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

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Abstract

This article investigates the economic value and the optimal expected traceback rate of success for a traceability system with a case study of injection-site lesions in fed cattle in the US. By maintaining the identity of the feedlot owners corresponding to retail beef cuts, a traceability system enables the employment of incentive mechanisms by a meat packer to overcome supply chain information asymmetry. Results of this article show that the first-best action of producers may be induced by meat packers with incentive mechanisms created with a low expected traceback rate of success. This suggests that even inexpensive traceability systems may induce appropriate actions by producers and objectives of inducing compliance by suppliers may be less costly than objectives of recall.

Keywords: Information Asymmetry, Identity Preservation, Meat Traceability, Supply Chain Management

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

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. In this market structure, downstream operations often do not have full information about food safety and food quality efforts exerted in upstream stages of production, and direct monitoring of production processes is often prohibitively expensive. Moreover, problems that 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., broken syringe needles from health treatments), bacterial contamination, and feeding of restricted ingredients (e.g., animal by-products in the case of BSE).

In response, efforts have been made to reduce supply chain 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 International Organization for Standardization (2000) states that traceability systems create the ability to retrieve the history and application or location of an article or an activity or process through a registered identification. Implementing traceability may go beyond information systems to include alteration of the production process. For instance, limitations on product mixing may be needed for segregating output to preserve its origin identity (Antle 2001).

Firms considering implementation of traceability must evaluate the direct costs and benefits of available traceability systems taking into account their breadth, depth and precision[1]. However, in addition to the direct cost-benefit analysis, the value of using traceability to improve the behavior and compliance of upstream suppliers is an important consideration. Product tracing can improve the quality or safety of the final product and also ensure that appropriate market signals are communicated, reducing the sub-par performance predicated on information asymmetry and improving the economic efficiency of the overall supply chain. This paper seeks to focus on key factors affecting the success of traceability in improving compliance and on how to evaluate incentives necessary to ensure compliance with traceability objectives. To do so, we use the illustrative case presented by injection site lesions in beef to complete a numerical simulation framework that has broad application to many similar issues of information asymmetry in food supply chains.

The Case of Injection Site Lesions (ISLs) in Beef

Management-related quality problems such as injection-site blemishes cause substantial losses for the beef industry in the United States. 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. Although the incidence of injection-site lesion defects in top sirloins is at a record low of 2.5% (McKenna *et al*. 2002), purveyors and retailers still ranked this as one of the greatest quality challenges facing the U.S. beef industry. In response, 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).

ISLs remain concealed within the muscles and subcutaneous fat which makes damage observable only during portioning of the primal cuts (Roeber *et al*. 2001). The meat packer fabricates carcasses 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). Therefore, there may be an economic incentive for a meat packer to use a traceability system to trace ISLs back to the animal and feedlot of origin so that price discounts and rewards can be implemented. However, traceability systems are costly and as with grading systems it is likely that there will be measurement error in traceability systems.

This article uses a principal agent game structure to identify optimal levels of traceability (probability of accurately identifying offenders) and to help quantify incentive mechanisms necessary to induce first best behavior on the part of risk averse agents. The generalized principal-agent framework necessary to numerically solve the problem is developed and parameterized using technical information on ISLs in beef. Two scenarios are compared to the present beef supply chain where information asymmetry exists and there is no traceability. One scenario assumes there is no information asymmetry (the first-best situation), and the other assumes there is information asymmetry but the packer can implement a traceability system to overcome the asymmetry.

Previous Research

Research related to the effect of information asymmetry on food safety and quality has focused on two alternative strategies: (1) to select producers' types on the basis of their levels of investment in product quality (overcoming adverse selection) and (2) to induce producers' levels of effort on product quality and safety by incentive mechanisms (overcoming moral hazard).

Hennessy (1996), Chalfant *et al*. (1999) and Bogetoft and Olesen (2003) address the adverse selection issue. Hennessy and Chalfant *et al.* show that measurement errors in testing and grading cause price-grade incentives to be insufficient to a market equilibrium in which the first-best level of investment in quality by producers is attained. And Bogetoft and Olson show that these results hold only when trade occurs after grading, but do not hold when trade occurs before grading as in the present case of ISLs.

Dubois and Vukina (2004), Starbird (2005) and King, Backus and Gaag (2007) are representative of studies investigating incentive mechanisms. In all cases, principal-agent models are employed to evaluate the impacts of alternative incentive schemes on inducing desired performance. King, Backus and Gage further show that reputation can be an added incentive mechanism to induce performance under a contract.

A common characteristic of all previous studies 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 begins, unobservable delivery characteristics may become observable. By this time the identity of the raw material supplier is likely to have been separated from the processed product. This is the situation of injection-site lesions in beef, which provides the case for modeling the potential value of traceability systems and extends previous research to include traits which are unobservable at the time of trade.

Conceptual Framework for the Principal-Agent Game

A stylized description of the characteristics of the injection lesion problem is developed in a principal-agent analytical framework. A meat packer (principal) purchases live animals from a group of homogeneous feedlot owners (agents) indexed by $i = 1,\ldots, N$ to run a one-time project.

Prior to this purchase, agent *i* (the feedlot owner) gives injections by a method that affects the frequency and type of injection-site damages in beef retail cuts. The action space for injection and for each agent *i* 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} which are unverifiable at the time of sale. Giving injections in the rear leg potentially results in lesions in the highest valued cuts of the animal, while giving injections in the neck area may still result in lesions but in lower valued cuts. The needle free injection method is most costly to implement, but is assumed to produce no lesions (Morgan, Tittor and Lloyd 2004). The feedlot owner could choose not to give any injection. However, we assume that the expected losses from animal diseases will be much higher than the costs of adopting a needle-free technique, so that not giving injections is a strictly dominated strategy for agent *i*.

A stylized traceability system is assumed to be added from the slaughter floor to the fabrication floor (traceability system's depth) in a typical beef packing plant. Basarab, Milligan and Thorlakson (1997) describe a traceability system that we will assume is employed. The system employs radio frequency identification, database management of products and flows, and sequential processing methods to maintain the identity of product to its origin.

The traceability system is fully characterized by its expected traceback success of preserving information on an animal ID, and its supplier identity attached to beef retail cuts defined as $t \in T$. Experiments conducted and reported by Basarab, Milligan and Thorlakson (1997) are used to set the expected traceback rates of success for three traceability systems as 38.9%, 43.7% and 95% respectively, so that T = {38.9%, 43.7% and 95%}.

Failures are expected to occur due to hardware and software breakdown and incompatibility, plant logistics and electromagnetic interferences with the radio frequency identification readers. However, whenever the system works properly it is 100% effective in tracing the product to the specific feedlot owner.

Given the above stylized premise of agents' injection actions affecting lesions and the beef packer purchasing the cattle employing a traceability system, the two-stage sequential game with complete and perfect information played by the principal and each agent *i* runs as shown in Figure 1[2].

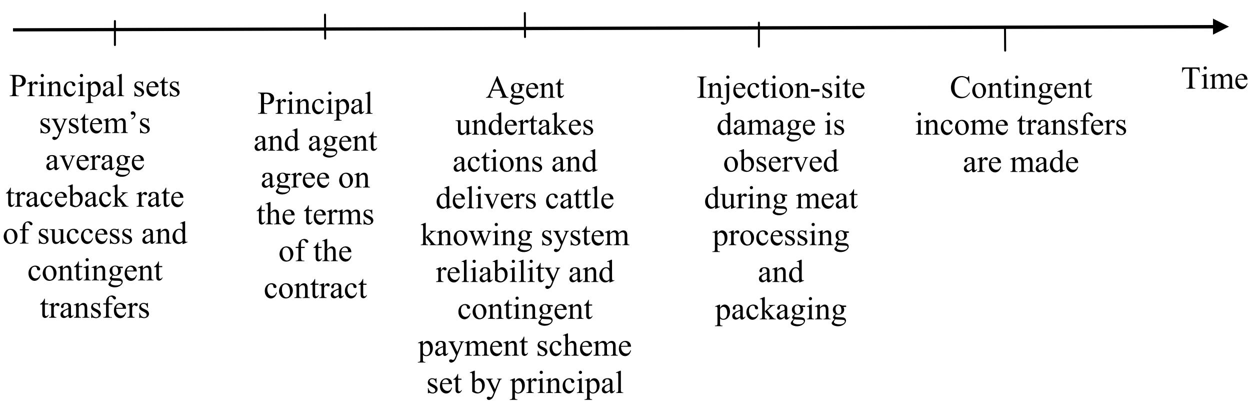

Figure 1. The timing of the principal-agent game with traceability

Mathematical Optimization of Principal Agent Game

The Principal's Cost Minimization Function

Every feasible event and its probability of occurrence is characterized in the context of injection-site lesions with a traceability system in place. The variable $P_{l,(j)}$ represents the probability of a particular injection site lesion outcome for the final product sold. For l=0, the traceability system fails to work, making the packer unable to identify the origin of a lesion even if it exists. For l=1, the traceability system works properly, making the packer able to identify the origin of the lesion if it exists. The cost of the system is assumed to be a function of the success rate, so that more reliable systems will cost more to implement and operate. Subscript j identifies the individual lesion or combination of lesions which can be found in each carcass' side[3]. There are sixteen possible combinations (eight for if the traceability system works (l=1), and eight for if the traceability system fails to work (l=0)). Using the subscripts 'c' for chuck steak, 'r' for round steak and 's' for sirloin steak the j subscript can take on any combination of these three types of lesions or none of them. So, for example, $P_{1,0}$ is the case where the traceability system works and no lesion is observed. Meanwhile, $P_{1,(c,r,s)}$ is the case where the traceability system works properly and there is at least one lesion in the chuck, in the round and in the sirloin, and so on. Finally, the probability that the traceability system will fail to work, P_{0*}, is calculated as the summation of all event's probabilities in which the traceability system fails to work ($P_{0*}=\sum_{j=0}^{(c,r,s)} P_{0,(j)}$).

All ISL event probabilities depend on the action undertaken by the agent i. Therefore, we define the probabilities of an ISL event for each of the random variables affected by the injection method used by agent i as follows: $F_c(a_i)$ at least one injection-site lesion in a chuck steak is observed given agent i undertook action $a_i \in A_i$; $F_r(a_i)$ at least one injection-site lesion in a bottom-round is observed given agent i undertook action $a_i \in A$; $F_s(a_i)$ at least one injection-site lesion in a top sirloin butt is observed given agent i undertook action $a_i \in A_i$. Given these definitions, it is possible to calculate all the probabilities in the model. For instance, to calculate the probability that the traceability system works properly when implemented and at least one lesion will be observed in the chuck, in the round and in the sirloin we use $P_{1,(c,r,s)}=tF_c(a_i)F_r(a_i)F_s(a_i)$. All the remaining events' probabilities in the model are calculated in this same fashion.

The packer (principal) makes an income transfer '$I_{l,(j)}$' to a particular feedlot (agent) as payment for the cattle. For l=0 the traceability system fails to work and the income transfer (I_{0*})

is made to the feedlot regardless of the type of lesions being observed or even if no lesion is observed at all. For l=1, the traceability system works and now the packer can make the adjusted income transfer ($I_{1,(j)}$) to the specific agent contingent on the combination of the three types of lesions or none of them.

The principal's objective is to minimize the costs of procuring the cattle subject to the costs and incidence of ISLs. This objective function (1) reflects the amount of contingent income transfers the principal will make to cattle suppliers, the cost of using a traceability system and the revenue lost due to injection-site lesions damage (opportunity cost). The function $E_c^{SB}(.)$ is the second-best expected cost per head to the principal.

$$
\begin{aligned}
(1)\quad E_c^{SB}(t, I_{0*}, \ldots, I_{1,(c,r,s)}) = 2[& P_{0*}I_{0*} + P_{0,c}p_c + P_{0,r}p_r + P_{0,s}p_s + P_{0,(c,r)}(p_c + p_r) + P_{0,(c,s)}(p_c + p_s) + \\
& + P_{0,(s,r)}(p_s + p_r) + P_{0,(s,c,r)}(p_s + p_c + p_r) + P_{1,0}I_{1,0} + P_{1,c}(I_{1,c} + p_c) + P_{1,r}(I_{1,r} + p_r) + \\
& + P_{1,s}(I_{1,s} + p_s) + P_{1,(c,r)}(I_{1,(c,r)} + p_c + p_r) + P_{1,(c,s)}(I_{1,(c,s)} + p_c + p_s) + \\
& + P_{1,(s,r)}(I_{1,(s,r)} + p_s + p_r) + P_{1,(c,r,s)}(I_{1,(c,r,s)} + p_c + p_r + p_s)] + g(t)
\end{aligned}
$$

In equation 1, $g(.)$ is the function that gives the cost ($/hd) of tracing an animal through a meat packing plant as a function of $t \in T$ and is increasing in T such that a packer can invest in a less expensive system with lower reliability or a more expensive system with greater reliability. The opportunity cost of an injection-site lesion in a chuck steak is $p_c \in \Re_+$ ($/carcass' side), the opportunity cost of an injection-site lesion in a round steak is $p_r \in \Re_+$ ($/carcass' side), and the opportunity cost of an injection-site lesion a sirloin steak is $p_s \in \Re_+$ ($/carcass' side).

Agents' Expected Utility Function

The agent's objective function is specified using the formulation proposed by Grossman and Hart (1983, p. 10), and assuming that agent i's utility function U: $\Re^2 \rightarrow \Re$ is of the following form.

(2) $U(I_{l,(j)}, a_i) = k(a_i)u(I_{l,(j)}) - d(a_i)$

In equation 2, $U(.)$ is a von Neuman-Morgenstern utility function and $u(.)$ is a Bernoulli utility function as defined by Mas-Collel, Whinston and Green (1996, p. 184).

Using equation 2, agent *i*'s expected utility per carcass' side conditional on the incentive mechanism set by the principal as a 10-tuple (t, I_{0*}, …, $I_{1,(c,r,s)}$) is given by equation 3.

$$(3)\quad U(a_i \mid s, I_{0*},...,I_{1,(c,r,s)}) = k(a_i)(u(I_{0*})P_{0*} + \sum_{j=0}^{(c,r,s)} P_{1,(j)}u(I_{1,(j)})) - d(a_i) \qquad \forall a_i \in A_i$$

We conduct all numerical exercises using a multiplicative separable utility function that respects all the conditions to obtain a well behaved problem (Grossman and Hart 1983, p. 38). Therefore, we set $k(a_i)=e^{kc_a}$, $u(I_{l,(j)})=-e^{kI_{l,(j)}}$, and $d(a_i)=0$. Finally, the resulting von Neuman-Morgenstern utility function is given by equation 4.

$$(4)\quad U(I_{l,(j)}, a_i) = -e^{-k(I_{l,(j)}-c_a)} \quad with\ k>0$$

where k is the coefficient of constant risk aversion and c_a is the cost of undertaking an action $a_i \in A_i$.

The constant absolute risk aversion (CARA) form of equation 4 allows setting the cost (c_a) of an action a_i exerted by the agent i as negative income. This feature makes it easier to interpret the resulting incentive mechanisms (Haubrich, 1994). In addition, this functional form eases the representation of an increase in risk aversion since it may be done just by increasing the value of k.

Given this framework, the principal first chooses an incentive mechanism (t, I_{0*},…, $I_{1,(c,r,s)}$) for each $\hat{a}_i \in A_i$ and then selects the action the principal would like agent i to undertake such that the overall minimum expected cost is obtained. In addition, any mechanism or contract should be incentive compatible so that it will be in agent *i*'s best interest to undertake the action chosen by the principal. Finally, any mechanism should be such that the agent *i* will accept the contract.

We adapt the solution framework developed by Grossman and Hart (1983) so that the principal-agent game with traceability is modeled as a two-step numerical optimization procedure. In the first step, the program 5 is solved for each combination between $\hat{a}_i \in A_i$ and $t \in T$.

(5a) $\min_{I_{0*},\dots I_{1,(c,r,s)}} E_c^{SB}(I_{0*},\dots,I_{1,(c,r,s)} \mid \hat{a}_i, t)$

Subject to:

(5b) $U(\hat{a}_i \mid t, I_{0*},\dots,I_{1,(c,r,s)}) \geq \overline{U}$

(5c) $U(\hat{a}_i \mid t, I_{0*},\dots,I_{1,(c,r,s)}) \geq k(a_i)(P'_{0*}u(I_{0*}) + \sum_{j=0}^{(c,r,s)} P'_{1,(j)}u(I_{1,(j)})) - d(a_i) \quad \forall a_i \in A_i$

In program 5, $U(\hat{a}_i \mid t, I_{0*},\dots,I_{1,(c,r,s)})$ is defined as equation 3 but with $\hat{a}_i$ in place of a_i; $\overline{U}$ is agent *i*'s opportunity utility calculated with the value of the best option available to trade a carcass' side[4]; $P_{l,(j)}$ denotes the probability of a particular injection site lesion outcome for the final product sold given action $\hat{a}_i$ was undertaken by agent *i*; $P'_{l,(j)}$ denotes conceptually the same probabilities but calculated as if agent *i* had undertaken a feasible action different from $\hat{a}_i$.

Equation 5b gives the individual rationality or participation constraint, whereas equation 5c gives the two incentive compatibility constraints in our model. To facilitate the numerical resolution of the program, all constraints have been set in terms of certainty equivalents.

The second step consists of choosing the payment incentive values that lead to the overall minimum expected costs per carcass' side to the principal among those results obtained with the first step.

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 programs given as equations 5a-5c are numerically solved with the Microsoft Excel add-in Solver that uses the Generalized Reduced Gradient (GRG2) nonlinear optimization code.

Parameter Specification

In regard to the costs of alternative injection sites, injections yield two outcomes: a healthier animal and a potential injection-site lesion. It is assumed that any location of the injection is equal in regards to health, which allows us to focus on the costs related to the placement of the injection and its impact on lesions. Table 1 summarizes the costs of the alternative injection sites available to feedlot owners.

Table 1. Value of the Parameters of the PA Model

Agent's Action	**Costs of Action ($ per carcass' side)**	**Expected Frequency of Injection Site Lesion in Top Sirloin Butt, $F_s(a_i)$ (%)**	**Expected Frequency of Injection Site Lesion in Bottom-Round, $F_r(a_i)$ (%)**	**Expected Frequency of Injection Site Lesion in Chuck Steak, $F_c(a_i)$ (%)**
Give all injections in the rear leg	Base cost = 0	2.50	11.30	9.98
Give all injections in the neck area	$0.17 more than rear leg	1.43	6.44	17.50
Give all needle-free injections	$0.204 more than rear leg	1.43	6.44	9.98

Source: Costs of actions were estimated based on Hilton (2005) and Dee Griffin (2005); Frequencies are calculated based on Roeber *et al*. (2000), Dee Griffin (2002) and Morgan, Tittor and Lloyd (2004).

Any intramuscular injection may or may not result in tissue irritation and scaring (Field and Taylor 2004). It is also assumed that feedlot owners are able to affect only 43% of the ultimate expected frequency of injection-site lesions[5]. The remaining 57% are assumed to come from the cow-calf stage of production and is outside the control of the feedlot owner. Using this assumption with the values reported by Dee Griffin (2002), Roeber et al. (2000) and Morgan, Tittor and Lloyd (2004) for the expected frequency of injection-site lesions in beef retail cuts, gives the expected frequency of injection-site lesion for each agent's action in Table 1.

It is assumed that the best reservation alternative available for a feedlot owner is to sell the cattle in the spot market rather than to a packer who may have implemented traceability. Assuming an average carcass weighs 787 pounds and may be sold at $1.22 a pound in the spot market (Roeber *et al*. 2000, p. 94), the feedlot owner has a risk-free alternative of selling a carcass' side in the fed cattle market at $480 and this is used as the reservation utility of the agent. Agents are also averse to the risk of being identified if the traceability system is implemented and we set a coefficient of absolute risk aversion equal to 0.75 to account for this risk aversion[6].

The opportunity cost of cuts with ISLs is the greatest single recurring cost within the simulation. 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. The opportunity cost of an injection-site lesion occurring in top sirloin butt (p_s) is $ 11.02 per side, the opportunity cost of an injection-site lesion occurring in bottom-round (p_r) is $ 9.91 per side, and the opportunity cost of an injection-site lesion occurring in chuck steak (p_c) is $2.50 per side.

As described earlier, the traceability system is fully characterized by its expected traceback rate of success $t \in T$. Pape *et al.* (2003) estimate that for a small sized (800 head per day) packing plant, implementing a traceability system using radio frequency identification technology with a 38.9% expected traceback rate of success would cost approximately $0.11 per head. Other levels of success are not provided, so we employ a cost function (equation 6) used in the PA literature (Prendergast 1999) to represent the relation between traceability cost per head and expected traceback rate of success, where $\gamma \in \Re_{++}$ is a constant.

(6) $g(t) = \gamma t^2/2$

We solve equation 6 for γ and then insert the values taken from Pape *et al.* (2003) to find the numerical value of γ. Using this value of γ, we solve for $g(t)$ taking the remaining element of the set T. Doing so yields the values \$0.139 and \$0.656 as the costs of traceability systems respectively with 43.7% and 95% of expected traceback rate of success.

Scenarios and Results

Three basic scenarios are created using characteristics and values of the case of injection-site lesions as a basis for the numerical simulations. The first scenario is a benchmark scenario where full information is assumed to exist. The second scenario represents the current situation of the existence of injection-site lesions with no traceability. The third scenario, which is the basis for the evaluation of traceability as a second-best solution in the absence of full information, is a scenario which assumes traceability levels of alternative effectiveness as described above. To numerically solve these scenarios it is necessary to specify parameters on the cost of injection site alternatives, the reservation utility of the agent, the opportunity cost of the ISLs, the cost of the traceability systems and the expected probability or incidences of injection-site lesions in cattle.

Full Information Scenario

Under full information every action undertaken by agent i is fully and freely verifiable by the principal. Therefore, there will be no economic incentive for the principal to use a traceability system as conceptualized in the present article.

The optimization problem shown in equation 7a and 7b , reflects the certain amount of money (I_{FB}) the meat packer transfers to cattle suppliers based on the action a_i being observed and the negative externality caused by the agent on the principal accounted by the revenue lost due to injection-site lesions damage (opportunity cost). All variables are as previously defined and the first step consists in solving equations 7a and 7b for every $a_i \in A_i$.

(7a) $$\min_{I_{FB}} E_c^{FB}(I_{FB} \mid a_i) = 2[I_{FB} + P_c p_c + P_r p_r + P_{(c,r)}(p_c + p_r) + P_s p_s + P_{(s,c)}(p_s + p_c) + \\ + P_{(s,r)}(p_s + p_r) + P_{(s,r,c)}(p_s + p_r + p_c)]$$

subject to:

(7b) $k(a_i)u(I_{FB})\text{-}d(a_i) \geq \overline{U}$

where the full-information scenario probabilities are calculated as $P_0 = (1\text{-}F_c(a_i))(1\text{-}F_r(a_i))(1\text{-}F_s(a_i))$, $P_c = F_c(a_i)(1\text{-}F_r(a_i))(1\text{-}F_s(a_i))$, $P_r = (1\text{-}F_c(a_i))F_r(a_i)(1\text{-}F_s(a_i))$, and so on. Note that under the full-information scenario there are only eight contingencies since the identity of an agent i is always known. In other words, t=1 without any cost under the full-information scenario. Table 2 shows the probability of lesions occurring in the full information scenario. The only reason for positive probabilities with the needle free injection is that cattle may have been needle injected at the cow-calf stage and cannot be affected by the feedlot's actions.

Table 2. Expected Cost to Principal, Income Transfers to Agents and Probability of Injection Site Lesions Based on Agent's Injection Method Under Full Information

Agent's Injection	Probability of Injection Site Lesion Occurrence (%)							
	P_0	P_c	P_r	$P_{(c,r)}$	P_s	$P_{(c,s)}$	$P_{(r,s)}$	$P_{(c,r,s)}$
In Leg	77.856	8.627	9.919	1.099	1.996	0.221	0.254	0.028
In Neck	76.086	16.140	5.238	1.111	1.100	0.233	0.076	0.016
Ndl-free	**83.026**	**9.200**	**5.716**	**0.633**	**1.200**	**0.133**	**0.083**	**0.009**

Agent's Injection	Expected Cost to the Principal, E_c^{FB} ($/head)	Income Transfers, I_{FB} ($/carcass' side)
In Leg	963. 29	480. 00
In Neck	962. 81	480. 17
Needle-Free	**962. 50***	**480. 20**

For P_j, j=0 for no lesion, j=c for lesion in chuck, j=r for lesion in bottom round, j=s for lesion in sirloin. Combinations indicate multiple lesions.

Because $E_c^{FB}(.)$ is strictly increasing in I_{FB}, the principal offers an income transfer for each action a_i that just guarantees that the agent's reservation utility will be obtained. In other words, the participation constraint (7b) is always binding at the optimum. This result, jointly with the assumption on the behavior of the utility function $u(.)$, implies that the optimal level of utility per carcass' side to be granted to the agent i is given by solving equation 8.

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

Having found the value of $u(I_{FB}^*)$, it is straightforward to calculate the income to transfer to the agent i whenever action a_i is observed by using equation 9.

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

Where $v(.)$ denotes the inverse function of the Bernoulli utility function $u(.)$. The second step consists of choosing the action that leads to the overall minimum expected cost for the principal.

The complete cost of ISLs to the principal and the income transfers made by the principal to the agent under various injection actions are also shown in table 2. This shows that the overall minimum expected cost to the principal (E_c^{FB*} = $962.50 per head) occurs when agent i gives all injections with a needle-free technique. Hence, under full information the meat packer would 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 the agent as a means of covering the additional costs the agent incurs in giving all injections with a needle-free technique. The feedlot owner will comply with the contract because the meat packer can observe the feedlot owner's action and punish the feedlot owner by giving zero payment whenever the contracted action is not performed.

Second-Best Scenarios - Injection Site Lesions without Traceability

The current situation in the beef industry is that there is information asymmetry and no traceability. Therefore, information on the identity of the fed cattle supplier is detached from carcasses along their disassembly and fabrication, so it is impossible for the principal to create incentive mechanisms based on the observed injection-site lesion damage. The only alternative left to the principal is to offer a constant payment per head to agent *i*.

Because the principal wants to minimize costs, 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. The expected costs for the first-best and for the second-best without traceability must be equal and the packer incurs the costs of ISL products and the expected cost for a meat packer that does not use a traceability system is $963.29 per head as shown in table 2.

Second-Best Scenarios – Injection Site Lesions with Traceability

The final scenario is the second-best scenario of implementing traceability. The solution procedure for this scenario was previously discussed in the context of program (5). With traceability the meatpacker incurs the costs of implementing traceability and these costs are a function of the level of reliability as described earlier. Therefore, it's necessary to solve the model for all combinations of traceability reliability and the injection action of the agents.

Before proceeding with solving the program 5, it is necessary to ensure that the Monotone Likelihood Ratio Condition (MLRC) is satisfied (Salanié 1997, p. 118). The MLRC is satisfied if:

(10) $\frac{P_{n,m}}{P_{q,m}} \geq \frac{P_{n,-m}}{P_{q,-m}}$ for every action n, $q \in A_i$

Where action n is more costly to agents than action q, and for all contingencies m preferred to $-m$ from the principal's perspective. The results to the MLRC test obtained by applying (10) showed that the Monotone Likelihood Ratio Conditions do not hold for the ISLs' case. To overcome this problem, eight additional constraints given as equation 11 are imposed to the program 5 to guarantee that the more preferred the outcome is the higher the contingent income transfer ($I_{l,(j)}$) will be[7].

(11) $I_{1,0} \geq I_0$; $I_0 \geq I_{1,c}$; $I_{1,c} \geq I_{1,r}$; $I_{1,r} \geq I_{1,(c,r)}$; $I_{1,(c,r)} \geq I_{1,s}$; $I_{1,s} \geq I_{1,(c,s)}$; $I_{1,(c,s)} \geq I_{1,(r,s)}$; $I_{1,(r,s)} \geq I_{1,(c,r,s)}$

Results obtained by solving the first-step of the second-best PA model with traceability are presented in table 3. The expected costs presented in the third column of table 3 are the values for the objective function of the program (equation 1) evaluated at the income transfer mechanism that minimizes it for each combination between agent's action and the traceability system's expected traceback rate of success.

Table 3. First-Step Results to the PA Game with Traceability

Agent's Action	Traceability System's Expected Traceback Rate of Success (%)	Expected Cost, E_c^{SB} ($/head)
(1)	38. 9	963.40
(2)	38. 9	963.08
(3)	**38. 9**	**962.82***
(1)	43. 7	963.43
(2)	43. 7	963.11
(3)	43. 7	962.84
(1)	95. 0	963.95
(2)	95. 0	963.62
(3)	95. 0	963.35

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 game with traceability consists of choosing the incentive mechanism that leads to the overall minimum expected cost to the principal and imposing the additional constraints of equation 11. From table 3, $962.82 per head is the overall minimum expected cost that the principal can obtain. The incentive mechanism that will induce the agent *i* in his/her best interest to give all injections with a needle-free technique (action 3) is given as follows. First, the principal announces to agents that the traceability system works with 38.9% of expected traceback rate of success. Second, the principal announces the income to be transferred to the agent in each alternative lesion outcome as dollars per carcass' side as presented in table 4.

Table 4. Incentive Mechanisms from the First-Step Solution to the PA Model with Traceability and Expected Frequencies of Occurrence of Each Contingency

Agent's Action	Traceability System's Expected Traceback Rate of Success (%)	Income Transfers ($/carcass' side)								
		I_{0*}	$I_{1,0}$	$I_{1,c}$	$I_{1,r}$	$I_{1,(c,r)}$	$I_{1,s}$	$I_{1,(c,s)}$	$I_{1,(r,s)}$	$I_{1,(c,r,s)}$
(1)	38. 9	480.00	480.00	480.00	480.00	480.00	480.00	480.00	480.00	480.00
(2)	38. 9	480.27	480.27	480.27	479.70	479.70	479.70	479.70	473.33	473.33
(3)	**38. 9**	**480.32**	**480.35**	**480.32**	**479.75**	**479.75**	**479.75**	**479.75**	**473.87**	**470.93**
(1)	43. 7	480.00	480.00	480.00	480.00	480.00	480.00	480.00	480.00	480.00
(2)	43. 7	480.28	480.28	480.28	479.69	479.69	479.69	479.69	473.49	473.49
(3)	43. 7	480.32	480.35	480.32	479.75	479.75	479.75	479.75	474.04	471.09
(1)	95. 0	480.00	480.00	480.00	480.00	480.00	480.00	480.00	480.00	480.00
(2)	95. 0	480.30	480.30	480.30	479.69	479.69	479.69	479.69	474.69	474.69
(3)	95. 0	480.32	480.36	480.32	479.77	479.59	479.77	479.59	475.23	472.23
		Probability of each Contingency Occurring (%)								
		P_{0*}	$P_{1,0}$	$P_{1,c}$	$P_{1,r}$	$P_{1,(c,r)}$	$P_{1,s}$	$P_{1,(c,s)}$	$P_{1,(r,s)}$	$P_{1,(c,r,s)}$
(1)	38. 9	61.10%	30.29%	3.36%	3.86%	0.43%	0.78%	0.09%	0.10%	0.011%
(2)	38. 9	61.10%	29.60%	6.28%	2.04%	0.43%	0.43%	0.09%	0.03%	0.006%
(3)	**38. 9**	**61.10%**	**32.30%**	**3.58%**	**2.22%**	**0.25%**	**0.47%**	**0.05%**	**0.03%**	**0.004%**
(1)	43. 7	56.30%	34.02%	3.77%	4.33%	0.48%	0.87%	0.10%	0.11%	0.012%
(2)	43. 7	56.30%	33.25%	7.05%	2.29%	0.49%	0.48%	0.10%	0.03%	0.007%
(3)	43. 7	56.30%	36.28%	4.02%	2.50%	0.28%	0.52%	0.06%	0.04%	0.0004%
(1)	95. 0	5.00%	73.96%	8.20%	9.42%	1.04%	1.90%	0.21%	0.24%	0.027%
(2)	95. 0	5.00%	72.28%	15.33%	4.98%	1.06%	1.04%	0.22%	0.07%	0.015%
(3)	95. 0	5.00%	78.87%	8.74%	5.43%	0.60%	1.14%	0.13%	0.08%	0.009%

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.

These results show that to induce agents to give all injections with a needle-free technique, \$480.32 will be paid to the agent if the traceability system fails to work. If the traceability system works then \$480.35 will be transferred when no damage is observed ($I_{1,0}$), \$480.32 will be transferred if at least one injection-site lesion is observed in chuck steak ($I_{1,c}$) and so on for the rest of results as presented in table 4. Except for the case in which an ISL is observed in the chuck, all other contingencies when the traceability works imply some sort of punishment on the agent since the income transfer is less than \$480 (market value of a carcass' side). Agents will only be rewarded in contingencies in which the traceability system fails to properly work or the traceability system works and no damage is observed or only damage in chuck is observed. But even the low level of reliability (38.9%) is sufficient to induce agents to use needle free injection methods.

The probability of the income transfers are shown in table 4. For the low level of traceback and the needle free injection method, the transfer I_{0*} = $480.32 will occur 61.1% of time, $I_{1,0}$ = $480.35 will occur 32.30% of the time and so on for the rest of the results. Using these values to calculate the expected transfer to agents yields $480.31 per carcass' side. Hence, the principal will pay an average price-premium of $0.31 per carcass' side to get agents to accept this incentive mechanism. This price-premium will serve to cover the higher costs the agent will incur to give all injections with a needle-free technique ($0.204) and to pay a risk-premium ($0.106). The income transfers will vary little across contingencies. This means that the principal should avoid imposing risk on agents to minimize risk premiums paid to agents.

Comparing Scenarios

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 solution 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 result of equation 12 gives the cost of living in a world with asymmetric information and also gives the "Agency Costs" that would be defined as the cost due to the separation of ownership and management. In the present context, the meat packer delegates the management of the feedlot to feedlot owners. 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).

Finally, the value of traceability is given by equation 13.

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

Inserting the costs of scenarios reported into equation 13, the cost of living in a second-best world (agency cost) is: min{963.29, 962.82} – 962.50 = \$0.32 per head. The \$0.32 per head is incurred because a traceability system has to be in place and a price-premium has to be paid to agents to get them to participate in the contract in a world with asymmetric information. The value of traceability calculated using equation 13 is \$963.29 - \$962.82 = \$0.47 per head, or an 800 head per day plant as assumed here would save approximately 800 head x \$0.47 per head = \$376 per day. Therefore, 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 the use of a traceability system, and with the payment of price premiums to compensate agents for accepting a risky payment scheme and undertaking a more costly action.

Sensitivity Analysis

The case of injection site lesions is indicative of a broad class of problems in the food chain where an upstream agent's actions affect downstream product attributes which may not be source verifiable when the adverse outcome is discovered. Choosing this case allowed us to parameterize and solve the underlying principal agent problem, but to further generalize the core implications, we conducted a sensitivity analysis of the key variables affecting the value of traceability. These insights are applicable to any problem characterized as above.

The primary factors affecting the economic value of traceability include the level of risk aversion of the agents, the agent's ability to affect the outcome of a product attribute, the cost of the system to the processor and the cost of the agent's actions. To consider how these factors interacted, we simulated the model with nine values for the absolute risk aversion parameter $k\in\{0.125, 0.250, \ldots, 1.125\}$, nine different frequencies by which lesions are produced $(EFOF)\in\{0.33, 0.40, 0.43, 0.50, 0.60, \ldots, 0.90, 0.95\}$ and nine different values for the costs of the traceability systems as percentage mark-ups of the base cost estimates $x\in\{1, 1.5, \ldots, 5\}$. For instance, by multiplying the original traceability costs by 1.5 we are simulating a 50% increase in their costs. Finally, we simulate the models using nine different values for the costs of agents' actions (CAA) by multiplying the original values of each injection action by a factor that belongs to the set $y\in\{1.1, 1.2, \ldots, 1.7\}$.

For each simulation we calculated the value of traceability according to equation 13 so that we generated a series of 27 values for the value of traceability. Using the values obtained with the simulations we estimated the following model.

Value of Traceability =-0.3761- 0.0221*x - 0.5363*y - 0.0327*ln(k) + 3.2494*EFOF,

$R^2 = 0.9961$

The estimated model shows that a 10% increase in the original traceability costs would cause a reduction of $0.00221 in the value of using a traceability system. We also found that if the original value of the costs of traceability systems increased more than five times, no traceability system would have economic value. Note that for the case of an increase of 10% in agents' cost of actions the value of traceability would decrease by $0.05363. From the estimated model we also note that the value of a traceability system decreases ($-0.0327k^{-1}$) with the coefficient of absolute risk aversion (k) of agents at increasing rates ($0.0327k^{-2}$). In the limit, a very high k might cause a traceability system to become economically infeasible. Finally, we observe that for each percent increase in the effect of feedlot owners' action on the final frequency of lesion (EFOF) the value of traceability goes up by $0.032494. This result shows that the less the upstream party (feedlot) can do to mitigate a problem, because it is created in early stages in the supply chain; the lower will be the value of a traceability system like the one we have modeled in this article.

For all simulations the traceability system with 38.9% of expected traceback rate of success is the one to be optimally chosen by the principal. This illustrates that the results are robust in regard to the underlying factors affecting investment decisions in traceability, and that even a relatively imperfect system can be sufficient to enforce first-best behavior in agents.

Conclusions

One of the key implications of traceability is that it has the potential to reduce information asymmetry in the supply chain and result in better allocation of economic value to participants. To illustrate this point, the case of ISLs in cattle was used to numerically simulate the economic incentives and economic values which can be attained through a prototypical reduction in information asymmetry. 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 world case-study.

Simulation results based on technical data on injection site incidence showed that a meat traceability system has 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. This is due to the fact that the agents are risk averse and the principal must avoid placing too much risk on the agents or they will choose not to participate. However, it was also shown 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.

The optimal traceability rate of success was also examined. This is important because as greater reliability of traceability is desired costs increase. 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. Hence, at least for purposes of enticing agents to undertake first best actions, it may be possible to have relatively low cost tracing systems in place.

Although injection site lesions are a relatively minor issue in food safety, it is indicative of a class of problems characterized by an attribute negatively affecting the value of a product which can only be discovered after the sales transaction is made and the supplier can no longer be identified. Other previous work has focused on cases where testing or grading could be completed at the time of the transaction so that the supplier could be penalized or rewarded immediately.

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Footnotes

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[1] Breadth is the amount of information recorded by the system, depth denotes 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] A game with complete and perfect information implies that players' payoff functions are common knowledge and that at each move the player with the move knows the full history of the game (Gibbons 1992, p. 55). By the time an agent moves he/she knows the traceability system's reliability and the contingent payment scheme previously set by the principal.

[3] Each carcass' side is assumed to be independent of the other for the same animal. Thus, the final expected cost per head is twice as much as the cost per carcass' side. Without this assumption, the number of events would have increased from sixteen to 256 with very low probability of occurrence for most of them. Furthermore, data on the incidence of injection-site lesions is reported in terms of carcass' sides with no reference to the correlation between sides.

[4] For instance, $\overline{U}$ should be thought of as the level of utility the agent i might get by trading with a meat packer that does not use a traceability system, paying the market price.

[5] Dexter et al. (1994) found that the majority (80 to 90%) of the blemishes found in top sirloin butts were originated at the cow-calf or stocker levels, or early in the finishing period. We could not find similar studies for the other beef cuts (e.g. chuck and round). Thus we consider (10%+20%)/2 and (100%-(10%+20%)/2)/3 as being the effect of feedlot owner in terms of producing ISLs respectively in the final and early stages of the finishing period. Sum the two values gives 43%.

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[6] Hardaker et al. (2004, p. 109) classifies farmers who are somewhat risk averse or normal as having a relative risk aversion equals to 1. Dividing 1 by 0.75 and applying the same scale of measure employed by Haubrich (1994, p. 264) we find $1.33 million as being the net worth a feedlot owner should have so that the coefficients absolute and relative risk aversion are equal. Note that 1.33 million would represent 1.85 times the value of 750 head sold at an average price of $960 per head. According to RTI International (2007), cattle-feeding operations with 500 or more head maintain 42% of cattle inventories, and half of those cattle are held on operations with 1,000 or more head.

[7] These constraints respect the fact that whenever no ISLs are found and the traceability system does not fail, the economic loss will be the lowest. The second lowest expected loss occurs when the traceability system fails because in this event it may happen that no ISLs have been found that produces a lower average loss compared with the other contingencies. The other constraints follows the same idea, an ISL in the chuck causes a lower economic loss than if it is in the bottom-round and an ISL in the bottom-round causes lower economic loss than an ISL in the top sirloin.