Value-added Traceability: Using a Whole-Chain Traceability System to Transfer Information about Multiple Attributes along a Multi-Stage Beef Supply Chain

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Abstract

Implementing a whole-chain traceability system (WCTS) in the beef industry may bring many benefits, but in order to realize these benefits, potential participants must be convinced that benefits are higher than the costs of participating. This paper simulates a WCTS and estimates the value of information in a fragmented beef supply chain and the optimal allocation of compensation to each supply chain participant that provides additional value. This research focuses on two specific value-added activities: selecting genetics to improve meat tenderness; and controlling injection-site lesions in cow-calf producer stage, cattle feeder stage, and meat processor stage. Results show that even though with two attributes, an extra profit of $9.53/animal is identified when a WCTS is implemented. The potential benefit could increase, if including more attributes and more stages. This suggests that a WCTS could promote value-based pricing without forgoing the efficiencies of the current commodity-based system.

Keywords: whole chain traceability, beef supply chain, information asymmetry, principal-agent model

Introduction

As cattle/beef products are transferred along the supply chain, the existence of information asymmetry causes market inefficiency and economic loss to the U.S. beef industry. For example, as Resende-Filho and Buhr (2008) – hereafter RFB – show, when cow-calf producers or cattle feeders vaccinate their animals, injection-site lesions may result. The existence of injection-site lesions causes meat packers to trim the lesion locations, or degrade the quality of the meat, causing large economic losses (Roeber et al. 2001).

The probability of lesions could be reduced by injecting in the animal's neck area or using a needle-free injection method (Resende-Filho and Buhr 2008). If cow-calf producers and cattle feeders do not bear losses caused by injection-site lesion directly, they have no incentives to change from a lower-cost injection site to a higher-cost injection site. Meat packers are only able to verify the existence of injection-site lesions at the time of meat processing, after all supply-chain transactions are made. Thus, costs of trimming lesion location or degrading of meat cuts are borne entirely by meat processors.

Grid pricing systems are commonly used in the U.S. beef cattle industry. Average carcasses receive base prices, while premiums and discounts are specified for carcasses with qualities above or below the base. However, grid pricing systems are unable to fully value all consumer-valued attributes, such as beef tenderness. Improving tenderness in beef may increase fed cattle value by almost $5/cwt (Riley et al. 2009). There is potential for U.S. beef producers to gain extra profit by improving tenderness of beef cuts.

According to Van Eenennaam et al. (2007), cattle carrying specific genotypes produce more tender meat. Thus, meat tenderness could be improved by appropriate selection of cattle genetics. Genetic selection would be done at the cow-calf producer stage, using artificial insemination. But since cow-calf producers are not compensated for the value of improved meat tenderness, they have no incentive to pay the extra costs of artificial insemination. On the other hand, even though meat processors may be willing to compensate producers for animals with preferred genetics, they likely cannot identify the source of those animals after moving through several stages of the supply chain.

According to Schroeder et al. (1998), the beef industry is interested in moving toward a value-based marketing/pricing system, which should improve pricing efficiency. With value-based marketing/pricing, meat price and meat quality attributes are linked more accurately, which better communicates consumers demands to producers (Schroeder et al. 1998). Meat processors that can more efficiently identify beef quality may be able to build their own brand and gain brand premiums (Schroeder et al. 1998). Beef traceability could be a feasible tool to achieve this goal.

Implementing a whole-chain traceability system (WCTS) can help solve the problems mentioned above. Moreover, traceability could reduce supply chain anonymity and information asymmetry (RFB). Reducing information asymmetry could facilitate allocating profits and costs more equitably in the beef supply chain, enhancing preferred behaviors that increase quality and reducing unwelcome operations that harm quality.

Implementing a WCTS in the beef industry could potentially provide other benefits also, such as improving food safety, enhancing disease prevention and mitigation, managing the supply chain more sufficiently, and providing value-added products to consumers (Golan, 2004 #7). In order for a sufficiently large number of producers in a fragmented supply chain to voluntarily adopt whole-chain traceability, though, participants must believe that individual benefits exceed costs.

Traceability is the ability to trace the activities of commodities/products under consideration. According to Thakur and Hurburgh (2009), traceability includes tracking (forward) and tracing (backward). Tracking forward is the ability to follow the product from one stage to the next, while tracing backward is the ability to identify the origin of products through several stages (Thakur and Hurburgh 2009). A whole-chain traceability system traces and tracks the product through all stages along the supply chain. But true whole-chain traceability systems have not been implemented on a large scale in the U.S. in fragmented supply chains, partly because of cost, but also because participants would be forced to reveal proprietary information to every other participant in the supply chain. USDA's attempts to implement a National Animal Identification System faced much resistance from producers due to cost, lack of confidentiality, and lack of accuracy of the system. The resulting low participation led to abandonment of these attempts in 2010 (Schroeder and Tonsor, 2012).

Recent innovations in traceability technology (see Adam et al. 2015, Adam et al. 2016, IBM-WalMart citation) offer the potential for WCTS systems that permit producers to provide the relevant information to those who are willing to pay for it, without giving up confidentiality of their information to other supply chain participants. The technology permits those who put information into the system to choose which participants in the supply chain have access to the information, and which pieces of the information they can access. This would reduce one of the disincentives producers face – lack of information confidentiality – when choosing whether to participate in a WCTS. Thus, value-added information can be transferred along the supply chain and traced back to a specific participant, which means that the producers who provide products with preferred attributes can be compensated by downstream participants who value the information.

Two valuable attributes in the beef industry are the focus of this paper: injection site and tenderness genetics. This research simulates a WCTS used along three stages of the beef supply chain: cow-calf producer, cattle feeder, and meat processor. Meat processors benefit from the information and improved attributes (injection site and tenderness genetics). They must choose how much of the added profitability to return to upstream participants (cow-calf producers and cattle feeders) in order to provide sufficient incentive for them to provide the information and the attributes, while maintaining or enhancing profitability.

The objective of this research is to determine the benefits relative to costs for an individual to participant in a WCTS in a fragmented beef supply chain. The specific objectives are:

1. Determine the benefits to meat processor of implementing a WCTS for injection-site and tenderness genetics problem simultaneously;
2. Determine the optimized income transfers from meat processor to cattle feeder and cow-calf producer;

Background

Various grid pricing systems exist, which may differ in the carcass traits they seek to reward or penalize (Feuz et al. 2004). With grid pricing, the beef cattle providers receive a price for each individual animal based on its actual carcass traits. But there still are some other valuable attribute that are not considered in grid pricing, such as injection sites and tenderness genetics.

Vaccinating beef cattle prevents or reduces the occurrence of disease. But an injection can cause a lesion when given in the muscle. Lesions caused by injections remain concealed within the muscles and fat which makes damage observable only during portioning of primal cuts (Roeber et al. 2001). Injection-site lesions caused great economic losses to the U.S. beef industry (RFB). According to Roeber et al. (2001), some producers have changed injection practices, so that the incidence of injection-site lesion in top sirloin butts decreased from 11.4% in November 1995 to 2.1% in July 2000 (Roeber et al. 2001).[1] However, the mean weight per injection-site lesion increased from 192.5 g to 249.8 g (Roeber et al. 2001), so injection-site lesions remain one of the quality challenges facing the U.S. beef industry. Roeber et al. (2001) also suggested that the majority of lesions happen at early stages, such as the cow-calf producer stage. Since meat processors do not directly interface with cow-calf producers, it is difficult for meat processors to control the occurrence of the injection-site lesions.

Similarly, improving beef tenderness has great potential to increase revenues and improve value to consumers. According to Lusk et al. (2001), Feuz et al. (2004), and Schroeder et al. (2010), consumers are willing to pay a price premium for a tender steak. The range of consumers' willingness-to-pay in these studies varied from \$0.42/lb. to \$5.57/lb. Producers can improve tenderness by selecting specific genes as they breed cattle. Schenkel et al. (2006) concluded that calpastatin (CAST) single nucleotide polymorphism (SNP) was associated with shear force. Van Eenennaam et al. (2007) tested the associations among commercial DNA tests and beef quality traits. Combined effects of two SNPs were verified: CAST and μ-calpain (CANP). The results showed that the genotype CC for both SNPs were favorable for tenderness, with cattle carrying CC.CC producing the most tender meat compared to other genetics. Thus, cow-calf producers could use artificial insemination (AI) technology to select favorable genetics

[1] It is assumed that the rates of injection-site lesions have not changed much compared with those reported by Roeber et al. (2001). It is unknown whether producers have continued to reduce incidence of lesions, but even if they have, the analysis is still helpful in illustrating the potential of a whole-chain traceability system for encouraging value-added practices. Analyzing lesions also helps to highlight the extensions of the work by Resende-Filho and Buhr.

and avoid unfavorable genetics. However, using AI increases costs to cow-calf producers. Without a direct connection between processors and cow-calf producers, tenderness premiums cannot be passed from meat processors to cow-calf producers (Riley et al. 2009), and without sufficient incentives, cow-calf producers would not be willing to incur the extra costs of providing animals with genetics that favor increased tenderness.

RFB estimated the value of a traceability system in controlling injection-site lesions. A two-stage production system including meat processor and cattle feeder implementing a beef traceability system was simulated. They concluded that even with the lowest traceability success rate (38.9%), cattle feeders would give injections to cattle using a needle-free method. By implementing a traceability system, approximately $12.8 million savings could be generated for beef industry per year (Resende-Filho and Buhr 2008).

This paper simultaneously considers both beef injection-site lesion control and improvement of beef tenderness. There are several contributions of this research. First, this paper estimates benefits of implementing a WCTS in a multiple-stage beef supply chain. Second, this paper estimates the benefits of more than one attribute simultaneously. Third, this paper considers costs of implementing a WCTS at all stages, rather than just the meat processor stage. Together, these will provide more realistic estimates of the benefits to individual beef producers from participating in a WCTS.

By quantifying benefits to individual producers from participating in a WCTS, this research will provide guidance to firms, the beef industry, and government agencies on the most promising incentives as well as remaining obstacles to implementing a voluntary whole chain traceability system. It will also provide a framework for evaluating other value-added opportunities, and will provide guidance for firms to use in allocating value-added benefits among supply chain participants.

Model

The model extends the two-stage principal-agent model by RFB to three stages: meat processor (principal), cattle feeder (agent), and cow-calf producer (agent); and by considering two attributes simultaneously – meat tenderness as well as injection site. Two special cases of the general model illustrate the use of the model in two important applications: injection site and meat tenderness.

Injection Site

In RFB's principal-agent model, a meat processor (principal) purchases live animals from cattle feeders (agents). Prior to the transaction, cow-calf producers, cattle feeders, or both give injections to the cattle, which affects the frequencies and types of injection-site lesions in beef retail cuts. Three injection methods a_i (i = 1, 2, 3) are: give injections in the rear leg (a_1), give injections in the neck area (a_2), and give injections with a needle-free method (a_3). Giving injections in the rear leg is least preferred by the meat processor, as it can result in lesions in high-valued meat cuts. Giving injections in the neck area can result in lesions in lower-valued meat cuts. The needle-free injection method is the most costly, but is assumed to produce no lesions (RFB).

According to RFB and Roeber et al. (2001), a majority of injection-site lesions happen at the cow-calf and stocker stages, or very early in the finishing stages. Without a WCTS, meat processors do not typically connect with cow-calf producers directly, so they have little effect on the incidence of injection-site lesions at cow-calf producer stage. But with a WCTS, a cow-calf producer can share injection site information with a meat processor and get rewards from meat processors.

Following RFB, there are eight possible events of injection-site lesions: “0” (no lesion detected), “c” (lesions in chuck area only), “r” (lesions in round area only), “s” (lesions in sirloin area only), “(c, r)” (lesions in chuck and round areas), “(c, s)” (lesions in chuck and sirloin areas), “(r, s)” (lesions in round and sirloin areas), “(c, r, s)” (lesions in chuck, round, and sirloin areas).

Referring to RFB, the model includes two parts: the principal’s cost minimization, and agents’ utility maximization. In the model, a meat processor (principal) purchases live animals from cattle feeders (agent). Prior to the transaction, the cow-calf producer and/or cattle feeder give injections to the cattle, which affects the frequencies and types of injection-site lesions in beef retail cuts. Three injection methods a_i (i =1, 2, 3) are: give injections in the rear leg (a_1), give injections in the neck area (a_2), and give injections with a needle-free method (a_3) (RFB). Giving injections in the rear leg is least preferred by the meat processor, as it can result in lesions in high-valued meat cuts. Giving injections in the neck area can result in lesions in lower-valued meat cuts (RFB). The needle-free injection method is the most costly, but is assumed to produce no lesion (RFB).

Meat Tenderness

In the tenderness problem, only the cow-calf producer and meat processor stages are considered. (Although feeding regimens by cattle feeders may also influence beef tenderness, this paper focuses specifically on the impact of genetics on beef tenderness.[2]) With a WCTS as described by Adam et al. (2016), participants can choose what information to upload and with whom to share the information. With the WCTS, the meat processor can identify the origins of cattle purchased and then reward cow-calf producers directly according to the genetic information shared. Cow-calf producers have two choices, b_k, in this problem: b_0 for breeding calves using natural service (NS), and b_1 for breeding calves using artificial insemination (AI). AI is assumed to cost more than than NS.

Part I. Principal’s Cost Minimization

Since this paper considers injection-site lesion and tenderness simultaneously, every event and its probability of occurrence must be identified. Variable $p_{(l)}$ represents the probability of one of the eight possible lesion events (l = 0, c, r, s, (c,r),(c,s),(r,s),(c,r,s)). Subscript l identifies the type of lesion or combination of lesions found in each carcass side. $p_{(l)}^{com}$ is the combined probability of $p_{(l)}^{1}$ and $p_{(l)}^{2}$, where $p_{(l)}^{n}$ is probability of lesion event l in stage n (cow-calf producer stage, n = 1; cattle feeder stage, n = 2). It is assumed

[2] The association of tenderness and genetics used here was obtained from Van Eenennaam (2007). In their paper, feeding regimens were not considered.

that when cow-calf producers and cattle feeders give injections to cattle, they do not know injection actions at the other stage; their decisions are independent. The probabilities of each lesion event in each stage depend on the method of injection a_i^n at each stage.

If cow-calf producers select genetics preferred by the meat processor by using AI (b_1), they receive rewards from meat processor. If cow-calf producers do not select genetics preferred by meat processor (b_0), they do not receive rewards. It is assumed that tenderness does not influence the probabilities of injection-site lesions. However, if lesions occur in valuable meat cuts, the value of tender meat may be affected. When the meat cuts are tenderer, $k = 1$; otherwise, $k = 0$;

The traceability system success rate is t. When $t = 0$, the traceability system is not working. When $t = 1$, the traceability systems works all the time. The principal (meat processor) makes income transfers $I_{m,(l),k}^1$ to cow-calf producers, and $I_{m,(l)}^2$ to cattle feeders, where m is the indicator of traceability success ($m = 1$ when traceability succeeds; 0 otherwise).

The meat processor's objective is to minimize the costs of cattle subject to the incidence of lesions and existence of tenderness. Equation (1) is the meat processor's cost function, including the amount of income transfers the principal makes to agents, the cost of using a WCTS to meat processors, the cost of trimming/degrading beef cuts with lesions, and the premiums for improved tenderness.

(1) $$E_c\left(I_{0*}^1, I_{1,(0),0}^1, \dots, I_{1,(c,r,s),1}^1, I_{0*}^2, I_{1,(0),0}^2, I_{1,(c,r,s)}^2\right) = 2\Big[p_{0*}I_{0*}^1 + \sum_{k=0}^{1}\sum_{l=(0)}^{(c,r,s)} p_{1,(l),k}^{com} I_{1,(l),k}^1 + \sum_{m=0}^{1}\sum_{k=0}^{1} p_{m,(c),k}^{com} P_{(c),k} + \sum_{m=0}^{1}\sum_{k=0}^{1} p_{m,(r),k}^{com} P_{(r),k} + \sum_{m=0}^{1}\sum_{k=0}^{1} p_{m,(s),k}^{com} P_{(s),k} + \sum_{m=0}^{1}\sum_{k=0}^{1} p_{m,(c,r),k}^{com}\left(P_{(c),k} + P_{(r),k}\right) + \sum_{m=0}^{1}\sum_{k=0}^{1} p_{m,(c,s),k}^{com}\left(P_{(c),k} + P_{(s),k}\right) + \sum_{m=0}^{1}\sum_{k=0}^{1} p_{m,(r,s),k}^{com}\left(P_{(r),k} + P_{(s),k}\right) + \sum_{m=0}^{1}\sum_{k=0}^{1} p_{m,(c,r,s),k}^{com}\left(P_{(c),k} + P_{(r),k} + P_{(s),k}\right) + p_{0*}I_{0*}^2 + \sum_{k=0}^{1}\sum_{l=(0)}^{(c,r,s)} p_{1,(l),k}^2 I_{1,(l),k}^2\Big] + g(t) - r.$$

where p_{0*} is the probability that traceability system fails to work, I_{0*}^1 and I_{0*}^2 are the income transfers from the principal to agents when the traceability system fails to work, $p_{1,(l),k}^{com}$ is the combined probability of lesion happen in (l) and tenderness level k, when the traceability system succeeds, $P_{(r),k}$ is the cost (\$/carcass side) to the meat processor to discard beef cuts at tenderness level k with lesions, $g(t)$ is the cost (\$/head) of a WCTS for meat processor as a function of success rate t, and r is the tenderness premium (\$/head) received by meat processor.

Generally, the total cost to the meat processor (principal) is the summation of income transfers to cattle feeders (agent) and cow-calf producers (agent), the cost of discarding meat cuts with injection-site lesion, and the cost of implementing a WCTS to the principal, minus the extra gain from the improvement of meat tenderness.

Part II. Agents' Utility Maximization
Following RFB, risk aversion coefficients for cow-calf producer and feedlot are both set at 0.75, and Equation (2) is the agents' utility function.

(2) $U^n\left(a_{i,j}^n \middle| I_{0*}^n, I_{1,(0),0}^n, \dots, I_{1,(c,r,s),1}^n\right) = \gamma(a_i^n)\left[p_{0*}^n u(I_{0*}^n) + \sum_{l=0}^{(c,r,s)} p_{1,(l),k}^n u(I_{1,(l),k}^n)\right] - d(a_{i,j}^n)$

where $U(.)$ is the von Neumann-Morgenstern utility function and $u(.)$ is a Bernoulli utility function. According to RFB, $\gamma(a_i^n)$ is set equal to $e^{\gamma^n(C_{a^n}+tr^n+br^n)}$, $u(I_{1,(l),k}^n) = -e^{-\gamma^n I_{m,(l),k}^n}$, and $d(a_i^n) = 0$. The von Neumann-Morgenstern utility function is represented as

(3) $U\left(I_{m,(l),k}^n, a_{i,j}^n\right) = -e^{-\gamma^n(I_{m,(l),k}^n - C_{a^n} - tr^n - br^n)}$

where γ^n is the risk aversion coefficient for agent *n*, $C_{a^n}$is the injection cost for agent *n* (\$/head), tr^n is the cost of participating in a WCTS for agent *n* (\$/head), $br^n$is the breeding cost for agent *n* (\$/calf).

Following RFB, the principal-agent problem with a WCTS is solved as a two-step numerical optimization. The first step is to solve the cost minimization problem for each combination of injection methods of cow-calf producer and cattle feeder, when *k* = 0 and *k* = 1. Then the lowest expected cost per head is selected among the calculated values in step one. The principal's cost minimization problem is:

(4)
$\mathbf{min}_{I_{0*}^1, I_{1,(0),0}^1, \dots, I_{1,(c,r,s),1}^1, I_{0*}^2, I_{1,(0),0}^2, I_{1,(c,r,s)}^2} E_c(I_{0*}^1, I_{1,(0),0}^1, \dots, I_{1,(c,r,s),1}^1, I_{0*}^2, I_{1,(0),0}^2, I_{1,(c,r,s)}^2 | a_{i,j}^1, a_{i,j}^2)$

Subject to:

(a) $U^n(a_{i,j}^n | I_{0*}^n, I_{1,(0),0}^n, \dots, I_{1,(c,r,s),1}^n) \geq \overline{U^n}$

(b) $U^n(a_{i,j}^n | I_{0*}^n, I_{1,(0),0}^n, \dots, I_{1,(c,r,s),1}^n) \geq U^n(a_j^n | I_{0*}^n, I_{1,(0),0}^n, \dots, I_{1,(c,r,s),1}^n)\ \forall a_{i,j}^n \neq a_{-i,-j}^n$

where $\overline{U^n}$ is the opportunity utility for agent *n* calculated as trading with a meat processor that does not implement traceability and pays market price. Equation (4a) gives the participation constraint, that participating in the WCTS should generate agents' utilities no lower than their opportunity utilities. Equation (4b) gives the two incentive compatibility constraints, that agents receive the highest utility from choosing injection method *i* instead of injection method *j*. All constraints must be satisfied to obtain the optimal solution of the program.

Parameter Identification
Parameters needed to solve the numerical problem include: costs of injections, frequencies of lesions using different injection methods, the original income transfers from the principal to agents, costs to meat processor of trimming/degrading beef cuts

with lesion,extra costs of discarding beef cuts with lesions if tenderness is improved, costs of a WCTS to meat processor, cattle feeder, and cow-calf producer, cost of using AI.

Values for injection costs and lesion frequencies are those used by RFB. Costs of gving injections in the rear leg, in the neck, and needle-free are $0 (base cost), $0.17, and 0.204, respectively (RFB). According to RFB, 43% of lesions occur at the feedlot, and 57% originate at an earlier stage of production. The stocker stage is not considered here, so it is assumed that 57% of lesions originate at the cow-calf stage. [Probabilities of lesions occuring in each meat cut are taken from RFB frequencies at the feedlot stage. These probabilities are adjusted for lesions occuring at the cow-calf stage by multiplying the RFB probabilities at the feedlot stage by 0.57/0.43, or $p_{(l)}^{1} * 0.57/0.43$.

Following RFB, average carcass weight of 787 lbs is assumed to be sold for $480/carcass side ($1.22/lb.) The opportunity costs of a lesion occuring in a chuck steak (P_c), a bottom-round, and a top sirloin butt (P_s) are $2.50, $9.91, and $11.02, respectively.

If cattle are carrying preferred genes, tenderness of beef cuts is improved, so opportunity costs of a lesion ocuring in a chuck steak, a bottom-round, and a top sirloin butt increase. Beef cuts with lesions lose any tenderness premium.[3] According to Van Donkersgoed et al. (1999), injection-site lesions in a chuck, bottom-round, and a top sirloin butt affect the value of 1.62, 3.71, and 2 steaks, respectively. Average weight of a steak is 0.67 kg (Van Donkersgoed et al. 1999), or 1.474 lb. Warner-Bratzler shear force (hereafter shortened as WBSF) is the average measure of force needed to shear a core of steaks.The tenderness premium for a 1-kg decrease in WBSF is set to be $138.144/cwt. This paper calculates the decreased amount of WBSF from favorable genetics from Van Eenennaam (2007). The tenderness premium losses from lesions in a chuck steak, a bottom-round, and a top sirloin butt are $0.30, $0.68, and $0.37, respectively.

Traceability costs in cow-calf producer stage and cattle feeder stage are obtained from Seyoum et al. (, 2013 #25). Participating in a WCTS costs cow-calf producers and cattle feeders $2.85/head, and $0.65/head, respectively. Cow-calf producers pay a higher cost because of the tag cost. According to RFB, cost of implementing a traceability system in meat processor stage is a function of traceability success rate.

(4) $g(t) = \eta t^2/2$

where $\eta = 1.4539$ (RFB). Results are calculated for several potential values for the traceability success rate: 0 (no traceability), 0.95 (traceability succeeds 95% of time. It is assumed that the WCTS only fails when there are breakdowns of devices or softwares. RFB chose 0.95 as the highest probability of a traceability system suceeds.), and 1 (traceability succeeds 100% of time), with costs of $0/head, $0.656/head, and $0.727/head, respectively.

[3] It is assumed that a beef cut with a lesion will be trimmed or graded lower. If the beef cut is trimmed, the meat processor loses all value of it, including any tenderness premium. If the beef cut is regraded and made into ground beef, the meat processor loses the difference in value, including any tenderness premium (Van Donkersgoed et al. 1999).

Cost of cattle artificial insemination is observed from Ge (, 2014 #26). Assuming an AI conception rate of 80%, using AI costs $5.102/calf more than using NS. If the AI conception rate increases to 90%, cost difference between AI and NS decreases to $0.361/calf.

According to Ge (, 2014 #26), tenderness premiums are calculated at 80% AI conception rate, $138.144/cwt tenderness premium, and 20% of tenderness proportion (the part of meat where consumers are willing to pay tenderness premiums) to be $15.825/head. This tendernss premium is obtained from identifying cattle's genetics, instead of using WBSF.[4]

Scenarios and Results

Depending on the traceability success rate *t*, this paper has three scenarios. As a baseline case, *t* = 0 represents a situation in which no traceability system exists, and meat processors do not observe actions taken by cow-calf producers or cattle feeders at the time transactions occur. When *t* = 1, meat processors observe the relevant actions cow-calf producers and cattle feeders take; informtion asymmetry is eliminated. When *t* = 0.95 (or any number between 1 and 0), meat processors observe actions taken by cow-calf producers and cattle feeders only when the WCTS works.

t = 0 (without a WCTS)

With no WCTS, meat processors (principal) do not observe actions by cow-calf producers and cattle feeders (agents), and do not pay incentives for no lesions or extra tenderness. The equlibrium for this scenario is for meat processors to pay the market price, $960/head, to cattle feeders, and nothing to cow-calf producers. Since cow-calf producers choose the lowest-cost method, they receive no incentives and do not select genetics. Processors pay $960/head to cattle feeders, and nothing to cow-calf producers. Since no incentives are received, cow-calf producers and cattle feeders would choose the most cost-saving method (inject in rear leg) to give injections. Similarly, cow-calf producers would not select genetics using AI. The expected cost in this scenario should equal the highest cost in information symmetric scenario, which is $967.23/head, including $7.23 from loss of lesion-damaged cuts.

*t = 1 (Symmetric Information)*Under this information-symmetric scenario, any action taken by an agent is observable to the principal. Then, the principal chooses lowest expected cost and contracts agents' actions which lead to that. The lowest cost happens when both cow-calf producer and cattle feeder choose the needle-free injection method, which causes lowest lesion costs. At the same time, the cow-calf producer chooses to do AI to increase the probabilities of favorable genetics that improve meat tenderness. The meat processor pays $954.71 per animal, including $2.65/head and $480.10/carcass side income transfer to cow-calf producer and cattle feeder. Meat processor compensates cattle feeder $0.10/carcass side to cover the extra costs of needle-free injection. Cow-calf

[4] The U.S. beef industry does not implement WBSF test because of multiple limitations, including the value of meat damaged in the test and time (O'Quinn 2016). A WCTS, as stated in this paper, may be used to identify the tenderness attribute instead of WBSF test.

producer receives a price premium of $2.65/animal to cover the cost of needle-free injection and artificial insemination.

t=0.95

When a WCTS is implemented yet some information asymmetry exists, the numerical problem is solved with two steps. Following RFB, additional constraints (5) are imposed to ensure a higher income transfer for more favorable actions taken.For example, if there is no lesion detected, the income transfers should be highest. If there are lesions found in chuck steaks, the income transfers should be higher than if lesions are found in sirloin steaks, as the loss of discarding sirloin steaks are higher than that of discarding chuck steaks.

(5)

$$I_{1,(0)}^{n} \geq I_{0*}^{n}; I_{0*}^{n} \geq I_{1,(c)}^{n}; I_{1,(c)}^{n} \geq I_{1,(r)}^{n}; I_{1,(r)}^{n} \geq I_{1,(s)}^{n}; I_{1,(s)}^{n} \geq I_{1,(c,r)}^{n}; I_{1,(c,r)}^{n} \geq I_{1,(c,s)}^{n}; I_{1,(c,s)}^{n} \geq I_{1,(r,s)}^{n}; I_{1,(r,s)}^{n} \geq I_{1,(c,r,s)}^{n}.$$

Results are shown in Table 3 and Table 4. According to Table 3, when cow-calf producers do not select genetics to improve meat tenderness, the meat processor's lowest cost happens when cow-calf producers and cattle feeders both choose to inject using needle-free method, which is $969.25/head. Similarly, according to Table 4, when cow-calf producers select genetics to improve beef tenderness, the meat processor's lowest cost happens when cow-calf producers and cattle feeders both choose to apply needle-free injections, which is $957.70/head. Thus, the lowest-cost ($957.70/head) combination is when cow-calf producers choose to do AI to select genetics, and both agents inject with a needle-free method.

Under circumstances when the WCTS fails (5% of the transactions), the meat processor transfers $4.15/head to cow-calf producers, and $480.57/head to cattle feeders. Those income transfers are to cover the cow-calf producers' and cattle feeders' cost of participating in a WCTS, applying AI (cow-calf producers), and injecting using needle-free method (cow-calf producers and cattle feeders). Since the WCTS fails to work, the meat processor has to bear any potential losses from injection-site lesion and not gaining tenderness premiums. When the WCTS works, the meat processor transfers $4.38/head to cow-calf producers, and $480.81/head to cattle feeders, if genetic information is identified and no lesions are found. Except for lesions in a chuck steak, all other lesions identified result in a reduction in income transfers. The higher the loss caused by lesions, the lower is the income transfer. Cattle feeders receive higher than $480/carcass side from meat processor only when traceability fails to work, and lesions are only found in a chuck steak.

Tables 3 and 4 show that when agents (cow-calf producer and cattle feeder) switch from injecting in the rear leg to the neck area, the principal (meat processor) offers higher income transfers when traceability fails, lesions happen in chuck area, lesions happen in round area, or when no lesions are detected and traceability works. If one agent is moving from a less preferred injection method to a more preferred injection method, while the other agent keeps the same choice, the former would get higher income transfers when traceability fails to work and lesions are detected in chuck area only, or when no lesions are detected when traceability works. Meanwhile, the agent making no change receives almost unchanged income transfers.

But the principal (meat processor) decreases the income transfers when lesions are detected in other areas or combination of areas. The reason for this may be that when agents (cow-calf producer and cattle feeder) switch from less-preferred to more-preferred injection methods, the probabilities of favorable occasions (no lesions, or lesions in chuck area only) increase, while the probabilities of unfavorable occasions (lesions in round, sirloin, or combinations) decrease. Thus, the principal (meat procesor) may reward agents more on the favorable occasions and decrease income transfer on unfavorable occasions.

Comparisons of Scenarios
With symmetric information ($t = 1$), the principal (meat processor) pays a minimum cost of $954.71/animal. With t < 1 (second-best scenarios), whether traceability works or not, the principal (meat processor) pays a minimum cost of $957.70/animal. Thus, information asymmetry costs the principal $2.98/animal.

Without a WCTS, the meat processor pays $967.23/animal, including income transfers to the agents and the costs of disgarding beef cuts with lesions. The benefit to the principal of implementing a WCTS is $9.53/animal, after paying the cost of implementing a WCTS.

Summary
Implementing a WCTS in the U.S beef supply chain may bring many benefits, such as improved food safety, improved supply chain management, and value-added opportunities. This analysis has shown that in a three-stage beef supply chain with two value-added attributes, injection site and tenderness genetics, implementing a WCTS in the U.S. beef supply chain brings an extra profit of $9.53/animal.

In a WCTS in which participants can choose what information to share in the system and with whom to share it, incentives for providing value-added attributes, even those which are not easily identified at intermediate stages of the supply chain, are more feasible. Even though this analysis considers only two attributes, an extra profit of $9.53/animal is identified. If more attributes and more stages are included, the potential benefit of implementing a WCTS could increase. This suggests that a WCTS could promote value-based pricing without forgoing the efficiencies of the current commodity-based system.

Table 1. Frequencies of Injection-Site Lesions

Cow-Calf Producer	Probabilities of Lesions in	*Cattle Feeder* Injection in Rear Leg	Injection in the Neck Area	Injection with Needle-Free Method
Injection in Rear Leg	Pc	15.9914%	21.9517%	17.0527%
	Pr	18.5452%	14.3907%	15.7024%
	Ps	3.5230%	2.8222%	3.0794%
	P(c,r)	4.7376%	5.2155%	3.9038%
	P(c,s)	0.9045%	1.0262%	0.7689%
	P(r,s)	1.0481%	0.6275%	0.6847%
	P(c,r,s)	0.2555%	0.2207%	0.1635%
	P0	54.9947%	53.7455%	58.6445%
Injection in the Neck Area	Pc	24.3962%	30.7517%	26.0153%
	Pr	12.8667%	9.2220%	10.0626%
	Ps	2.5316%	1.8832%	2.0548%
	P(c,r)	5.2192%	4.7657%	3.9251%
	P(c,s)	1.0304%	0.9761%	0.8044%
	P(r,s)	0.5694%	0.2946%	0.3215%
	P(c,r,s)	0.2168%	0.1446%	0.1177%
	P0	53.1698%	51.9621%	56.6985%
Injection with Needle-Free Method	Pc	17.2392%	23.7573%	18.3834%
	Pr	14.3338%	10.2181%	11.1494%
	Ps	2.8216%	2.0876%	2.2779%
	P(c,r)	3.7521%	3.7697%	2.8383%
	P(c,s)	0.7404%	0.7717%	0.5814%
	P(r,s)	0.6289%	0.3237%	0.3532%
	P(c,r,s)	0.1574%	0.1155%	0.0860%
	P0	60.3267%	58.9564%	64.3304%

Table 2. Expected Costs to the Principal and Income Transfers to Agents Under Symmetric Information

Cow-Calf Producer Selecting Genetics	Cow-Calf Producer's Injection	Cattle Feeder's Injection	Meat Processor's Expected Cost	Average Income Transfer to Cow-Calf Producer	Average Income Transfer to Cattle Feeder
		Rear Leg	967.23	0.00	480.00
No	Rear Leg	Neck Area	966.68	0.00	480.09
		Needle-Free	966.39	0.00	480.10
		Rear Leg	968.25	1.00	480.00
No	Neck Area	Neck Area	967.59	1.00	480.09
		Needle-Free	967.34	1.00	480.10
		Rear Leg	968.10	1.15	480.00
No	Needle-Free	Neck Area	967.48	1.16	480.08
		Needle-Free	967.18	1.15	480.10
		Rear Leg	957.01	2.55	480.00
Yes	Rear Leg	Neck Area	956.44	2.55	480.09
		Needle-Free	956.11	2.55	480.10
		Rear Leg	956.15	2.63	480.00
Yes	Neck Area	Neck Area	955.47	2.64	480.08
		Needle-Free	955.19	2.64	480.10
		Rear Leg	955.70	2.66	480.00
Yes	Needle-Free	Neck Area	955.04	2.65	480.08
		Needle-Free	954.71	2.65	480.10

Table 3. Minimized Cost of the Principal and Income Transfers to Agents with Injection-Site Only with a P-WCTS (95% success rate)

Cow-Calf Producer's Injection		Cattle Feeder's Injection		
		Rear Leg	*Neck Area*	*Needle-Free*
	Minimized costs	971.39	970.84	970.54
	Ia,0,*	1.42	1.42	1.43
	Ia,1,(c)	1.42	1.42	1.43
	Ia,1,(r)	1.42	1.42	1.43
	Ia,1,(s)	1.42	1.42	1.43
	Ia,1,(c,r)	1.42	1.42	1.43
	Ia,1,(c,s)	1.42	1.42	1.43
	Ia,1,(r,s)	1.42	1.42	1.43
	Ia,1,(c,r,s)	1.42	1.42	1.43
Rear Leg	Ia,1,(0)	1.42	1.42	1.43
	Ib,0,*	480.32	480.81	480.74
	Ib,1,(c)	480.32	480.81	480.74
	Ib,1,(r)	480.32	479.15	479.02
	Ib,1,(s)	480.32	479.15	479.02
	Ib,1,(c,r)	480.32	479.15	478.60
	Ib,1,(c,s)	480.32	479.15	478.60
	Ib,1,(r,s)	480.32	476.69	476.08
	Ib,1,(c,r,s)	480.32	476.69	475.67
	Ib,1,(0)	480.32	480.81	480.97
Neck Area	*Minimized costs*	970.57	969.92	969.66
	Ia,0,*	1.80	1.72	1.72
	Ia,1,(c)	1.80	1.72	1.72
	Ia,1,(r)	0.47	0.47	0.47
	Ia,1,(s)	0.47	0.47	0.47
	Ia,1,(c,r)	0.47	0.47	0.47
	Ia,1,(c,s)	0.47	0.47	0.47
	Ia,1,(r,s)	0.00	0.00	0.00
	Ia,1,(c,r,s)	0.00	0.00	0.00

	Ia,1,(0)	1.80	1.72	1.72
	Ib,0,*	480.32	480.68	480.58
	Ib,1,(c)	480.32	480.68	480.58
	Ib,1,(r)	480.32	479.10	479.03
	Ib,1,(s)	480.32	479.10	479.03
	Ib,1,(c,r)	480.32	479.10	478.49
	Ib,1,(c,s)	480.32	479.10	478.49
	Ib,1,(r,s)	480.32	476.77	476.30
	Ib,1,(c,r,s)	480.32	476.77	475.64
	Ib,1,(0)	480.32	480.68	480.84
Needle-Free	*Minimized costs*	970.15	969.54	969.25
	Ia,0,*	1.69	1.61	1.61
	Ia,1,(c)	1.69	1.61	1.61
	Ia,1,(r)	0.28	0.30	0.29
	Ia,1,(s)	0.28	0.30	0.29
	Ia,1,(c,r)	0.28	0.22	0.25
	Ia,1,(c,s)	0.28	0.22	0.25
	Ia,1,(r,s)	0.00	0.00	0.00
	Ia,1,(c,r,s)	0.00	0.00	0.00
	Ia,1,(0)	1.94	1.85	1.84
	Ib,0,*	480.33	480.68	480.57
	Ib,1,(c)	480.33	480.68	480.57
	Ib,1,(r)	480.33	479.10	478.96
	Ib,1,(s)	480.33	479.10	478.96
	Ib,1,(c,r)	480.33	479.10	478.54
	Ib,1,(c,s)	480.33	479.10	478.54
	Ib,1,(r,s)	480.33	476.77	476.20
	Ib,1,(c,r,s)	480.33	476.77	475.69
	Ib,1,(0)	480.33	480.68	480.81

Table 4. Minimized Costs of the Principal and Income Transfers to the Agents with Injection-Site and Tenderness Improvement

Cow-Calf Producer's Injection		*Cattle Feeder's Injection*		
		j=1	*j*=2	*j*=3
	Minimized costs	971.39	959.06	959.09
	Ia,0,*	3.98	3.98	3.98
	Ia,1,(c)	3.98	3.98	3.98
	Ia,1,(r)	3.98	3.98	3.98
	Ia,1,(s)	3.98	3.98	3.98
	Ia,1,(c,r)	3.98	3.98	3.98
	Ia,1,(c,s)	3.98	3.98	3.98
	Ia,1,(r,s)	3.98	3.98	3.98
	Ia,1,(c,r,s)	3.98	3.98	3.98
Rear Leg	Ia,1,(0)	3.98	3.98	3.98
	Ib,0,*	480.33	480.81	480.74
	Ib,1,(c)	480.33	480.81	480.74
	Ib,1,(r)	480.33	479.15	479.02
	Ib,1,(s)	480.33	479.15	479.02
	Ib,1,(c,r)	480.33	479.15	478.60
	Ib,1,(c,s)	480.33	479.15	478.60
	Ib,1,(r,s)	480.32	476.69	476.08
	Ib,1,(c,r,s)	480.32	476.69	475.67
	Ib,1,(0)	480.33	480.81	480.97
Neck Area	*Minimized costs*	959.14	958.45	958.17
	Ia,0,*	4.34	4.26	4.26
	Ia,1,(c)	4.34	4.26	4.26
	Ia,1,(r)	3.08	3.07	3.07
	Ia,1,(s)	3.08	3.07	3.07
	Ia,1,(c,r)	3.08	3.07	3.07
	Ia,1,(c,s)	3.08	3.07	3.07
	Ia,1,(r,s)	1.76	1.70	1.70

	Ia,1,(c,r,s)	1.76	1.70	1.70
	Ia,1,(0)	4.34	4.26	4.26
	Ib,0,*	480.33	480.68	480.58
	Ib,1,(c)	480.33	480.68	480.58
	Ib,1,(r)	480.33	479.10	479.03
	Ib,1,(s)	480.33	479.10	479.03
	Ib,1,(c,r)	480.33	479.10	478.49
	Ib,1,(c,s)	480.32	479.10	478.49
	Ib,1,(r,s)	480.33	476.77	476.30
	Ib,1,(c,r,s)	480.33	476.77	475.64
	Ib,1,(0)	480.33	480.68	480.84
Needle-Free	*Minimized costs*	970.15	958.03	957.70
	Ia,0,*	4.23	4.16	4.15
	Ia,1,(c)	4.23	4.16	4.15
	Ia,1,(r)	2.92	2.92	2.91
	Ia,1,(s)	2.92	2.92	2.91
	Ia,1,(c,r)	2.92	2.83	2.86
	Ia,1,(c,s)	2.92	2.83	2.86
	Ia,1,(r,s)	1.35	1.28	1.28
	Ia,1,(c,r,s)	1.35	1.28	1.28
	Ia,1,(0)	4.47	4.40	4.38
	Ib,0,*	480.32	480.68	480.57
	Ib,1,(c)	480.32	480.68	480.57
	Ib,1,(r)	480.32	479.10	478.96
	Ib,1,(s)	480.32	479.10	478.96
	Ib,1,(c,r)	480.32	479.10	478.54
	Ib,1,(c,s)	480.32	479.10	478.54
	Ib,1,(r,s)	480.32	476.77	476.20
	Ib,1,(c,r,s)	480.32	476.77	475.69
	Ib,1,(0)	480.32	480.68	480.81

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