with respect to the trait of interest. The difference is that while the phenotypic value merely refers to the presence or absence of the trait in the animal, the genetic value indicates the potential (probability) that this animal if bred will give birth to calves with the desired traits. It is not unusual for example to have a white-coated animal giving birth to a completely black-coated calf. Hence although this animal has a higher phenotypic value for white coat color, its genetic value could actually be in favor of a coat with a black color. Similarly high phenotypic values for marbling and tenderness do not necessary imply a high genetic value for these traits. Therefore an animal with good tenderness quality could sire offsprings with tough carcass. By and large, the phenotypic expression of a trait (e.g tenderness) in an animal is controlled by genes. Even while the genes for a specific trait are present in an animal, they might not be transferred to their offspring. The genetic value of an animal with respect to a trait thus indicates the ease with which she would transfer the genes

responsible for that trait to its offspring. This argument brings to light an immediate challenge faced by the Seedstock Producer. Assuming his goal is to produce calves to be fattened into beef cattle. Then he would be interested in the eventual marbling and tenderness qualities of their carcasses, downstream in the supply chain. Thus his challenge is to determine which cows and bulls to breed, in order to obtain good quality progeny with respect to the tenderness and marbling traits.

Within the industry, the marbling quality in beef is represented by the Marbling Score (MS) with beef of higher marbling assigned higher scores than those of relatively lower marbling. Marbling Scores cannot be obtained from the animals until they are slaughtered and hence do not serve as a useful selection criteria in the seedstock sector. Fortunately, the advent of ultrasound technology made possible the scanning of the muscles in live animals in the determination of their Percentage Intramuscular Fat (%IMF). Expectedly several studies have established a positive correlation between an animal's %IMF and the MS of its beef. Both measures are largely in use by the beef industry today. However the %IMF has more practical value to the seedstock operator in the selection of candidate animals with regards to marbling quality. Table 2.1 shows the relationship between percentage IMF (a live animal selection criteria) and Marbling Score (a beef grading criteria) as reported by Agriculture Canada. Table 2.2 shows the relationship between numerical Marbling Scores, % IMF and US beef quality grades.

Table 2.1
Relationship between Marbling Scores and % Intramuscular Fat

Marbling and Intramuscular Fat	
Marbling Score	**% Intramuscular Fat**
Slightly Abundant	10.13
Moderate	7.25
Modest	6.72
Small	5.04
Slight	3.83
Trace	2.76
Practically Devoid	< 2.76

Source: Handley (1997).

Table 2.2
Relationship between Marbling Scores, % Intramuscular Fat and US quality grades

US Quality Grade	Numerical Marbling Score	% Intramuscular Fat
Prime+	10.0-10.9	
Prime	9.0-9.9	> 12.2%
Prime-	8.0-8.9	9.9-12.1%
Choice+	7.0-7.9	7.7-9.8%
Choice	6.0-6.9	5.8-7.6%
Choice-	5.0-5.9	4.0-5.7%
Select	4.0-4.9	2.3-3.9%
Standard	3.0-3.9	< 2.3%

Source: Greiner (2002)

Similar to the case for marbling quality, the industry also implements a quantitative measure of the tenderness attribute in beef. This is achieved by the Warner Bratzler Shear Force (WBSF) Technique. The technique measures beef tenderness by how much force is needed to cut through a ¾ - inch core of beef steak. Unfortunately, unlike in the case of marbling where %IMF data can be obtained from the live animal, there had been no technological innovation to enable the collection of tenderness data from live animal.

Hence the tenderness potential of animals was never known until they were slaughtered and became “too dead” to be selected for breeding. Thus the inability of obtaining tenderness data from live animals was the reason for the industry’s lack of a useful seedstock selection criterion with regards to tenderness quality (Anecdote)[1].

For the marbling trait and indeed for other traits where live measures have existed, the techniques of ranking and selecting seedstock on the bases of the live measures of these qualities have evolved through different stages with each successive stage being an improvement over the preceding one. Today, the beef industry utilizes the quantitative data in a statistical procedure to calculate Estimated Breeding Values for the animals. An animal’s Estimated Breeding Value (EBV) with respect to a particular trait is regarded as its genetic worth for the trait, expressed as a deviation from the mean genetic worth among a population. The EBV techniques are amenable for several traits in the animals and can be implemented across herds and across age. In most cases, EBV estimates are halved and reported as Expected Progeny Difference. A detailed discussion of EBV (EPD) is presented below.

2.11) Selection Based on Expected Progeny Differences (EPD)

Being one half of EBV, Expected Progeny Difference is an index of the expected quality of an animal’s progeny if that animal is used as a parent. EPD values are calculated with respect to a particular trait (e.g. marbling, carcass weight, etc.). EPD estimation uses data relating to the trait in the animal as well as in his siblings and half siblings. NSIF (2003)

[1] Please refer to Appendix C for a list of experts with which telephone interviews were held in the Fall of 2005. All errors and omissions remain the responsibility of the author.

provide the basis for the simple theoretical equation specified below, in explaining the computational procedure for EPD, with respect to the marbling trait.

$$EPD = \frac{1}{2} EBV = \frac{1}{2}\left[\beta_1 (IMF_I - \overline{IMF}_I) + \beta_2 (IMF_{FS} - \overline{IMF}_{FS}) + \beta_3 (IMF_{HS} - \overline{IMF}_{HS})\right]$$

Where:

- β_1, β_2 and β_3 are the weighting factors associated with records on the animal, its full-siblings and half-siblings respectively. These betas are calculated using information on the number of records, inheritability of the marbling trait as well as relationships between an animal and its sibling;
- IMF_I is the percentage Intramuscular Fat of the animal for which EBV and EPD is being calculated;
- IMF_{FS} and IMF_{HS} are records of the average percentage Intramuscular Fat among the animal's full siblings and half siblings respectively; and
- $\overline{IMF}_I$, $\overline{IMF}_{FS}$ and $\overline{IMF}_{HS}$ are the population mean values of percentage Intramuscular Fat among the contemporaries of the animal, its full siblings and half siblings respectively.

EPDs are still largely used today and the computational technique has undergone several modifications to improve on its accuracy. Known as the Best Linear Unbiased Prediction (BLUP), the latest computational technique employs a system of simultaneous equations in a statistical procedure. This procedure takes account of the quality being considered among all of the animal's relatives including cousins and grand siblings, the relationships between these relatives, as well as the genetic correlations between different traits. Additionally, the BLUP also accounts for any differences in age, management and environmental conditions among the animals (NSIF, 2003; Evans and Buchanan, 2004).

Thus current EPDs are directly comparable for all individual animals within a breed in all locations and management systems across the year

Be that as it may, estimated EPDs can vary considerably in terms of their accuracy. The accuracy of EPD is reported as ranging from 0 to 1. While accuracy estimates closer to one indicate more reliability, accuracy indicators closer to zero imply that the EPD measures are less reliable. With specific reference to marbling quality, the accuracy of EPD estimates is directly related to the probability that the seedstock will produce progenies with the associated EPDs. A bull with a high-accuracy high marbling EPD has a higher probability of producing calves with good marbling than a bull with the same marbling EPD but at a lower accuracy (Greiner 2002). Hence as the accuracies of marbling EPDs increase, farmers make better prediction regarding the relative values of progeny's marbling qualities and hence are more able to discriminate against bulls with low potential for this quality. Therefore increased prediction accuracies results in increased efficacy of the selection criteria and thus increased production of good marbling beef.

The accuracies of calculated EPDs increase as more information is available to furnish the estimation. As bulls get older and sire more progenies, data is obtained from these progenies and used to upgrade the existing EPD of the bull. Therefore the accuracy of EPDs depends on the age of the bull, with older bulls (sires) having higher accuracies than the younger bulls. While younger Angus bulls within the beef industry may have accuracies as low as 0.36 for their marbling EPDs, the older population of Angus bulls

has records of marbling EPDs for which accuracy is as high as 0.94 (Anecdote). A 94 percent chance of rightly accepting a high EPD bull or rightly rejecting a low EPD bull would ultimately result in a high proportion of desirably marbled beef at the end of the supply chain. It is no surprise therefore that 93% percent of Canadian graded beef in 2004 had at least some trace marbling, which qualified it as belonging to the top 4 of Canada's 13 grades of beef (CCA; 2005). However the industry must constantly replace old bulls with younger ones and hence must continually recruit low-accuracy, high EPD young bulls into the seedstock. Thus the industry believes that gene marker technology could help in the accelerated selection of high performance young bulls. (Anecdote)

2.12) Selection Based on Gene Marker Tests

In an attempt to improve on the success rate of producing good quality beef, the industry is currently exploring the possibility of using recent Gene Marker innovations in the seedstock selection process. The innovation is the result of scientific research in the field of genomics. Australia has been at the fore front of this development with research conducted by the Commonwealth Scientific and Industrial Research Organization (CSIRO), in conjunction with Meat and Livestock Australia (MLA) as well as the Beef Cooperative Research Centre.

It is believed by the developers of this technology that gene markers provide more accurate prediction regarding the potential quality of animals and hence will eventually fully replace the EPD technique. This confident disposition is justified by the fact that the use of a gene marker test as a selection tool directly confirms the transferability of the

genes that impact the desired quality in the animal by studying the very genes themselves. This approach is in contrast with the EPD technique which indirectly infers transferability of the genes by an observation or measurement of the qualities they control in the individual animal and its relatives. Thus the gene marker test is portrayed to be analogous to chasing the substance itself, rather than its shadow.

A foray into the nature of genes is required to fully understand the gene marker tests. Genes are the molecular store of information relating to the characteristics in the animal. These characteristics are numerous and include the easily visible fur color and animal size, the readily measured birth and carcass weight, and such not-easily-observed qualities as marbling and tenderness. Information regarding an animal's endowment of any given trait is coded in the gene which controls that trait. A gene may not directly control the presence or absence of the trait. Rather it may influence the production of an enzyme (a biological catalyst) which in turn influences the development or suppression of the trait in question. For example, the Thyroglobulin gene controls the secretion of the Thyroglobulin enzyme which facilitates the extent of marbling in the animal. In the same way, the Leptin gene is responsible for the secretion of Leptin which promotes the animal's appetite and energy balance and also marbling. Similarly, the Calpastatin gene influences the secretion of Calpastatin, which inhibits post mortem tenderizing in the animal's tissues.

One of the findings of bovine genomic research is that two different animals may vary in the form of a specific gene. For example, given two bulls (A and B), the form of the Calpastatin gene in bull A may not exactly be the same as the form of the same gene in

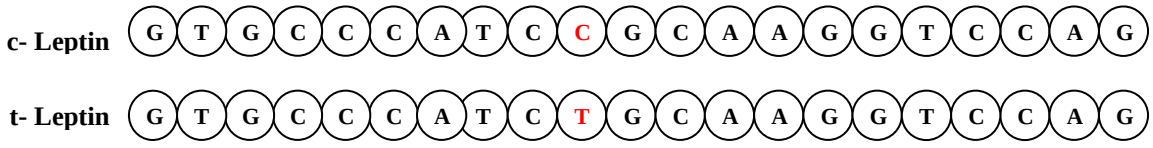
bull B. If one regards the Calpastatin gene as a molecular coding of signals for suppressing tenderness in beef, then it becomes reasonable to expect that different forms of the Calpastatin gene would produce different levels of the Calpastatin inhibitor and consequently would result in different degrees of tenderness in the beef. The same argument holds for the Thyroglobulin and Leptin genes, and their attendant marbling quality. It should be noted that even though Thyroglobulin and Leptin are not the only genes that influence marbling in beef, these two genes have been credited with playing a significant role in impacting these characteristic. In the same way the tenderness quality in beef is determined by several genes among which Calpastatin and Calpain have been identified as most significant.

A natural question to ask here pertains to how the same gene could possible vary across animals in the same breed and herd. To understand this, it is worth noting that genes themselves are comprised of individual protein molecules called nucleotides. Only four types of nucleotides are known to be present in genes. These are Adenine, Cytosine, Thymine and Guanine, labelled for convenience as A, C, T and G nucleotides respectively. Every gene has several of each of these nucleotides placed in an end-to-end arrangement. For example, a hypothetical “x” gene such as ACTTGAACGGTGACCA could be responsible for quality “X” in “bull “i”. Variation occurs when a given gene type contains a different nucleotide in one of its locations. The hypothetical gene as used above may be present in “bull “j” as ACTT**A**AACGGTGACCA. In this case the “x” gene in bull “j” has the same nucleotides as in bull “i” in all its locations except at the fifth

location where Guanine has been replaced by Adenine. Thus bull "i" and "j" vary[2] in their form of the "x" gene and consequently, the two bulls would vary in their endowment with quality "X", with one bull having a more favorable endowment than the other. Hence what the gene marker test does, is to analyze the gene of interest to determine if the form of gene possessed by the animal is one which would give a favorable endowment of the quality in the animal.

In Figure 2.1 below, the "c-Leptin" and "t-Leptin" are illustrated as two forms of the Leptin gene that have been discovered in beef cattle. Both forms differ in the nucleotide at their tenth location with Cytosine in c-Leptin replaced by thymine in t-Leptin. The slight alteration in structure between these two forms results in an alteration of function and the extent to which they impact the marbling quality in the animal. Specifically the t-Leptin has been associated with higher marbling scores (and %IMF) than the c-Leptin. (http://ca.igenity.com/igenity_beef1.html).

Figure 2.1
c-Leptin and t-Leptin: Two Known Forms of the Leptin Gene in Cattle



Source: Forbes (2005)

In practice the gene marker test for marbling and other associated traits of interest involves isolating the appropriate genes from the animal and analyzing their marker location to determine if the form of the gene possessed by the animal is likely to be

[2] Such variation in the form of a specific gene is referred to as polymorphism. If polymorphism is due to the substitution of a single nucleotide with another, it is referred to as Single Nucleotide Polymorphism.

favorable for the trait of interest. Interestingly, every animal possesses two copies of each gene, with one copy (paternal copy) inherited from its father and the other copy (maternal copy) inherited from its mother. Therefore the gene marker test on a random draw of an animal from a population would find him as belonging to one of these 4 possible categories:

i) the animal has both maternal and paternal copy of the gene in the form which is unfavorable for the trait of interest;

ii) the animal's paternal copy of the gene is favorable and the maternal copy is unfavorable;

iii) the animal's paternal copy of the gene is unfavorable while the maternal copy is favorable; and

iv) the animal has both paternal and maternal copies of the gene in the form which is favorable for the trait of interest.

With respect to the marbling trait, the gene marker test for the Leptin gene would find an animal as possessing either two copies of c-Leptin (category i), or a copy each of the t-Leptin and c-Leptin (category ii or iii) or two copies of the t-Leptin (category iv). Therefore a seedstock operator relying solely on the gene marker test for Leptin would show preference for those animals which fall into category iv (or at least those in categories ii, iii and iv).

However, several experts have voiced their opinion of the danger inherent in relying on a single gene test as a seedstock selection criterion. The marbling and tenderness qualities

in the cattle are known to be determined by several genes. For example, Calpastatin explains only 45% of the variation in tenderness (USDA 2005). It is anticipated that in the future, multi gene tests will be available to account for at least more than one of the many genes that affect a particular trait. The industry is already stepping towards this direction with the development of a 2-gene test for tenderness which tests for markers in both the Calpastatin and Calpain genes. Table 2.3 below shows how the currently available 2-gene test for tenderness is used for rating and selecting bulls with regards to their potential to sire offspring with desirable tenderness quality. The test is commercialized as *GeneStar Tenderness 2.*

By and large, industry scientists believe that insufficient gene markers have been developed to warrant complete reliance on gene marker tests. Research is evolving towards the development of more than 11 additional Gene markers addressing growth, tenderness and marbling trait (Mullen 2005). In all it may take a long time to develop markers for all the genes that influence economically important traits. Meanwhile, in an attempt to reap the benefit of the few available markers while at the same time accounting for the effect of those genes for which no markers have yet been developed, the industry is exploring the opportunities of incorporating the tests for the few available markers with conventional seedstock selection techniques, most notably Expected Progeny Difference.

Table 2.3
Possible Results from GeneStar Tenderness 2 Test

CALPAIN GENE		**CALPASTATIN GENE**		**RATING OF BULL**	**SELECTION DECISION**
Maternal	Paternal	Maternal	Paternal		
-	-	-	-	0 Star	Not Recommended
✖	-	-	-	1 Star	Not Recommended
-	✖	-	-	1 Star	Not Recommended
-	-	✖		1 star	Not Recommended
-	-	-	✖	1star	Not Recommended
✖	✖	-	-	2 Star	
✖	-	✖	-	2 Star	
✖	-	-	✖	2 Star	
-	✖	✖	-	2 Star	
-	-	✖	✖	2 Star	
-	✖	-	✖	2 Star	
✖	✖	✖	-	3 Star	Highly Recommended
-	✖	✖	✖	3 Star	Highly Recommended
✖	-	✖	✖	3 Star	Highly Recommended
✖	✖	-	✖	3 Star	Highly Recommended
✖	✖	✖	✖	4 Star	Highly Recommended

" ✖" indicates gene in favorable form for tenderness; " –" indicates gene in an unfavorable form.

2.13) Selection by Both Expected Progeny Differences and Gene Marker Tests

The proposals for incorporating gene marker results along with EPDs in the beef industry are most relevant for the case of marbling quality because EPDs are widely available for that trait. Dekkers (2004) discusses three possible methods by which gene marker test

results may be used in conjunction with the EPD criteria in the seedstock selection process.

The first method is a tandem selection comprised of two stages.

Stage (i): Animals are first selected based on their gene marker tests; and

Stage (ii): Animals which are selected in the first stage are further screened based on their EPDs.

The second proposed method is one which would calculate a Selection Index as a function of the weighted values of the animal's gene marker status and EPD. Such index for marbling might be calculated as

$$Marbling\ Index = \beta_1 \left(Marbling\ Gene\ Star \right) + \beta_2 \left(Marbling\ EPD \right)$$

Within this equation, β_1 and β_2 represent a pair of weights attached to the gene marker results and the EPD results, respectively. It should be noted that the above equation is only illustrative. The development of more marbling gene markers will result either in the addition of more variables to the equation or at least in the adjustment of the *GeneStar* to include results of the marker tests on all marbling-influencing genes for which markers have been developed. Importantly, it is expected that the melding of gene marker results with the EPDs would result in increased accuracies of the selection criteria and therefore increased efficacy of selection.

The third possible method as discussed in Dekkers (2004) is selection of potential seedstocks at a young age based on their gene marker status followed by selection at a later age based on their EPDs.

Importantly, the gene marker innovation has provided a means of estimating the tenderness potential in live animals. Unlike marbling which could be predicted in live animals by reliance on percentage Intra Muscular Fat, predicting tenderness in live animals was impossible due to the industry's lack of a live-measures technique for tenderness. Therefore before the innovation in gene markers, there were no EPDs for tenderness. Fortunately, the beef industry is currently considering the opportunity of using results from gene marker tests in computing tenderness EPDs. Ahead of this trend is the American Simmental Association, which is already using tenderness EPDs in their seedstock selection process. However these EPDs were developed for only the Calpain gene marker and therefore do not factor in the effect of other genes such as Calpastatin, for which markers have also become available (Anecdote).

Summarily, as the gene marker innovation continues to advance, the beef industry will for some time need to continually adjust its selection equations and/or criteria to suite the changing times. In the meantime, despite the cautious optimism regarding the use of gene markers, industry participants are reminded that beef quality is not all about seedstock selection. Indeed, the industry cannot completely rely on seedstock selection criteria while neglecting other facilitating practices and technologies that have been

proven to enhance beef quality. These practices are discussed in the section which follows.

2.2) OTHER FACILITATING TECHNIQUES

2.21) Ante-mortem Facilitating Techniques

Management practices other than seedstock selection which affect the final quality of beef can generally be categorized as ante-mortem (pre slaughter) or post-mortem (post slaughter) practices. Pre-slaughter practices which facilitate beef marbling and tenderness include nutrition and health management (Gordon, 2001). Some of the suggested management practices for marbling include feeding the animals with high-energy-based diets (Miller; 2002), feed supplementation to mitigate animals' stress when they are transported to, and held in abattoirs in the 48-hour period before slaughter (Schaefer et al, 2001), and castration to enhance both marbling and tenderness (Tatum, Smith and Belk; 2000). Additionally avoidance of growth hormones may be a useful strategy for enhancing tenderization of beef.

2.22) Post-mortem Facilitating Techniques

The bulk of industry discussion regarding post-mortem quality enhancing practices and technologies is with regards to beef tenderness. In the early post-mortem phase, tenderness of carcass has been shown to be affected by the chilling temperatures. Additionally, several studies have associated tenderness in beef with post-mortem ageing. It is believed that beef tenderness improves with age up till the 28th day. It is strongly

recommended that beef be left to age for at least 14 days to get a desirable level of tenderness (USDA, 2005).

In addition to ageing and chilling temperatures in the early post-mortem phase, technologies have been proposed for inducing tenderization of non conforming (tough) products in the late post-mortem stage. These technologies, which are discussed in Tatum, Smith and Belk (2000), include Calcium-Activated Tenderization (CAT), Hydrodyne, Blade tenderization (Needling), and Marination. CAT has generally not been adopted by both the Canadian and US beef industries due to the difficulty of implementing the technology, which involves infusing a solution of calcium into the carcass' tissues. There are also concerns over consumer acceptance of the technology because it leaves the beef with a metallic off flavor (Anecdote). The Hydrodyne technique involves application of electrical waves generated in water to break down the structure of the beef. The technique has been proven to induce a considerable level of tenderness in otherwise tough cuts of beef. However the technology is still mainly in its developmental stage and is yet to be commercially adopted by the Canadian beef industry. Additionally, it is quite expensive to carry out and is not cost effective for beef that would age for up to 28 days (Anecdote).

Blade Tenderization and Moisture Enhancement are two post mortem technologies that have been adopted by both the Canadian and US beef industries for inducing tenderness in otherwise tough beef. Commonly referred to as needling, blade tenderization involves passing beef through conveyor belts where they are punched with needles. The technology is relatively cheap to implement and in use mostly for food service products

(Anecdote). However a notable food safety concern has been raised as to the possibility of cross contamination occurring among meat cuts during the course of needling. Researchers are currently engaged in this risk assessment with respect to the *e-coli* bacteria which could be pushed into the meat during the process of needling. Such could result in food borne disease if the meat is cooked to rare doneness.

Moisture Enhancement is a marination technique which involves adding a solution of salt and other compounds to the beef. This technique could add up to 10% extra weight to the beef due to the solution that is being added. Marination also adds flavor to the beef while making it more tender and juicy. The technique is relatively expensive due to the cost of the ingredients. Although households have been practicing marination for a long time, its commercial application as Moisture Enhancement in the beef industry is very recent. A developing trend in the beef industry is the simultaneous application of needling and moisture enhancement. At least 25% of the beef sold in the US has been moisture enhanced and Needled. However, with specific reference to Moisture Enhancement, this statistics is relatively lower in Canada with adoption being higher among producers in the eastern region (Anecdote).

To identify the meat cuts for which tenderness can be enhanced, producers first have to sort the products into grades and then select the grades of lower quality. Although there is no one-on-one correspondence between grades and tenderness, lower quality grades are typically associated with older animals which produce tougher beef. Applying Needling and Moisture Enhancement to lower quality grades rather than to the entire production

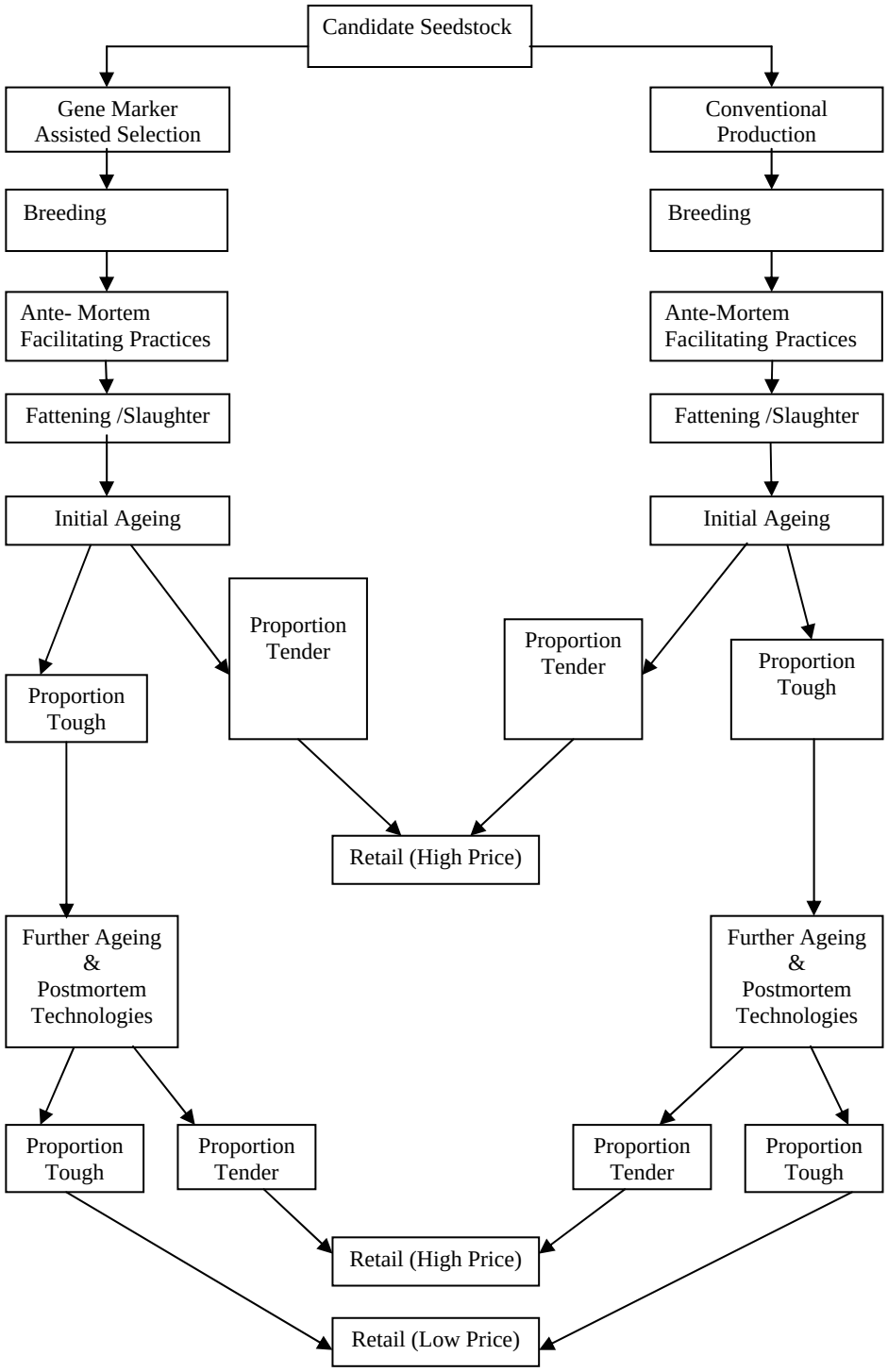
line is one way by which beef producers minimize the cost associated with the use of these post-mortem techniques (Anecdote) Importantly, these techniques do not guarantee a 100% success rate because some products still end up being tough even after attempts have been made to tenderize them..

By and large, the proportion of beef that achieves the desired level of tenderness is determined by the efficacy of seedstock selection as well as live cattle management practices and post-mortem technologies. While these processes and inputs have not necessarily been described as substitutes, it has been suggested that achieving efficiency at one stage would necessarily reduce the intensity with which inputs at the other stages are needed to produce the same proportion of tender beef. Thus, increasing selection efficiency by the use of gene markers could increase the proportion of beef that tenderizes naturally and hence reduce the proportion for which tenderization should be induced. By implication, the cost effectiveness of gene marker assisted seedstock selection depends on the extent to which it reduces the overall post-mortem technology cost as well as the extent to which it increases the overall proportion of tender beef produced. One advantage of seedstock selection over post-mortem technologies is its potential for achieving a genetic improvement over time. While recommending the use of seedstock selection to enhance the tenderness quality in beef, Dr. Elizabeth Dressler, the Director of Product Enhancement Research of the NCBA states;

> "While there are technologies that can address tenderness in the post-mortem phase, they are a perpetual cost. Making genetic improvements with sires that possess the desired tenderness and quality attributes presents a permanent fix to an old problem." (NCBA 2004a)

Further, Colorado State University research indicates that while post-mortem technologies alone could reduce the tenderness failure rate of top sirloin steaks to 18 percent, seedstock selection combined with post-mortem technology could reduce the failure rate to 5 percent (NCBA, 2004b). These results compare closely with Tatum, Smith and Belk (2000) which suggests that combining seedstock selection with pre slaughter and post slaughter practices could reduce tenderness failure rate from 25% to 4% and 1% for top sirloin steaks and strip loin steaks respectively. Figure 2.2 below summarizes the preceding discussions on quality enhancing practices in the beef industry with particular regards to tenderness quality.

Figure 2.2
Schematic Representation of Outputs of Tough and Tender Beef with (and without) Gene Marker Assisted Seedstock Selection



3. COMMERCIALIZATION OF THE GENE MARKER INNOVATION

This chapter discusses the commercialization of the gene marker innovation. It answers the question; “how is the laboratory science discussed in section 2.12 packaged into a product for sale to beef producers?” Highlight is made of the structure of the genomics sector which comprises of life science companies that provide the marker tests to farmers. The discussion identifies two most dominant firms in the sector and their commercial marker products (tests) are categorized into 4 groups based on the trait they address.

3.1) INDUSTRY STRUCTURE OF THE GENE MARKER COMPANIES

Owing to issues relating to intellectual property rights on innovation, the gene marker sector is highly concentrated. Although market share data is currently unavailable, it appears that Brisbane based Genetic Solutions and Multinational Merial Animal Health Inc. are the two most dominant firms in the industry. However, the suite of available tests as well as the array of countries that have access to these tests is growing rapidly. For example, in North America, Quantum Genetics (based in Saskatoon), Genaissance Pharmaceuticals (Connecticut) and Biogenetic Services (South Dakota) are currently utilizing technologies similar to those of Genetic Solutions and Merial. Additionally, in 2004, Genetic solutions announced that license to use its technology would be held by U.S based Bovigene Solutions. Bovigene thus became the commercialization division for Genetic Solutions in both North and South America.

By and large the gene marker industry is yet new and rapidly developing. At the time of this writing, the array of marker test being commercialized by the existing companies includes only 4 major categories that are relevant to beef producers[3]. These are tests for tenderness, marbling, coat color and parentage.

The test for tenderness are marbling are important because these traits have been associated with consumer demand for beef. The test for coat color is useful in selecting animals with high chances of producing offspring with black coats which currently earn a premium in the beef cattle market. The parentage test is important because most breeders utilize more than one bull during breeding. Thus the test helps to identify a calf's sire for EPD calculations. Within each class of marker tests, the available products come in different brand names with each brand being specific to a company. Following is a discussion of commercial marker products with respect to the class of traits they address.

3.2) COMMERCIALLY AVAILABLE GENE MARKER TESTS

3.21 Commercialization of Tenderness Markers

Research leading to first successful commercialization of a gene marker test for tenderness was carried out by an Australian Consortium which included the Cattle and Beef Quality Research Centre, CSIRO Livestock Industries and Genetic Solutions. The test was commercially released by Genetic Solutions in 2002 as *GeneSTAR Tenderness.* The test focused on marker region in the Calpastatin gene in selecting animals for beef tenderness.

[3] Markers have also been developed for traits of importance in dairy cattle. These however do not fall within the scope of this study.

Later in 2003, Genetic Solutions lunched a multi gene tests for tenderness with the brand name *GeneSTAR Tenderness 2*. This latter release was regarded as an improvement over the earlier test because it utilized markers in both Calpastatin and Calpain-1 gene unlike the former which focused only the Calpastatin gene. Development of the multi gene tests was made possible after the USDA discovered a link between beef tenderness and Calpain-1 gene.

While the commercialization of Genetic Solutions tenderness test was taking place in Australia, Frontier Beef Systems in the US was actively developing and commercializing its beef tenderness test. The tests was based on the Calpain-1 gene and marketed as *TenderGENE*. By 2004, Frontier Beef Systems had been acquired by Merial Animal Health Inc. which subsequently took over marketing of the *TenderGENE* tests through its Igenity division. Interestingly, the test has since been modified to a multi gene tests incorporating both the Calpain-1 and Calpastatin genes. It is worthy of note however that the variant of Calpastatin being tested in Merial's *Igenity TenderGENE* is different from the type in Genetic Solutions' *GeneSTAR Tenderness 2* test.

3.22 Commercialization of Marbling Markers

The first commercial marker test for marbling was introduced in 2000 by Genetic Solutions Australia, under the brand name *GeneSTAR Marbling*. The test focused on the marker region in the Thyroglobulin gene. By December 2004, Genetic Solutions had obtained license for additional marbling markers which led to the commercial release of *GeneSTAR Feedlot*; a three gene test for marbling. This latest release combined the

already existing Thyroglobulin marker with a receptor of vitamin A. *GeneSTAR Feedlot*, being a multi gene test for marbling was hailed as giving a better prediction for the quality trait than the formerly existing single gene based *GeneSTAR Marbling*.

Meanwhile in 2004, Merial Animal Health Inc. commercially released its test for marbling under the brand name, *Igenity L*. The test was based on the markers in the Leptin gene which has been associated with energy balance and marbling.

3.23 Commercialization of Markers for Coat Color

As of today, the two most popular tests for coat color in beef cattle are Genetic Solutions' *GeneSTAR Black* and Merial's *Igenity DoubleBLACK*. The tests were made possible by gene marker research which discovered three possible variants in the gene responsible for coat color. The variants are the black form (referred to as E^D), the red form (e) and the neutral form (E+). Since black coated animals earn a premium in the beef industry, the essence of the test is to verify if a black coated animal carries both paternal and maternal copy of the gene in the E^D form. The black variant is dominant over the red and neutral forms. Hence animals with (Paternal copy / maternal copy) e / E^D , E^D / e, E^D /E+, E+/ E^D, and E^D / E^D, will all be black. Confirmation that both copies are E^D helps to ensure that the potential seed stock is homozygous black (double black) and will transfer only the black variant to its progeny.

3.24 Commercialization of Parentage Markers

In a multi-sire breeding environment, semen from several bulls is used on a heifer. Hence it was difficult before now to determine paternity of the resulting progeny whose quality

may be found as desirable for reproduction and preservation in a herd. In the light of this, Merial Animal Health Inc. in February 2006 launched Igenity ParentMATCH MultiSIRE, to enable the determination of paternity for high quality progeny. Development of this test was made possible by research and pilot project conducted by US based National Beef Cattle Evaluation Consortium NBCEC.

In a related development, Genetic Solutions has commercially introduced its own test for paternity under the brand name, SireTRACE. These tests are based on a comparison of a panel of gene markers between the bulls and the progeny. Genetic Solutions SireTRACE for example uses 12 *microsatelite* gene markers. SireTRACE is reported to detect the actual sire to a progeny with an accuracy of more than 99%. Paternity testing facilitates the calculation of EPDs for bulls. Those with desirable EPDs can then be selected into (or retained in) the Seedstock.

Although each of the commercial products were launched and initially implemented as tests for single quality traits, the companies have started to offer their suite of available tests in bundles. Producers now have a choice of testing either for a single trait (e.g. tenderness) or simultaneously running more than one test on the same sample. For example with the expansion of Genetic Solutions array of marker tests, the company in march 2006, introduced the Standard GeneSTAR test which incorporates four tenderness markers and 3 marbling markers in a simultaneous tests for tenderness and marbling.

Test fees have changed rapidly over the past few years due to increasing competition as well as improvement in testing technology. In the November 4, 2005 publication of Cow Calf Weekly, it was reported that Bovigene Solutions had reduced its tests fees by almost 60 percent over a period of 18 months. As with any new innovation, test prices are expected to fall while testing technology improves and competition strengthens, but may possibly rise in the future after the industry consolidates.

A crucial component of gene marker commercialization is the independent evaluation of the technology's real world performance. In the U.S a first round evaluation involving Genetic Solutions /Bovigene and Merial was recently completed by the National Beef Cattle Evaluation Consortium (NBCEC). The purpose of NBCEC commercial DNA test validation is to independently verify associations between the genetic tests and traits as claimed by the gene marker companies. Overall the lead scientist at the NBCEC concludes that the validated markers were quite effective in sorting cattle for measures of the traits of interest (Peck, 2005).

4. THEORETICAL CONSIDERATIONS

This chapter reviews the literature on the economic impact of agricultural innovations with a view to identifying a suitable theoretical framework for analyzing the impact of the gene marker innovation. Attempt is made to construct an economic model of a beef supply chain which utilizes the gene marker tests described in chapter three. Parameterization of the model is done with specific respect to the tenderness quality in beef.

4.1) LITERATURE REVIEW

Based on the modeling approach adopted, previous literature on the welfare implications of innovation in a multistage agricultural production system can be grouped into two general categories: - an earlier group, and a more recent group. A central issue in the earlier group of literature is that these papers analyzed changes in economic surplus that results from innovation under the implicit assumption that markets are perfectly competitive at all the stages in the production system. With this assumption, the increased productivity associated with technological improvement at any sector of the production system was modelled as inducing a downward shift in the relevant supply curve, which altered the equilibrium conditions within this sector as well as every other sector of the system (Freebairn, Davis and Edwards, 1982; Alston, Norton and Pardey, 1995). The key findings of the earlier literature are that innovation at any stage of the production system always yields positive benefits for producers and consumers in all stages of the system, and that the distribution of the aggregate benefit is independent of the stage from which

the innovation emanates. These models are particularly relevant when innovation is the outcome of research by universities and other public institutions, in which case it is either freely supplied, or at least competitively priced.

Increased private participation in agricultural research and development (R&D) implies that early approaches should be modified to reflect the fact that private innovations are not freely supplied or competitively priced. Indeed, the protection of private innovation by patents and Intellectual Property Rights (IPRs) confers limited monopoly power on the inventor, thereby resulting in the non competitive pricing of innovated technologies. Recent literature explicitly addresses these changes. Moschini and Lapan (1997) suggested that the measurement of research benefits from the IPR protected innovation would be overestimated if the assumption of competitive pricing of the innovation is not modified to accommodate the market power of the private inventor. With regards to the improved efficiency of the innovated inputs, they characterized the pricing strategy of the private inventor as either drastic or non drastic. The innovation is drastic when the inventor sets a price f_M for the innovated input such that $f_M < (1+\kappa) f_N$, where κ is the improved efficiency of the new technology, and f_N is the price of the traditional input. On the other hand a non drastic innovation is one in which the inventor charges $f_M = (1+\kappa) f_N$. This strategic pricing framework was also adopted by Falck-Zepeda, Traxler and Nelson (2000) as well as Lence et al (2002).

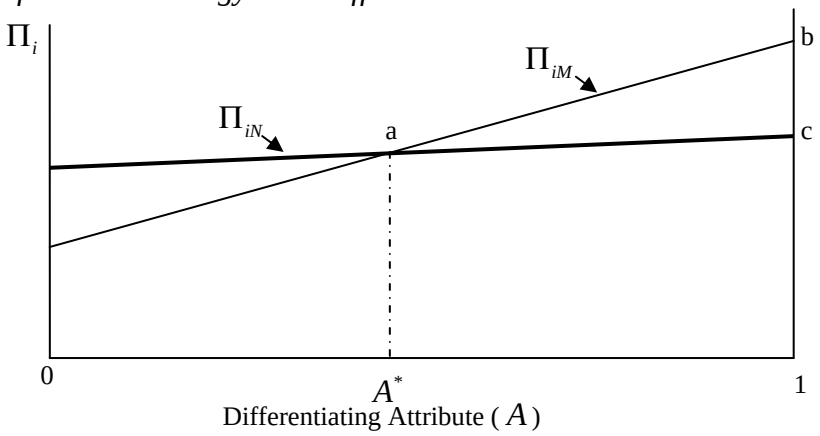
Although there is a general agreement within the literature that the optimal pricing strategy of the monopolist inventor is non drastic, results from Moshini and Lapan suggest that the non drastic pricing strategy may result in no change in surplus for the

producers adopting the input. Essentially, while the improved input productivity shifts the producer's supply curve downward, the increased marginal cost ($f_M > f_N$) associated with the use of the innovated input shifts the curve back to its original position. Moshini and Lapan conclude that because the effective price of inputs is unchanged, with non-drastic pricing, output quantity and price are unchanged and hence both the producers and consumers are unaffected by the innovation.

Fulton and Keyowski (1999) show that an important limitation in Mochini and Lapan's framework concerns the assumption that adoption of the innovation is by all producers (complete adoption). They argue that due to the heterogeneous nature of producers, only a fraction of them would benefit from the innovation. While the fraction which benefit from the improved inputs typically adopts the new technology, the remaining fraction for which profit is greater with the use of the traditional inputs would refuse to adopt the new technology (incomplete adoption). Hence Fulton and Keyowski develop a conceptual model in which technology is not thought of as drastic and non drastic but rather where both the traditional and improved inputs are allowed to co exist in the market. Thus given the increased productivity associated with the use of the new input, their model identifies the equilibrium price for the monopolist and the point of separation for the two groups of producers: those who adopt the new technology and those who do not. Their intuition is summarized in figure 4.1, given the assumption that farmers are differentiated uniformly between zero and one. In the figure, Π_{iN} is the net return for the i^{th} producer with the traditional input, Π_{iM} is his net return with the innovated input and 'A' is the differentiating attribute. The producer with $A = A^*$ is indifferent between the existing

and new technologies. Only producers for which $A > A^*$ will adopt the innovation. Area abc in Figure 4.1 represents producers' benefit from the innovation. An implicit assumption in this framework is that the adoption decision by producers is motivated solely by their prospect of appropriating additional benefits. The key point is that producers who adopt the technology always benefit while those who would not benefit from adoption would continue to use the old input.

Figure 4.1
The Benefits of New Technology with Differentiated Producers



Source: Fulton and Keyowski (1999)

Fulton and Keyowski's (1999) viewpoint is somewhat different than that of Mochini, Lapan and Sobolevsky (2000), who argue that a superior technology may not be adopted immediately and that new and old technologies may coexist at any given point in the time process of diffusion for the following two reasons: - (a) uncertainties and information considerations which impose some delay in the time path of adoption of a superior innovation and (b) the strategic pricing behavior of the monopolist who aims to appropriate the entire benefit from the increased input efficiency and might result in

conditions whereby some producers are discouraged and adoption is incomplete. Hence while allowing for producer heterogeneity, their model determines the price charged by the monopolist inventor by building in the efficiency gain of the new technology into the buyer's demand function. Although this is similar to the conceptual framework developed by Fulton and Keyowski as discussed above, actual simulations by Mochini, Lapan and Sobolevsky did not produce a positive benefit for those producers who adopted the technology. They state that adoption increase supply and depress prices for farmers, who due to competition, really have no choice but to adopt the technology. Their conclusion is that such proprietary yield-increasing innovations are likely to negatively affect the welfare of producers while generating positive changes in surplus for both the consumers and the inventor.

Models incorporating producer heterogeneity with strategic pricing of innovated inputs have also been used by Lemarie and Marette (2002) as well as Fulton and Giannakas (2004). This research follows these two papers when constructing a simulation model for evaluating the welfare effects of gene marker innovation in the beef industry. Major differences between the model developed below and the pair of papers previously mentioned are worthy of discussion. Firstly while the farm input sector represents the source of innovation in all the literatures cited, such cannot be said about the problem under consideration. The Gene Marker companies do not produce a farm input but rather provide services (marker tests) to the input (seedstock) sector. Second and perhaps most importantly, the final output market consist of two types of products (high and low quality beef), with the producer having a limited ability to determine the proportion of

each type in his final output. Finally, the efficiency gain of the innovated input does not refer to an increase in the composite supply of both products but rather to the change in proportions of the product types in favor of the high quality product.

4.2) THEORETICAL SIMULATION MODEL

This model assumes a four-sector supply chain consisting of the consumer sector, a competitive producer sector, which contains vertically integrated fattening and processing operations, the seedstock sector and a monopolist farm service sector, which can be viewed as the gene marker company.

4.21) The Consumers

For simplicity, consumer demand for tenderness can be analysed by categorising available beef grades into two main groups as tender and tough. Following such categorization, Canada's 13 grades of beef can be grouped into two broad classes as:

- the tender class which includes Canada AAAA, AAA, AA, A, B1, B2, B3 and B4, grades; and
- the tough class which includes Canada D1, D2, D3, D4, and E grades

While classification into the two broad groups is based on tenderness quality, classification within the tender group, into the B grades is for otherwise 'A' grade beef with certain off characteristics such as dark colour, yellow fat layer e.t.c. Further, classification of the 'A' group beef into AAAA, AAA, AA or A is mainly with respect to marbling quality as well as retail beef yield, with AAAA having the most marbling and A, the least.

In the United States beef is classified into eight quality grades of which the top three are USDA Prime, Choice and Select. Classification into these 3 groups is based on a number of factors most significant of which is marbling and tenderness (age of slaughter). While the Prime and Choice grades are essentially tender cuts, tough meat with slight marbling may qualify as USDA Select. Beef that would be classified among the lower five grades (USDA Standard, Commercial, Utility, Cutter and Canner) are often tough and are referred to as "no roll" beef as most producers prefer to leave them ungraded. Table 4.1 compares Canada's and USDA beef quality grades. The table shows that USDA quality grades can be classified into two broad tenderness classes with Prime and Choice belonging to the tender class while Select and all no-roll beef are categorized as tough. Importantly Canada's A grade has no correspondence with any USDA quality grade.

Table 4.1
Comparison of USDA and Canada's Beef Quality Grades

USDA	CANADA (Age at slaughter)
Prime	AAAA or B grades (<30 months)
Choice	AAA or B grades (<30 months)
Select	AA or B grades (<30 months) D or E grades (30 - 42 months)
No roll	D and E grades (More than 42 months)

Source: See http://www.aamp.com/links/documents/USDAGradingSystem.pdf
- American Association of Meat Processors

To analyze the effect of marker assisted selection with respect to the tenderness quality, it is necessary to focus on the two group classification as tender and tough. Specifically, let the tender group be referred to as high quality grade, and let the tough group be referred to as low quality grade. This two-group classification is consistent with the findings of

the Carcass Merit Project regarding consumer perception of beef tenderness. The study revealed that about three in four steaks have Warner Bratzler Shear Force (WBSF) value of less than 11 pounds and are considered as tender by consumers, while the remaining proportion have shear force of 11 pounds or greater and are considered tough by consumers (NCBA, 2004a). Unfortunately, due to the high cost of implementing the WBSF tenderness test on a carcass, use of this technique is restricted only to experimental cases and is seldom adopted on a commercial scale. Hence Canada's (and USDA) beef grading with respect to tenderness is mainly based on guess work with regards to the age of the animal; given that younger slaughter produce more tender beef than older animals.

Irrespective of the tenderness grading system adopted by the relevant authorities, implementation of marker assisted selection will increase the proportion of beef that are classified among the tender grade. For example this may be by way of increasing the number of animals that pass the WBSF test, or by some increase in the average cut-off age for classifying slaughter among the tender grades. Further, it is assumed that consumers have complete information about the tenderness quality of their beef purchases. This is a reasonable assumption given that quality grades are included on retail beef labels.

Thus, following the paper by Ramos, Drogue and Marette (2005), this study assumes that consumer demand for the two differentiated beef products can be represented as

(1) $$Q_H^D = \alpha - \delta P_H + \gamma P_L$$

(2) $$Q_L^D = \eta - \psi P_L + \omega P_H$$

where Q_H^D, Q_L^D, P_H and P_L are quantities demanded of high and low grades and prices of high and low grades respectively ($P_H > P_L$). δ and ψ are slope parameters capturing the own price effects while γ and ω are interaction terms which capture the cross price effects, with higher values for γ and ω associated with greater substitutability between the two products. Further, the own price parameters must take on a higher value than the cross price parameters in order to ensure the concavity of the respective utility functions (Ramos, Drogue and Marette, 2005).

4.22) The Producers

Cost Function

Suppose vertically integrated cattle producers and processors operate in a perfectly competitive market with identical technologies, moreover, suppose that the production cost for a representative producer can be decomposed into two parts:

i) cost of acquiring the semen input; and

ii) the cost associated with all other inputs.

Let the per unit price of semen input be W_M for semen with gene marker information and W_N for semen without gene marker information ($W_M > W_N$). And let the cost associated with all other inputs be represented by the equations

(3) $C(q) = \frac{\beta}{2}q^2 + Vq + F$ if semen with gene marker information is used and

(4) $C(q) = \frac{\beta}{2}q^2 + Uq + F$ if semen without gene marker information is used.

q is the output by the producer under consideration, F is his fixed cost, and β, V and U are parameters of the cost functions. The difference in these associated costs arises from the difference in the cost of postmortem technologies and other facilitating practices necessary to promote the desired tenderness quality in the final beef cuts. Additionally, because marker based semen (or seedstock) selection is believed to lead to a higher proportion of beef tenderizing naturally, thereby resulting in less need for postmortem technologies and other facilitating practices, the restriction $U > V$ must hold so that the marginal cost associated with these additional inputs is less for the marker assisted selection. On this premise, $U - V$ represents the reduction in the marginal cost associated with the facilitating practices as the producer switches from the use of non-marker semen to the use of marker semen. Let $U - V = \phi$. This parameter ϕ shall be referred to henceforth, as the *cost effectiveness* associated with the use of marker semen.

Expected Profit Function

Figure 2.2 reveals that in a single production period an integrated cattle producer will produce both high quality and low quality grades irrespective of the type of semen (seedstock selection) adopted. However because marker assisted selection is expected to result in a larger proportion of tender beef cuts, the producer has greater probability of producing high quality grade beef with marker assisted selection than with the traditional production method. By regarding the proportion of high quality beef produced per unit of semen as an index of productivity, those semen units screened by a gene marker test should be assigned higher productivity values than those selected by traditional methods. Let the productivity per unit of semen (i.e., the probability of achieving high quality beef)

without marker test (non marker semen) be denoted as θ_N . This is assumed to be constant across all producers. The feasibility of this assumption derives from the optimizing behavior of producers given that technologies are identical across farms. Specifically, if θ_N is the highest productivity that can be obtained from any breed, then a firm producing at $\theta_{iN} < \theta_N$ would make long run changes to his inputs and/or breed type until $\theta_{iN} = \theta_N$. Given that the traditional selection method has been in place for several generations of seedstocks, θ_{iN} can be assumed to be in long run equilibrium and hence constant across producers.

In this regard the gene marker innovation represents a potential distortion to this equilibrium to the extent that the expected marker-induced productivity increases varies across producers. In the first period of adoption, variation in the productivity of marker semen is attributed to varying effect of the gene marker test across breeds. For instance with regards to the calpain gene (one of the tenderness genes for which markers are available), while the gene marker test could be employed to increase the proportion of high quality beef in the *Taurus* cattle, no productivity increase can be obtained in the *Indicus* cattle by marker assisted selection. On this premise, and following the suggestions by Moschini and Lapan (1997), the productivity of maker semen can be expressed in the productivity units of non marker semen as

(5) $$\theta_{iM} = (1 + \kappa_i)\theta_N$$

Where θ_{iM} is the productivity per unit of marker semen for the *ith* producer, and $\kappa_i\theta_N$ is the change in productivity due to the inclusion of the marker test in the selection process.

The variable κ_i is directly proportional to this productivity change and shall be referred to as the *Marker Efficiency* associated with the *ith* producer**.** The marker efficiency varies[4] across farmers and is assumed to be uniformly distributed between 0 and $\hat{\kappa}$, where $\hat{\kappa}$ is the highest possible marker efficiency and is represented as $\hat{\kappa} = \frac{1-\theta_N}{\theta_N}$. This is derived from equation (5) by noting that at the highest possible marker efficiency, $\theta_{iM} = 1$.

Assuming that fixed cost is zero, (one implication of this assumption is that the entire surplus generated by the producer can be interpreted as profit rather than rents) the expected profit function of the i^{th} producer with *non-marker semen* and with *marker semen* is represented respectively by equations (6) and (7) as

(6) $$E(\Pi_{iN}) = \theta_N q_N P_H + (q_N - \theta_N q_N) P_L - W_N q_N - \frac{\beta}{2} q_N^2 - U q_N$$

(7) $$E(\Pi_{iM}) = \theta_{iM} q_M P_H + (q_M - \theta_{iM} q_M) P_L - W_M q_M - \frac{\beta}{2} q_M^2 - V q_M$$

where $E(\Pi_{iN})$ and $E(\Pi_{iM})$ indicate expected profit with non marker and marker semen respectively and q_N and q_M indicate the respective quantities produced by the *ith* producer. Further by substituting $(1 + \kappa_i)\theta_N$ for θ_{iM} , equation (7) can be written as

(8) $$E(\Pi_{iM}) = [(1+\kappa_i)\theta_N] q_M P_H + \left(q_M - [(1+\kappa_i)\theta_N] q_M\right) P_L - W_M q_M - \frac{\beta}{2} q_M^2 - V q_M$$

[4] It must be emphasized here that variation of the Marker Efficiency among farmers might only be in the short run. Once again in the long run, farmers with $\kappa_i < \hat{\kappa}$ might make changes to their breed type, until $\kappa_i = \hat{\kappa}$. To this extent, the model developed here actually pertains to the short run period of the introduction of the innovation.

Equations (6) and (8) can be maximized with respect to q_N and q_M respectively to give the profit maximizing quantities of beef production with non marker semen and marker semen:

(9) $$q_{iN}^{*} = \frac{1}{\beta}\left[\theta_N (P_H - P_L) + P_L - W_N - U\right]$$

(10) $$q_{iM}^{*}(\kappa_i) = \frac{1}{\beta}[(1+\kappa_i)\theta_N (P_H - P_L) + P_L - W_M - V]$$

where q_{iN}^{*} is the profit maximizing quantity for the *ith* producer with non marker semen, and $q_{iM}^{*}(\kappa_i)$ the profit maximizing quantity for this producer with marker semen.

Further by substituting q_{iN}^{*} and $q_{iM}^{*}(\kappa_i)$ for q_N and q_M respectively into equations (6) and (8), the expected profits for the *ith* producer in each case is found to be

(11) $$E(\Pi_{iN}^{*}) = \frac{1}{2\beta}\left[\theta_N (P_H - P_L) + P_L - W_N - U\right]^2$$

and

(12) $$E(\Pi_{iM}^{*}) = \frac{1}{2\beta}\left[(1+\kappa_i)\theta_N (P_H - P_L) + P_L - W_M - V\right]^2$$

Equations (11) and (12) show the maximized profits with non marker and maker semen respectively. The *ith* producer's choice of the type of semen to be used depends on the relative magnitudes of $E(\Pi_{iM}^{*})$ and $E(\Pi_{iN}^{*})$. Specifically, marker semen is preferred as long as the expected profit with marker semen is greater than the profit expected with non marker semen. However, an increase in the cost of acquiring marker semen (W_M) induces a reduction in the amount of profit that can be obtained with marker semen *(centeris paribus)*. Suppose W_M rises to the point where expected profits are the same with marker

and non maker semen, the producer would become indifferent between the two types of semen. The extent to which the price of marker semen can rise before the *ith* producer becomes indifferent to the two semen types depends on the magnitude of the maker efficiency parameter, κ_i. Given the cost of marker semen, as well as all other variables, equating the optimized profits ($E(\Pi^*_{iM}) = E(\Pi^*_{iN})$) and solving for κ_i gives an expression for the critical Maker Efficiency κ^* of the producer in the boundary point between the adopters and non adopters of the marker technology as

$$\kappa^*(W_M) = \frac{W_M - W_N - U + V}{\theta_N(P_H - P_L)} \tag{13}$$

Further by substituting the cost effectiveness parameter, ϕ for $(U - V)$, equation (14) can be expressed as

$$\kappa^*(W_M) = \frac{W_M - W_N - \phi}{\theta_N(P_H - P_L)} \tag{14}$$

In explaining why the critical marker efficiency is a function of the price of marker semen, we note that an increase in W_M implies a decrease in the expected profit $E(\Pi_{iM})$ associated with marker semen. Holding the profit associated with non marker $E(\Pi_N)$ constant across producers, as W_M increases, only producers whose marker efficiency is high enough to guarantee $E(\Pi_{iM}) > E(\Pi_N)$ will continue to use the marker semen. Hence the cut-off marker efficiency is an increasing function of the price of marker semen.

The cut-off value κ^* is important because it divides producers into adopters and non adopters. Specifically, while producers with κ_i less than κ^* will rather continue to use

the traditional non maker semen, those with κ_i greater than (or at least equal to) κ^* will adopt the marker technology. This model assumes that every producer is aware of the marker efficiency associated with his production.

Recall that κ_i is assumed to be uniformly distributed between 0 and $\hat{\kappa}$. Thus, with J producers in the market, the market quantity of beef produced with non marker semen is calculated as

(15) $$Q_N^S = \frac{J\,\kappa^*\,q_{iN}^*}{\hat{\kappa}}$$

which after substituting q_{iN}^* from equation (9), κ^* from equation (14) and $\hat{\kappa} = \frac{1-\theta_N}{\theta_N}$ gives

(16) $$Q_N^S = \frac{J(W_M - W_N - \phi)\left[\theta_N(P_H - P_L) + P_L - W_N - U\right]}{\beta(P_H - P_L)(1-\theta_N)}$$

Also the market quantity of beef produced with marker semen is calculated as

(17) $$Q_M^S = \frac{J\int_{K^*}^{\hat{K}} q_{iM}^*(\kappa_i)\,d\kappa_i}{\hat{\kappa}}$$

where the expression for $q_{iM}^*(\kappa_i)$ is given by equation (10).

The aggregate market supply of high quality beef is given by the sum of the total quantity of high quality beef produced from both non marker and marker semen as

(18) $$Q_H^S = \theta_N Q_N^S + \frac{J\int_{K^*}^{\hat{K}} (1+\kappa_i)\theta_N q_{iM}^*(\kappa_i)\,d\kappa_i}{\hat{\kappa}}$$

Within equation (18), Q_H^S is the market supply of high quality beef, $\frac{J\int_{K^*}^{\hat{K}}(1+\kappa_i)\theta_N q_{iM}^*(\kappa_i)d\kappa_i}{\hat{\kappa}}$ is the total supply of high quality beef by producers who adopted the marker technology while $\theta_N J\kappa^* q_{iN}^*$ is the total supply of high quality beef by non adopting producers.

By subtracting the quantities of high quality beef, from the total production by each group of producers, an expression is obtained for the market supply of low quality beef as

(19) $$Q_L^S = (Q_N^S - \theta_N Q_N^S) + (Q_M^S - \frac{J\int_{K^*}^{\hat{K}}(1+\kappa_i)\theta_N q_{iM}^*(\kappa_i)d\kappa_i}{\hat{\kappa}})$$

4.23) The Seedstock Operators

The Price of Marker Semen

Consider a Seedstock Operator deciding the better of two possible forms in which to market semen from his bulls.

i) with gene marker information

ii) without gene marker information

If he decides to market the semen with gene marker information, then he would need to send samples (hair, semen or other parts) from his bulls to the gene marker companies for analysis. Of course, not all of his animals will be found as possessing the favorable form of the genes under analysis and these would be “rejected” by the Seedstock Operator. Only those bulls found possessing the favorable gene forms will be selected for semen

production. For instance following the reports by Davis (2004), only about 10% and 12% of the Angus and Simmental cattle respectively currently test as “two star” with respect to the marbling gene (Thyroglobulin). Additionally, Page et al (2004) report the frequencies of the favorable forms of the Calpain marker for tenderness in the range between 17% and 37%.

Let f be the test fee that the seedstock operator pays per bull, and let Ω be the probability that a bull will be found as having the favorable form of gene and hence selected for semen production. For convenience Ω will henceforth be referred to as *gene frequency***.** Since the Seedstock Operator has to incur the cost of testing the selected bulls as well as those that were rejected, the cost for each successfully selected bull is $\frac{f+K}{\Omega}$, where K represents all other cost associated with raising the bulls (feeding, housing e.t.c). An implicit assumption made here is that rejected bulls have zero value. This assumption however is for simplicity as rejected bulls could be culled and sold off at low prices. Be that as it may, this assumption is not expected to change the results of this analysis especially given the fact that culling should occur at a relatively early age when not much has been spent on feeding and housing the rejected bulls.

An important point to note is that each bull is tested only once and produces several units of semen over its lifetime. A typical AI (Artificial Insemination) bull produces more than 1,000 units of semen per year (Anecdote). Thus denoting the units of semen produced per bull as X , the per unit cost of semen with marker information can be written as

$$W_M = \frac{f + K}{\Omega X} \tag{20}$$

On the other hand, a Seedstock Operator deciding not to market semen with the gene marker information would only incur a cost of $\frac{K}{X}$ in producing each unit of semen.

Therefore by substituting $\frac{f + K}{\Omega X}$ for W_M in equation (8) and $\frac{K}{X}$ for W_N in equation (6) all other relevant expressions (κ^*, Q_N^S, Q_M^S, Q_H^S, and Q_L^S) can be expressed as functions of the test fee, f as well as the gene frequency Ω. The assumption made here is that the Seedstock Operator sets the price of semen equal to marginal cost. One justification for this assumption is the very low level of concentration in the Canadian Seedstock / Cow-calf sector (see Brocklebank and Hobbs (2004) and Schroeder (2003)).

Meanwhile the Seedstock Operators' supply of marker semen can be expressed as a function of the number of animals tested as

$$S_M^S = \Omega Y X \tag{21}$$

where S_M^S and Y denote the supply of marker semen and number of animals tested respectively. The variable Y, which is explicitly chosen by the Seedstock Operator, is determined as part of the overall equilibrium (discussed below).

4.24) Equilibrium Conditions

The equilibrium prices in the beef market for high and low quality beef can be obtained by simultaneously solving $Q_H^D = Q_H^S$, and $Q_L^D = Q_L^S$ from equations (1) and (18), and equations (2) and (19) respectively. By substituting the calculated prices $P_H(\Omega, \phi, f)$ and

$P_L(\Omega, \phi, f)$ into equation (10) and consequently equation (17), the quantity of marked beef, Q_M^S needed to satisfy this equilibrium condition is obtained. Further, the equilibrium condition in the semen market can thereafter be represented by equating this derived quantity of marked beef $Q_M^S(\Omega, \phi, f)$ to the supply of marker semen S_M^S, from equation (21). That is

(22) $$Q_M^S(\Omega, \phi, f) = \Omega YX$$

Then noting that Y is the number of animals tested, equation (22) can be explicitly solved for Y to obtain the Seedstock Operators' demand for marker test, Y as a function of the test fee f as well as the gene frequency and cost effectiveness of marker semen. Denoting the demand functions by D, this can be implicitly stated as

(23) $$Y = D(f, \Omega, \phi)$$

4.25) The Monopolist Gene Marker Company

Owing to patent protection of innoations, the gene marker sector is highly concentrated. As at the time of this writing, only two companies (Merial and Genetic Solutions) appear to be commercializing the gene marker tests for tenderness. High market concentration implies that the companies will exercise market power in determining number of animals tested as well as the test fees. This tendency is captured below by assuming the sector to comprise of a monopolist test provider. The gene marker test provider faces the demand function given by equation (23). Suppose the monopolist's profit function takes the following form:

(24) $$\pi = (f - c)Y - FC$$

where c is the marginal cost of implementing the test and FC is the fixed cost, for simplicity, both the marginal and fixed cost can be assumed to be zero. Assuming a fixed cost of zero however implies that calculated marker-induced changes in economic surpluses would not account for the fixed costs of the life science companies.

Now substitute equation (23) into equation (24) to obtain

(25) $$\pi = (f - c)D(f, \Omega, \phi) - FC$$

Equation (25) can be maximized with respect to *f* to obtain the profit maximizing test fee for the genomics company as a function of the gene frequency and cost effectiveness of the marker technology.

Finally, this test fee can be substituted back into the equations (23), (22) and (20) to obtain the equilibrium number of animals tested, the supply of marked beef and the price of marker semen, respectively. Additionally, the test fee can be substituted into the equilibrium prices, $P_H(\Omega, \phi, f)$ and $P_L(\Omega, \phi, f)$ to obtain the prices for high and low quality beef respectively. In other words, the equilibrium for the entire vertical market chain can be established.

5. SIMULATIONS AND RESULTS

This chapter adopts the theoretical model developed in chapter four, in simulating the economic impact of the gene marker innovation on the beef industry. Again the focus is on beef tenderness and demand elasticity data is obtained from four secondary sources. The elasticity data are used to calibrate the model and then the simulations are implemented. The chapter then concludes with a discussion of the results from simulations and sensitivity analysis.

5.1) DATA SOURCES, MODEL CALIBRATION AND SIMULATIONS

5.11) Sources of Data on Price Elasticity of Demand

The model developed in section 4.2 is used to simulate the changes in surpluses that could result from the introduction of the gene marker innovation, which targets beef tenderness. An important assumption is that producers are able to classify beef based on tenderness into high and low quality grades, and that consumers have complete information regarding the tenderness quality of each grade. Estimates of the elasticity of demand for high and low quality beef are adopted from selected literatures. Table 5.1 below shows the estimates of own and cross price elasticity of demand for high and low quality beef within the North American beef industry.

The data from Lusk et al were estimated in a study of wholesale demand for pork, chicken and quality differentiated beef. The study used macro level data of total pounds of USDA Choice and Select beef for the period 1986 to 1999. The grades differ both in

terms of marbling and tenderness with Choice grades having more tenderness while some Select cuts are actually tough. In estimating the elasticity reported above, Lusk et al defined as "Select", all beef which fall into the "USDA Select" or "no roll" category. As shown in table 4.1, all no roll beef and some select beef belong to Canada's D or E grades which are tough. Hence Lusk et al elasticity estimates for "Select" and Choice is representative of the elasticity of demand for tough (low quality) and tender (high quality) cuts respectively.

Table 5.1
Estimates of Own and Cross Price Elasticity of Demand for High and Low Quality Beef in North America

Literature	Elasticity Estimates			
	High Quality		Low Quality	
	Own Price	Cross Price	Own Price	Cross Price
Lusk and Norwood, 2003 (Model 1)	-1.837	1.165	-2.723	2.371
Lusk and Norwood, 2003 (Model 2)[5]	-0.86	0.076	-0.7	0.556
Lusk et al (2001)	-0.43	0.196	-0.63	0.269
Tvedt et al (1991)	-0.774	0.728	-1.816	1.292

Estimates from Lusk and Norwood were derived from a study of supply and demand elasticities which assumed product quality differentiation at the farm, wholesale and retail levels. Again USDA data were categorized into two groups with Prime and Choice grades constituting the high quality group while Select and no-roll category made up the low quality group. The major difference between this study and the one by Lusk et al is that it accounted for demand and supply interaction across the retail, wholesale and farm sectors, as opposed to Lusk et al which focused only on the retailer's demand for

[5] *The estimates from Lusk and Norwood (2003) were derived from two alternative model specifications*

wholesale beef. In other words while the demand elasticity estimates reported by Lusk et al are for wholesale beef, the ones reported by Lusk and Norwood were estimated for retail beef from a market equilibrium across a 3 sector supply chain. Additionally, unlike in Lusk et al, where the retailer demanding wholesale beef was assumed to have non constant returns to scale technology, Lusk and Norwood assumed constant returns to scale for both the wholesalers and retailers on the beef supply chain.

One difference between models 1 and 2 from Lusk and Norwood is that they assume different elasticity of substitution between the "Choice" and "Select" grades, thereby implying different levels of product differentiation. For instance, the elasticity of substitution at the retail level between "Choice " and "Select" is assumed to be smaller in model 2 than in model 1, implying that model 2 allows for less substitutability and hence more product differentiation.

The estimates from Tvedt et al were derived in a study of demand and supply elasticity for pork, poultry and quality differentiated beef in twelve regions of the world. The study used aggregate and cross sectional data for the period 1961 to 1987. Beef was divided into grain-fed and grass-fed due to substantial difference in quality and price. A major quality difference between grain-fed and grass-fed cattle is beef tenderness with grain-fed cattle producing more tender beef than the grass fed. The elasticity estimates were calculated specific to each of the twelve regions. The ones reported in table 5.1 were estimates for the United States.

It is worthy of note that three of the four groups of estimates suggest that demand for high quality is more inelastic than for low quality, which is what is expected.

Additionally, all four groups of estimates suggest that the two different types of beef are substitutes, as revealed by their positive cross price elasticities.

5.12) Model Calibration

The elasticity estimates were applied to the pre-innovation market to calibrate the model. Specifically, the elasticities along with observed price ratio between high and low quality beef, as well as assumed values for supply schedule parameters were used to derive estimates of the various parameters of the demand functions given by equations (1) and (2), as well as the pre-innovation prices for the high and low quality beef. At the same time the equilibrium condition in the pre-innovation market was simulated. The following points highlight the steps taken in calibrating the model in the pre innovation period.

1) The relevant demand and supply equations in the pre innovation period was set up in MATHEMATICA PROGRAM and the equations for equilibrium prices derived from the market clearing conditions $Q_H^D = Q_H^S$ and $Q_L^D = Q_L^S$. The pre marker equations follow the model described in section 4.2 without the variables (ϕ, Ω, Y, κ_i, κ^*, $\hat{\kappa}$, W_M) which are only relevant in the post innovation market. Also producers do not have a choice between marker and non marker beef. Every producer chooses an optimum quantity of non marker beef to produce. There is no Gene marker sector, no supply of, and no demand for marker semen.
2) The equations derived in step 1 for equilibrium P_H and P_L in the pre innovation market were copied into an excel spreadsheet. The prices are functions of the supply parameters (J, U, X, β, K and θ_N) for which values were to be assumed and the demand parameters (α, η, γ, ω, ψ and δ) for which values were to be

calculated. The value of 0.75 assumed for θ_N was observed from literatures (about 1 in 4 beef steaks are tough). The value of 5000 assumed for X was obtained from telephone interviews and literatures (a typical Artificial Insemination bull produces thousands of units of semen per year over a period of at least 5 years). The values assumed for J, β and K were to achieve a good calibration for the model. These values are reported in the tables below.

3) The demand equations (1) and (2) were also entered in excel to represent the equilibrium quantities of high and low quality beef, given the equilibrium prices for which equations were found in step 1, as well as the demand parameters (α, η, γ, ω, ψ and δ) for which values were to be solved.

4) Secondary data was observed for the price ratio, P_H/P_L of high and low quality beef and this was assumed to be the price ratio in the pre innovation market. Specifically, P_H/P_L was observed[6] to be 4.7

5) From the demand schedules, the equations calculating the elasticities were derived and entered into the excel spreadsheet. These equations are

$$E_H^{Own} = -\delta \frac{P_H}{Q_H^D(P_H, P_L)},\ E_H^{Cross} = \gamma \frac{P_L}{Q_H^D(P_H, P_L)}$$

$$E_L^{Own} = -\psi \frac{P_L}{Q_L^D(P_H, P_L)},\ E_L^{Cross} = \omega \frac{P_H}{Q_L^D(P_H, P_L)}$$

where $E_{H,}^{Own}$ and $E_{H,}^{Cross}$ respectively represent own and cross price elasticity for the

[6] The ratio of the prices for high and low quality beef was estimated from the average market prices of Steers (generally A grade cattle) and D3 cattle as reported in CANFAX WEEKLY SUMMARY of May 6, 2005. While the median price of Steers was observed at about $80, the D3 cattle were sold for about $17.

high quality beef, while $E_{L,}^{Own}$ and $E_{L,}^{Cross}$ are own and cross price elasticities for the low quality beef respectively.

6) Arbitrary values were entered for the demand parameters α, η, γ, ω, ψ and δ.

7) Using the solver routine in excel, we set $P_H / P_L = 4.7$, by changing α, η, γ, ω, ψ and δ subject to 4 constraints. The four constraints were defined by equating each elasticity formula in step 5 to the corresponding data reported in table 5.1.

8) The calibrated model was entered into MATHEMATICA program and the simulation tried in the post innovation period to ensure that $0 \le \kappa^* \le \hat{\kappa}$

9) Otherwise the three variables J, β and K were adjusted and steps 7 and 8 repeated until the model calibrated with the pre innovation data satisfied $0 \le \kappa^* \le \hat{\kappa}$ in the post innovation market.

Table 5.2 shows the estimates of demand parameters as well as the respective equilibrium prices in the pre innovation market.

Table 5.2
Estimates of Demand Parameters Obtained Using the Elasticity Data from Secondary Sources

	Estimated Demand Parameters $(\frac{P_H}{P_L} = 4.7),\ \theta_N = 0.75,\ X = 5000$ $\beta = 700,\ U = 20,\ J = 1000,\ K = 800$						**Pre-Marker Equilibrium Prices**	
Elasticity Data	α	δ	γ	η	ψ	ω	P_H	P_L
Lusk and Norwood, 2003 (Model 1)	235.497	1.392	4.075	62.247	3.175	0.588	185.54	39.47
Lusk and Norwood, 2003 (Model 2)	238.348	0.637	0.265	50.947	0.812	0.137	180.37	38.33
Lusk et al (2001)	231.069	0.332	0.711	84.950	0.762	0.069	242.63	51.57
Tvedt et al (1991)	217.434	0.603	2.667	105.599	2.218	0.336	266.77	56.77

5.13) Simulations

Combining the slope estimates in table 5.2 with the assumed supply parameters, the pre innovation market is simulated with the aid of MATHEMATICA program. A sample of the MATHEMATICA programs for the pre innovation market is presented in appendix D. The prices that result from this simulation are essentially the same as the base prices that were derived during model calibration as displayed on the last two columns of table 5.2. The purpose of carrying out this simulation for the pre innovation market is that it enabled us to explicitly determine the pre marker equilibrium quantities as well as producer and consumer surpluses which were not part of the calibration.

The market is then shocked by the introduction of gene marker innovation. In doing this the gene marker sector is introduced into the supply chain along with the variables f, W_M, Y, Ω, V, ϕ, κ_i, κ^* and $\hat{\kappa}$ which were not present in the pre innovation period. A sample of the MATHEMATICA programs for the post innovation markets is presented in appendices E.

In the post innovation period, the cost effectiveness ϕ of the marker semen was initially assumed to be zero. This is actually a worst case scenario in that it assumes the producer incurs an extra cost $(W_M - W_N)$ in purchasing the marker semen and yet is unable to reduce the marginal cost associated with other production inputs (e.g tenderization facilitating technologies). A ϕ of zero implies that $V = U$. In other words, it implies that the non semen part of the producer's cost function does not change irrespective of the type of semen input used. If this worst case scenario holds, then any increase in

surpluses would be due purely to productivity gains rather than to cost savings. As was defined earlier in section 4.1, productivity gain here refers to an increase (decrease) in the proportion of high (low) quality beef produced.

5.2) RESULTS

5.21) Changes in Prices and Quantities of High and Low Quality Beef

Table 5.3 below compares the simulation results for equilibrium prices and quantities in the pre and post innovation periods for each group of elasticity estimates, assuming the use of marker semen does not generate any cost savings for the producer (i.e ϕ = 0). First we note that the quantities Q_H^S and Q_L^S supplied respectively, of high and low quality beef, are equilibrium quantities and therefore $Q_H^S = Q_H^D$ and $Q_L^S = Q_L^D$. The changes in the quantities as shown in the table are due to the availability of more productive inputs (marker semen) in the post innovation period. As expected, the increased productivity in this period results in the supply of more (less) of the high (low) quality beef. For example, for the simulations using elasticity data from Tvedt et al, quantity supplied of high quality beef, Q_H^S is 208 in the pre innovation period and 239 in the post innovation period. This trend is the same across the four groups of elasticity data.

The results show that the model is consistent with standard demand theory: market-clearing price decreases with an increasing supply of the product. Hence with increased production of the high quality beef, the equilibrium price P_H for this premium product decreases. For Tvedt et al, P_H falls from 267 in the pre marker period to 262 in

the post marker period. On the other hand, the price P_L for the low quality beef increases due to the fact that producers find it easier to clear the reduced quantity produced of this type of product. For Tvedt et al, P_L rises from 57 in the pre marker period to 67 in the post marker period. Again these trend in P_H and P_L are consistent across the four groups of elasticity estimates.

Table 5.3
Simulation Results for Equilibrium Prices and Quantities in the Pre and Post Innovation Periods under the Assumption of Zero Cost Effectiveness of the Innovation

$\phi = 0,\ \beta = 700,\ \theta_N = 0.75,\ J = 1000,\ K = 800,\ X = 5000, U = 20,\ \Omega = 0.15$								
Elasticity Estimate	**Period**	f	W_M	P_H	P_L	Q_H^S	Q_L^S	$\sum Q$
Lusk and Norwood (2003); Model 1	Pre innovation	-	-	185	39	138	46	184
	Post innovation	12,901	18	184	44	160	29	189
Lusk and Norwood (2003); Model 2,	Pre innovation	-	-	180	38	134	44	178
	Post innovation	11,458	16	168	56	146	29	175
Lusk et al (2001)	Pre innovation	-	-	243	52	187	62	249
	Post innovation	15,546	22	231	79	210	41	251
Tvedt et al (1991)	Pre Innovation	-	-	267	57	208	69	277
	Post Innovation	18,544	26	262	67	239	44	283

However the effect of the marker innovation on the overall supply of beef is different with the data from Lusk and Norwood (model 2) than with the other 3 groups. Using data from Lusk and Norwood (Model 2), the total supply of beef $\sum Q$, decreases from 178

(pre marker), to 175 (post marker). On the other hand, the other 3 groups of elasticity data predict that the gene marker innovation would result in increased aggregate supply of beef. Other factors being constant, the fact that the gene marker innovation results in the increased production of the premium product (increased revenue) implies that, producers have a prospect of obtaining increased profit per unit of intput used. Such prospect should induce producers to produce more of the product and hence aggregate supply is expected to increase. Therefore the trend predicted by Lusk and Norwood (model 2) is unexpected. We wish to remind the reader that Lusk and Norwood (model 2) was the group of elasticity data which suggested demand for high quality beef to be more elastic than for the low quality product. This was unexpected.

5.22) Welfare Changes

Table 5.4 presents simulation results for the welfare impact of the innovation on consumers, producers and the genomic companies. Please refer to appendix A for the calculation of aggregate producer surplus using the model of differentiated producers (and incomplete adoption) as illustrated by figure 4.1 of section 4.1. Also refer to appendix B for the calculation of aggregate consumer surplus from the demand specifications for high and low quality beef as represented in equations (1) and (2) of section 4.2.

The results presented in table 5.4 were derived under the assumption of zero cost effectiveness ($\phi = 0$) of the marker technology. Hence the welfare simulations presented are due only to productivity gains brought about by the technology. This productivity

Table 5.4
Simulation Results for Surplus Changes from Gene Marker Innovation under the Assumption of Zero Cost Effectiveness of the Innovation
Note: $\bigcup_C$ = Aggregate Consumer Surplus, $\prod_P$ = Aggregate producer net return and π = Profit of monopolist test provider

$\phi = 0,\ \beta = 700,\ \theta_N = 0.75,\ J = 1000,\ K = 800,\ X = 5000, U = 20,\ \Omega = 0.15$					
Elasticity Estimate	**Production Period**	$\bigcup_C$	$\prod_P$	π	**Social Surplus**[7]
Lusk and Norwood (2003); Model 1	Pre innovation	7,181	11,862	0	19,043
	Post innovation	9,378	12,634	1,621	23,634
	% change in surpluses	**31**	**7**		**24**
Lusk and Norwood (2003); Model 2	Pre innovation	15,233	11,107	0	26,341
	Post innovation	17,261	10,698	1,161	29,120
	% change in surpluses	**13**	**-4**		**10**
Lusk et al (2001)	Pre innovation	55,322	21,801	0	77,123
	Post innovation	67,775	22,133	2,303	92,211
	% change in surpluses	**23**	**2**		**20**
Tvedt et al (1991)	Pre innovation	36,947	26,912	0	63,860
	Post innovation	47,818	28,141	3,413	79,372
	% change in surpluses	**29**	**5**		**24**

gains accrue from the marker efficiency $\kappa \sim (0, \hat{\kappa})$. As indicated earlier, this is a worse case scenario. A better scenario would be if the technology leads to gains in productivity as described above, while at the same time generating some cost savings for the producer ($\phi > 0$). A positive welfare impact in the worst case suggests that welfare

[7] It is once again emphasized here that the post innovation social surpluses do not account for the fixed cost of the life science companies. Taking account of these fixed cost will result in smaller estimates of the post innovation social surpluses and hence smaller estimates of the changes in social surplus

changes would be positive in the better cases. These are confirmed later by the results of sensitivity analysis

The simulation results in table 5.4 imply that the marker technology would induce increased surpluses even with no cost savings, as long as it is associated with productivity gains. For instance, simulations using Lusk and Norwood: model 1, predict a 31% gain in consumer surplus, a 7% gain in producer surplus and a 24% gain in social surplus[8] from the introduction of a non cost effective marker technology. These increases in surpluses are also derived with elasticity data from Lusk et al and Tvedt et al.

A notable observation is that the producer sector generates surpluses despite the assumption of perfect competition for this sector. To explain this it is worth bringing to mind that this analysis is short run to the extent that the innovation distorts a pre existing equilibrium in which productivity of traditional technology was constant across all producers. In the first period of introduction / adoption of marker technology, some producers have marker advantage based on their breed type. These are the producers who adopt the technology and are able to capture the quasi rents simulated above. These rents will gradually disappear as currently disadvantaged producers in a bid to remain competitive make long run substitution towards breeds that are best suited for the marker technology. Thus we envisage a long run equilibrium in which productivity will be once again constant across all producers. Then the economic profit will return to zero as one

[8] These surplus changes were simulated under the assumption that the gene marker company has zero marginal cost. With positive marginal cost, we expect the equilibrium marker fee to be higher and all surplus measures to be smaller. Additionally there would be a smaller range of fixed cost that ensures a positive social surplus.

expects of perfect competition. But in the meantime, the short run holds and the producer sector is able to generate positive changes in surplus.

However the elasticity data from Lusk and Norwood model 2, predicts a negative change in producer surplus from the adoption of the innovation. Be that as it may, overall social surplus with this elasticity data is still positive due to offsetting gains in consumer surplus as well as the profits generated by the genomic companies. This particular trend did not change for this specific elasticity data, even with different assumptions of the cost effectiveness of the marker technology.

Further discussion is needed on the unexpected trend in producer surplus with Lusk and Norwood model 2. First, the unusual direction of change in producer surplus associated with this data set may be purely attributed to its unusual reporting that the demand for high quality beef is more elastic than for low quality. That not withstanding, the negative change in producer surplus generated by this data set, leaves room for concern as to how much of game theory was ignored by our analysis. It is possible that when the adoption decision by each individual producer is independent of the decision by others, then every producer may end up adopting the innovation to the extent that the aggregate supply of the premium product is more than the existing demand can handle. The result would be that prices depress below marginal cost and producers end up with a loss.

The gain in consumer surplus as reported in table 5.4 is due to the increased availability of high quality beef at a lower price. Surpluses that accrue to producers are due to

increases in the production of premium beef from adoption of the technology. The benefit that accrues to the gene marker company comes from the fee that adopting producers have to pay for the marker test.

Although the distribution of this gain varies across the sources of elasticity estimates, further analysis reveal that a larger chunk of the benefit will accrue to the consumer group. Table 5.5 below shows the distribution of gains, assuming a zero percent cost effectiveness of the innovation. Consumers' share in the benefit from the technology is estimated as 48%, 73%, 83% and 70% with elasticity estimates from Lusk and Norwood model 1, Lusk and Norwood Model 2, Lusk et al, and Tvedt et al, respectively.

Table 5.5
Distribution of Gains from the Gene Marker Innovation under the Assumption of Zero Cost Effectiveness of Innovation

$\phi = 0,\ \beta = 700,\ \theta_N = 0.75,\ J = 1000,\ K = 800,\ X = 5000, U = 20,\ \Omega = 0.15$				
Elasticity Estimate	**Distribution of Gains in Social Surplus (%)**			
	$\cup_C$	$\prod_P$	π	Total
Lusk and Norwood (2003) Model 1	48	17	35	100
Lusk and Norwood (2003); Model 2	73	-14	41	100
Lusk et al (2001)	83	2	15	100
Tvedt et al(1991)	70	8	22	100

Additionally, 35%, 41%, 15% and 22%, respectively of the estimated changes in social surplus constitute the rents for gene marker companies, while the estimated producers' share of the benefit is 17%, -14%, 2% and 8% respectively. Notably, these estimated distributions show very little sensitivity to the values of ϕ and Ω.

5.23) Sensitivity of Results to Different Assumptions of ϕ and Ω

Table 5.6 illustrates the sensitivity of the simulated changes in social surplus to different assumptions of the percentage cost effectiveness of the marker technology.

Table 5.6
Percentage Cost Effectiveness of Marker Assisted Selection and its Impact on Social Surplus

$\beta = 700,\ \theta_N = 0.75,\ J = 1000,\ K = 800,\ X = 5000, U = 20,\ \Omega = 0.15$												
Elasticity Estimate	Lusk and Norwood (2003) Model 1			Lusk and Norwood (2003) Model 2			Lusk et al (2001)			Tvedt et al (1991)		
Cost Effectiveness	**0%**	**5%**	**25%**	**0%**	**5%**	**25%**	**0%**	**5%**	**25%**	**0%**	**5%**	**25%**
Percentage Change in Social Surplus	24.1	25.1	29	10.6	11.1	13.7	19.6	20.1	22.5	24.3	24.8	27.1

The cost effectiveness (ϕ) of marker semen was interpreted in section 4.2 as relating to the cost savings from the reduced need for facilitating practices due to the adoption of marker semen. With respect to the tenderness marker for example, this cost savings would be from the reduced need for moisture enhancement, needling and other postmortem tenderization technologies which would be implemented with a greater intensity if non marker semen were used. As expected the change in social surplus is an

increasing function of the cost effectiveness of the marker technology. For example with elasticity data from Lusk and Norwood model 1, the innovation is expected to result in a 24.1%, 25.1% and 29% change in social surplus when it is respectively 0%, 5% and 25% cost effective.

The increment in social surplus that emanates from increasing cost effectiveness is due not only to increasing profit of the producer but also to increment in the surpluses of consumers and the gene marker test providers. Specifically, producer surpluses increase due to increased cost savings on tenderness facilitating practices. This can be conceptualized as a downward shift in the marginal cost curve (or an increase in supply). Also with increased cost effectiveness, producers increased valuation of the marker semen would enable the test provider the opportunity of raising the test fee in an attempt to maximize profit. Thus increased cost effectiveness of the technology translates into increased profit for the test provider. Also consumer benefit increases with the cost effectiveness of marker semen because with more producers adopting marker assisted selection, the quantity produced of high quality beef increases while its price decreases.

Table 5.7 illustrates the sensitivity of simulated changes in social surplus to different assumptions regarding the frequency of the favorable gene in a population. As mentioned before in section 4.23, the frequency of the favorable gene varies with the breed of cattle. For example only about nine percent of the Angus population will carry the favorable forms of the tenderness markers in both its paternal and maternal genes.

Table 5.7: Frequency of the Favorable Gene and Its Impact on Social Surplus

$\beta = 700,\ \theta_N = 0.75,\ J = 1000,\ K = 800,\ X = 5000, U = 20,\ \phi = 25\%$												
Elasticity Estimate	Lusk and Norwood (2003) Model 1			Lusk and Norwood (2003) Model 2			Lusk et al (2001)			Tvedt et al (1991)		
Frequency of Favourable Gene	**9%**	**15%**	**21%**	**9%**	**15%**	**21%**	**9%**	**15%**	**21%**	**9%**	**15%**	**21%**
Percentage Change in Social Surplus	28.3	29	29.3	13.2	13.7	13.9	22.1	22.5	22.7	26.7	27.1	27.3

The changes in social surplus that result from the adoption of marker technology would be greater for breeds which have a higher proportion of their population carrying the favorable form of the gene. Notably, the increased ease of marker assisted selection implies that producers would not have to incur so much cost on several unsuccessful tests. The cost savings from unsuccessful test transforms into additional surpluses for the producers and reduces the disincentive for adoption. Thus adoption would be higher for breeds with a higher frequency of the favorable gene. With increased adoption, the production of high quality beef increases resulting in a fall in its price and thereby an increase in consumer surplus.

Although higher gene frequency implies that fewer animals will be tested, the profit of the genomic companies was simulated as an increasing function of the gene frequency. To explain this, it is worth bringing back to mind that the genomic sector is concentrated. Thus the test provider with market power would increase the marker fee as the demand for marker test becomes less elastic. Indeed the increased ease of selection associated with higher gene frequency can be argued to result in a lower elasticity of demand for

marker test. Farmers with a higher probability of recording a successful test are less likely to shy away from higher test fees.

Thus for breeds with higher gene frequencies, the combined effects of producer cost savings from reduced test failure rate, consumer benefit from lower prices of the premium beef, as well as the gene marker companies' ability to charge higher test fees ultimately results in an increase in the social surplus associated with the innovation. For example for Lusk et al (2001), social surplus change from adoption of Marker Assisted Selection is simulated as 22.1%, 22.5% and 22.7% under the assumption that the favorable gene is present in 9%, 15% and 21% respectively of the population.

Finally we note that the comparative statics results do not indicate significant percentage increases in social surplus, across different values of the exogenous variables (ϕ and Ω). For example, from table 5.6, results with elasticity data of Tvedt et al only indicate about 3 percent increase in social surplus as cost effectiveness (ϕ) is increased from 0% to 25%. The rate of increase in social surplus appears to be even smaller for the Ω variable. Data for Tvedt et al in table 5.7 show that social surplus only increases by 0.6% when Ω is more than doubled from 9% to 21%. The low rate of increase in social surplus might be attributed to the relatively high productivity (θ_N) of the existing technology. In this simulation, we have fixed θ_N at 0.75 to represent the fact that about 75% of beef produced with non marker semen are tender. Given this existing productivity, any tenderness enhancing technology that is being introduced is only an attempt to provide the remaining 25% productivity. Recall that the frontier of marker efficiency was defined

as $\hat{\kappa} = \frac{1-\theta_N}{\theta_N}$ which will give 0.33 for θ_N = 0.75. It is no surprise therefore, that such narrow frontier after inducing some increase in social surplus, would leave only very little room for comparative statics. The possibility of comparative static analysis might even be less for the marbling trait[9] for which θ_N would be 0.9 thereby constraining[10] the frontier of marker efficiency to $\hat{\kappa}$ = 0.11.

Unfortunately, we note that due to model limitation, comparative statics could not be implemented for Ω values beyond the ones used in tables 5.7. Justification for the range of values used is found in literatures and expert opinions which report these figures as the frequencies of the marker genes with respect to tenderness. For example as was mentioned in section 4.23, Page et al (2004) report the frequency of the favorable form of the Calpain marker gene for tenderness, in the range between 17 percent and 37 percent. Thus the model was intentionally calibrated to accommodate the figures reported. Hence plugging in values beyond these range would throw κ^* outside the boundary (0, $\hat{\kappa}$), and thereby render the results meaningless. An immediate consequence of this limitation was that we could not completely ascertain if the change in surplus is monotonically increasing in Ω.

[9] About 90% of currently available beef cuts have an acceptable marbling quality.
[10] As the productivity of the existing technology tends towards 100%, the marker induced productivity gain tends towards 0. The effect on surpluses would however depend on other parameters of the model as well as elasticities which are not the same for all traits.

6. CONCLUSION AND RECOMMENDATIONS

This chapter draws conclusion from the preceding discussions and gives recommendations for beef producers as to the use of the gene marker innovation. The chapter concludes with suggestions for further research.

6.1) CONCLUSION

This study attempted to measure the impact of the adoption of gene marker innovation on societal welfare. The study was implemented with respect to tenderness quality in beef. Beef was categorized into two groups viz the tender group denoted as high quality and the tough group denoted as low quality.

The simulated surplus changes were achieved by building a simplified model to represent the beef supply chain. The chain comprised of the consumer, the producer/processor group and the genomic sector. Surplus changes that result from the adoption of the innovation were simulated for each of the sectors using 4 sets of demand elasticity data. The data sets had some things in common, they were all from secondary sources (selected literatures), and they all report the high and low quality beef as substitute.

However, while three of the four data sets suggested that demand for the high quality product is more inelastic than for the low quality, (which is what is expected), the

remainder set of data implied a more elastic demand for the high quality than for the low quality beef.

Under the assumption of zero marginal cost for the gene marker company, simulations using each of these 4 sets of elasticity data produced positive changes in surplus for the consumer as well as the gene marker sector. Additionally, producer surplus was simulated as positive with the three elasticity data sets for which high quality beef was reported to be more inelastic than the low quality. When the data set which reported demand for high quality to be more elastic was adopted for simulation, marker assisted selection was predicted to result in a negative change in producer surplus. Be that as it may, overall changes in social surplus were positive[11] for all four groups of elasticity data. Notably, the simulated changes in social surplus would most likely be a decreasing function of both the actual marginal and fixed cost of the gene marker company.

Assumption of higher values of cost effectiveness of the technology generated larger increases in social surpluses due to both enhanced productivity and cost savings from tenderness facilitating /inducing technologies. Productivity was defined in this study as the proportion of high quality beef produced from a unit of semen.

However there is need for caution in generalizing the results for the beef tenderness trait for other traits. For example, while the tenderness trait was not used as a seedstock selection criterion until recently, marbling was already factored into the traditional

[11] It is important to note that the simulated increases in social surplus include deadweight loss due to non competitive pricing by the gene marker companies. Under competitive pricing, social surplus increases would be higher, although there would be less incentive for innovation by the genomic sector.

selection criteria (EPD). This may imply large differences in parameter values between marbling and tenderness. For instance θ_N was generally adopted in this study as 0.75 due to literature evidence which suggests that 75 percent of available beef are tender. In the same manner, literature evidence suggests that 90 percent of beef in the market would qualify as high quality with respect to the marbling trait, thereby implying that an analysis with respect to the marbling trait would adopt θ_N as 0.9. Such differences in parameter values, elasticity estimates, and modeling framework for marbling might imply a different conclusion regarding the impact of the gene marker innovation on the industry.

This study also reveals the breed-effect associated with the gene marker innovation. While the simulation results suggest that adoption of tenderness markers would result in an industry-wide increase in economic surplus, experts' opinion suggest that producers gain from adoption varies with the breed of cattle. For example the calpain marker is said to have no effect with the *indicus* breed of cattle.

Experts' opinion also suggests that economically important traits such as tenderness and marbling are influenced by a number of genes as well as by management factors. Hence the fact that only a handful of the more than 30,000 genes in cattle have been marked, does suggests that a seedestock selection criterion which relies solely on the few available markers might not produce the expected gains in surpluses. Hence the suggestion that the innovation be incorporated into existing selection criteria and management practices appears to be the best at this point in time. In concise terms, this

study has neither discarded the gene marker innovation nor recommended that it be adopted as a lone standing seedstock selection criterion.

6.2) RECOMMENDATIONS

The following recommendations for beef producers emerge from the above discussions

- Producers should not get caught up by the hype surrounding the gene marker innovation. The array of markers in the market is yet too small to guarantee the technology as a cutting edge seedstock selection technique.
- Producers should not get discouraged by the absence of markers for all the genes of economically important traits. Advantage can be taken of the presently available markers by incorporating them into existing seedstock selection criteria.
- Producers should be very familiar with the EPD technique for seedstock selection in order to understand how an overall approach that includes gene-marker-assisted selection can be effectively developed
- Producers should stay abreast of new developments, products and firms in the rapidly changing market for gene marker tests. Reports of independent evaluation agencies should be actively sought to ascertain the validity of any test claims.

6.3) SUGGESTIONS FOR FURTHER RESEARCH

A major weakness in the model adopted for this study is that it assumes the price of the non marker (traditional) semen to be exogenous and therefore unaffected by the introduction of the marker semen. In reality, introduction of the marker technology implies increased competition in the semen market which could ultimately result in a

decline in price of the traditional semen. Therefore, a completely representative model would account for the effect of the price of the innovated input (marker semen) on the traditional input (non marker semen).

The simulation model adopted had circumvented the problem associated with variability of marker effect across breed, by assuming that this effect (net benefit) is uniformly distributed across producers. How close this assumption is to reality is yet to be verified. A more thorough analysis would involve a case by case consideration of marker effect by breed, by trait and by gene. The practicality of such analysis however stands to be questioned.

Finally, while this study has focused primarily on beef cattle, it is worthy of note that gene markers have also become relevant in the production of dairy cattle. One might be making a worse blunder to generalize the results for beef cattle to include the dairy industry. Further research is needed to ascertain the innovation's impact on the dairy industry.

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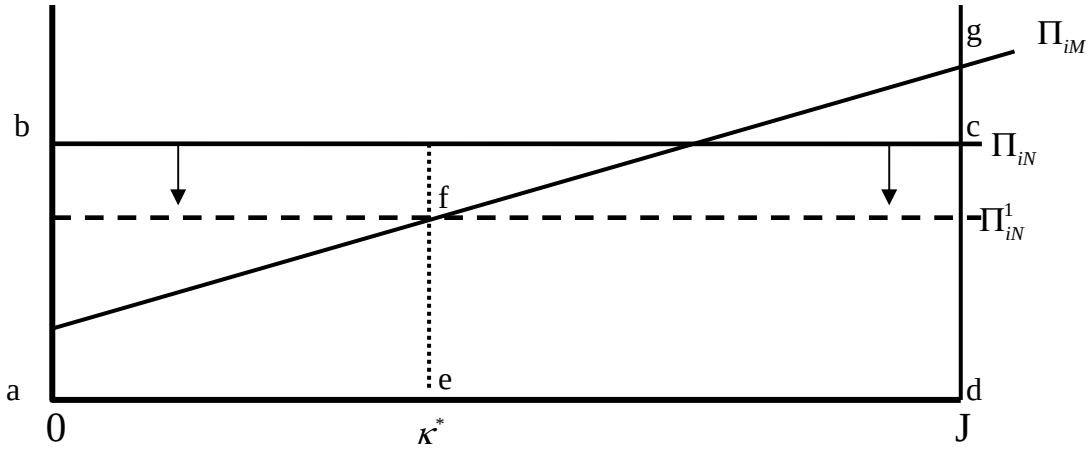
APPENDICES

APPENDIX A

Estimation of Producer Surpluses; Pre and Post Innovation

Figure 4.1 of section 4.1 is repeated and modified below as figure AI to suit the problem under consideration. The major difference between this figure and the one in section 4.1 is that the net return (Π_{iN}) from the use of the traditional input is flat reflecting the fact that the efficiency of non marker semen θ_N is constant across all producers. Thus the expected profit (Π_{iN}) with non adoption is the same across all producers.

Figure A1
Net Returns for Producers in the Pre and Post Innovation Periods



Net Returns in the Pre Innovation Period

Let the line Π_{iN} represent the net return for producers in the pre innovation era. Then the aggregate producer return is represented by the entire area of rectangle abcd. With J number of producers, the aggregate net returns becomes $\prod_P = J\Pi_{iN}$.

Net Returns in the Post Innovation Period

In the post innovation period the net returns for a farmer on non maker semen is given by Π_{iN}^{1} . The difference between Π_{iN} and Π_{iN}^{1} arises from the fact that prices for both the high and low quality beef are different in the two periods. Then with $\frac{\kappa^{*}}{\hat{\kappa}}$ fraction of farmers still on the non marker semen, the aggregate net return from non adopting producers is $(J\kappa^{*}\Pi_{iN}^{1})/\hat{\kappa}$ where J again represents the total number of producers in the market. Also the aggregate net return for the adopting farmers is calculated as the area of trapezium defg. This is given as $\left(J\int_{\kappa^{*}}^{\hat{\kappa}} \Pi_{iM}\, d\kappa_{i} \right) \Big/ \hat{\kappa}$ Where Π_{iM} is the net revenue function from adoption.

Therefore the total producer net benefit in the post innovation regime is given by

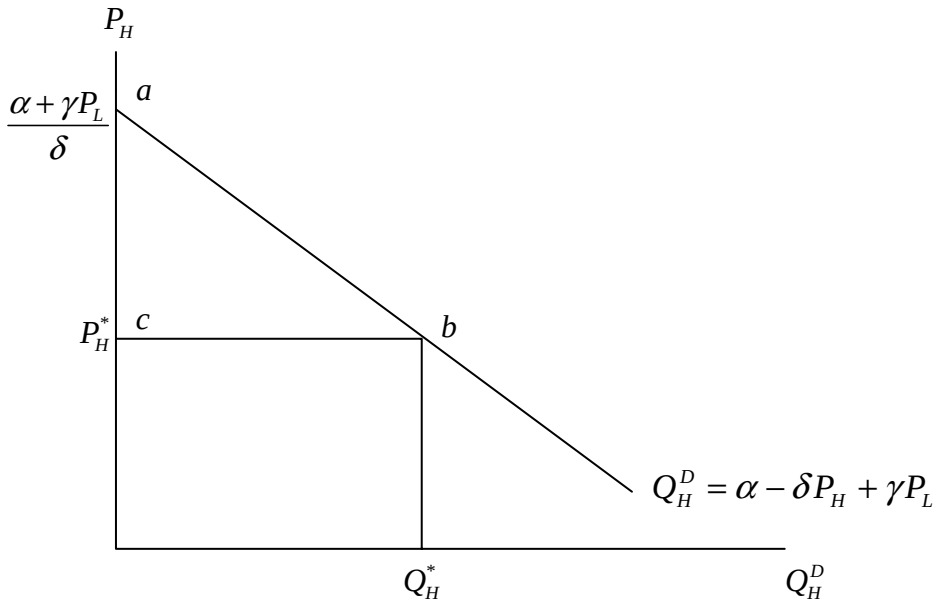
$$\Pi_{P} = (J\kappa^{*}\Pi_{iN}^{I})/\hat{\kappa} + \left(J\int_{\kappa^{*}}^{\hat{\kappa}} \Pi_{iM}\, d\kappa_{i} \right) \Big/ \hat{\kappa}$$

APPENDIX B

Estimation of Consumer Surpluses from the Demand Specifications in Equations (1) and (2)

The demand for high quality beef was specified in equation (1) as $Q_H^D = \alpha - \delta P_H + \gamma P_L$. This is represented in figure A2 below.

Figure A2
Demand Curve for High Quality Beef



The intercept is calculated by equating $Q_H^D = 0$ (that is $\alpha - \delta P_H + \gamma P_L = 0$) and solving for P_H. The price P_H at this intercept is found to be

$$P_H = \frac{\alpha + \gamma P_L}{\delta}$$

The consumer surplus is represented by the area abc in figure A2 and can be calculated as

$$\int_{P_H}^{\frac{\alpha+\gamma P_L}{\delta}} (\alpha - \delta P_H + \gamma P_L) dP_H$$

By the same logic the consumer surplus from the demand specification for low quality beef ($Q_L^D = \eta - \psi P_L + \omega P_H$) can be calculated as

$$\int_{P_L}^{\frac{\eta+\omega P_H}{\psi}} (\eta - \psi P_L + \omega P_H) dP_L$$

Hence the aggregate consumer surplus becomes

$$\bigcup_C = \int_{P_H}^{\frac{\alpha+\gamma P_L}{\delta}} (\alpha - \delta P_H + \gamma P_L) dP_H + \int_{P_L}^{\frac{\eta+\omega P_H}{\psi}} (\eta - \psi P_L + \omega P_H) dP_L$$

APPENDIX C

Questions used for Telephone Interview

The telephone interviews were generally open ended conversations. However the following questions helped to guide the respondents on the issues being considered. In all four experts were interviewed. They comprised of three cattle genetists (Dr. Alison Van Eenennaam of the University of California at Davis, Professor Emil J. Pollak of Cornell University and Professor Dorian J. Garrick of Colorado State University) and one meat scientist (Dr. Phyllis Shand of the University of Saskatchewan). All errors and omissions remain the responsibility of the author.

Interview with the Cattle Genetists

1) First, on a general note, I would like to know if you think for a producer, gene markers are worth their costs.

2) How accurate are currently available marbling EPDs
- Angus Breed
- Hereford Breed

3) What is the accuracy of the newly developed tenderness EPDs being used by the American Simmental Association?

4). Is there any breed for which the use of gene markers will have little or no effect?

5) On what breed do you think gene markers will have the most effects?

6) Assuming farmers decide to adopt the use of markers, what is the probability of getting an animal with a favorable rating for tenderness? (What percentage of animals tested are likely to be rejected?)
- Angus Breeds
-Hereford Breed

7) It is said that beef has to be left to age for about 14 days to get an acceptable tenderness level. Assuming we get all the genes right by the use of gene markers, will this reduce the number of days that is required for tenderization?

8) What is the minimum desirable marbling score? (or percentage IMF)

9) What average percentage of beef tested currently have this score?

10) From literatures I understand that marker assisted selection results in increase in the frequency of favorable allele. Is it likely that in the future 100% of cattle tested will have favorable forms?

Interview with the Meat Scientist

1) The Calpastatin and Calpain enzymes have been associated with tenderness in beef. What is the nature of the association? Do these enzymes affect the **degree,** to which the carcass tenderizes, or the **rate** of tenderization, or both?

2) It is suggested that carcasses have to be left for 14 days in order to get the desired level of tenderness. To what extent is this practiced by Canadian beef processors?

3) Could you give me an idea of the daily cost of post mortem storage per carcass?

4) Several literatures have suggested that the following postmortem technologies could be used to induce tenderization in carcass? In Practice, are these tenderization technologies used in the Canadian beef industry?
- Calcium Activated Tenderization,
- Hydrodyne,
- Needling

5) Could you quantify the average cost of using the tenderization technology per non-conforming carcass (i.e any carcass that is discovered to be tough)?
-Calcium Activated Tenderization,
-Hydrodyne,
-Needling

6) For how long have these technologies been in use?

7) Are their uses associated with any policy barriers or food safety concerns?

8) On what proportion of carcasses does tenderization has to be induced (i.e the percentage of carcasses that is discovered to be non-conforming).

9) What other tenderization technologies are used by Canadian beef Processors?

10) What is the success rate of using tenderization technologies? (What proportion of beef treated with such tenderization technologies actually become tender?)

APPENDIX D

MATHEMATICA File for Simulating the Pre Innovation Market (Lusk et al, 2001)

```
α = 231.069;

η = 84.950;

δ = 0.332;

γ = 0.711;

ψ = 0.762;

ω = 0.069;

B = 700;

U = 20;

θn = 0.75;

J = 1000;

K = 800;

X = 5000;

Wn = K / X;

QHD = α - δ * PH + γ * PL;

QLD = η - ψ * PL + ω * PH;
```

ConsumerSurplus =

$$\left(\int_{PH}^{\frac{\alpha+(\gamma*PL)}{\delta}} (\alpha - (\delta * PH) + (\gamma * PL))\, d[PH]\right) +$$

$$\left(\int_{PL}^{\frac{\eta+(\omega*PH)}{\psi}} (\eta - (\psi * PL) + (\omega * PH))\, d[PL]\right)$$

$$85146.2 - 223.377\,PH + 0.169124\,PH^2 + 409.9\,PL - 0.78\,PH\,PL + 1.14233\,PL^2$$

PH = (PL + P);

QHD

$$231.069 + 0.711\,PL - 0.332\,(P + PL)$$

```
QLD
84.95 - 0.762 PL + 0.069 (P + PL)
q*ni = (1 / B) * ((θn * (PH - PL)) + PL - Wn - U);
Πin = (1 / (2 * B)) * ((θn * (PH - PL)) + PL - Wn - U) ^ 2;
Qn = J * q*ni;
QHS = θn * Qn;
QLS = Qn - QHS;
Solve[{QLS == QLD}, {PL}]
{{PL → 0.952251 (92.15 - 0.198857 P)}}

PL = 0.9522513943681131`
    (92.15` - 0.1988571428571429` P);

Solve[{QHS == QHD}, {P}]
{{P → 191.058}}

P = 191.05786970668598`;
PL
51.5709
PH
242.629
PH / PL
4.70476
```

Qn

249.578

QHS

187.183

QHD

187.183

QLS

62.3944

QLD

62.3944

θ_n

0.75

q^*_{ni}

0.249578

Π_{in}

21.8011

$\Pi_{Producers} = J * \Pi_{in}$

21801.1

ConsumerSurplus

55321.9

SS = ConsumerSurplus + $\Pi_{Producers}$

77123.

APPENDIX E

MATHEMATICA File for Simulating the Post Innovation Market (Lusk et al, 2001)

```
α = 231.069;

η = 84.950;

δ = 0.332;

γ = 0.711;

ψ = 0.762;

ω = 0.069;

B = 700;

K = 800;

ϕ = 0;

U = 20;

V = U - ϕ;

θn = 0.75;

J = 1000;

X = 5000;

Ω = 0.15;

QHD = α - δ * PH + γ * PL;

QLD = η - (ψ * PL) + (ω * PH);
```

ConsumerSurplus =

$$\left(\int_{PH}^{\frac{\alpha + (\gamma * PL)}{\delta}} (\alpha - (\delta * PH) + (\gamma * PL))\, d\,PH \right) +$$

$$\left(\int_{PL}^{\frac{\eta + (\omega * PH)}{\psi}} (\eta - (\psi * PL) + (\omega * PH))\, d\,PL \right)$$

$$85146.2 - 223.377\,PH + 0.169124\,PH^2 + 409.9\,PL - 0.78\,PH\,PL + 1.14233\,PL^2$$

Wm = (f + K) / (Ω * X);

Wn = K / X;

Wm - Wn;

PH = P + PL;

QHD

$$231.069 + 0.711\,PL - 0.332\,(P + PL)$$

QLD

$$84.95 - 0.762\,PL + 0.069\,(P + PL)$$

$\theta_{mi} = (1 + \kappa_i) * \theta_n$;

$$q^*_{ni} = (1 / B) * ((\theta_n * (PH - PL)) + PL - Wn - U);$$

$$q^*_{mi} = (1 / B) * (((1 + \kappa_i) * \theta_n * (PH - PL)) + PL - Wm - V);$$

$$\kappa^* = (Wm - Wn - \phi) / (\theta_n * (PH - PL));$$

```
ProfitMforindiferentfarmer =
 (1 / (2 * B)) * (((1 + κ*) * θn * (PH - PL)) + PL - Wm - V) ^
    2 /. {f → 10, P → 12, PL → 15}
```

```
0.0105326
```

```
ProfNforindiferentfarmer =
 (1 / (2 * B)) * ((θn * (PH - PL)) + PL - Wn - U) ^ 2 /.
  {f → 10, P → 12, PL → 15}
```

```
0.0105326
```

$$\Pi_{in} = (1 / (2 * B)) * ((\theta_n * (PH - PL)) + PL - Wn - U) ^ 2;$$

$$\Pi_{im} = (1 / (2 * B)) *$$
$$(((1 + \kappa_i) * \theta_n * (PH - PL)) + PL - Wm - V) ^ 2;$$

$$Khat = (1 / \theta_n) - 1$$

```
0.333333
```

$$Qn = (J * \kappa^* * q^*_{ni}) / Khat;$$

$$Qm = \left(J * \int_{\kappa^*}^{Khat} q^*_{mi} \, d\kappa_i\right) / Khat;$$

$$QHn = \theta_n * Qn;$$

$$QLn = Qn - QHn;$$

$$QHm = \left(J * \int_{\kappa^*}^{Khat} ((1 + \kappa_i) * \theta_n * q^*_{mi})\, d\kappa_i \right) \Big/ Khat;$$

QLm = Qm - QHm;

QHS = QHn + QHm;

QLS = QLn + QLm;

Solve[{QLS == QLD}, {PL}] Output truncated

PL = Input truncated

Solve[{QHS == QHD}, {P}] Output truncated,
five solutions found

P3 = Input truncated, third solution for P accepted

P = P3;

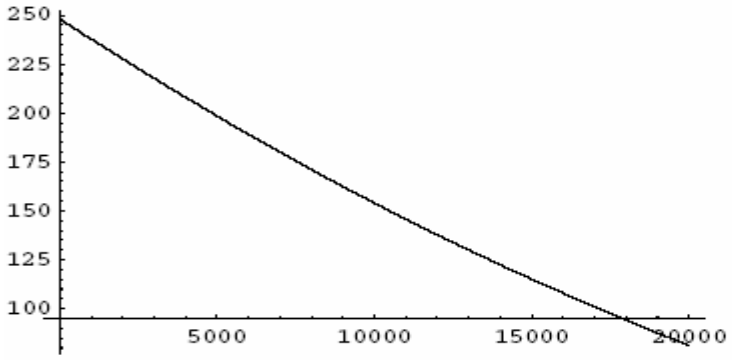
PL;

PH = P + PL;

Qm;

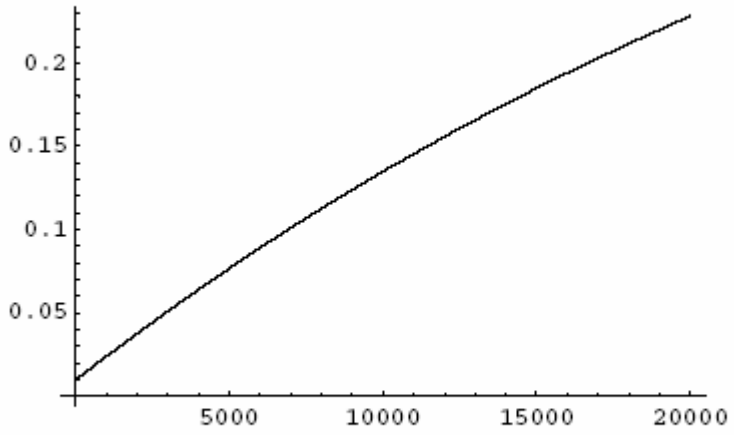
PLOTS TO VALIDATE ACCEPTED SOLUTION FOR P

Plot[{Qm}, {f, 0, 20000}]



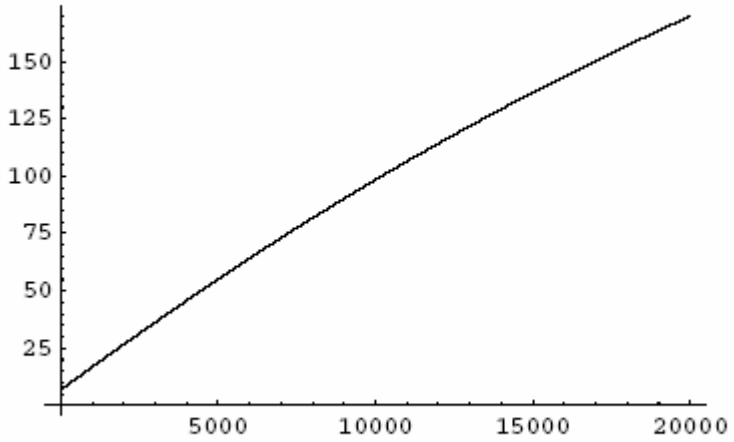
- Graphics -

```
Plot[{κ*}, {f, 0, 20000}]
```



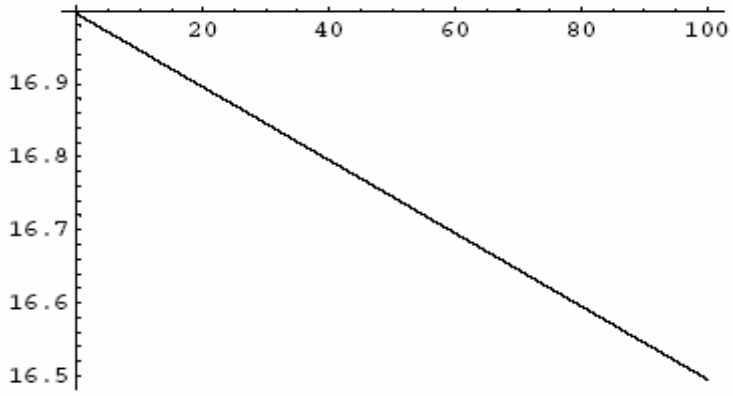
- Graphics -

```
Plot[{Qn}, {f, 0, 20000}]
```



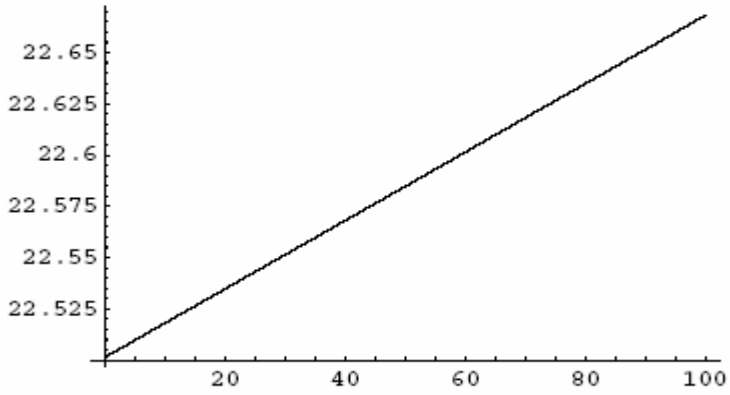
- Graphics -

```
Plot[{PL}, {f, 0, 100}]
```



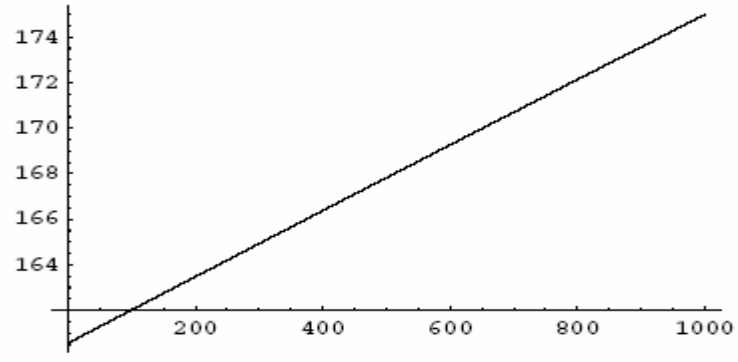

```
- Graphics -
```

```
Plot[{PH}, {f, 0, 100}]
```




```
- Graphics -
```

```
Plot[{QLS}, {f, 0, 1000}]
```



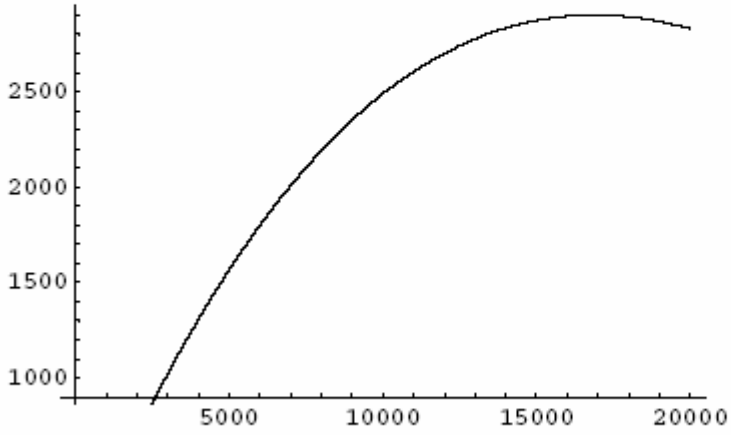

```
- Graphics -
```

```
Sm = Ω * Y * X;

Solve[{Qm == Sm}, {Y}] Output truncated
Y = Input truncated
 π_testprovider = (f - c) * Y;

 c = 0;

 Plot[{π_testprovider}, {f, 0, 20000}]
```




```
 - Graphics -
NMaximize[{π_testprovider}, {f}]

NMaximize::cvdiv :
 Failed to converge to a solution.
   The function may be unbounded. More…

{2302.76, {f → 15546.3}}
f = 15546.26755443742`;

π_testprovider

2302.76
```

Y

0.148123

Sm

111.092

Qm

111.092

Qn

140.273

PH

230.587

PL

78.6137

Wm

21.795

QHS

210.408

QHD

210.408

QLS

40.9569

QLD

40.9569

q^*_{ni}

0.246334

q^*_{mi}

$$\frac{1}{700}\left(36.8186 + 113.98\left(1 + \kappa_i\right)\right)$$

$$\partial_{\kappa_i}\, q^*_{mi}$$

0.162829

κ^*

0.189814

```
MProfitforindiferentfarmer = (1 / (2 * B)) *
   (((1 + κ*) * θn * (PH - PL)) + PL - Wm - V) ^ 2
```

21.2382

```
NProfforindiferentfarmer =
  (1 / (2 * B)) * ((θn * (PH - PL)) + PL - Wn - U) ^ 2
```

21.2382

ConsumerSurplus

67774.9

$\Pi_{in} = (1 / (2 * B)) * ((\theta_n * (PH - PL)) + PL - Wn - U)^2$

21.2382

$\Pi_{producersn} = (J * \kappa^* * \Pi_{in}) / Khat$

12093.9

$$\Pi_{producersm} = J * \left(\int_{\kappa^*}^{Khat} \Pi_{im} \, d\kappa_i \right) / Khat$$

General::spell1 :
Possible spelling error: new symbol name "producersm" is similar to existing symbol "producersn". More…

10039.2

$\Pi_{producers} = \Pi_{producersn} + \Pi_{producersm}$

General::spell :
Possible spelling error: new symbol name "producers" is similar to existing symbols {producersm, producersn}. More…

22133.1

$SocialSurplus = \pi_{testprovider} + \Pi_{producers} + ConsumerSurplus$

92210.8