THE VALUE OF A WHOLE-CHAIN TRACEABILITY SYSTEM IN TRANSMITTING GENETIC INFORMATION ABOUT BEEF TENDERNESS

By

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THE VALUE OF A WHOLE-CHAIN TRACEABILITY SYSTEM IN TRANSMITTING GENETIC INFORMATION ABOUT BEEF TENDERNESS

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Title of Study: THE VALUE OF A WHOLE-CHAIN TRACEABILITY SYSTEM IN TRANSMITTING GENETIC INFORMATION ABOUT BEEF TENDERNESS

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Abstract: Traceability in food supply chains has many potential benefits, including increased food safety, more efficient supply chain management, and greater opportunities for providing value-added products to consumers. In the case of livestock, traceability can provide enhanced disease prevention and mitigation. For these reasons and more, many major beef producing countries have implemented beef traceability systems. Of these, some are mandatory (such as European Union, Canada, Mexico, and Japan) while other countries such as the U.S. have encouraged voluntary systems. Especially where traceability systems are voluntary, in order for a large number of producers to participate in a whole-chain traceability system, they must believe that the benefits outweigh the costs.

In this study, we estimate the benefits relative to the costs of implementing a whole-chain-traceability-system (WCTS) in a supply chain composed of three stages: cow-calf producer, feedlot, slaughter/packing plant, by selecting genetics that produce beef that is more tender than average. As a first step in estimating benefits of WCTS, separate from effects of market linkages between stages of supply chain, we provide upper-bound estimates by assuming a vertically-integrated company. Profits in two scenarios are estimated and compared. In Scenario I, the enterprise uses artificial insemination to select favorable genes, implements a WCTS to track and trace genetically-improved animals, and tests for beef tenderness. In Scenario II, the enterprise chooses not to use artificial insemination or WCTS, so there is no improvement in the distribution of genotypes.

Results show that revenue could increase by $58.53/head, compared to additional costs of $5/head for implementing WCTS and $16/head extra cost for using artificial insemination for improving beef tenderness, and costs of testing for beef tenderness. If tenderness testing costs less than $37.53/head, or if other benefits of implementing WCTS can be realized, there is incentive for such a company to implement WCTS for the purpose of improving beef tenderness.

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CHAPTER I

INTRODUCTION

Problem Statement

Animal identification and traceability systems are being urgently pursued worldwide. Many major beef producers have implemented beef traceability systems and countries and regions like the European Union, Canada, Mexico, and Japan have established mandatory beef-cattle traceability systems. Some other countries, including the United States, have voluntary beef-cattle traceability systems.

Animal identification is not a new concept, though; it has existed for hundreds of years. It was mainly used as a method to specify the animal ownership, or to control and eradicate animal disease. Conceptually, traceability refers to the "ability to trace the history, application or location of that which is under consideration" (ISO, 2000). It indicates two parts of traceability – 'tracking' and 'tracing'. Tracking (forward) is the ability to follow the downstream path of a particular trade unit in the supply chain, while tracing (backward) is the ability to identify the origin of the products used in a particular trade unit (Thakur and Hurburgh, 2009).

Traceability in the U.S. beef-cattle industry is not mandatory, as in some countries. Thus, companies need incentives to develop and implement traceability systems. Some U.S. beef companies have already implemented traceability systems (Anderson, 2010; Chryssochoidis et al., 2009; Pendell et al., 2010; Schulz and Tonsor, 2010; Smith et al., 2005; Souza Monteiro and Caswell, 2004). However, most of the systems in use are "one-up, one-down" systems, which focus on transactions within the company, and with its direct suppliers and customers. Also, different standards exist across different companies (Golan et al., 2004; Murphy et al., 2008; Pendell et al., 2010). Thus, a whole-chain traceability system (WCTS) along the beef supply chain is needed, from cow-calf producers to consumers. The objective of this research is to evaluate the costs and benefits of implementing a WCTS for the part of the beef supply chain from cow-calf producers to slaughter/packing plants.

Implementation of a WCTS potentially brings several benefits to the company. Commonly, traceability systems are used for quality control and food safety purpose. But more and more companies have realized the benefit of using a traceability system to improve supply chain management or to transfer credence attributes along the supply chain. According to Golan et al (2004), the three main objectives of firms developing, implementing, and maintaining traceability systems are: to improve supply chain management, to facilitate trace back for food safety and quality, and to differentiate and market products with subtle or undetectable quality attributes.

Genetic information, for example, is one attribute that can be transferred along the chain. DeVuyst et al. (2007) and Weaber and Lusk (2010) found that that certain genetic characteristics have a higher likelihood of resulting in tenderer beef cuts. Lusk et al. (2001) found that consumers were willing to pay a premium for a tender steak versus a tough one. Information about willingness to pay for particular characteristics is difficult to pass along a complex supply chain with many transactions involving products with multiple quality characteristics, so even though consumers are willing to pay more for it, producers receive very little price incentive to provide more meat with greater tenderness. If producers could receive a price incentive large enough to cover additional production costs, they could increase profitability by increasing production of tender meat. This additional production could lead to added value to other participants in the chain. This research evaluates the value of transferring particular genetic information regarding beef tenderness along the beef supply chain. In order to simplify the problem, only three stages are considered in the analysis: cow-calf producer stage, feedlot stage, and slaughter/packing plant stage.

Objectives

The general objective of this research is to determine by what amount a whole-chain traceability system (WCTS) can increase profitability of a livestock supply chain by facilitating economic incentives for producers to increase tenderness of meat produced. The specific objectives are to: (1) determine the total profit of a vertically-integrated company combining cow-calf producer, feedlot, and slaughter/packing plant, with artificial insemination and a WCTS; (2) determine the total profit of a vertically-integrated company combining cow-calf producer, feedlot, and slaughter/packing plant, without artificial insemination or a WCTS; (3) determine the value of selecting specific genotypes and implementing WCTS by comparing the above results.

Summary of Methods

As a first approximation to estimating the value to cow-calf producers of using a whole-chain traceability system (WCTS) to provide information about their animals' genetics to beef processors, this thesis compares the profitability to producers from using the system with the profitability of not using it. In order to focus on the value of the information flow, without the complications that arise from price transmission across different stages in the supply chain, we assume that the supply chain is vertically integrated.

Within this vertically-integrated supply chain, the profitability of a cow-calf production enterprise passing information about the calves' genetics through a WCTS is compared to the profitability of a cow-calf enterprise that cannot pass information, but that is similar in all other respects. By focusing on just the flow of information about genetics in a vertically-integrated supply chain, the estimation provides an upper bound on the value of the WCTS to a cow-calf producer providing information about genetics that influence beef tenderness. There are many other kinds of value-added information that could be passed through a WCTS, and the value of that information is not considered here. However, this thesis provides a framework for valuing the role of a WCTS in facilitating flow of value-added information through a beef supply chain.

Two scenarios are considered: a vertically-integrated company including a cow-calf producer stage, a feedlot stage, and a slaughter/packing plant stage, with WCTS and artificial insemination (AI); and a vertically-integrated company including those same stages, but without WCTS or AI implemented. Two types of products are considered in each stage and each scenario, with different proportions.

In Scenario I, choice variables are the proportion of calves produced from AI and the total number of cattle sold. Parameters for the numerical equations include: wholesale prices for regular-tenderness meat, price premiums for tender meat, quantities sold at the slaughter/packing plant level, input cost in cow-calf producer level, feeding costs in cow-calf producer and feedlot levels, processing cost at the slaughter/packing plant level, traceability costs, costs of AI and natural service, beef by-products price, and tenderness test cost.

Outline of Study

The research is presented as follows. In chapter II, a discussion is presented on traceability systems and genetic information, along with description of the U.S. beef supply chain and past work relevant to this research. Chapter III describes the procedures used to accomplish the objectives, along with the data, conceptual framework and empirical models used. Chapter IV presents and discusses results. Chapter V summarizes the study and provides suggestions for future research.

CHAPTER II

LITERATURE REVIEW

Animal Traceability

Traceability has the potential to be used as a tool for product differentiation and marketing, as well as for food safety and quality control purposes.

Definitions and Concepts

While there is no exact definition for traceability, Souza- Monteiro and Caswell (2004) referred traceability as "the ability to follow the movement of a food through specified stages of processing, production, and distribution". Pouliot and Sumner (2008) define traceability as "the ability to trace the history of a product's origin including the identity of the farms and the marketing firms along a supply chain." Thakur and Hurburgh (2009, pp. 617) note that under European Union Law, "traceability" is defined as "the ability to track any food, feed, food-producing animal or substance that will be used for consumption, through all the stages of production, processing and distribution." They also distinguish between "tracking" and "tracing." Tracking is the ability of following a product as it moves forward the supply chain, while tracing is the ability to trace back each step the product took previously as it moved through the supply chain to this point (Thakur and Hurburgh, 2009). Traceability represents the ability to identify the farm from where food originates and the sources of input materials, as well as the ability to conduct full backward and forward tracking to determine the specific location and life history in the supply chain through records (Opara, 2003). Smith et al (2005) also defined animal traceability as "the ability to identify farm animals and their products according to their origin, as far back in the production sequence as is necessary to (a) ascertain ownership, (b) identify parentage, (c) improve palatability, (d) assure food safety, and (e) assure compliance." The Meat and Poultry Business Data Standards Organization (known as mpXML), issued the "Traceability for Meat and Poultry U.S. Implementation Guide (MPXML, 2010)." MPXML (2010) refer to supply chain traceability as "the net result of two complementary business processes, referred to as external and internal traceability." External traceability involves product identity communication and information transportation between trading partners, while internal traceability involves the inputs and outputs within one trading partner (MPXML 2010).

According to Golan et al (2004), traceability systems have three characteristics: breadth, depth, and precision. Breadth is the amount of information the traceability system records. Depth is how far back or forward the system tracks. Precision is the degree of assurance with which the tracing system can pinpoint a particular food product's movement or characteristics. These three characteristics are important in developing a traceability system.

Traceability systems can be divided into three types according to the amount of data transferred (Meuwissen et al., 2003). In the first type of system, each link in the supply chain gets relevant information from the previous link. In the second type of traceability system, each link receives the relevant information from all former links. The third type of system contains a third party who receives relevant information from all links in the supply chain. Based on depth, traceability can be divided into two types: life-cycle traceability and partial traceability (Smith et al., 2008). Jensen and Hayes (2006) referred to "farm to retail traceability" in the case of a livestock supply chain as "the ability to maintain the identity of all cuts from the farm through the cutting and distribution system." This can also be called a whole-chain traceability system (WCTS).

Current Situation of Beef Traceability

Among world major beef producing and exporting countries, a majority of them have established mandatory beef traceability systems nationwide, such as the European Union (EU), Japan (JN), etc. EU and JN have the deepest, broadest, and most precise systems. They encompass birth to retail, with a large amount of data. Also, because they rely on verification by public or private auditors, they have to assure the preciseness. Australia (AU) and Brazil (BR) also have the mandatory systems, but their purposes are only for export. However, AU and BR are still among the broadest and most precise. Following are Argentina (AR) and Canada (CN), who have simpler traceability systems in terms of breadth and, depending on information provided by farmers and processors without public or private verification, less precise (Smith et al., 2008; Souza Monteiro and Caswell, 2004).

The U.S., however, has voluntary traceability systems rather than mandatory ones. According to Golan et al. (2004), traceability systems in the U.S. tend to be motivated by economic incentives, not government traceability regulation. The mpXML leads the industry coordination of product tracing. MPXML 2010 is based on GS1 global standards for supply chain management and product identification (MPXML 2010).

RFID Technology

Smith et al. (2008; 2005) summarized the means of identifying individuals or groups/ lots of live cattle: paper records (e.g. passport), electronic records (e.g. RFID), brands, tattoos, tags (in the ear or tail), transponders, biometrics (DNA fingerprint). They also referred to Bass et al. (2007), who reported that only paper records, electronic tags, and human readable tags are acceptable to operators of US cattle.

As indicated by Meuwissen et al. (2003), the eartag system of farm animal identification might be replaced by radio frequency identification devices. McMeekin et al. (2006) also stated that "the use of RFID tags and readers will revolutionize the way the supply chain data is captured and communicated". Regattieri, Gamberi, and Manzini (2007) described RFID as an identification tool using wireless microchips to create tags that do not need physical contact or particular alignment with the reader. RFID tags are small and they have no compatibility problem with foods. There are significant advantages and benefits of using RFID technology in animal identification and traceability.

Benefits of using RFID include: reducing labor costs; more efficient control over supply chain due to increased information accuracy; enhanced profit margins; improved knowledge of customer behavior; and improved knowledge of inventory (Shanahan et al., 2009). Regattieri, Gamberi, and Manzini (2007) also specified several benefits specific to the food sector: improved management of perishable items; improved tracking and tracing of quality problems; improved management of product recalls.

Benefits and Costs of Traceability

While much of the literature on traceability has focused on the technical issues, much less has focused on the economic issues. Since the U.S. does not mandate traceability in beef industry, profit is the most important incentive for beef supply chain partners to participate in traceability systems. Thus, understanding of the financial implications is essential.

Costs were analyzed in several studies. Chryssochoidis et al.(2009) built a cost-benefit evaluation framework of an electronic-based traceability system for a mineral water company. In their evaluation, costs were separated into two parts: initial investment costs (including hardware, software, communication, data input/ conversion, system integration, education and training, and business process reengineering) and ongoing costs (including hardware/ software maintenance, support, ongoing training, upgrades, staff-related cost, consumables, and licenses). Benefit analysis is much more complicated than the cost analysis because of the uncertainty existing in benefits, as well as the difficulty in quantifying benefits, especially benefits in supply-chain management. Chryssochoidis et al. (2009) grouped traceability benefits into three aspects. The first aspect is supply chain operation efficiency. The value of traceability in terms of supply chain efficiency, cost reduction through the supply chain, and reduced cycle time are within this category. The second group is improved trading partner relationships, which contains value of traceability in terms of supply chain integration and synchronization, improved trading partner relationships, and inter-organizational coordination and synergies. The last group refers to operational advantages within the company, including value of traceability in terms of increased productivity, economies of scale, organizational efficiency, and operational excellence. There are other benefits pointed out as well, such as improving product safety, reducing recall expenses, increasing customer service level, and inclusion of extra information which enhances product differentiation and branding (Golan et al., 2004; Meuwissen et al., 2003; Regattieri et al., 2007).

According to most benefit-cost analyses, food companies do not need to consider traceability as an economic burden, but can view it as an opportunity for system growth. However, there are still some other problems existing in the livestock/meat sector. There are two distinct sets of traceability systems existing: one set for live animals and another for meat. The challenge the industry faces now is to coordinate and link many disparate animal and meat traceability systems and develop a standardized system for identifying farm-level, live-animal attributes in finished meat products (Golan et al., 2004).

Beef Supply Chain

The following information comes primarily from www.ExploreBeef.org.The stages of beef production include cow-calf producer, backgrounder/stocker, auction market, feedlot, and processing facility (www.explorebeef.org, 2009). Figure 2.1 shows a simple beef cattle supply chain.

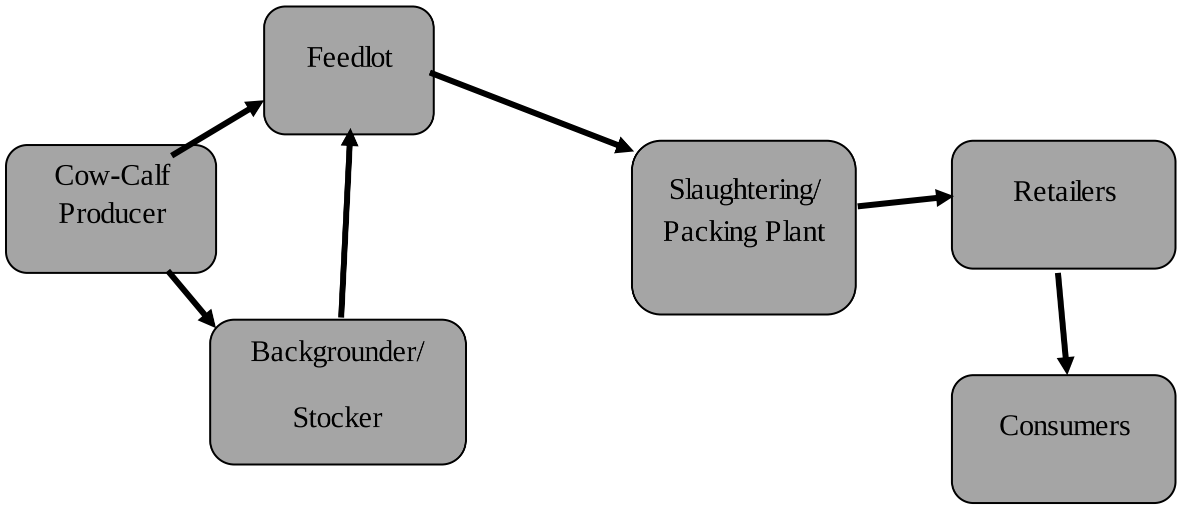

Figure 2.1 Simple Version of Beef Supply Chain

Beef production begins with ranchers who breed herds of cows that nurture calves every year. This stage would include breeding, calving, weaning, branding, and turning out to pasture. Calves mostly live on mothers' milk and grazing grass in pasture. When a calf is born, it weighs about 60 to 100 lbs. At the age of six to ten months, beef calves are weaned when they weigh 450 to 700 lbs.

After weaning, some calves are sold at livestock auction markets. About 20-25% of them stay on farm for breeding purposes. Calves that weigh enough will be moved into feedlots, while many will continue to grow and gain weight during the stocker and backgrounder phase, and then moved into feedlots.

Considerable assembly and comingling of animals occurs in the stocker/backgrounder and feedlot phases. Upon arrival in feedlots, feeder cattle typically are identified and grouped based on a variety of physiological characteristics, such as breed, sex, weight, and expected degree of finish at the time of sale. The feedlot period will last approximately four to six months. During this period, animals have constant access to water, room to move around, and grain-based food. The animals will gain about 3.5 lbs. per day.

Once cattle reach market weight (1,200 lbs to 1,400 lbs and 18 to 22 months of age), they are sent to a processing facility. USDA inspectors are stationed in all federally inspected packing plants and oversee the implementation of safety, animal welfare, and quality standards from the time animals enter the plant until the final beef products are shipped to grocery stores and restaurants establishments. The packer operations include slaughter/harvest, cooler, fabrication floor, holding cooler and shipping. Boxes of beef cuts are sorted and stored in supermarkets/restaurants before being consumed. These boxes contain several prices of the same items, cuts from several animals.

Economics of Genetics in the Beef Industry

The economics of genetic information in the beef-cattle industry is relatively new and not many studies have been published. Weaber and Lusk (2010)) analyzed how to improve steak tenderness and economic profitability by appropriately selecting genome-enabled bulls and heifers. Incentives for individual producers to adopt genetic testing technology were also discussed. The authors constructed a Monte Carlo simulation model of marker-assisted selection for improving Warner-Bratzler shear force (WBSF) in a beef herd. The results indicated that a selection strategy in the upper 30% level of genetic merit would lead to an increased profitability of $9.60/head for feeder cattle and $1.23/head for fed cattle within 20 years.

Holt (2010)) attempted to determine the economic value of genotypic information from the Merial Igenity panel for fed cattle, using data from 2,201 fed cattle. He concluded that the Merial Igenity panels, especially IG_{MAR} and IG_{ADG}, affected fed cattle profitability. If information is available, feedlot operators may select cattle having high IG_{MAR} scores and feed them out accordingly. This would lead to new penning and grouping strategies.

Lusk (2007) investigated whether fed cattle profit was associated with single nucleotide polymorphisms (SNPs) in the leptin gene. He analyzed a microsatellite of the leptin gene in a sample of 1,668 commercial feedlot cattle, and found that use of genotypic information potentially added $28 per head for heifers and $23 per head for steers if producers were willing to selectively group and feed cattle based on genotype. An even higher value of $60 per head would be realized if animals were optimally marketed based on genetic traits.

Genetics and Beef Tenderness

Schenkel et al. (2006) studied the association of the calpastatin (CAST) SNP with carcass and meat quality traits. Results showed that the CAST SNP was associated with WBSF across days of postmortem aging. The beef produced from genotype CC was more tender than beef from genotype GG, while tenderness of beef from genotype CG was between CC and GG. Also, for the CAST SNP, the favorable allele C was more frequent in the crossbred cattle population than allele G (Schenkel et al. 2006).

Casas et al. (2006) assessed the association of SNPs developed at CAST and μ-calpain (CAPN1) genes with meat tenderness and palatability traits in populations with diverse genetic backgrounds. There were three populations considered in their study. Results showed that a SNP at the CAST gene had a significant effect on WBSF and tenderness score in two of the three populations. However, the favorable genotype was different from the results of Schenkel et al. (2006). Per Casas et al. (2006), animals inheriting the TT genotype at CAST produced more tender meat than those inheriting the CC genotype. At CAPN1, the CC genotype is favorable over the TT genotype (Casas et al. 2006). Animals with the CC genotype at CAST and the TT genotype at CAPN1 produce the toughest steak compared to others (Casas et al. 2006).

Van Eenennaam et al. (2007) studied the associations among commercial DNA tests for quantitative beef quality traits. Combined 3-marker genotypic effects on WBSF (kg) were studied for the GeneSTAR Tenderness and Igenity TenderGENE panels. Effects of two SNPs were studied simultaneously: calpastatin and μ-calpain. The GeneSTAR Tenderness panel is a composition of CAST-T1, CAPN1 316-T2, and CAPN1 4751-T3. The Igenity Tender-GENE marker panel consists of the 2 μ-calpain SNPs as above, and a calpastatin SNP U_0G-CAST (Van Eenennaam et al. 2007). The genotypic and allelic frequencies of calpastatin SNP were consistent with the results report by Schenkel et al. (2006) for crossbred population. Genotype CC for both SNPs are favorable. For a crossbred population, genotype CC.CC.CC produces the most tender meat, as measured by both GeneSTAR and Igenity tenderness tests (Van Eenennaam et al. 2007).

Economics of Improving Beef Tenderness

Previous literature indicates that consumers are willing to pay a price premium to get a tender steak (Feuz et al., 2004; Lusk et al., 2001; Miller et al., 2001; Mintert et al., 2000; Platter et al., 2005; Schroeder et al., 2010). Consumers' willingness to pay for tender steak varied from $0.42/lb. to $5.57/lb. According to Mintert et al. (2000), more than 25% of consumers were willing to pay $1.33/lb. as a premium for tender steak, while about 13% were willing to pay $2.67/lb. extra. Table 2.1 summarizes the price premiums consumers are willing to pay according to previous literature.

Table 2.1 Price Premiums for Tender Steak ($/cwt)

Retail Premium	Wholesale Premium	Ungraded	Select	Choice	Prime
[b]$42.00	$23.36	$21.63	$22.50	$23.53	$27.76
[c]$48.00	$26.69	$24.71	$25.71	$26.89	$31.72
[d]$50.00	$27.81	$25.75	$26.79	$28.02	$33.06
[e]$95.00	$52.83	$48.92	$50.90	$53.24	$62.80
[f]$114.00	$63.40	$58.70	$61.08	$63.88	$75.36
[g]$123.00	$68.40	$63.33	$65.90	$68.92	$81.30
[h]$125.00	$69.51	$64.36	$66.97	$70.04	$82.63
[h]$151.00	$83.97	$77.75	$80.90	$84.61	$99.82
[h]$197.00	$109.55	$101.44	$105.54	$110.39	$130.22
[h]$203.00	$112.89	$104.53	$108.76	$113.75	$134.19
[h]$221.00	$122.90	$113.80	$118.41	$123.85	$146.10
[h]$223.00	$124.01	$114.82	$119.47	$124.96	$147.41
[h]$300.00	$166.83	$154.47	$160.73	$168.11	$198.31
[d]$311.00	$172.95	$160.14	$166.62	$174.27	$205.58
[d]$339.00	$188.52	$174.56	$181.63	$189.96	$224.10
[h]$557.00	$309.75	$286.80	$298.42	$312.12	$368.20

[a]Assuming Wholesale Premium is 55.61% of Retail Premium;
[b]Source: Miller et al. (2001) ; [c]Source: Feuz et al. (2004) ; [d]Source: Schroeder et al. (2010)
[e]Source: Platter et al. (2005) ; [f]Source: Loureieo and Umberger (2004);
[g]Source: Lusk et al. (2001) ; [h]Source: Gao and Schroeder (2007)

CHAPTER III

METHODOLOGY

Analytical Framework

As a first approximation to estimating the value to cow-calf producers of using a whole-chain traceability system (WCTS) to provide information about their animals' genetics to beef processors, this thesis compares the profitability to producers from using the system with the profitability of not using it. In order to focus on the value of the information flow, without the complications that arise from price transmission across different stages in the supply chain, we assume that the supply chain is vertically integrated.

Within this vertically-integrated supply chain, the profitability of a cow-calf production enterprise passing information about the calves' genetics through a WCTS is compared to the profitability of a cow-calf enterprise that cannot pass information, but that is similar in all other aspects. By focusing on just the flow of information about genetics in a vertically-integrated supply chain, the estimation provides an upper bound on the value of the WCTS to a cow-calf producer providing information about genetics that influence beef tenderness. There are many other kinds of value-added information that could be passed through a WCTS, and the value of that information is not considered here. However, this thesis provides a framework for valuing the role of a WCTS in facilitating flow of value-added information through a beef supply chain.

Previous literature (DeVuyst et al., 2007; Lusk, 2007) shows that specific genes influence beef tenderness. But there is only a probability that this genetic information is realized, in other words, a particular genotype does not necessarily result in the preferred phenotype. DNA test can be used to assure that selected calves carry the gene. However, such testing is expensive. According to genetics, if both parents carry one specific gene, their offspring have a higher probability of carrying the same gene, and thus have a higher probability of realizing it. Thus, they are more probable to produce tender meat than regular calves do.

We consider a vertically-integrated company with a cow-calf producer stage, a feedlot stage and a slaughter/packing plant stage. The company receives higher price for tender meat, so they have an incentive to breed calves with genes that increase meat tenderness (referred from here on as high-tenderness gene, or HTG; the genes that produce regular-tenderness meat are referred as RTG). When a WCTS is implemented, it is possible for the company to differentiate calves with HTG from other calves without testing, because the breeding information is conveyed through the WCTS from the cow-calf producer stage to the slaughter/packing plant stage. WCTS can help record and pass the genetic information along the supply chain. To maximize total profit, decision makers are assumed to choose the proportion of calves bred with AI, as well as the total quantity of calves bred. The qualities products in each stage are assumed to fall into one of two distributions: high quality and regular quality. Calves with HTG have a higher probability of producing tender meat than regular calves do. The slaughter/packing plant can test the tenderness of meat and receive higher price for more tender meat. And with a WCTS, they can pass a portion of the price difference back to cow-calf producers.

Two scenarios are considered in this paper. Scenario I is the general model, which is a vertically-integrated company using WCTS through the three stages to provide information about meat tenderness to the cow-calf production stage and information about calf genetics to the slaughter/packing stage. The company may also AI to breed calves with HTG. Scenario II is identical to Scenario I in all aspects, except that there is no WCTS and thus no extra incentive for the cow-calf producer stage to increase the number of animals with HTG. (HTG may influence other animal characteristics, such as feeding efficiency, but for this research, we only consider its effect on meat tenderness.)

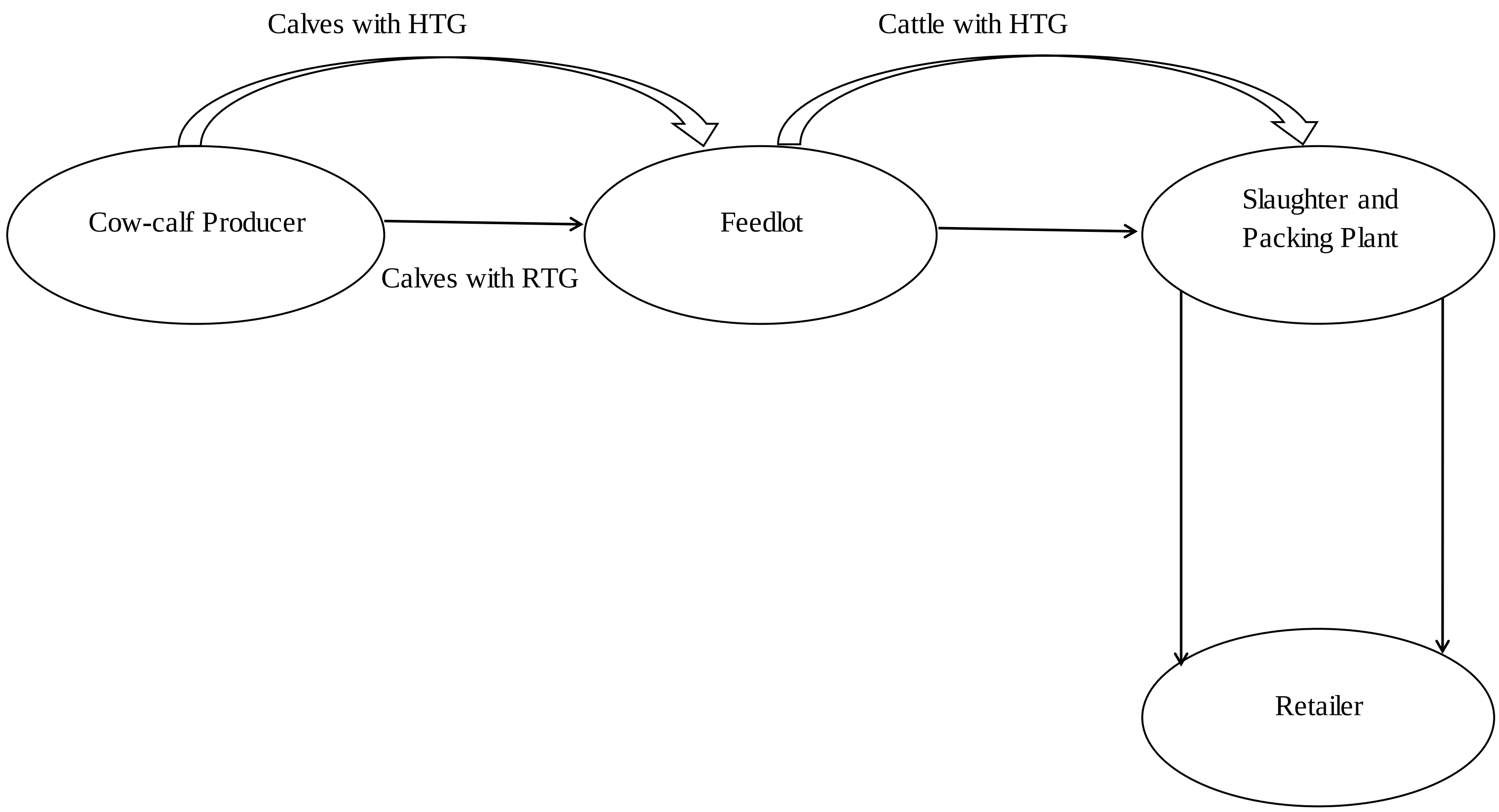

Figure3.1 General Model (Scenario I)

In Scenario I, we consider a profit-maximizing vertically-integrated firm that includes a cow-calf production stage, a feedlot stage, and a slaughter/packing plant stage. The firm's profit is

$$\Pi = TR - TC \tag{1}$$

Revenues (TR)

We assume that the least expensive way for a producer to select for HTG is through artificial insemination (AI). That is, the operator can choose the percentage (λ) of the total herd to be produced from AI, in order to obtain a higher percentage of cattle carrying HTG. Since cost per head of doing artificial insemination is essentially constant, we assume this cost is a linear function of the number of pregnancies. We assume, based on Miller (2011), that the AI success rate is 65%. The total number of calves produced using artificial insemination is calculated below:

$$N_{AI} = \lambda * N \tag{2}$$

where N is the herd size in head, λ is less than or equal to AI success rate. AI allows the firm to choose semen with specific genotypes. Calves born using AI to select for higher levels of meat tenderness are assumed to generate two distributions of tenderness: tender, and regular. The percentages of calves in the two distributions are μ_{11}, and μ_{12} in Scenario I, and μ_{21} and μ_{22} in Scenario II. The firm expects a higher proportion of calves with HTG will be produced with AI than from natural service. Thus, μ_{11}, which is the percentage of calves carrying HTG in Scenario I, is expected to be higher than μ_{21}, which is the percentage of calves carrying HTG in Scenario II. As a result, μ_{12} (the percentage of calves carrying RTG) is expected to be smaller than μ_{22} (the percentage of calves carrying RTG in Scenario II), as the sum of μ_{11} and μ_{12}, along with the sum of μ_{21} and μ_{22}, both equal to 1.

Notation and Variables

Choice variables:

λ: percentage of calves produced from artificial insemination

N: number of calves produced, either with or without selection for high-tenderness genetics (HTG)

Parameters & Subscripts:

CY: carcass yield of cattle

P_j: price for regular-tenderness meat cuts in grade j (j = 1, 2, 3, 4), ($/cwt), at wholesale level

$$j = \begin{cases} 1, \text{Ungraded} \\ 2, \text{Select} \\ 3, \text{Choice} \\ 4, \text{Premium} \end{cases}$$

δ_j: price premium for extra-tender meat cuts in grade j (j = 1, 2, 3, 4), ($/cwt), at wholesale level

τ_j: price discount for tough meat cuts in grade j (j = 1, 2, 3, 4), ($/cwt), at wholesale level

μ_{ik}: percentage of cattle carrying genotypes for tenderness level k (k = 1, 2), in breeding method i (i = 1 - AI, 2 - NS)

$$k = \begin{cases} 1, \text{tender} \\ 2, \text{regular} \end{cases}$$

$$i = \begin{cases} 1, \text{cattle is produced by successful artificial insemination} \\ 2, \text{cattle is produced by natural service} \end{cases}$$

ρ: dummy variable; $\rho = 1$ if producer invests in traceability system and use AI, 0 otherwise (e.g. if $\lambda > 0, \rho = 1$)

η_j: percentage carcass meat grading j (j = 1, 2, 3, 4)

θ: dressing percentage

HCW: hot carcass weight of regular cattle

P_{by}: by-product price which is equivalent to dressing, ($/cwt)

ΔC: cost difference between artificial insemination and natural service, ($/head)

PC: total feeding and operating costs along the three stages, ($/head)

TRC: traceability cost, ($/head)

TTC: cost of doing tenderness test per carcass

BC: breeding cost per pregnancy by natural service

Because of two tenderness levels, there are two portions of revenues received for cattle with AI. The revenue received for cattle carrying HTG is,

(3) $$R_{11} = \lambda * N * \mu_{11} * HCW * [CY * \sum_j (P_j + \delta_j) * \eta_j + P_{by}]$$

The revenue received for cattle carrying RTG is,

(4) $$R_{12} = \lambda * N * \mu_{12} * HCW * [CY * \sum_j P_j * \eta_j + P_{by}]$$

Thus, the revenue R_{AI} from total number of AI-produced cattle are,

(5) $$R_{AI} = \sum_k R_{1k} = \lambda * N * HCW * \{CY * [\mu_{11} * \sum_j (P_j + \delta_j) * \eta_j + \mu_{12} * \sum_j P_j * \eta_j] + P_{by}\}$$

The proportion of calves produced from natural service (NS) is (1-λ). So the number of calves produced from natural service is,

$$(6) \qquad N_{NS} = (1-\lambda)*N$$

As with cattle produced using AI, there are also two tenderness distributions in cattle produced by natural service: tender, and regular. With a WCTS and tenderness test, the producer receives price premiums for tender meat. Similar to expressions (3) and (4) above, revenues for each tenderness level for cattle produced using NS are calculated as follows:

$$(7) \qquad R_{21} = (1-\lambda) * N * \mu_{21} * HCW* [CY*\sum_{j}(P_j + \delta_j) * \eta_j + P_{by}]$$

$$(8) \qquad R_{22} = (1-\lambda) * N * \mu_{22} * HCW * [CY *\sum_{j}P_j * \eta_j + P_{by}]$$

So the revenue R_{NS} from total number of cattle produced from natural service is,

$$(9) \qquad R_{NS} = \sum_{k} R_{2k} = (1-\lambda)*N*HCW*\{CY*[\mu_{21}*\sum_{j}(P_j + \delta_j)*\eta_j + \mu_{22}*\sum_{j}P_j*\eta_j] + P_{by}\}$$

Total return is

$$(10) \qquad R_T = R_{AI} + R_{NS}$$

Costs (TC)

Using AI generates a linear cost function with respect to number of cows artificially inseminated, whether or not it succeeds. Thus, the cost of artificial insemination is as shown in equation (11):

$$(11) \qquad C_{AI} = (BC+\Delta C)*\lambda*N$$

where BC is the breeding cost per pregnancy of using NS, ΔC is the cost difference per pregnancy between AI and NS. It is assumed that WCTS is used as a tool to record and transfer the selected genotype information from cow-calf producer stage to feedlot stage, then to slaughter and packing plant stage. When the enterprise chooses to use AI ($\lambda > 0$), the WCTS is in use. Otherwise, a traceability system is not implemented. Thus, we define a dummy variable ρ for the cost of implementing a WCTS, where $\rho = 0$ indicates that the enterprise chooses not to use AI in the herd, and thus incurs no cost of implementing WCTS and $\rho = 1$ means the producer incurs the cost. The cost of implementing WCTS is,

$$C_{TR} = \rho * TRC * N \quad (12)$$

Let TTC be the cost of testing beef tenderness. The total cost of conducting tenderness tests is

$$C_{TT} = \rho * TTC * N \quad (13)$$

By assuming the same feed efficiency for all genotypes, we set the feeding and operating costs of both breeding types the same, which is:

$$PC_T = PC * N \quad (14)$$

Total costs are

$$TC = C_{AI} + C_{TR} + C_{TT} + PC_T \quad (15)$$

By inserting equations (5), (9), (11), (13), (14) into equation (1), we get the final profit function as following:

$$\text{Profit} = N * HCW * \{CY * [\lambda * (\mu_{11} + \mu_{21}) * \textstyle\sum_j (P_j + \delta_j) * \eta_j + (1-\lambda) * (\mu_{12} + \mu_{22}) * \textstyle\sum_j P_j * \eta_j] + P_{by}\} - (BC + \Delta C) * \lambda * N - \rho * (TRC + TTC) * N - PC * N - BC * (1 - \lambda) * N \quad (1.1)$$

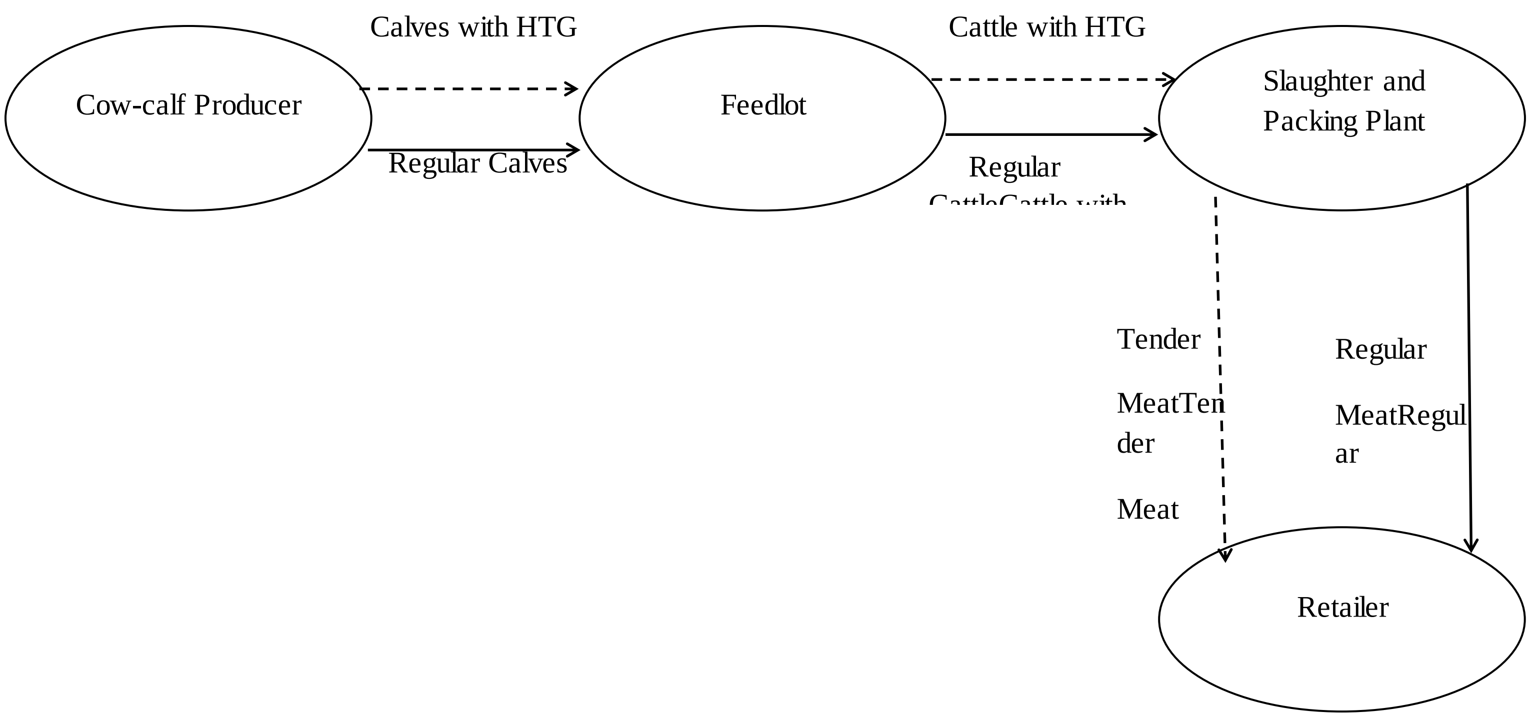

Figure 3.2 Alternating Model (Scenario II)

In the alternative model, which is Scenario II, the company does not use any method to select genetics and improve tenderness. All cattle are produced from natural bull service. However, this does not mean that no cattle are carrying HTG - even with natural service, there is a proportion of cattle carrying HTG. But the percentage in Scenario II is expected to be lower than that in Scenario I, where AI is used to select specific genes. Similarly, in the feedlot stage, cattle carrying HTG also exist. But as the company neither selects genes specifically, nor uses a traceability system to trace and pass the information along the chain, there is no easy, inexpensive way to identify whether an animal is carrying HTG or RTG. However, when cattle are processed and packed in slaughter and packing plant, the company can choose to test the tenderness of a carcass or not.

Scenario II - Option I: Company chooses not to test meat tenderness.

If the company chooses not to test meat tenderness, all meat cuts in the same grade level are sold at the same price. There are no price premiums for tender meat, or price discounts for tough meat.

Scenario II - Option II: Company chooses to test meat tenderness.

If the company chooses to test meat tenderness, meat cuts can be divided into two groups, even within the same grade level: tender, and regular. Price premiums are received for tender cuts. Costs of tenderness tests are incurred.

When the company chooses option I, to not test for tenderness, it receives average prices for each grade of meat cuts, with no premiums for tenderness. Thus the total profit is:

$$(1.2) \quad \text{Profit} = N*HCW*(CY*\textstyle\sum_j P_j*\eta_j+P_{by}) - PC*N - BC*N$$

It is assumed that if the company expects to get premiums for tender meat cuts produced, it must conduct tenderness tests. Testing the tenderness of the carcass will identify the tender meat. Thus the company can receive price premiums for cattle carrying HTG and average prices for cattle carrying RTG. The profit function is as shown below:

(1.2.1) $\text{Profit} = N*HCW*\{CY*[\mu_{21}*\sum_j(P_j + \delta_j)*\eta_j + \mu_{22}*\sum_j P_j*\eta_j] + P_{by}\} - PC*N - C_{TT}*N - BC*N$

Data

Carcass Traits

Hot carcass weight, or carcass weight on some reports, is the hot or un-chilled weight of the carcass after slaughter and the removal of the head, hide, intestinal tract, and internal organs (Knight, 2013).

Dressing percentage is a measure of the proportion of carcass weight in live weight. According to McKiernan et al. (2007), dressing percentage is simply carcass weight as a percentage of live weight. Per Knight (2013) and McKiernan et al. (2007), the dressing percentage for beef cattle is normally 60% – 64%. Here, cattle ending weight is set to be 1,300lbs, on average, and 62% is used as the dressing percentage. Thus, the hot carcass weight is calculated as 1300*62%, which is 806lbs.

Yield Grade is the indicated yield of closely trimmed (1/2 inch fat or less), boneless retail cuts expected to be derived from the major wholesale cuts (round, sirloin, short loin, rib, and square-cut chuck) of a carcass. Yield Grade is indicated on a scale of 1 to 5, with Yield Grade 1 representing the highest degree of cutability. According to Knight (2013), yield grade equals 2.50 + (2.50 x adjusted fat thickness, inches) + (0.20 x percent kidney, pelvic, and heart fat) + (0.0038 x hot carcass weight, pounds) – (0.32 x ribeye area, square inches).

Percentages of pounds of meat graded and yield grades are obtained from a USDA data entitled– Historical Beef Grading Summary. It contains yearly data from 1930 to 2013. We selected 5 years' data, from 2009 to 2013, and calculated averages of percentages of different grades. The averaged percentages are used in this paper. Yield grades are also obtained from this report. The average yield grade is 2.5, which is about 75% of carcass yield.

Feed Cost

Data for feed cost in cow-calf producer stage was obtained from Oklahoma State Agricultural Enterprise Budget (http://www.agecon.okstate.edu/budgets/). Cow-Calf Enterprise Budget is calculated with 87% calving percentage, and 3% death loss. Thus, on average, one cow produces 0.87*(1-0.03) = 0.844 calves per year. Cost obtained from this budget is $534.13 per cow. In order to change it to per-calf cost, we divide $534.13 by 0.844, and get $632.86. It costs $632.86 to raise one calf in the cow-calf producer stage.

Feedlot cost data was obtained from Oklahoma Cooperative Extension Service. Gill et al. (1992) estimated costs of feeding a steer from 600 lbs. to 1,050 lbs., with 1% death loss. Here, we assume the starting weight at the feedlot is 530 lbs., and the ending weight is 1,300 lbs. The estimated feed cost in the feedlot stage is $397.29 per head.

Ward (1993) conducted a comparative analysis on cattle slaughtering and fabricating costs. A binary variable regression model was estimated. Binary changing variables included plant size measured in head per hour, hours per shift, shifts per day, days per week, and capacity utilized in percent (Ward, 1993). According to Ward (1993), for an integrated slaughter-fabrication plant, Sersland analysis give a minimum cost per head is $53.95, and a maximum cost per head is $82.82, while Duewer and Nelson analysis showed a minimum cost per head of $59.92, and a maximum cost per head of $87.22. There are also estimated quadratic costs for beef packing plants from the two studies, and the results are $115.58, and $89.95 average cost per head - for Sersland and Duewer, respectively, per Ward (1993). In our paper, we use $89.95 as the average slaughter and fabrication cost per head.

Costs of Artificial Insemination vs. Natural Service

The difference in cost of doing artificial insemination vs. natural service is obtained from Virginia Cooperative Extension. Miller (2011) compared costs of artificial insemination vs. natural service. Setting semen cost at $15, and conception rate at 65%, he obtained a cost per pregnancy of $51 with artificial insemination, and $35 per pregnancy for natural service, so that the difference between artificial insemination and natural service is $16 per pregnancy.

Wholesale Prices

Wholesale prices for different grades of meat were obtained from comprehensive boxed beef cutout. As shown in Figure 3.3, beef prices fluctuated within a small range from 2003 to 2008. From 2009, beef prices went up rapidly, for each grades. In this paper, we take prices from the most recent five years and average them to get one five-year average price for each grade.

Thus, the wholesale prices used in our analysis are $162.89, $169.49, $177.27, and $209.12, per cwt, for Ungraded, Select, Choice, and Prime, respectively.

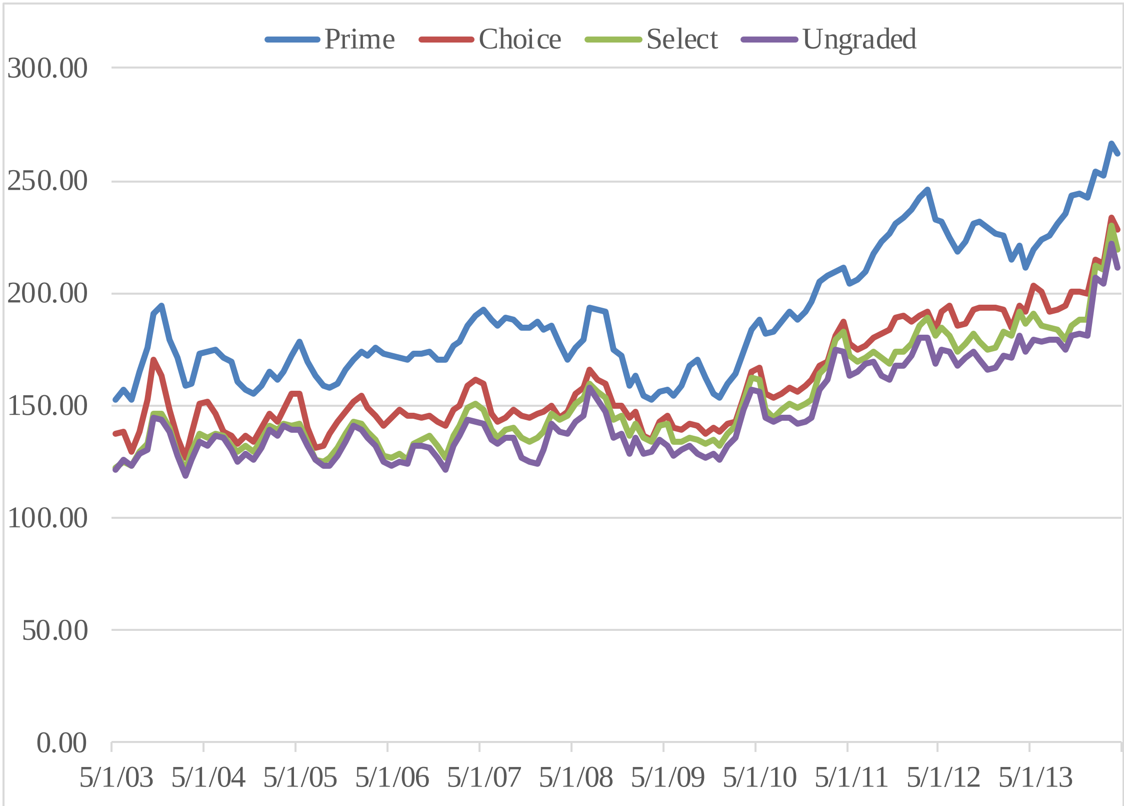

Figure 3.3 Cutout Prices for Prime, Choice, Select, and Ungraded Beef

By-Products Value

By-products values are obtained from USDA BY-PRODUCT DROP VALUE (CATTLE). To be consistent, we take the data from April 2009 to April 2014. Figure 3.4 shows the trend of changes in by-product prices per cwt and indicates that by-products prices more than doubled from 2009 to 2014.

The average hide and offal value from typical fed cattle (steers and heifers 1,300lbs) was assumed to be $12.45 per cwt live. Since we used an average live weight of 1,300 lbs, the by-products value per animal is 12.45*(1300/100), which is $161.85/head. On a dressed equivalent basis, the by-products value is $20.08/cwt with a dressing percentage of 62%.

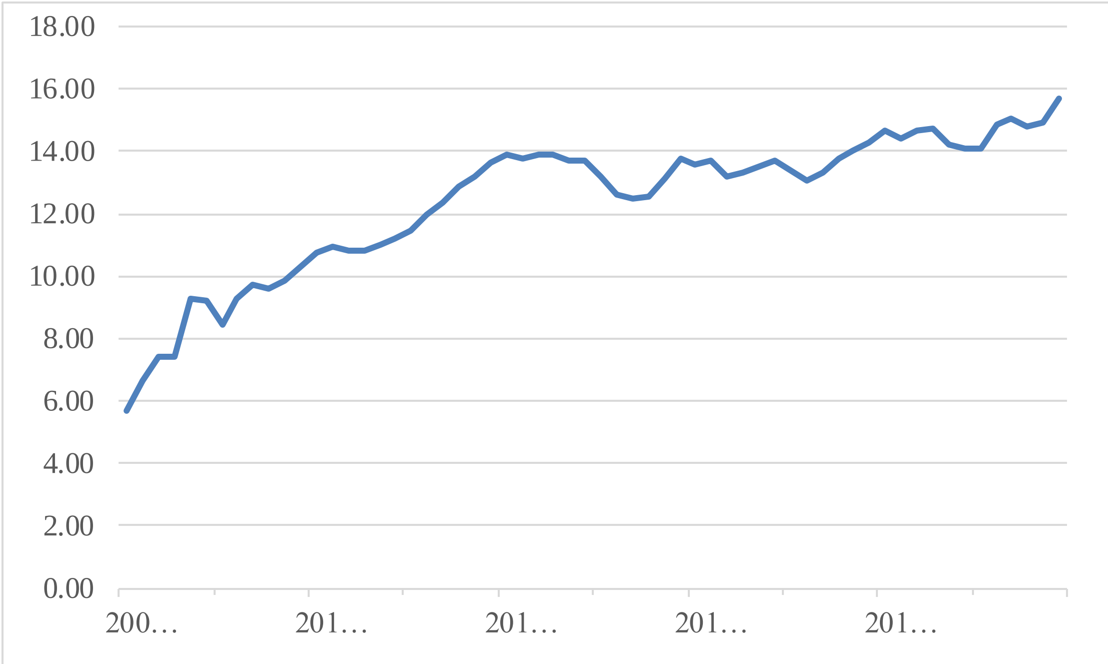

Figure 3.4 By-Products Values ($/ cwt)

Price Premiums for Tender Meat

Mintert et al. (2000) studied the value of beef tenderness. Two experiments were done in order to estimate consumers' willingness to pay for tender steak. Experiment 1 was with blind taste test only, while experiment 2 is with tenderness label and taste test. Consumers in experiment 2 (including both a taste test and a tenderness label) were willing to pay more for tender steak. In our model, we use AI to select tenderness genes and use WCTS to record and pass the information along the supply chain. Thus, we choose to use the values in experiment 2 to calculate premiums paid for tender steak graded as Select. Table 3.1 is the distribution of willingness-to-pay premiums for tender steak in experiment 2.

Table 3.1 shows the premiums that consumers were willing to pay (WTP) and the percentages of consumers willing to pay those premiums. A weighted average of those, $96.13/cwt, is used as the price premium received for tender meat at retail level. As shown in Figure 3.3, beef prices have increased rapidly since 2009. Thus, we can reasonably assume that consumers may be willing to pay more as premiums on tender meat now than those in 2000. However, since the price data in year 2000 is not available, we use $96.13 as the average price premium at retail.

Table 3.1 Distribution of WTP Premiums for Tender Steak

Price Premiums($/cwt)	Percent of Consumers (%)
0	38.50
33	3.00
67	5.50
100	6.50
133	27.50
200	6.00
233	0.00
267	12.00
300	0.00
333	1.50

We obtained annual retail- and wholesale-level prices for beef from the USDA beef data ("Choice beef values and spreads and the all-fresh retail value"), as shown in Table 3.2. We take the average whole/retail price (WP/RP) ratio to calculate the average price premium for tender meat at the wholesale level, which is $96.13*55.61% = $53.46 per cwt.

In order to estimate price premiums for each grade, we make an assumption that the premium-price ratio (price premium/regular price) for all grades are the same. That is, the price premium over regular price for Select level is the same as for the Ungraded, Choice, and Prime levels. Let us say that the ratio is represented by ɵ. Then the price premium of grade j can be represented as $P_j*\theta$. Average price premium is calculated as $\sum_j(\eta_j*P_j*\theta)$,

Table 3.2 Average Annual Retail and Wholesale Prices and Ratios

Year	Retail Price	Wholesale Price	% WP/RP	Average
2009	425.80	217.20	51.01	
2010	438.40	241.10	55.00	
2011	480.70	275.70	57.35	55.61%
2012	498.60	290.60	58.28	
2013	528.90	298.30	56.40	

which equals to \$53.46. Solving this equation for ɵ, we get ɵ equals to 0.5464. Thus, the price premium received for tender beef is about 54.64% of regular wholesale price. Price premiums per cwt for Ungraded, Select, Choice, and Prime are calculated to be \$49.50, \$51.51, \$53.87, and \$63.55/cwt, respectively. Adding the premiums to regular beef prices, the prices for high-tenderness beef graded as Ungraded, Select, Choice, and Prime are \$212.39, \$221.00, \$231.14, and \$272.67, respectively.

Frequencies of Favorable Genotypes and Tenderness

Percentages of favorable alleles are estimated using the results from Van Eenennaam et al. (2007). Data of cross-bred cattle was analyzed by them. The favorable alleles for calpastatin and μ-calpain are both C alleles. They investigated the frequencies of unfavorable and favorable alleles for many cattle breeds, which include Charolais × Angus, Brangus, Red Angus, Brahman, Angus, Hereford, Limousin, Simmental, and others. Van Eenennaam et al. (2007) conducted a genotypic analysis on a cross-bred cattle population including Charolais × Angus, Hereford, Brahman, Brangus, and Red Angus. In order to keep the consistency of data, we took the allelic frequencies of Charolais × Angus, Hereford, Brahman, Brangus, and Red Angus and calculated the weighted average of frequencies on unfavorable and favorable alleles for both calpastatin and μ-calpain. For calpastatin, the frequency of the favorable allele C is 62.00%, while the frequency for the unfavorable allele is 38.00%. For μ-calpain, the frequency of the favorable allele C is 15.27%, while the frequency for the unfavorable allele G is 84.73%.

According to Van Eenennaam et al. (2007), the frequencies of Igenity U_0G-CAST1 haplotypes – CC, CG, and GG – are 53.3%, 37%, and 9.7%, respectively. Frequencies of different CAPN1 316 haplotypes – CC, CG, and GG – are 3.3%, 27.1%, and 69.6%. The data is based on cross-bred cattle. For both SNPs (single nucleotide polymorphisms), the haplotype CC will result in a lower Warner-Bratzler shear force. They studied combined 3-marker genotypic effects on Warner-Bratzler shear force (kg). In our study, we consider the effect of two SNPs, calpain and μ-calpastatin. Thus, we calculate the weighted average of the estimates of Warner-Bratzler shear force of 9 combinations of genotypes. The results are shown in Table 3.3.

Previous studies on beef tenderness value ((Platter et al., 2003; Shackelford et al., 1999) showed that consumers had about 20% higher acceptance when Warner-Bratzler shear force is about 0.7 kg lower. Thus, in our paper, we assume that 0.7 kg is the break-point between extra-tender meat and meat of regular tenderness.

Table 3.3 shows that the most favorable genotype is CC.CC, which produces the most tender meat. The toughest meat will be produced from the genotype GG.GG. In order to improve the tenderness, we would choose to increase the frequencies of favorable genotypes.

In this paper, we use artificial insemination as a tool to increase frequencies of favorable genotypes. Based on the frequencies above, we calculate the improved frequencies for favorable genotypes. The original frequencies and improved frequencies are shown in Table 3.3.

Table 3.3 shows that the original frequencies of high-tenderness genes and regular-tenderness genes are 53.30% and 46.70%, respectively. Using AI to select specific genes, the frequencies of high-tenderness gene and regular-tenderness gene change to 78.46% and 21.54%, respectively. Thus, by using AI, the frequency for favorable genotype increases by 25.16 percent points, from 53.30% to 78.46%. At the same time, the frequency of regular-tenderness genotype decreases by 25.16 percent points, from 46.70% to 21.54%.

Table 3.3 Frequencies of Genotypes from NS vs AI

Genotypes	Regular %	WBS kg	Tenderness	%	AI Genotype	Genotypes		Modified %	%
CC.CC		-0.84				CC.CC	2.20%		
	2.20%							**6.20%**	
CC.CG		-0.74	tender	53.30%		CC.CC	2.43%		78.46%
	15.90%					CC.CG	13.47%	**72.26%**	
CG.CC		-0.74				CC.CC	0.54%		
	0.80%					CG.CC	0.26%	**0.00%**	
CC.GG		-0.56				CC.CG	35.20%		
	35.20%							**20.30%**	
CG.CG		-0.51				CC.CC	1.03%		
	9.90%				X CC.CC	CC.CG	5.70%	**1.24%**	
						CG.CC	0.48%		
						CG.CG	2.68%		
GG.CC		-0.50	regular	46.70%		CG.CC	0.30%		21.54%
	0.30%							**0.00%**	
CG.GG		-0.39				CC.CG	17.88%		
	26.30%					CG.CG	8.42%	**0.00%**	
GG.CG		-0.29				CG.CC	0.20%		
	1.30%					CG.CG	1.10%	**0.00%**	
GG.GG		0.00				CG.CG	8.10%		
	8.10%							**0.00%**	

Traceability Costs

Costs of whole-chain traceability systems were obtained from Seyoum (2013). He compared traceability costs per head for cow-calf producers, stockers and feedlots. For feeders of size 10,000 cattle, the costs of implementing a traceability system in cow-calf producer and feedlot level were $3/head and $1/head, respectively. There is no data shown on traceability costs at the slaughter/packing plant level. However, Seyoum (2013) noted that a large proportion of the traceability system cost is the cost of tagging ($2/head), which would be undertaken primarily in the cow-calf stage. And the cost of an RFID tag is $2. Thus, we assume that cost of implementing traceability system in slaughter/packing plant to the point of receiving the animals, is the same as that in the feedlot, which is $1/head. The cost of implementing a whole-chain traceability system from cow-calf producer to slaughter and packing plant is $5/head.

Cost of Tenderness Test

There are two ways to do tenderness tests. The first is by Warner-Bratzler shear force for measurements, and the second one is by testing genetics.

Since there is no data available for the cost of doing Warner Bratzler shear force test, DNA testing is assumed to be the method of testing tenderness. According to Weaber and Lusk (2010), depending on the number of head genotyped, the GeneSTAR panel for several markers including tenderness can be purchased at a per-head price ranging from $45 to $75. In this study, we assume a per-head cost of $55. The cost of doing Warner-Bratzler shear force test might be lower than this.

Another way of conveying information about tenderness is for the cow-calf producers to conduct DNA tests for tenderness, since WCTS can be used to record and transfer information along the supply chain, in order to get price premiums for providing cattle carrying HTG. The value of this is not evaluated here.

Procedures

Profit Maximization for Scenario I

Profit maximization is done using Excel Solver. The profit function is shown in equation (1.1). Percentage of calves born from artificial insemination (λ) and total number of cattle sold (N) are choice variables. Take first order conditions with respect to N and λ from equation (1.1), we get the following two F.O.C.s:

(3.1) $$\frac{d\pi}{dN} = \lambda*V_{AI} + (1-\lambda)*V_{NS} - \Delta C*\lambda - \rho*(TRC+TTC) - PC - BC$$

(3.2) $$\frac{d\pi}{d\lambda} = N*V_{AI} - N*V_{NS} - \Delta C*N$$

V_{AI} and V_{NS} are revenues received from AI-produced cattle and revenues received from naturally produced cattle in Scenario I, respectively. Let λ be fixed, we can see from (3.1) that the profit function with respect to N is a linear function. Total profit goes up/down as N increases/decreases. There is no profit maximizing point with respect to N. However, the amount of profit change with respect to unit change of N depends on the value of λ. In this paper, we normalize N at a value of 1, in order to simplify the calculations.

(3.2) shows the derivative of profit with respect to λ. Let N be fixed, the profit maximizing point is where $\frac{d\pi}{d\lambda}$ equals zero. Thus, revenues received from AI-produced cattle should equal to revenues received from NS-produced cattle plus the cost difference of AI and NS.

Profit Maximization for Scenario II

Maximum profit for Scenario II is also estimated using Excel Solver. The model is similar to that in Scenario I, but in Scenario II, the company does not use AI to select preferable genes or traceability system. Instead, NS is the only way to produce calves. Thus, the number of cattle to be sold is the only choice variable in Scenario II. Take derivative with respect to N:

(3.3) $$\frac{d\pi}{dN} = V_{NS}' - PC - BC$$

V_{NS}' is the revenue received from naturally produced cattle, which received regular prices. From (3.3), we can see that total profit in Scenario II increases/decreases with of N. There is no maximized point if there is no constraint on N. As in Scenario I, we normalize N at a value of 1 to simplify the problem.

There is also another choice for company in Scenario II. Even though without artificial insemination, the company can still choose to test the tenderness of beef and receive price premiums for extra-tender meat. In that case, taking the derivative with respect to N, we get:

(3.4) $$\frac{d\pi}{dN} = V_{NS} - PC - BC - C_{TT}$$

V_{NS} is the revenue received from naturally produced cattle, when price premiums are paid for extra-tender meat. As PC and BC are fixed values, if $V_{NS} - C_{TT}$ is greater than V_{NS}', it is better for the company to test tenderness and receive price premiums. Otherwise, the company should not invest in tenderness test.

Comparison

When profits are maximized in both scenarios, we make comparisons on the values of profits. If profit received in Scenario I is greater than that in Scenario II, we would suggest the company to use artificial insemination to select genetics and use traceability system to record and transfer related information. Otherwise, we suggest the company to use natural service to breed cattle.

CHAPTER IV

RESULTS AND DISCCUSSION

Results

Scenario I

For Scenario I, in which the vertically-integrated company participates in a WCTS and can choose to breed calves for high-tenderness genetics (HTG) using AI (solved using Excel Solver), the company chooses $\lambda = 0$, so that NS is the only method of breeding calves. The maximum total profit along the three stages is $70.20 per head, as shown in Table 4.1. If the company chooses to do AI on cows, the profit received per head is $58.32.

Table 4.1 shows base prices of $209.12, $177.27, $169.49, and $162.49/cwt. for meat graded Prime, Choice, Select, and Ungraded, respectively. With no premium for tender meat, the revenue per head is $1,225.30 (price for each grade, multiplied by proportion of animals receiving that grade, multiplied by 13 cwt. times dressing percentage times yield).

It is assumed that when the company breeds its cows using NS, 53.30% of the slaughter animals produce tender meat and 46.70% produce regular meat. When AI is used to select specifically for HTG, it is assumed that 78.46% of the slaughter animals produce tender meat and 21.54% produce regular meat. For meat that meets criteria for designating it tender (WBSF measure less than 0.70 kg), premiums are $63.55, $53.87, $51.51, and $49.50/cwt., respectively, for grades of Prime, Choice, Select, and Ungraded. Multiplying the proportion of animals whose meat qualifies for a tenderness designation by the proportion of animals receiving the grade associated with that premium, and again multiplying by 13 cwt. times dressing percentage times yield, gives the extra value per head received for tenderness. As price premiums for tenderness only apply to steak, which is 26% in weight of all beef cuts, we multiply the above value by 0.26 and get the extra revenue per head received for tenderness. That premium is $58.53/head. Adding that revenue premium to the base revenue gives the total revenue per head for animals raised using WCTS and AI, $1,283.82.

From that revenue are subtracted the production costs as well as the costs of implementing WCTS ($5/head), costs of AI ($51/head), and costs of testing for tender meat ($55/head). This gives the net revenue of participating in a WCTS and using AI to increase tenderness of meat. That net revenue is $58.32/head, compared to the net revenue of $70.20/head when the company is not participating in a WCTS, a profit decrease of $11.87/head.

From another perspective, the extra revenue is $58.53/head, compared to extra costs of $5/head for WCTS, $16/head for AI compared to natural service, and $55 for tenderness testing. If tenderness testing were not included, the net revenue would be $58.53/head less $21/head, or $37.53/head. With $55/head added for tenderness testing, the net revenue drops to negative $17.47/head.

Scenario II

As stated above, if the company has neither WCTS nor AI capability, and chooses natural service as the only breeding method, profit is $70.20 per head. As shown in Table 4.2, since the company does not use AI or WCTS, all beef cuts sold at wholesale level are at regular prices. The portions of extra-tenderness meat and regular-tenderness meat do not influence the total profit.

If the company does not implement WCTS and does not use AI, but uses tenderness tests to differentiate tender beef from regular beef, it can receive price premiums. In this case, the profit per head is $59.98, which is $10.22 lower than that in the previous situation. From another perspective, the extra revenue is $44.78/head, but the extra cost is $55/head, for a negative net revenue of $10.22.

Comparison between Scenario I and Scenario II

By comparing the results in Scenario I and Scenario II, we find that when the company chooses not to select HTG or do tenderness test, the profit received is the highest, which is $70.20 per head. When the company does not select HTG but conducts tenderness tests to supply “guaranteed tender” meat, the profit per head would decrease $10.22, to $59.98. When the company uses both artificial insemination to select HTG and WCTS and conducts tenderness tests, the profit per head is even lower. In this case, the profit per head is $58.32, which is $11.87 lower than when the company does not select HTG or test tenderness. Stated differently, when testing for beef tenderness, but using natural service with no WCTS, the extra revenue is $44.78/head, but the extra cost is $55/head. When using AI and implementing WCTS, the extra revenue is $58.53/head, compared to extra costs of $5/head for WCTS, $16/head for AI compared to natural service, and $55 for tenderness testing. If tenderness testing were not included, the net revenue would be $58.53/head less $21/head, or $37.53/head. With $55/head added for tenderness testing, the net revenue drops to negative $17.47/head.

Thus, implementing a WCTS and using AI to increase beef tenderness could increase revenue per head by more than $58/head, compared to costs of WCTS and AI of $21/head. The most the company could pay for tenderness testing and still break even is $37/head. The company would benefit if it could reduce costs below those levels.

Table 4.1 Profit under Scenario I, with AI and WCTS

Meat Grade (% by weight)	Prime (3.50%)	Choice (65.10%)	Select (31.10%)	Ungraded (0.30%)	By-Product	Revenues ($/head)
Meat Prices ($/cwt) and Revenue ($/head)	209.12	177.27	169.49	162.89	20.08	1,225.29
Premiums ($/cwt) and Revenue ($/head)	63.55	53.87	51.51	49.50		58.53
Prices for Tender Meat ($/cwt) and Revenue ($/head)	272.67	231.14	221.00	212.39	20.08	1,283.82
						Total Revenue: 1,283.82

Costs	Breeding Cost	ΔC	Calf	Feedlot	Slaughter/Packing	Tenderness Test	Traceability	
($/head)	35	16	632.86	397.29	89.95	55.00	5.00	**1,225.50**
								Profit:58.32

Proportions of tender meat produced by NS and AI are 53.30% and 78.46%.
Live weight = 1,300 lbs.; Dressing % = 62; Yield % = 75; AI Success Rate = 65%.
ΔC: difference in cost of AI and NS

Table 4.2 Maximum Profit under Scenario II

Maximum Profit without AI or WCTS						
Meat Grade (% by weight)	Prime (3.50%)	Choice (65.10%)	Select (31.10%)	Ungraded (0.30%)	By-Product	Revenues ($/head)
Meat Prices ($/cwt) and Revenue ($/head)	209.12	177.27	169.49	162.89	20.08	1,225.30
						Total Revenue: 1,225.30
Costs ($/head)	Breeding Cost 35	Calf 632.86	Feedlot 397.29		Slaughter/Packing 89.95	**1,155.10**
						Profit: 70.20
Maximum Profit with Tenderness Test but no WCTS or AI						
Meat Prices ($/cwt) and Revenue ($/head)	209.12	177.27	169.49	162.89	20.08	1,225.30
Premiums ($/cwt) and Revenue ($/head)	63.55	53.87	51.51	49.50		44.78
Prices for Tender Meat ($/cwt) and Revenue ($/head)	272.67	231.14	221.00	212.39	20.08	**1270.08**
						Total Revenue:1270.08
Costs ($/head)	Breeding Cost 35	Calf 632.86	Feedlot 397.29	Slaughter/Packing 89.95	Tenderness Test 55.00	**1,210.10**
						Profit: 59.98

Proportions of tender meat produced by NS and AI are 53.30% and 78.46%.
Live weight = 1,300lbs.; Dressing % = 62; Yield % = 75; AI Success Rate = 65%.

Discussion

Price Premiums

As mentioned in Chapter 3, the retail price premiums for tender steak varied from \$0.42/lb. to \$5.57/lb., which is shown in Table 2.1. In the analysis above, we chose \$0.9613/lb. as the premium received on average. Different price premiums from previous literature are shown in Table 2.1. In order to find out the effect of changing price premium on the company's decision, we estimate the premiums for each grade in the same way with above analysis, which are shown in Table 2.1 as well. Total profits are then estimated with different sets of price premiums.

Profit differences are calculated as profits with artificial insemination minus profits with only natural service. From Figure 4.1, we can see the relationship between profit differences and price premiums. The relationship between profit differences and price premiums is linear. This is because that we assumed fixed portions of different grades of beef cuts. When the success rate of AI is fixed at 65%, the break-even point is when price premium is about \$64/cwt. That is, when the average price premium for tender meat is more than \$64/cwt, the company is suggested to use artificial insemination, in order to get more tender meat. Otherwise, the company should not spend extra money to select HTG.

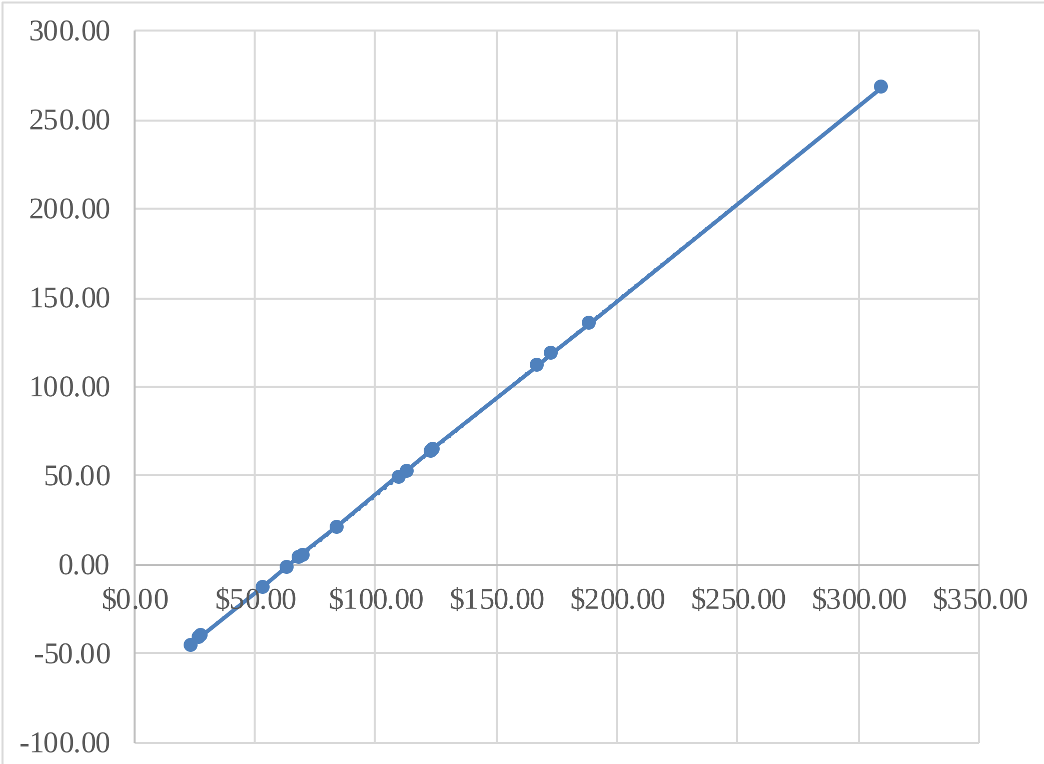

Figure 4.1 Profit Differences w.r.t Price Premiums

Artificial Insemination Success Rate

The success rate of artificial insemination has an important effect on the profit as well. If the success rate is too low, which makes the cost of doing artificial insemination much higher, even though there are high premiums for tender beef, the company may still choose not to do artificial insemination.

As stated in the data part, the cost of doing artificial insemination is assumed to be $33 per time. We also assume the success rate of artificial insemination is 65%. Table 4.4 shows the costs per pregnancy of doing artificial insemination and the profit differences between using artificial insemination and natural service.

Figure 4.2 shows us that, as the success rate of AI increases, the maximum profit also increases, at an almost constant rate. As the success rate of doing artificial insemination goes up, cost per pregnancy goes down. When average price premium is fixed at $53.46/cwt, the profit break-even point is when success rate is around 86%, as shown in Figure 4.2. At this point, the company does not earn any extra profit from AI and WCTS, but it does not lose money from doing AI and using WCTS either. To the left of this point, the company loses money by doing AI and WCTS. To the right of this point, when success rate is higher than 86%, the company is more likely to do artificial insemination in order to select HTG. Since the highest success rate for AI is 100%, the maximum extra profit earned from increasing success rate is $7.77/head.

Table 4.4 Costs of AI and Profit Differences between AI and NS

AI $/cow	success rate	AI Cost $/calf	Profit λ=0.65	Profit λ =0	Profit Difference
$33.00	35%	$94.71	$41.48	$70.20	-$28.72
	40%	$82.88	$44.29	$70.20	-$25.91
	45%	$73.67	$47.10	$70.20	-$23.10
	50%	$66.30	$49.90	$70.20	-$20.30
	55%	$60.27	$52.71	$70.20	-$17.49
	60%	$55.25	$55.52	$70.20	-$14.68
	65%	$51.00	$58.32	$70.20	-$11.88
	70%	$47.36	$61.13	$70.20	-$9.07
	75%	$44.20	$63.94	$70.20	-$6.26
	80%	$41.44	$66.75	$70.20	-$3.45
	85%	$39.00	$69.55	$70.20	-$0.65
	90%	$36.83	$72.36	$70.20	$2.16
	95%	$34.89	$75.17	$70.20	$4.97
	100%	$33.15	$77.97	$70.20	$7.77

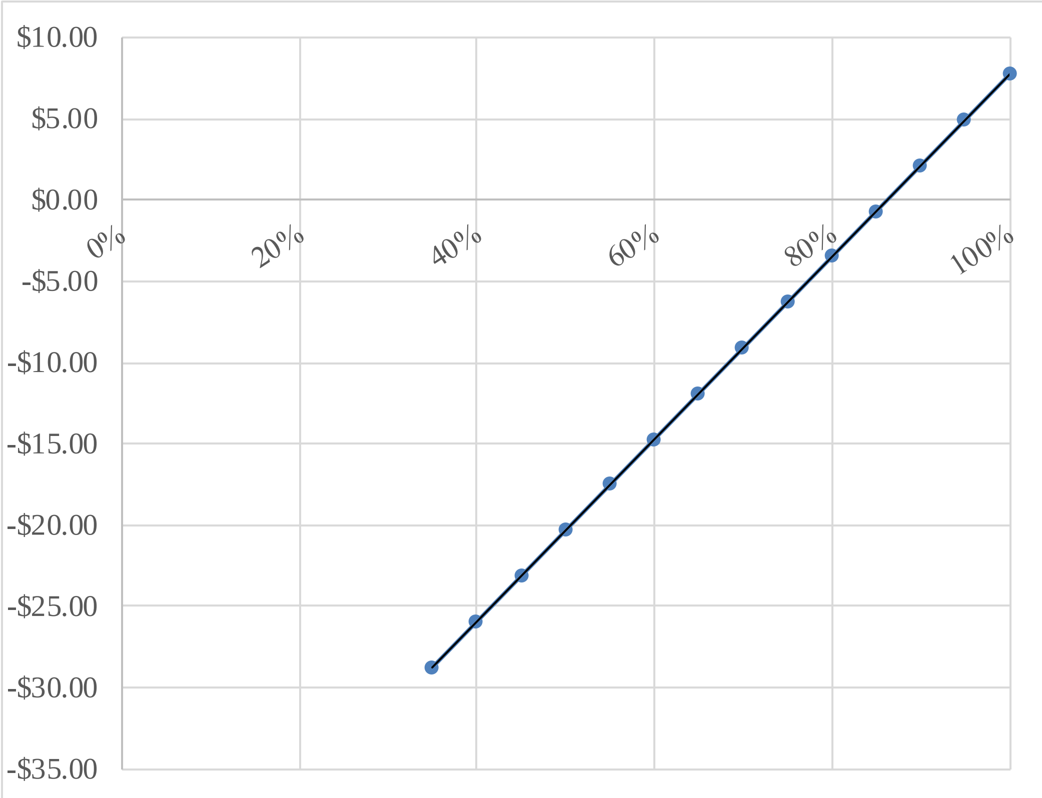

Figure 4.2 Profit Difference w.r.t AI Success Rate

Combined Effect of Price Premiums and AI Success Rate

Price premiums for tender beef and the success rate of artificial insemination are two most important variables that affect the profits. Thus, we put combination effect of these two variables into consideration. Figure 4.3 is a 3-D surface of profit differences with respect to price premiums and AI success rates.

As shown in Figure 4.3, when price premium and AI success rate are both low, the company does not earn extra profit by doing artificial insemination. When price premiums for tenderness are lower than $60/cwt, even though the AI success rate is as high as 100%, the company still loses money by doing AI. When the price premiums for tenderness per cwt is between $60 and $84, if AI success rate is higher than 55%, the company earns extra profit by using AI and WCTS. Otherwise, it loses money. When price premiums for tenderness is higher than $84/cwt, no matter what AI success rate is, the company earns extra profit by using AI and WCTS. The higher the price premium and AI success rate are, the higher extra profit will be earned by this company.

These profits are calculated under the cost assumptions made previously; if those costs change (e.g., if costs of AI, implementing WCTS, or testing for beef tenderness change), the numerical results provided here would change. However, this analysis illustrates the effects of changes in price premiums for tender meat and AI success rate affect profitability.

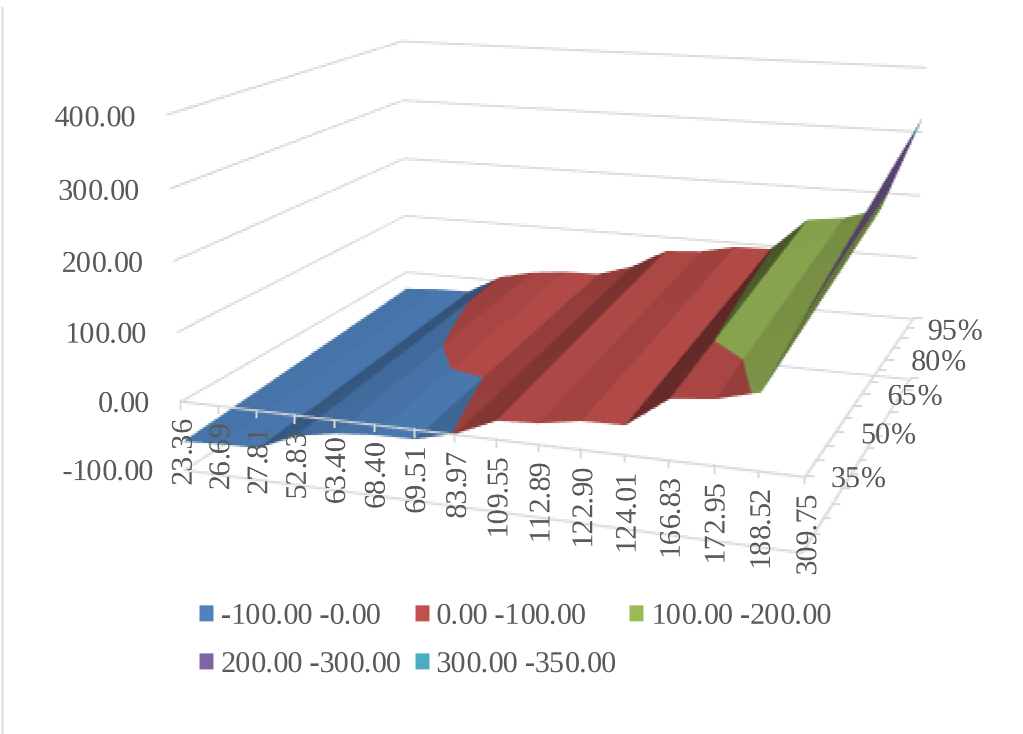

Figure 4.3 Combined Effect of Price Premiums & AI Success Rate on Profits

CHAPTER V

CONCLUSION

Results Summary

This research considers a vertically-integrated company that includes cow-calf producer, feedlot, and slaughter/packing plant stages. Two scenarios are analyzed. In Scenario I the company participates in a whole-chain traceability system (WCTS) and uses artificial insemination (AI) to increase production of cattle with genetics for high-tenderness beef (HTG). The company also uses testing to verify tenderness of individual cuts of meat. In Scenario II, the company does not participate in WCTS, does not use AI to increase production of HTG, and does not conduct tenderness testing.

In Scenario II the company profits $70.20/head, without participating in WCTS and using AI, if it conducts tenderness testing by doing DNA test in cow-calf producer level, profit decreases by $10.22/head, to $59.98/head. If the company uses AI, WCTS, and conducts tenderness tests (Scenario I), its profit decreases by $11.87/head to $58.32/head, from $70.20/head.

Those estimates are under reasonably conservative assumptions. For higher price premiums for tender meat, or for a higher AI success rate, profits from those activities would increase. If the price premium for tender meat increases by $100/cwt, profit would increase by about $110/head. Similarly, higher success rates for AI increase profits of WCTS, AI, and tenderness testing.

Considering the simultaneous effect of price premiums and AI success rate, when price premiums are higher than $84/cwt, even if the AI success rate is as low as 35%, the company earns more by doing artificial insemination and implementing a whole-chain traceability system. When price premiums are between $60/cwt and $84/cwt, if AI success rate is higher than 55%, the company earns extra profit by doing AI and using WCTS. In other word, when the price premium is under $84/cwt, and the AI success rate under 55%, using a WCTS and AI is not profitable. For a fixed wholesale price premium of $53.46 per cwt, if the AI success rate is lower than 86%, the company would not profit from participating in WCTS and using AI. Similarly, for an AI success rate of 65%, if price premium is less than $64 per cwt producers will not have an incentive to use WCTS and AI.

The objective of this research was to determine the potential value of a whole-chain traceability system in the beef supply chain for improving meat tenderness. Under assumptions based on livestock production and genetics literature, we conclude that this extra value obtained would be $58.53/head. The costs of this gain are $5/head for implementing WCTS, an extra $16/head for AI, and some amount for testing for beef tenderness. If tenderness testing cost less than $37.53/head there would be an incentive to implement WCTS for purposes of improving beef tenderness. Further, in this study the entire costs of implementing WCTS have been compared with only one of its benefits, improving beef tenderness. If other benefits were obtained from implementing WCTS the costs attributable to this one benefit would be less.

Implications for Future Research

In this research, we assumed a vertically-integrated company. This assumption gives us an upper bound of implementing a WCTS and using AI. Future research should consider the costs and benefits of implementing a WCTS in a non-vertically-integrated beef supply chain, since price transmission and market linkages between stages may affect the magnitude and distribution of benefits at each stage, especially if there are differences in relative market power among stages.

This study has considered the benefits of using WCTS to increase meat tenderness only. There are potentially many other benefits to implementing WCTS in the beef supply chain that have not been studied, such as improved herd management and supply chain management, improved disease detection, mitigation, and prevention, and value-added opportunities for supplying specific quality characteristics that are difficult or expensive to provide without a WCTS. Further research should evaluate these potential benefits.

Further research should also evaluate the more intangible costs of implementing WCTS at each stage of the beef supply chain. Direct costs of implementing WCTS have been estimated by several studies. Also, although they are more difficult to quantify and the estimates are less precise, costs of adjusting individual operations to facilitate implementing a WCTS have been addressed. However, costs incurred by supply chain participants in the form of increased risk of liability have not been adequately addressed. Institutional structures and arrangements that could reduce these costs should also be evaluated.

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APPENDICES

Appendix Table 1. Calculation of Modified Frequencies of Genotypes

Haplotypes	U0G-CAST1	C	68.00%
		G	32.00%
	CAPN1 316	C	15.27%
		G	84.73%
Choose Bull	Genotypes (Regular %)	Genotypes (Modified %)	
CC.CC X	CC.CC 2%	CC.CC	2.20%
	CC.CG 16%	CC.CC	2.43%
		CC.CG	13.47%
	CG.CC 1%	CC.CC	0.54%
		CG.CC	0.26%
	CC.GG 35%	CC.CG	35.20%
	CG.CG 10%	CC.CC	1.03%
		CC.CG	5.70%
		CG.CC	0.48%
		CG.CG	2.68%
	GG.CC 0.3%	CG.CC	0.30%
	CG.GG 26.3%	CC.CG	17.88%
		CG.CG	8.42%
	GG.CG 1.3%	CG.CC	0.20%
		CG.CG	1.10%
	GG.GG 8.1%	CG.CG	8.10%
		Total:	100.00%

Appendix Table 2. Price Premiums Calculation

		regular wholesaleprices	162.89	169.49	177.27	209.12
		% of Grades	0.30%	31.10%	65.10%	3.50%
Retail Premium	Wholesale %	Wholesale Premium	Ungrade d	Select	Choice	Prime
$42.00	55.61%	$23.36	$21.63	$22.50	$23.53	$27.76
$48.00		$26.69	$24.71	$25.71	$26.89	$31.72
$50.00		$27.81	$25.75	$26.79	$28.02	$33.06
$95.00		$52.83	$48.92	$50.90	$53.24	$62.80
$114.00		$63.40	$58.70	$61.08	$63.88	$75.36
$123.00		$68.40	$63.33	$65.90	$68.92	$81.30
$125.00		$69.51	$64.36	$66.97	$70.04	$82.63
$151.00		$83.97	$77.75	$80.90	$84.61	$99.82
$197.00		$109.55	$101.44	$105.54	$110.39	$130.22
$203.00		$112.89	$104.53	$108.76	$113.75	$134.19
$221.00		$122.90	$113.80	$118.41	$123.85	$146.10
$223.00		$124.01	$114.82	$119.47	$124.96	$147.41
$300.00		$166.83	$154.47	$160.73	$168.11	$198.31
$311.00		$172.95	$160.14	$166.62	$174.27	$205.58
$339.00		$188.52	$174.56	$181.63	$189.96	$224.10
$557.00		$309.75	$286.80	$298.42	$312.12	$368.20

VITA

Candi Ge

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