A Principal-Agent Model for Evaluating the Economic Value of a Beef Traceability System: A Case Study with Injection-site Lesions Control in Fed Cattle in the US

The meat supply chain is traditionally a chain of independent production firms where product moves from one supplier to the next through open market transactions. Qualities, quantities and prices are established through observation and negotiation. However, downstream parties often do not have full information about food safety and food quality efforts exerted in upstream stages of production. Direct monitoring of production processes is prohibitively expensive in most cases. Moreover, problems which occur at an upstream stage of production often manifest themselves in downstream stages of production at which point the original supplier identity is lost. Some of the more prominent issues include toxic substances such as dioxin, foreign objects in products (e.g., syringe needles from treatments), bacterial contamination, feeding of restricted ingredients (e.g., animal by-products in the case of BSE).

Anonymity in which transactions occur in the open market limits the ability of upstream firms to drive unverifiable efforts and actions in a context of conflicting interests. Efforts have been undertaken to reduce anonymity by implementing production protocols, information technology and supply chain management processes to improve identification of products and suppliers throughout the supply chain. This complex process is referred to as traceability.

The implementation of a traceability system does not imply direct interventions in procedures and processes in the production to improve quality controls already in place. Yet some changes may be necessary, for instance limitations on product mixing may be needed for segregating output and thus preserve its origin identity (Antle, 2001). The International Organization for Standardization (ISO) points out that a traceability system just creates capability for the retrieval of the history, use or location of a product and activity or process through a registered identification (EAN.UCC, 2003). Therefore a traceability system is just an information system.

Traceability systems have been used as a tool to accomplish predetermined objectives regarding security improvement, quality control, fraud detection, fulfillment of consumer demands, compliance with international market standards and management of complex logistical chains (EAN International, 2003; Moe, 1998). Therefore, firms and government agencies first look at their predetermined objectives, the costs and benefits of available traceability systems and then determine the type of traceability system in terms of its breadth, depth and precision[1].

This article studies a traceability system that, with certain average traceback rate of success, maintains the identity of fed cattle suppliers attached to the meat being processed. This traceability system allows for linking problems which may occur at a downstream stage of production to the origin of the raw material. By doing so, this traceability system makes it feasible for a downstream firm to create and use incentive mechanisms. These incentive mechanisms are employed as a manner of driving actions to be undertaken by upstream firms. We first study the optimal level of expected traceback of success a traceability system should have to efficiently create incentive mechanisms. Second, we inquire into the economic value of this type of traceability system. The illustrative example of injection site lesions in beef production is used to examine the optimal expected traceback rate of success and the economic value of a beef traceability system from the slaughter floor to the fabrication floor in a meat packing plant in the US.

Research related to the effect of information asymmetry on food safety and quality seems to have developed in two directions: (1) works to study the effect of using a noisy grading or testing technology to infer producers' behaviors regarding their investment in product quality (adverse selection issue),

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[1] Breadth is the amount of information recorded by the system, depth defines how far backward and forward traceability is maintained, and precision represents the system's ability to pinpoint the original source of a problem (Golan et al., 2004).

(2) works to inquire into the effect of using a noisy grading or testing technology as a tool to create incentive mechanisms driving the level of effort put by producers on product quality and safety. The second group of works often apply the Pricipal-Agent (hereafter referred to as PA) framework.

As examples of the first group of works, Hennessy (1995) constructs a conceptual model wherein, by assumption, food processors test raw material supplied by producers as a method to protect their reputations in the consumer marketplace. Using this model, he shows that a price-grade type incentive is incapable of producing a market equilibrium wherein the first-best level of investment in quality by producers is attained. According to his model, sampling and measurement errors in the testing and grading are the reason for this to happen. As a solution to the underinvestment in quality by producers, he advocates that processors and producers will vertically integrate or source via product contracts. Along this same line of reasoning, Chalfant et al. (1999) argue that imperfect verification of quality may be mitigated by grading. However, incentives based on an imperfect grade will not be strong enough to induce producers to incur first-best investments in higher value product. The reason for this is that incentives to produce high quality raw material are lowered because grading a lower quality product as being of higher quality (type II error in grading) is a feasible event. In fact, this is the same explanation previously given by Hennessy (1995). Also Bogetoft and Olesen (2003) study the effect of using a noisy grading technology to infer producers' behaviors regarding investing in product quality. They show that the results obtained by Hennessy (1995) and Chalfant et al. (1999) hold only for a perfectly competitive market structure where trade occurs after grading (*a posteriori* competition) but does not necessarily hold for a competitive setting where all trade occurs before grading (*a priori* competition).

As examples of the second group of works, Dubois and Vukina (2004) adapt the closed form solution for a PA model with linear contracts, normally distributed measurement errors and Agent's exponential utility to econometrically estimate farmers' degree of risk aversion in contracting production of hogs. Their results give empirical evidence that Agent's degree of risk aversion constrain the set of possible incentive mechanisms to be offered by the Principal to Agents as predicted by the PA model. Starbird (2005) examines the effect of inspection policies set by the Principal on the efforts exerted by producers (Agents) concerning product safety. His findings support the idea that inspection policies are effective tools for improving food safety. King, Backus and Gaag (2004) develop and apply a dynamic principal-agent model for salmonella control in pork production in the Netherlands. By their model the Principal offers a contract to the Agent specifying the frequency at which the Agent's hogs will be tested on delivery, the share of the expected testing cost paid by producer, and the level of penalty per hog for a salmonella prevalence test that exceeds a tolerance level pre-defined by the Principal. The Agent may influence the salmonella prevalence in his/her hogs by adopting salmonella control packages that are more costly the more it reduces the expected prevalence level. Also, the Agent's salmonella control package choices affect his/her reputation over time and consequently the frequency at which the Agent's hogs will be tested. This feature gives the dynamic aspect in this study. The main contribution of this paper is to show that reputation-based contracts affect Agents' behavior.

A common characteristic of all those studies previously mentioned is that, at the time a signal correlated with an Agent's action is observed, the Principal knows the Agent's identity. This is certainly the case when raw material is tested on delivery. However, once the processing of the raw material starts, unobservable characteristics on its delivery may become observable. But at this time, the identity of the raw material supplier is likely to have been definitively separated from the processed product. This is exactly the case for injection-site lesions in meat. Because lesions can only be observed after processing cattle into beef, no incentive mechanism can be created if the identity of fed cattle suppliers is systematically separated from carcasses during their processing.

Management-related quality problems such as injection-site blemishes still cause losses for the beef industry in the US. Beef cattle are given injections of biological or antibiotic compounds at various stages of their lives to prevent disease and facilitate recovery from illness (Field and Taylor, 2004). When given intramuscularly these injections may cause tissue damage.

Results of the National Beef Quality Audit in 2000 revealed that beef packers believed the greatest quality improvement since 1991 has been the decreased frequency of injection-site lesions found in beef top sirloin subprimals (McKenna et al., 2002). Although the incidence of injection-site lesion defects in top sirloins is at a low record of 2.5%, purveyors and retailers still ranked this as one of the greatest quality challenges facing the U.S. beef industry. The National Cattlemen's Beef Association has recommended all injections, regardless of age, be moved to the neck and that subcutaneous injections be administered when allowable (Morgan, Tittor and Lloyd, 2004). However large muscle masses of the rear quarters provides a better target than the neck and animals do not need to be restrained if it is not necessary to inject a precise location (Hilton, 2005).

At the meat packer, carcasses are reduced into many beef products and like cuts from different carcasses are commingled to create consistent boxes of beef cuts and products. Hence, the direct tracking of products back to an individual animal and feedlot of origin is very difficult (Robb and Rosa, 2004). Injection-site lesions remain concealed within the muscles and subcutaneous fat which makes damage observable only during portioning of the primal cuts (Roeber et al., 2001). At this time, the identity of fed cattle supplier and animal ID are likely to have been detached from the primal cuts. Therefore, there may be an economic incentive for a meat packer to use a traceability system to trace injection-site lesions back to the animal and feedlot of origin. This article addresses this issue by examining the economic value and optimal traceback rate of success of a beef traceability system from the slaughter floor to the fabrication floor in a meat packing plant.

The Context for the Principal-Agent Game with a Traceability System in Place

An injection-site lesion is fully characterized by the beef retail cut being damaged. Three types of injection-site lesions may be observed: an injection-site lesion in the top sirloin butt, an injection-site lesion in the round and an injection-site lesion in the chuck steak. Feedlot owners may affect the type and frequency of injection-site lesion occurring in carcasses. Basically, a feedlot owner has three mutually exclusive actions to undertake. He/she may choose to give all injections in the rear leg, or in the neck area of an animal, or to use a needle-free technique regardless of the area. Based on how costly each action is, the order of preferences for the actions available to the feedlot owner is: to give all injections in the rear quarters is preferred to give all injections in the neck area, and to give all injections in the neck area is preferred to give all injections with a needle-free technique. On the other hand, according to the market value of beef retail cuts the meat packer prefers no injection-site lesions rather than injection-site lesions in chuck steak and injection-site lesions in chuck steak rather than injection-site lesions in top sirloin and round. Therefore, the order of preferences for the meat packers and feedlot owners are diametrically opposite which characterizes the conflicting interests between meat packers and feedlot owners in the present setting.

Injection-site lesions in cattle are concealed within the muscles and subcutaneous fat which makes damage observable only during portioning of the primal cuts (Roeber et al., 2001). In a typical meat packing plant, batches of carcass are broken down into primals, sub-primals and retail cuts at fabrication floor (Robb and Rosa, 2004). A traceability system in place makes it possible, with certain probability of success, that the identity of the fed cattle supplier and animal ID are still attached to the beef retail cuts when injection-site lesion damage is observed. Thus, a traceability system is added from the slaughter floor to the fabrication floor (traceability system's depth) in a typical meat packing plant. Information on a unique 20 digit animal ID number encoded in an electronic button tag is read on cattle delivery and stored by the traceability system. After a carcass is processed into sides, each carcass' side is individually identified with a lot and sequence number representing the order in which the electronic ID numbers were read (kill order). There is a rail for each carcass' side.

The traceability database system stores data on lot number, kill order, animal electronic ID number and the identity of fed cattle supplier (traceability system's breadth). Failures are expected to occur due to hardware and software breakdown and incompatibility, plant logistic and electromagnetic interferences with the Radio Frequency ID readers (Basarab, Milligan and Thorlakson, 1997). Hence the traceability system's precision is 100% whenever the system works properly, otherwise zero.

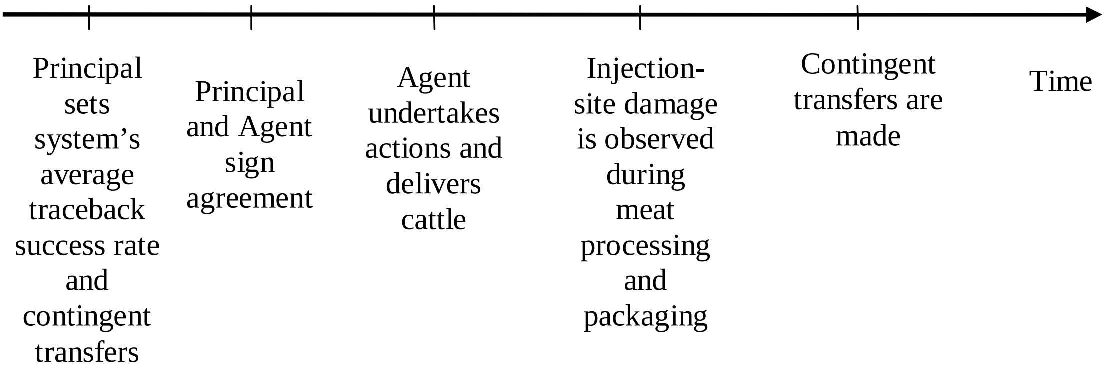
The Principal-Agent Game with a Traceability System in Place

A meat packer (Principal) purchases live animals from a group of homogeneous growers (Agents) indexed by $i = 1, ..., n$ to run a one-time project. Agent i undertakes actions that affect the frequency and type of injection-site damages in beef retail cuts. More specifically, an action a_i undertaken by Agent i belongs to the action space defined as A_i and are unverifiable by the time transactions take place. For the case study with injection-site lesions in cattle the action space will comprise three actions as $A_i = \{$To give all injections in the rear leg, To give all injections in the neck area, To give all injections with a needle-free technique$\}$.

The average rate by which a traceability system works, in terms of tracing back injection-site damage to the animal and fed cattle supplier, determines the expected traceback rate of success and fully characterizes a traceability system. Thus, the expected traceback rate of success from the slaughter floor to the fabrication floor gives the system's degree of reliability.

The two-stage sequential game with complete[2] and perfect information[3] played by the Principal and each Agent i runs as follows (see Figure 1). First, the expected traceback rates of success for the beef traceability system is set and announced to the Agents by the Principal; also, contingent income transfers are accorded. Second, the Principal and the Agent agree on the terms of a future transaction, even if a formal agreement or legal contract is not signed. Third, Agent i undertakes actions regarding the production of injection-site lesions in cattle and delivers fed cattle to the Principal. Fourth, injection-site lesions are observed or are not observed during beef processing and packing. Also, the traceability system works or does not work along the cattle processing and packing. Fifth, contingent payments are made.

Figure 1: The Principal Agent Game with Traceability



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[2] Players' payoff functions are common knowledge (see Gibbons, 1992).

[3] It means that at each move in the game the player with the move knows the full history of the game thus far (Gibbons, 1992: p.55). By the time an Agent moves he/she knows the expected traceability rate of success and also the contingent payment scheme.

The Model for the PA Game with a Traceability System

Every feasible event is defined for a carcass' side, assuming that what happens with a carcass' side is independent of what happens with the other carcass' side of an animal. Therefore, the final expected cost per head is just twice as much as the cost per carcass' side. In a setting wherein there is a traceability system in place and three types of injection-site lesions, the sample space comprises sixteen feasible events defined as follows.

Definition 1 *A collection of 4-tuples composes the sample space for the asymmetric information setting with traceability* $E = \{(z_1, z_2, z_3, z_4) : z_1 = 0 \text{ or } 1; z_2 = 0 \text{ or } 1; z_3 = 0 \text{ or } 1; z_4 = 0 \text{ or } 1\}$. *Where* z_1 *equals* 1 *if the traceability system works, otherwise* 0*;* z_2 *equals* 1 *if a lesion in a top sirloin butt is observed, otherwise* 0*;* z_3 *equals* 1 *if a lesion in a bottom-round is observed, otherwise* 0*;* z_4 *equals* 1 *if a lesion in chuck steak is observed, otherwise* 0*.*

The Principal task is to set contingent income transfers as \$ per carcass' side so that an incentive mechanism is created and offered to each Agent. Thus, let $v(z_1, z_2, z_3, z_4)$ be the income transfer to Agent i as \$ per carcass' side contingent on the event $(z_1, z_2, z_3, z_4) \in E$ occurring.

A meat packer has no means of making contingent transfers to a feedlot owner based on the observed injection-site damage whenever the traceability system does not work. The reason for this is that it will be impossible to traceback the injection-site lesion damage to the animal and to the feedlot of origin. This will be the case for these eight feasible events $(0, 0, 0, 0)$, $(0, 0, 0, 1)$, $(0, 0, 1, 0)$, $(0, 0, 1, 1)$, $(0, 1, 0, 0)$, $(0, 1, 0, 1)$, $(0, 1, 1, 0)$ and $(0, 1, 1, 1)$. Thus, let I_0 be the income transfer to the Agent as \$ per carcass' side whenever the traceability system does not work (contingency 0).

On the other hand income transfers to Agents contingent on observed injection-site lesion damage become feasible whenever the traceability system works. These contingent income transfers to Agent i as \$ per carcass' side are defined as follows. $I_1 \equiv v(1, 0, 0, 0)$ is the income transfer when no injection-site lesion damage is observed (contingency 1); $I_2 \equiv v(1, 0, 0, 1)$ is the income transfer when at least one injection-site lesion in chuck steak is observed (contingency 2); $I_3 \equiv v(1, 0, 1, 0)$ is the income transfer when at least one injection-site lesion in bottom-round is observed (contingency 3); $I_4 \equiv v(1, 0, 1, 1)$ is the income transfer when at least one injection-site lesion is observed in bottom-round and chuck steak (contingency 4); $I_5 \equiv v(1, 1, 0, 0)$ is the income transfer when one injection-site lesion in top sirloin butt is observed (contingency 5); $I_6 \equiv v(1, 1, 0, 1)$ is the income transfer when at least one injection-site lesion is observed in top sirloin butt and chuck steak (contingency 6); $I_7 \equiv v(1, 1, 1, 0)$ is the income transfer when at least one injection-site lesion is observed in top sirloin butt and bottom-round (contingency 7); $I_8 \equiv v(1, 1, 1, 1)$ is the income transfer when at least one injection-site lesion is observed in top sirloin butt, bottom-round and chuck steak (contingency 8).

The probabilities of a success event for each random variable in the model are given as follows. $s \equiv F_1(z_1 = 1)$ is the probability that the traceability system works in terms of preserving animal ID and the identity of fed cattle supplier attached to beef retail cuts; $F_2(a_i) \equiv F_2(z_2 = 1|a_i)$ is the probability that at least one injection-site lesion in a top sirloin butt is observed given Agent i undertook action $a_i \in A_i$; $F_3(a_i) \equiv F_3(z_3 = 1|a_i)$ is the probability that at least one injection-site lesion in a bottom-round is observed given Agent i undertook action $a_i \in A_i$; and $F_4(a_i) \equiv F_4(z_4 = 1|a_i)$ is the probability that at least one injection-site lesion in chuck steak is observed given Agent i undertook action $a_i \in A_i$.

Probabilities of Events in which the Traceability System Does not Work

Assuming every random variable is independent from each other, the probabilities of occurrence for each feasible event in which the traceability system does not work for a carcass' side are given as follow. $P(0, 0, 0, 0) = (1-s)(1-F_2(a_i))(1-F_3(a_i))(1-F_4(a_i))$ is the probability that no injection-site lesion occurs; $P(0, 0, 0, 1) = (1-s)(1-F_2(a_i))(1-F_3(a_i))F_4(a_i)$ is the probability that at least one injection-site lesion is observed in chuck steak; $P(0,0,1,0) = (1-s)(1-F_2(a_i))F_3(a_i)(1-F_4(a_i))$ is the probability that at least one injection-site lesion is observed in bottom-round; $P(0,0,1,1) = (1-s)(1-F_2(a_i))F_3(a_i)F_4(a_i)$ is the probability that at least one injection-site lesion is observed in bottom-round and chuck steak; $P(0,1,0,0) = (1-s)F_2(a_i)(1-F_3(a_i))(1-F_4(a_i))$ is the probability that at least one injection-site lesion is observed in top sirloin butt; $P(0,1,0,1) = (1-s)F_2(a_i)(1-F_3(a_i))F_4(a_i)$ is the probability that at least one injection-site lesion is observed in top sirloin butt and chuck steak; $P(0,1,1,0) = (1-s)F_2(a_i)F_3(a_i)(1-F_4(a_i))$ is the probability that at least one injection-site lesion is observed in top sirloin butt and bottom-round; $P(0,1,1,1) = (1-s)F_2(a_i)F_3(a_i)F_4(a_i)$ is the probability that at least one injection-site lesion is observed in chuck steak, in bottom-round and in top sirloin butt;

Finally, the probability that the contingency 0, defined as when the traceability system does not work, is given by: $P_0 \equiv P(0,0,0,0) + P(0,0,0,1) + P(0,0,1,0) + P(0,0,1,1) + P(0,1,0,0) + P(0,1,0,1) + P(0,1,1,0) + P(0,1,1,1)$

Probabilities of Events in which the Traceability System Works

The probabilities of events in which the traceability system works and income transfer I_m is granted to Agent i are given as follows. $P_1 = s(1-F_2(a_i))(1-F_3(a_i))(1-F_4(a_i))$ is the probability that no injection-site lesion occurs; $P_2 = s(1-F_2(a_i))(1-F_3(a_i))F_4(a_i)$ is the probability that at least one injection-site lesion is observed in chuck steak; $P_3 = s(1-F_2(a_i))F_3(a_i)(1-F_4(a_i))$ is the probability that at least one injection-site lesion is observed in bottom-round; $P_4 = s(1-F_2(a_i))F_3(a_i)F_4(a_i)$ is the probability that at least one injection-site lesion is observed in bottom-round and chuck steak; $P_5 = sF_2(a_i)(1-F_3(a_i))(1-F_4(a_i))$ is the probability that at least one injection-site lesion is observed in top sirloin butt; $P_6 = sF_2(a_i)(1-F_3(a_i))F_4(a_i)$ is the probability that at least one injection-site lesion is observed in top sirloin butt and chuck steak; $P_7 = sF_2(a_i)F_3(a_i)(1-F_4(a_i))$ is the probability that at least one injection-site lesion is observed in top sirloin butt and bottom-round; $P_8 \equiv sF_2(a_i)F_3(a_i)F_4(a_i)$ is the probability that at least one injection-site lesion is observed in chuck steak, in bottom-round and in top sirloin butt.

Second-Best Expected Cost per Head to the Principal Using a Traceability System

Having previously defined all the necessary terms, the second-best expected cost per head to the Principal is given by (1).

$$
\begin{aligned}
E_c^{SB}(s, I_0, \ldots, I_8|a_i) = 2[&P_0 I_0 + P(0,0,0,1)p_c + P(0,0,1,0)p_r + P(0,0,1,1)(p_c + p_r) + \\
&+ P(0,1,0,0)p_s + P(0,1,0,1)(p_s + p_c) + P(0,1,1,0)(p_s + p_r) + \\
&+ P(0,1,1,1)(p_s + p_r + p_c) + P_1 I_1 + P_2(I_2 + p_c) + P_3(I_3 + p_r) + \\
&+ P_4(I_4 + p_c + p_r) + P_5(I_5 + p_s) + P_6(I_6 + p_s + p_c) + \\
&+ P_7(I_7 + p_s + p_r) + P_8(I_8 + p_s + p_r + p_c)] + g(s)
\end{aligned} \tag{1}
$$

where $g(s)$ gives the cost as \$ per head to trace an animal through a meat packing plant as a function of $s \in S$. Where s is the expected probability of success of preserving information on an animal ID and its supplier identity attached to beef retail cuts.; $p_c \in \Re_+$ is the opportunity cost of an injection-site lesion occurring in chuck steak as \$ per carcass' side; $p_r \in \Re_+$ is the opportunity cost of an injection-site lesion occurring in bottom-round as \$ per carcass' side; and $p_s \in \Re_+$ is the opportunity cost of an injection-site lesion occurring in top sirloin butt as \$ per carcass' side.

Expected Utility Function

Agents are homogeneous. Therefore, it is enough to set the utility function for one representative Agent. According to the crucial assumption in the model proposed by Grossman and Hart (1983: p.10) Agent i's utility function $U : \Re^2 \rightarrow \Re$ must be set as (2).

$$(2) \quad U(I_m, a_i) = k(a_i)u(I_m) - d(a_i)$$

where I_m is the income transfer as \$ per carcass' side from the Principal to Agent i in contingency $m \in \{0, 1, .., 8\}$; and $k(.)$ and $d(.)$ are real-valued, continuous functions defined for $a_i \in A_i$.

Grossman and Hart (1983) points out that to obtain a well behaved problem the real-valued function $u(.)$ must be strictly increasing, continuously differentiable and concave on the open interval $(\underline{I}, +\infty)$ with $\lim_{I_m \rightarrow \underline{I}} u(I_m) = -\infty$ that implies the Inada condition[4] $\lim_{I_m \rightarrow \underline{I}} u'(I_m) = \infty$. They also assume that $k(.)$ and $d(.)$ are real-valued, continuous function defined on the action space and that $k(.)$ is strictly positive.

Given an incentive mechanism set by the Principal as a 10-tuple $(s, I_0, .., I_8)$, Agent i's expected utility per carcass' side for every action $a_i \in A_i$ is given by (3).

$$(3) \quad U(a_i|s, I_0, .., I_8) = \sum\nolimits_{m=0}^{8} P_m k(a_i)u(I_m) - d(a_i) \;\; \forall a_i \in A_i$$

The Program for the Principal-Agent Model with Traceability

The Principal's problem is to determine $(s, I_0, .., I_8)$ for each level of $\widehat{a}_i \in A_i$ and then to select the action to be undertaken by Agent i's such that the overall minimum expected cost is obtained. In this way, the incentive mechanism $(s, I_0, .., I_8)$ should be such that it is going to be Agent's best interest to undertake the action chosen by the Principal. In the same fashion of the article by Grossman and Hart (1983), this problem is set as a two-step optimization procedure as follows.

First step: To solve the program (4) for each combination between $\widehat{a}_i \in A_i$ and $s \in S$. This implies that the program (4) has to be solved for each element of the set $A_i \times S$.

$$(4a) \quad \min_{I_0,..,I_8} E_c^{SB}(s, I_0, .., I_8|\widehat{a}_i) \text{ for every } \widehat{a}_i \times s$$

Subject to:

$$(4b) \quad \sum\nolimits_{m=0}^{8} P_m k(a_i)u(I_m) - d(\widehat{a}_i) \geq \overline{U}$$

$$(4c) \quad \sum\nolimits_{m=0}^{8} P_m k(\widehat{a}_i)u(I_m) - d(\widehat{a}_i) \geq \sum\nolimits_{m=0}^{8} P_{-m} k(a_i)u(I_m) - d(a_i) \forall \; a_i \in A_i$$

where $\overline{U}$ denotes Agent i's opportunity utility level associated with the best option available to trade a carcass' side[5]; P_m is the probability of each contingency m occurring calculated for a given action $\widehat{a}_i$; P_{-m} denotes the probability of contingency m for each feasible action other than $\widehat{a}_i$; The individual rationality or participation constraint is given by (4b); Finally, the incentive compatibility constraints are set as (4c). In our model, because the action space A_i is composed of three actions, two incentive compatibility constraints are necessary to be set (4).

With s and $\widehat{a}_i$ fixed at some level, the probabilities become constants or parameters for the model. Therefore, the constraint set is determined by the intersection of convex equations that assures a

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[4] See MacLeod (2003: p.218-19).

[5] For instance, $\overline{U}$ may be thought of as the level of utility Agent i can get by trading with a meat packer that does not use a traceability system and pays, in every contingency, the price given by the market equilibrium.

convex opportunity set for the program (4). Further, the objective function (4a) is linear in $I_0, .., I_8$. All of these characteristics together leads the program (4) to be a typical convex programming program. Therefore, if there exists a vector $I_0, .., I_8$ that solves program (4), then it generates a global minimum.

To facilitate the numerical resolution of the program (4), the participation constraint and incentive compatibility constraints are set in terms of certainty equivalent. Therefore, constraints (4b) and (4c) are respectively reset as (5) and (6).

$$v\left(\sum_{m=0}^{8} P_m k(a_i)u(I_m) - d(\widehat{a}_i)\right) \geq v(\overline{U}) \tag{5}$$

$$v\left(\sum_{m=0}^{8} P_m k(\widehat{a}_i)u(I_m) - d(\widehat{a}_i)\right) \geq v\left(\sum_{m=0}^{8} P_{-m} k(a_i)u(I_m) - d(a_i)\right) \forall\ a_i \in A_i \tag{6}$$

where $v(.)$ denotes the inverse function of the utility function $u(.)$.

The **Second step** consists of choosing, among those results obtained with the first step, the one that leads to the overall minimum expected costs per carcass' side to the Principal.

The Model for the Full Information Setting

Under the full information every action undertaken by Agent i is fully and freely verifiable by the Principal. Therefore contracts can be made on Agents' actions and the Principal has no incentive to use a traceability system as conceptualized in the present article. The reason is that there is a cost of imposing risk on Agents. This cost comes from the need of paying risk-premiums for risk averse Agents to get them to accept a risky contract. Therefore, if Agents' actions are verifiable it will be cheaper for the Principal to contract on Agents' actions than to condition payments on injection-site lesions occurring. By doing so, the Principal will avoid paying risk-premiums to Agents, and also will avoid costs incurred with a traceability system use. Summing up, the traceability system becomes unnecessary in the full information context.

Definition 2 *A collection of 3-tuples composes the full information setting sample space defined as* $E_{FB} = \{(z_2, z_3, z_4) : z_2 = 0 \text{ or } 1; z_3 = 0 \text{ or } 1; z_4 = 0 \text{ or } 1\}$ *where* z_2 *is* 1 *if a lesion in a top sirloin butt is observed, otherwise* 0*;* z_3 *is* 1 *if a lesion in a bottom-round is observed, otherwise* 0*; and* z_4 *is* 1 *if a lesion in a chuck steak is observed, otherwise* 0*.*

The sample space for the full information setting comprises eight events. Their probabilities of occurrence for a carcass' side are given as follows. $P(0,0,0) = (1 - F_2(a_i))(1 - F_3(a_i))(1 - F_4(a_i))$ is the probability that no injection-site lesion is observed; $P(0,0,1) = (1 - F_2(a_i))(1 - F_3(a_i))F_4(a_i)$ is the probability that at least one injection-site lesion is observed in chuck steak; $P(0,1,0) = (1 - F_2(a_i))F_3(a_i)(1 - F_4(a_i))$ is the probability that at least one injection-site lesion is observed in bottom-round; $P(0,1,1) = (1 - F_2(a_i))F_3(a_i)F_4(a_i)$ is the probability that at least one injection-site lesion is observed in bottom-round and chuck steak; $P(1,0,0) = F_2(a_i)(1 - F_3(a_i))(1 - F_4(a_i))$ is the probability that at least one injection-site lesion is observed in top sirloin butt; $P(1,0,1) = F_2(a_i)(1 - F_3(a_i))F_4(a_i)$ is the probability that at least one injection-site lesion is observed in top sirloin butt and chuck steak; $P(1,1,0) = F_2(a_i)F_3(a_i)(1 - F_4(a_i))$ is the probability that at least one injection-site lesion is observed in top sirloin butt and bottom-round; $P(1,1,1). \equiv F_2(a_i)F_3(a_i)F_4(a_i)$ is the probability that at least one injection-site lesion is observed in chuck steak, in bottom-round and in top sirloin butt;

The first-best expected cost per head to the Principal given Agent i undertakes action a_i is given by (7) :

$$\begin{aligned} E_c^{FB}(x_{FB}|a_i) &= 2[I_{FB} + P(0,0,1)p_c + P(0,1,0)p_r + P(0,1,1)(p_c+p_r) + P(1,0,0)p_s + \\ &\quad +P(1,0,1)(p_s+p_c) + P(1,1,0)(p_s+p_r) + P(1,1,1)(p_s+p_r+p_c)] \end{aligned} \tag{7}$$

where I_{FB} is the income the meat packer will transfer to Agent i if the action a_i is observed. The first-best PA model is solved with a two-step optimization procedure as follows.

First step: To solve the program (8).

(8a) $\min\limits_{I_{FB}} E_c^{FB}(I_{FB}|a_i)$ for every $a_i \in A_i$

Subject to:

(8b) $k(a_i)u(I_{FB}) - d(a_i) \geq \overline{U}$

Since $u(.)$ is strictly increasing in I_{FB}, $E_c^{FB}(I_{FB}|a_i)$ is also strictly increasing in I_{FB}. Therefore, the Principal offers an income transfer for each action a_i that just guarantees that the Agent's reservation utility is obtained. In other words, the participation constraint (8b) always binds. This result, jointly with the assumption on the behavior of the utility function $u(.)$, will imply that the optimal level of utility per carcass' side to be granted to the Agent i is given by solving (9).

(9) $u(I_{FB}^*) = \frac{\overline{U}+d(a_i)}{k(a_i)}$

Having found the value of $u(I_{FB}^*)$ it is straightforward to calculate the income to transfer to the Agent i if action a_i is observed as given by (10).

(10) $I_{FB}^* = v(u(I_{FB}^*))$

Second step: to choose among $a_i \in A_i$ the action that leads to the overall minimum expected cost for the Principal.

The Model for the Principal-Agent Game without Traceability

Without a traceability system being used, information on the identity of the fed cattle supplier and animal ID is detached from carcasses along their disassembly and fabrication. Therefore, without this information it becomes impossible for the Principal to create incentive mechanisms based on the observed injection-site lesion damage. Hence, the only alternative left to the Principal is to offer a constant transfer per head to Agent i. Because the Principal wants to minimize his/her costs he/she offers to pay exactly the value of the equilibrium price in the fed cattle market to Agent i. As a result Agent i will undertake the least costly action for him/her. Ultimately, the expected cost per head for the Principal that is not using a traceability system (E_c^{WT}) is given by (11).

$$\begin{aligned} E_c^{WT}(\overline{U}|a_i) &= 2[v(\overline{U}) + P(0,0,1)p_c + P(0,1,0)p_r + P(0,1,1)(p_c+p_r) + P(1,0,0)p_s + \\ &\quad +P(1,0,1)(p_s+p_c) + P(1,1,0)(p_s+p_r) + P(1,1,1)(p_s+p_r+p_c)] \end{aligned} \tag{11}$$

where $v(\overline{U})$ stands for the market value of a carcass' side; The remaining terms determine the expected cost of the negative externality created with injection-site lesion damage and is fully borne by the Principal that does not use a traceability system.

The first-best solution for the injection-site lesion case study is compared with the second-best solution by using equation (12).

(12) $\min\{E_c^{WT*}, E_c^{SB*}\} - E_c^{FB*}$

where E_c^{WT*} is the expected cost per head obtained for the second-best without traceability, and E_c^{SB*} is the overall minimum expected cost per head obtained for the second-best with traceability; E_c^{FB*} is the overall minimum expected cost per head obtained for the first-best problem.

The value obtained with (12) gives the cost of living in a world with asymmetric information as $ per head. This also gives the "Agency Costs" due to the separation of ownership and management. In the present context, the meat packer delegates the management of the feedlot to fed cattle suppliers. The Agency Cost is in theory mitigated by the use of incentive mechanisms and eliminated either by the meat packer buying the feedlot or vice versa (vertical integration).

The value of traceability as $ per head will be given by (13).

(13) $E_c^{WT*} - E_c^{SB*}$

where E_c^{WT*} is the expected cost for the second-best case without traceability as $ per head; and E_c^{SB*} is the overall minimum expected cost for the second-best model with traceability as $ per head.

Parameterizing and Calibrating the Models

Numerical exercises are conducted using the multiplicative separable utility functions (see Grossman and Hart, 1983: p.38) set by making $k(a_i) = e^{kc_a}$, $u(I_m) = -e^{-kI_m}$, and $d(a_i) = 0$. Thus, the multiplicative separable utility function is given as (14).

(14) $U(I_m, a_i) = -e^{-k(I_m - c_a)}$ with $k > 0$

where k is the coefficient of constant risk aversion.

By this utility functional form, the cost of effort appears just as negative income. Grossman and Hart (1983) uses this utility functional form to study the effect of the Agent's degree of risk aversion on the loss to the Principal from being unable to observe the Agent's action. The advantage of using (14) is that an increase in risk aversion can be represented simply by an increase in k. Further, treating effort as negative income makes the resulting contract easier to interpret (Haubrich, 1994).

Cost of Actions and Reservation Utility

First of all an injection yields two outcomes: a healthier animal and a potential injection-site lesion. Since the focus in this study is on the injection-site lesion case, we ignore the costs of producing a healthier animal and focus instead on the costs of causing an injection-site lesion. Table 1 summarizes the costs of the actions available to feedlot owners to undertake (see more details in Resende Filho, 2006).

The level of an Agent's reservation utility $(\overline{U})$ is calculated assuming that an average carcass weighs 787 pounds and is sold at $1.22 a pound (Roeber et al. 2000: p. 94). Therefore, a feedlot owner has a risk-free alternative of selling a carcass' side in the fed cattle market at $480. The level of an Agent's reservation utility $(\overline{U})$ is calculated using this value.

Table 1: Feedlot Owners' Actions and their Costs

Agent's Action	Cost ($ per carcass's side)
To give all injections in the rear leg	0
To move all injections to the neck area	0.17
To give all injections with a needle-free technique	0.204

Source: Based on Dee Griffin (2005).

Expected Frequency of Injection-Site Lesions in Beef Retail Cuts

Any intramuscular injection results in tissue irritation and scaring (Field and Taylor, 2004). However, it is not the case that every injection will with certainty cause a future lesion. Because a production function relating injections to lesions is not available, it is used observed frequencies of lesions at meat processing plant.

Based on Dee Griffin (2002), the average frequency of injection-site lesions in the chuck steak is set as 17.5%. It means that a meat packer that uses the market to buy all his/her raw material should expect that 17.5% of the chuck steaks fabricated in his/her plant will present at least one injection-site lesion. Relying on Roeber et al. (2000), we set the frequency by which injection-site lesions occurs in top sirloin butt as 2.5% and in bottom-round as 11.3%. Finally, the probability of a needle-free technology causing any type of injection-site lesion is set as zero (see Morgan, Tittor and Lloyd, 2004).

One may argue that the feedlot owner may choose not to give any injection, eliminating any chance of injection-site lesion. However, by not using a preventive vaccination program expected losses from animal diseases are assumed to be much higher than the costs of adopting a needle-free technique. Therefore, not giving injections at all is assumed to be a strictly dominated strategy for Agent i.

Opportunity Cost of Damaged Beef Retail Cuts

We use the same procedure employed by Roeber et al. (2000: p. 98-100) to estimate the expected loss with injection-site lesions per side of a fed steer and heifer harvested in 2000. Thus, we find that $p_s = \$11.02$ is the opportunity cost of an injection-site lesion occurring in top sirloin butt as $ per carcass' side; $p_r = \$9.91$ is the opportunity cost of an injection-site lesion occurring in bottom-round as $ per carcass' side; and $p_c = \$2.5$ is the opportunity cost of an injection-site lesion occurring in chuck steak as $ per carcass' side.

Expected Traceback Rates of Success and their Costs

Values for expected traceback rates of success are taken from experiments carried out by Basarab, Milligan and Thorlakson (1997) with traceability systems like those under analysis in this study. The expected traceback rates of success respectively for the traceability system 1, 2 and 3 are set as $S = \{38.9\%, 43.7\%, 95\%\}$. Therefore, a traceability system is fully characterized by its expected traceback rate of success.

Because there is no information linking those expected traceback rate of success with costs, we use a common cost functional form used in the PA literature (Prendergast, 1999) to represent the relation between traceability cost per head and expected traceback rate of success as follows:

$$(15) \quad g(s) = \kappa\frac{s^2}{2}$$

where $g(s)$ is the cost of tracing two carcass' sides from the slaughter floor to the fabrication floor in a meat packing plant with an expected traceback rate of success s; and $\kappa \in \Re_{++}$ is a constant.

We model a small-sized meat packing plant slaughtering 800 head per day with a Radio Frequency ID solution for each rail (one rail per each carcass' side) which leads to a traceability cost of \$0.11 per head (Pape et al., 2003). We assume that \$0.11 per head is the cost of a traceability system with a 38.9% expected traceback rate of success per head. We plug these values into equation (15) to calculate $\kappa = 2 * 0.11/0.389^2 = 1.4539$. Finally, plugging each element of the set S into $g(s) = 1.4539s^2/2$ yields the values presented in the third column of Table 2.

Table 2: Expected Traceback Rate of Success and their Costs

Traceability System	Expected Traceback Rate of Success: $F_1(a_i)$ (%)	Cost (\$/head)
1	38.9	0.110
2	43.7	0.139
3	95.0	0.656

Source: Expected traceback rates were observed by Basarab, Milligan and Thorlakson (1997); Costs are based on Pape et al. (2003) estimates.

Methods and Procedures to Solve the Models

Numerical solutions for the PA model with traceability are obtained using macros built with Visual Basic for Applications linking Microsoft Excel and Microsoft Excel Solver. The nonlinear convex programs (4) are numerically solved with the Microsoft Excel Solver using the Generalized Reduced Gradient (GRG2) nonlinear optimization code. The solution for the First-Best program (8) is analytically obtained by solving equation (9) for each Agent's action. With these results, it is calculated income transfers as given by (10) and the minimum first-best cost as given by (7). These calculations are also executed in a Microsoft Excel spreadsheet for each feasible action of Agent i.

Scenario Analysis and Discussion

In this article, we present the baseline scenario taken from a bigger study conducted by Resende Filho (2006), as a means of exemplifying how our models work. This scenario study is also enough to show one of the key results obtained in that study. The baseline scenario is constructed for agents with coefficient of absolute risk aversion set equal to 1.125 as also used by Haubrich (1994: p. 264).

Baseline Scenario

The baseline scenario for the Principal-Agent Model is characterized by feedlot owners being able to affect 75% of the ultimate expected frequency of injection-site lesions. Because part of the cattle production occurs in the cow-calf stage, the remaining 25% of the expected frequencies comes from this stage of production. Table 3 gives the expected frequency of injection-site lesion for each Agent's action. Details on how those frequencies are obtained can be found in Resende Filho (2006).

Table 3: Actions and Expected Frequency of Injection-site Lesion per Carcass' Side under the Baseline Scenario

Agent's Action	Expected Frequency of Injection Site Lesion in Top Sirloin Butt: $F_2(a_i)$ (%)	Expected Frequency of Injection Site Lesion in Bottom-Round: $F_3(a_i)$ (%)	Expected Frequency of Injection Site Lesion in Chuck Steak: $F_4(a_i)$ (%)
To give all injection in the rear leg	2.50	11.30	4.38
To move all injections to the neck area	0.63	2.83	17.50
To give all injections with a needle-free technique	0.63	2.83	4.38

Source: Based on Roeber et al. (2000), Dee Griffin (2002) and Morgan, Tittor and Lloyd (2004).

First-Best Results under the Baseline Scenario with the Coefficient of Absolute Risk Aversion Set Equal to 1.125

Results obtained by solving the first-best program (8) are shown in Table 4.

Table 4: First-Step Solution to the First-Best Model under the Baseline Scenario with the Coefficient of Absolute Risk Aversion Set Equal to 1.125

Agent's Action	Probability of First-Best Events							
	P (0,0,0)	*P* (0,0,1)	*P* (0,1,0)	*P* (0,1,1)	*P* (1,0,0)	*P* (1,0,1)	*P* (1,1,0)	*P* (1,1,1)
				(%)				
(1)	82.6989	3.7836	10.5355	0.4820	2.1205	0.0970	0.2701	0.0124
(2)	79.6683	16.8993	2.3161	0.4913	0.5011	0.1063	0.0146	0.0031
(3)	**92.3428**	**4.2248**	**2.6845**	**0.1228**	**0.5808**	**0.0266**	**0.0169**	**0.0008**

Agent's Action	E_c^{FB}: Expected Cost to the Principal ($/head)	I_{FB}: Income Transfers ($/carcass' side)
(1)	963.01	480.00
(2)	961.91	480.17
(3)	**961.32***	480.20

Note: (1) denotes the action of giving all injections in the rear leg, (2) refers to the action of giving all injections in the neck area, and (3) refers to the action of giving all injections with a needle-free technique; * denotes the overall minimum expected cost to the Principal.

Table 4 shows that the overall minimum expected cost to the Principal ($E_c^{FB} = \$961.32$ per head) occurs when Agent i gives all injections with a needle-free technique (action 3). Hence, the meat packer should contract every Agent to give all injections with a needle-free technique by offering a fixed income transfer of \$480.20 per carcass' side. Since \$480 is the value of a carcass' side in the market, \$0.20 per carcass' side is the price-premium the Principal pays to the Agent as a means of covering the additional costs the Agent incurs in giving all injections with a needle-free technique plus a risk-premium.

As it is a full information setting, if an Agent deviates from the contracted action, the Principal will know this for sure. For instance, if the Principal contracts an Agent to give all injections with a needle-free technique and the Agent gives instead all injections in the rear leg, the Principal will know this and may just pay nothing to the Agent as a punishment. Therefore, the Agent is always better off complying with the contract.

Since the meat packer contracts feedlot owners to give all injections with a needle-free technique, probabilities for each element in the First-Best sample space (E_{FB}) are given as follows (see these values in Table 4). No injection-site lesion will be observed in 92.3428% of the carcass' sides; At least one injection-site lesion will be observed in chuck steak in 4.2248% of the carcass' sides; At least one injection-site lesion will be observed in bottom-round in 2.6845% of the carcass' sides; At least one injection-site lesion will be observed in bottom-round and chuck steak in 0.1228% of the carcass' sides; At least one injection-site lesion will be observed in top sirloin butt in 0.5808% of the carcass' sides; At least one injection-site lesion will be observed in top sirloin butt and chuck steak in 0.0266% of the carcass' sides; At least one injection-site lesion will be observed in top sirloin butt and bottom-round in 0.0169% of the carcass' sides; And at least one injection-site lesion will be observed in chuck steak, in bottom-round and in top sirloin butt in 0.0008% of the carcass' sides. The reason for positive probabilities with the needle free injection is that cattle may have been needle injected at the cow-calf stage.

Second-Best without Traceability: Result under the Baseline Scenario with the Coefficient of Absolute Risk Aversion Set Equal to 1.125

The equilibrium for the game without traceability is for the Principal to pay the market equilibrium price \$960 per head (fed cattle market price), and for Agent i to give all injections in the rear leg since this is a zero cost action for him/her to undertake (see Table 1). Since the cost of giving all injections in the rear leg is zero, the expected costs for the first-best calculated with equation (7) and for the second-best without traceability calculated by equation (11) are equal. Therefore, the expected cost for a meat packer that does not use a traceability system is \$963.01 per head as presented in Table 4. Notice that this value is the same as if a meat packer had contracted feedlot owners to give all injections in the rear leg in a full information setting. Since to give all injections in the rear leg is the least costly action available to the Agent, there would be no gain for the Agent if he/she deviates from undertaking this action.

Second-Best with Traceability: Results under the Baseline Scenario with the Coefficient of Absolute Risk Aversion Set Equal to 1.125

The order of preference with respect to outcomes by the Principal's perspective is contingency 1 $\succ$ contingency 0 $\succ$ contingency 2 $\succ$ contingency 3 $\succ$ contingency 5 $\succ$ contingency 4 $\succ$ contingency 6 $\succ$ contingency 7 $\succ$ contingency 8. Income transfers (I_m) should be higher the more preferred is the contingency occurring. According to Salanié (1997: p.118) this will be the case only if a high action increases the probability of getting a high outcome at least as much as it increases the probability of getting a low outcome. This condition is called the Monotone Likelihood Ratio Condition (MLRC) and is formalized as follows:

$$(16) \quad \frac{P_{l,m}}{P_{j,m}} \geq \frac{P_{l,-m}}{P_{j,-m}}$$

for all action $l, j \in A_i$ with action l being more costly to Agents than action j, and for all contingencies m preferred to $-m$ from the Principal's perspective. The results to the MLRC test obtained by applying 16 showed that the Monotone Likelihood Ratio Conditions do not hold for the baseline scenario. To overcome this problem, the following eight additional constraints are imposed to the program (4) to guarantee that the more preferred the outcome is the higher the income transfer (I_m) will be[6]:

$$I_1 \geq I_0;\ I_0 \geq I_2;\ I_2 \geq I_3;\ I_3 \geq I_5;\ I_5 \geq I_4;\ I_4 \geq I_6;\ I_6 \geq I_7;\ I_7 \geq I_8$$

Results obtained by solving the first-step of the second-best PA model with traceability are presented in Table 5 and Table 6.

Table 5 shows in the third column the expected costs to the Principal for each combination between an action by the Agent and an expected traceback rate of success of a traceability system. The expected costs presented in the third column of Table 5 are the values for the objective function of the program (4) evaluated at its minimizer for each combination between Agent's action and traceability system's expected traceback rate of success.

Table 5: First-Step Results to the PA Model with Traceability under the Baseline Scenario with the Coefficient of Absolute Risk Aversion Set Equal to 1.125

Agent's Action	Traceability System's Expected Traceback Rate of Success (%)	Expected Cost: E_c^{SB} ($/head)
(1)	38.9	963.12
(2)	38.9	962.05
(3)	**38.9**	**961.47***
(1)	43.7	963.15
(2)	43.7	962.08
(3)	43.7	961.50
(1)	95.0	963.67
(2)	95.0	962.59
(3)	95.0	962.01

Note: (1) denotes the action of giving all injections in the rear leg, (2) refers to the action of giving all injections in the neck area, and (3) stands for the action of giving all injections with a needle-free technique; * denotes the overall minimum expected cost to the Principal.

The second-step in solving the PA model with traceability consists of choosing the equilibrium strategies that lead to the overall minimum expected cost to the Principal. From Table 5, $961.47 per head is the overall minimum expected cost that the Principal can obtain. This expected cost can be obtained if an incentive mechanism can induce the Agent i in his/her best interest to give all injections with a needle-free technique (action 3). Such an incentive mechanism presented in Table 6 is set as follows.

First, the Principal announces that his/her traceability system will be set a 38.9% of expected traceback rate of success. This informs Agents that there will be 38.9% chance that their identities will remain attached to final beef retail cuts. Therefore, the traceability system with the lowest expected traceback rate of success among those under analysis is capable of generating an incentive mechanism strong enough to lead Agents in his/her best interest to give all injections with a needle-free technology. The role played by the traceability system is to allow for an incentive scheme that makes the preferred action by the Principal also the preferred action by the Agent. In the present setting the action to be induced happens to be the action that would have been contracted in a full information setting.

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[6] We thank Robert P. King for his comments and suggestions regarding this point.

Second, the Principal announces the income to be transferred to the Agent in each contingency as \$ per carcass' side. In order to induce Agents to give all injections with a needle-free technique, \$480.23 will be paid to the Agent if the traceability system does not work (contingency 0). For instance, if the traceability system works then \$480.26 will be transferred if no damage is observed (contingency 1), \$479.72 will be transferred if at least one injection-site lesion is observed in chuck steak (contingency 2) and so on for the rest of results.

Notice that all incentive scheme respect the order of preference regarding the outcomes from the Principal's perspective (contingency 1 $\succ$ contingency 0 $\succ$ contingency 2 $\succ$ contingency 3 $\succ$ contingency 5 $\succ$ contingency 4 $\succ$ contingency 6 $\succ$ contingency 7 $\succ$ contingency 8) since income transfers (I_m) respect the the order given as $I_1 \geq I_0 \geq I_2 \geq I_3 \geq I_5 \geq I_4 \geq I_6 \geq I_7 \geq I_8$.

Table 6: Incentive Mechanisms Obtained with the First-Step Solution to the PA Model with Traceability under the Baseline Scenario with the Coefficient of Absolute Risk Aversion Set Equal to 1.125

Agent's Action	Traceability System's Expected Traceback Rate of Success (%)	Income Transfers								
		I_0	I_1	I_2	I_3	I_4	I_5	I_6	I_7	I_8
		($/carcass' side)								
(1)	38.9	480.00	480.00	480.00	480.00	480.00	480.00	480.00	480.00	480.00
(2)	38.9	480.18	480.18	480.18	479.99	479.99	479.99	479.99	475.48	475.48
(3)	**38.9**	**480.23**	**480.26**	**479.72**	**479.72**	**479.71**	**479.72**	**479.71**	**475.40**	**475.39**
(1)	43.7	480.00	480.00	480.00	480.00	480.00	480.00	480.00	480.00	480.00
(2)	43.7	480.19	480.19	480.19	479.99	479.99	479.99	479.99	475.58	475.58
(3)	43.7	480.23	480.26	479.76	479.76	479.76	479.76	479.76	475.50	475.50
(1)	95.0	480.00	480.00	480.00	480.00	480.00	480.00	480.00	480.00	480.00
(2)	95.0	480.19	480.19	480.19	479.99	479.99	479.99	479.99	476.32	476.32
(3)	95.0	480.22	480.24	479.98	479.98	479.97	479.98	479.97	476.18	476.18

Note: (1) denotes the action of giving all injections in the rear leg, (2) refers to the action of giving all injections in the neck area, and (3) stands for the action of giving all injections with a needle-free technique.

Because the incentive compatibility constraints are satisfied, it will be in the Agents' best interest to give all injections with a needle-free technique given such an incentive mechanism. Therefore, the probability of each contingency $m \in \{0, 1, ..., 8\}$ is shown in Table 7 in the row with Agent's action 3 and expected traceback rate of success of 38.9%. Hence, the Principal will transfer to the agent \$480.23 per carcass side 61.1% of time, \$480.26 per carcass side 35.9214% of the time and so on for the rest of results. Using these values to calculate the expected transfer to Agent i yields \$480.22 per carcass' side. In other words, the Principal will pay a premium of \$0.22 per carcass' side to get Agents to accept this incentive mechanism. This price premium is to cover the higher costs the Agent will incur to give all injections with a needle-free technique and to pay the risk-premium necessary to get Agents to participate. Further, notice that the income transfers will vary little across contingencies. This is a sign that the Principal avoids imposing risk on Agents in order to minimize the need for paying risk premiums to Agents.

The cost of living in a second-best world as given by equation (12) is

$$\min\{963.01, 961.47\} - 961.32 = \$0.15 \text{ per head}$$

Table 7: Frequency of Income Transfers to the PA Model with Traceability under the Baseline Scenario

Agent's Action	Traceability System's Expected Traceback Rate of Success (%)	Probability of Contingency *m* Occurring (%)								
		P_0	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8
(1)	38.9	61.1000	32.1699	1.4718	4.0983	0.1875	0.8249	0.0377	0.1051	0.0048
(2)	38.9	61.1000	30.9910	6.5738	0.9009	0.1911	0.1949	0.0413	0.0057	0.0012
(3)	**38.9**	**61.1000**	**35.9214**	**1.6435**	**1.0443**	**0.0478**	**0.2259**	**0.0103**	**0.0066**	**0.0003**
(1)	43.7	56.3000	36.1394	1.6534	4.6040	0.2106	0.9267	0.0424	0.1181	0.0054
(2)	43.7	56.3000	34.8151	7.3850	1.0121	0.2147	0.2190	0.0464	0.0064	0.0014
(3)	43.7	56.3000	40.3538	1.8463	1.1731	0.0537	0.2538	0.0116	0.0074	0.0003
(1)	95.0	5.0000	78.5639	3.5944	10.0087	0.4579	2.0145	0.0922	0.2566	0.0117
(2)	95.0	5.0000	75.6849	16.0544	2.2003	0.4667	0.4760	0.1010	0.0138	0.0029
(3)	95.0	5.0000	87.7257	4.0136	2.5503	0.1167	0.5517	0.0252	0.0160	0.0007

Note: (1) denotes the action of giving all injections in the rear leg, (2) refers to the action of giving all injections in the neck area, and (3) stands for the action of giving all injections with a needle-free technique.

Notice that \$0.15 per head is incurred because a traceability system has to be in place and price-premiums have to be paid to Agents. According to Agency Theory, such cost could be avoided if ownership and management were put together by either the feedlot owner buying the meat packing plant or vice versa (vertical integration).

The value of traceability calculated using equation (13) is

$$\$963.01 - \$961.47 = \$1.54 \text{ per head}$$

Recall that without a traceability system in place the identity of the cattle suppliers and animal ID will certainly be lost during carcass fabrication and processing, which will preclude any incentive mechanism from existing. Thus, the reduction in the losses with injection-site lesions by inducing an Agent to give all injections with a needle-free technique offsets the costs incurred with a traceability system, price premiums to compensate Agents for undertaking a more costly action and for Agents to accept a risky incentive mechanism.

Finally, a meat packing plant processing 800 head per day would save $800 * \$1.54 = \$1,232$ per day if a traceability system from the slaughter room to the fabrication floor were in place in a setting like the baseline scenario with risk averse Agents with coefficient of absolute risk aversion equal to 1.125.

Conclusions

Damages from injection-site lesions are still a concern in the beef industry. This study has adapted the general two-step procedure developed by Grossman and Hart (1983) to model and solve a Principal-Agent model wherein a meat traceability system is in place to affect the decision of injection-site choice in cattle. This extends the Grossman and Hart (1983) work to make it applicable to a real case-study.

The objectives of the present work were to investigate the economic value and the optimal expected traceback rate of success for a traceability system from the slaughter floor to the fabrication floor in a meat packing plant. Hence, the conclusions are presented in two blocks as follows.

Regarding the economic value of a traceability system:

It has been found that a meat traceability system may have economic value as a device allowing for an incentive mechanism to exist. Yet, the incentive mechanisms made feasible with the use of a traceability system are not expected to offer much different income transfers across contingencies. The Principal chooses not to put much risk on the Agents, therefore avoiding to pay high risk-premiums to get Agents to participate.

It has been observed that, by allowing the Principal to create and use incentive mechanisms, a meat traceability system could induce Agents in his/her best interest to undertake the first-best action.

Regarding the optimal expected traceback rate of success of the traceability system:

We found that 38.9% is the optimal expected traceback rate of success to be chosen by the Principal among those considered as feasible in the present study. This is the lowest expected traceback rate of success among those evaluated in this article. This finding supports the idea that it is possible for a relatively unreliable traceability system to allow for incentive mechanisms strong enough to induce feedlot owners in their best interest to undertake the first-best action.

The Principal-Agent model developed in the present study shows potential to be employed in studying other problems in which identity preservation is a concern. For instance, our conceptual model might be adapted to study the case of non point source pollution. To see the similarities with the injection-site lesion case, suppose that there exist alternative technologies based on markers making it possible to trace a type of pollution to an Agent (source). Further, marker based technologies show different costs and expected traceback rate of success. Agents affect with their actions the type and the probability of pollution occurring with more costly actions to Agents being preferred actions from the Principal perspective (conflicting nature of the problem). The information asymmetry exists because monitoring actions undertaken by the Agents is too costly to be economically feasible. Finally, the Principal seeks to minimize the society's costs with pollution. Since the level of type of pollution occurring is observable, the Principal wants to be capable of devising incentive mechanisms. Therefore, based on the level of type of pollution occurring and on the expected traceback rate of success of marker based technology the Principal may create incentive mechanisms to drive unverifiable action by Agents.

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