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

Resende-Filho, Moises and Buhr, Brian

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Moises A. Resende-Filho and Brian L. Buhr

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

The authors are Assistant Professor, Departamento de Análise Econômica, Universidade Federal de Juiz de Fora, Juiz de Fora, MG 36033-220. Brazil, and Professor, Department of Applied Economics, University of Minnesota, St. Paul, MN 55108-6040. Corresponding author is Moises Resende-Filho, FEA/UFJF. Campus Universitário. Martelos. Juiz de Fora, MG. 36036-330. Brazil. moises.resende@ufjf.edu.br

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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 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., broken syringe needles from health treatments), bacterial contamination, 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 (ISO) states that traceability systems create the ability to retrieve the use or location of a product and activity or process through a registered identification. For instance, traceability systems collect and store information about product attributes, including quality and origin, as the product moves through the supply chain. 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).

Traceability systems have been employed 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 (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 their breadth, depth and precision[1].

While there may be many objectives for implementing traceability, the issue of using traceability to improve the behavior and compliance of upstream suppliers is an important consideration. This can improve the quality or safety of the final product and also insure 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 precisely this issue.

Previous Research

Research related to the effect of information asymmetry on food safety and quality has developed in two directions: (1) 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), (2) to investigate the use of a noisy grading or testing technology as a tool to create incentive mechanisms driving the level of effort on product quality and safety by producers.

As an example of the first group of works, Hennessy (1996) constructs a conceptual model wherein food processors test raw material supplied by producers as a method to protect their reputation in the consumer marketplace. Using this model Hennessy shows that as a result of measurement errors in testing and grading a price-grade incentive is incapable of producing market equilibrium where the first-best level of investment in quality by producers is attained.

As a solution to the underinvestment in quality by producers, he advocates that processors and producers 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.

Bogetoft and Olesen (2003) also 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 (1996) 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 principal-agent (PA) model with linear contracts, normally distributed measurement errors and agents' exponential utility to econometrically estimate farmers' degree of risk aversion in contracting production of hogs. Their results give empirical evidence that agents' 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. In 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 main contribution of this article is to show that reputation-based contracts affect agents' behavior.

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 starts, unobservable delivery characteristics may become observable, but 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 (ISLs) in beef which provides the case for modeling the potential value of traceability systems in similar situations.

The Case of Injection Site Lesions in Beef

Management-related quality problems such as injection-site blemishes cause substantial 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. 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). However, large muscle masses of the rear quarters provide 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).

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). The meat packer reduces 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 injection-site lesions back to the animal and feedlot of origin. 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. First, the generalized principal-agent framework necessary to numerically solve the problem is developed. This model is then parameterized by providing further technical information on injection-site lesions in beef. Finally, three scenarios are developed to evaluate the difference between the present beef supply chain where information asymmetry exists and there is no traceability, the case where there is no information asymmetry (the first-best situation), and third the situation in which there is information asymmetry but the packer can implement a traceability system to overcome the asymmetry.

Conceptual Framework for the Principal-Agent Game

The following framework provides the structure for the principal agent game to be solved numerically for the case of injection site lesions and for each of the three scenarios. First a stylized description of the characteristics of the injection lesion problem is developed to allow definition and incorporation of the sequencing of the game that the meat packer (principal) and cattle feeder (agent) play into a principal-agent analytical framework. Once the nature of the problem is defined, the principal and agents' optimization criteria are established and the method for solving this optimization problem is provided.

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, hence we do not consider reputation aspects of repeated games. 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 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. In addition, the feedlot owner could choose not to give any injection, eliminating any chance of injection-site lesion. However, we assume that by not using a preventive vaccination program the expected losses from animal diseases will 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.

At the same time, 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. Based on this system, 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 and the traceability database system stores data on lot number kill order, animal electronic ID number and the identity of the fed cattle supplier (traceability system's breadth). 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.

In our conceptual model, a traceability system is fully characterized by its expected traceback rate of success of preserving information on an animal ID and its supplier identity attached to beef retail cuts defined as $s \in S$. We take values of experiments conducted and reported by Basarab, Milligan and Thorlakson (1997) to set the expected traceback rates of success respectively for traceability system 1, 2 and 3 as 38.9%, 43.7% and 95%. Thus, the set of traceability systems are defined as $S = \{38.9\%, 43.7\% \text{ and } 95\%\}$.

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[2] and perfect information[3] played by the principal and each agent i runs as shown in figure 1. The critical feature of this sequence is that the ISLs are observed only after the animal is processed and the identity of the feedlot is no longer part of the information flow and that the payments are made at the end of the process so that traceability can influence payments.

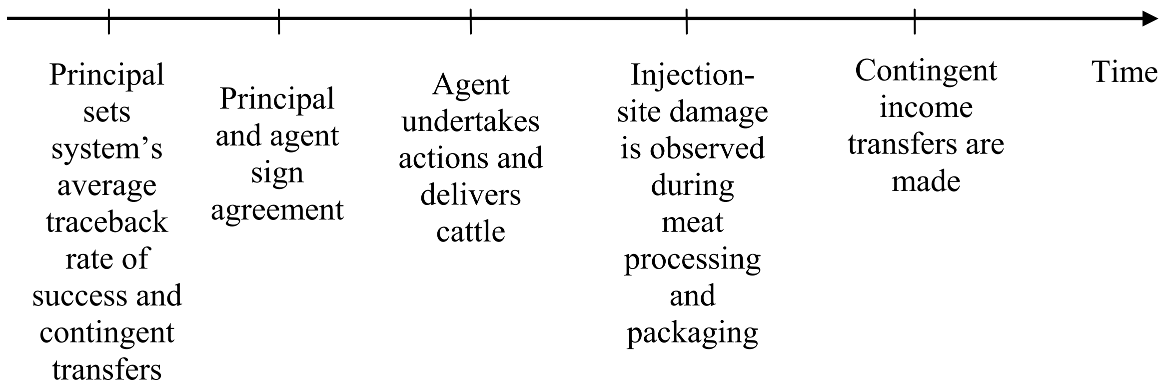

Figure 1. The principal-agent game with traceability

The Principal's Cost Minimization Function

Given this background for the existence of the principal-agent problem, the principal's objective is to minimize the costs of procuring the cattle subject to the costs and incidence of injection site lesions. This objective function 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). We call the function $E_c^{SB}(.)$ as the second-best expected cost per head to the principal.

$$
\begin{aligned}
(1)\quad & E_c^{SB}(s, I_{0,0},..., I_{1,(c,r,s)}) = 2[P_0 I_{0,0} + P_{0,c} p_c + P_{0,r} p_r + P_{0,s} p_s + P_{0,(c,r)}(p_c + p_r) + P_{0,(c,s)}(p_c + p_s) + \\
& + P_{0,(s,r)}(p_s + p_r) + P_{0,(s,c,r)}(p_s + p_c + p_r) + P_{1,0} I_{1,0} + P_{1,c}(I_{1,c} + p_c) + P_{1,r}(I_{1,r} + p_r) + \\
& + P_{1,s}(I_{1,s} + p_s) + P_{1,(c,r)}(I_{1,(c,r)} + p_c + p_r) + P_{1,(c,s)}(I_{1,(c,s)} + p_c + p_s) + \\
& + P_{1,(s,r)}(I_{1,(s,r)} + p_s + p_r) + P_{1,(c,r,s)}(I_{1,(c,r,s)} + p_c + p_r + p_s)] + g(s)
\end{aligned}
$$

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 $s \in S$. 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).

All terms, $P_{l,(j)}$, represent the probability of a particular injection site lesion outcome for the final product sold. For l=0, the traceability system does not work and the packer is unable to identify the origin of a lesion even if it exists. For l=1, the traceability system works and the packer is able to identify the origin of the lesion if it exists. Subscript j identifies the individual lesion or combination of lesions which can be found in each carcass side[4]. There are sixteen possible combinations (eight for if the traceability system works (l=1), and eight for if the traceability system does not 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 and there is at least one lesion in the chuck, in the round and in the sirloin, and so on. Finally, the term P_0 denotes the probability of the traceability system not working, calculated as the summation of all event's probabilities in which the traceability system does not work.

Except for the probability of the traceability system working, all remaining event's probabilities depends on the action undertaken by the agent i. Therefore, we define the probabilities of a successful event for each of the random variables affected by action undertaken by agent i as follows: $F_2(a_i)$ at least one injection-site lesion in a top sirloin butt is observed given Agent i undertook action $a_i \in A_i$; $F_3(a_i)$ at least one injection-site lesion in a bottom-round is observed given Agent i undertook action $a_i \in A$; and $F_4(a_i)$ at least one injection-site lesion in chuck steak 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 as a function of the expected traceback rate of success and the three random variables which depends on agent *i*'s actions. For instance, to calculate the probability that the traceability system will work and at least one lesion will be observed in chuck, in round and in sirloin we use $P_{1,(c,r,s)}=sF_2(a_i)F_3(a_i)F_4(a_i)$. All the remaining event's probabilities in the model are calculated in this same fashion.

The principal (packer) makes an income transfer '$I_{l,(j)}$' to a particular agent as payment for the cattle. For l=0 the traceability system does not work and the income transfer ($I_{0,0}$) 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 accounting for the lost opportunity of cut value due to the feedlot causing an injection site lesion.

Agents' Expected Utility Function

Having specified the principal's objective function, the agent's objective function now needs to be identified. We accomplish this using the formulation proposed by Grossman and Hart (1983, p. 10), and assume that the agent *i*'s utility function U: $\Re^2 \rightarrow \Re$ is of the following form.

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

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

To obtain a well behaved problem, the real-valued function $u(.)$ should be strictly increasing, continuously differentiable and concave on the open interval ($\underline{I}$, $+\infty$). In addition, $u(.)$ should be specified such that $\lim_{I_{l,(j)} \rightarrow \underline{I}} u(I_{l,(j)}) = -\infty$ which implies that the Inada condition[5]

$\lim_{I_{l,(j)} \to \underline{I}} u'(I_{l,(j)}) = \infty$ holds. Further, both $k(.)$ and $d(.)$ should be real-valued, continuous functions defined on the action space and $k(.)$ should be strictly positive (Grossman and Hart, 1983). This kind of *von Neuman Morgenstern* utility functional form imposes independence of agent's preferences over income lotteries and perfectly certain actions. In addition, it generalizes additive and multiplicative separability between the utility of income $u(.)$ and the disutility of actions, $k(.)$ and $d(.)$ (Haubrich 1994).

Using equation 2, agent i's expected utility per carcass side conditional on the incentive mechanism set by the principal as a 10-tuple $(s, I_{0,0}, \ldots, I_{1,(c,r,s)})$ is given by equation 3.

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

Given this framework, the principal first chooses an incentive mechanism $(s, I_{0,0}, \ldots, I_{1,(c,r,s)})$ 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 optimization procedure. In the first step, the program 4 is solved for each combination between $\hat{a}_i \in A_i$ and $s \in S$.

(4a) $\min_{I_{0,0},\ldots I_{1,(c,r,s)}} E_c^{SB}(s, I_{0,0},\ldots, I_{1,(c,r,s)} \mid \widehat{a}_i)$

Subject to:

(4b) $U(\widehat{a}_i \mid s, I_{0,0},\ldots, I_{1,(c,r,s)}) \geq \overline{U}$

(4c) $U(\widehat{a}_i \mid s, I_{0,0},\ldots, I_{1,(c,r,s)}) \geq \sum_{j=0}^{(c,r,s)} P'_{0,(j)} k(a_i) u(I_{0,0}) + \sum_{j=0}^{(c,r,s)} P'_{1,(j)} k(a_i) u(I_{1,(j)}) - d(a_i) \quad \forall\ a_i \in A_i$

Where $U(\widehat{a}_i \mid s, I_{0,0},\ldots, I_{1,(c,r,s)})$ is defined as equation 3 but with $\widehat{a}_i$ 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[6]; $P_{l,(j)}$ denotes the probability of a particular injection site lesion outcome for the final product sold given action $\widehat{a}_i$ 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 $\widehat{a}_i$.

It should be noticed that the individual rationality or participation constraint is given by equation 4b[7], whereas the two incentive compatibility constraints in our model are set in equation 4c[8]. In order to facilitate the numerical resolution of the program, all these constraints have been set in terms of certainty equivalents.

We conduct all numerical exercises using a multiplicative separable utility functions (Grossman and Hart 1983, p. 38). Therefore, we set $k(a_i)=e^{kc_a}$, $u(I_{l,(j)})=-e^{kI_{l,(j)}}$, and $d(a_i)$ equals to zero. Finally, the resulting von *Neuman-Morgenstern* utility function is given by equation 5.

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

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) type of the von *Neuman-Morgenstern* utility function given by equation 5 allows setting the cost of actions (c_a) just 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 by increasing the value of *k*. For instance, Grossman and Hart (1983) use this utility functional form to study the effect of changes in the agent's degree of risk aversion on the loss to the principal in an asymmetric information setting.

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 4a-4c are numerically solved with the Microsoft Excel add-in Solver that uses the Generalized Reduced Gradient (GRG2) nonlinear optimization code.

Scenario Construction, Parameter Specification and Results

Using the above analytical framework, 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. This scenario provides the first-best result to which the second best scenarios can be compared. The second is a scenario which essentially represents the current situation of the existence of injection-site lesions with no traceability. The final 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. Solving the problem allows us to determine the level of traceability that should be invested in as well as the incentive structures which can be implemented by the packer.

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 injection site lesions, the cost of the traceability system and the expected probability or incidences of injection-site lesions in cattle.

In regard to the costs of alternative injection sites, it is recognized that an injection yields two outcomes: a healthier animal and a potential injection-site lesion. It is assumed that as far as animal health is concerned, any location of the injection is equal, this allows us to simply focus on only the costs related to the placement of the injection and its impact on lesions. Table 1 summarizes the costs of the actions available to feedlot owners.

Table 1. Feedlot Owners Injection Actions and Their Costs

Agent's Actions (a_i)	Cost ($ per carcass side)
Give all injections in the rear leg	Base cost = 0
Give all injections in the neck	$0.17 more than rear leg
Give all needle free injections	$0.204 more than rear leg

In order to solve equations 4a-4c for the PA model with traceability, it is also necessary to set a numerical value for the reservation utility $(\overline{U})$. Therefore, we assume that the best 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. Therefore a coefficient of risk aversion must be specified as part of the agent's utility. The coefficient of absolute risk aversion is set equal to 1.125 as also used by Haubrich (1994, p. 264).

The opportunity cost of cuts with injection site lesions 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 $s \in S$. The only information linking traceback success rates to costs is provided by Pape et al (2003). They 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 use a cost function (equation 6) frequently used in the PA literature (Prendergast 1999) to represent the relation between traceability cost per head and expected traceback rate of success, where $\kappa \in \Re_{++}$ is a constant..

(6) $g(s) = \kappa s^2/2$

Solving equation 6 for κ and inserting the values obtained from Pape et al into this formula we obtain $\kappa = 2(0.11)/(0.389)^2 = 1.4539$. Using this value of κ, g(s) can then be solved for each remaining element of the set S. Doing so, 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 (%)	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.

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, we use 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 occur 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 (Morgan, Tittor and Lloyd 2004).

It is also assumed that feedlot owners are able to affect 75% of the ultimate expected frequency of injection-site lesions. The remaining 25% of the expected frequencies of injection site lesions 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 previously defined 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 as presented in table 3.

Table 3. Actions and Expected Frequency of Injection-site Lesion per Carcass Side

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, $F_4(a_i)$ (%)
Give all injections in the rear leg	2. 50	11. 30	4. 38
Give all injections in the neck area	0. 63	2. 83	17. 50
Give all needle-free injections	0. 63	2. 83	4. 38

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

These values are substituted into the principal-agent specification defined earlier and the model is solved for the three scenarios: (1) a scenario in which there is full information to provide a first-best solution, (2) the current situation with no traceability and (3) a scenario in which there is asymmetric information, but traceability can be employed at the various levels of reliability described here.

Full Information Scenario

Under 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 it will be cheaper for the principal to contract on agents' actions than to condition payments on the occurrence and observation of injection-site lesions. By doing so, the principal also will avoid the need to pay risk-premiums to risk averse agents so that they accept a risky contract, and also will avoid costs incurred with a traceability system use.

As in the PA game with traceability, we want to set the full information setting as a mathematical programming problem. The objective function for the meat packer given as equation 7, 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). We call the equation (7) as the first-best expected cost per head to the principal.

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

where $P_{(j)}$ stands for the probability of a particular injection site lesion outcome for the final product sold under full information and subscript j identifies the individual lesion or combination of lesions which can be found in each carcass side.

Finally, we have all the elements to set the mathematical programming problem for the full information setting as a two-step optimization procedure. The first step consists in solving the program (8) for every $a_i \in A_i$.

$$(8a)\quad \min_{I_{FB}} E_c^{FB}(I_{FB} \mid a_i)$$

Subject to:

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

Because the *Bernoulli utility function* $u(.\ )$ is strictly increasing in I_{FB}, $E_c^{FB}(.)$ will also be 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 will be obtained. In other words, the participation constraint (8b) always binds. This result, jointly with the assumption on the behavior of the utility function $u(.\ )$, imply that the optimal level of utility per carcass side to be granted to the agent i is given by solving equation 9.

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

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 10.

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

Where *v*(.) denotes the inverse function of the *Bernoulli* utility function *u*(.).

The second step consists in choosing the action that leads to the overall minimum expected cost for the principal.

Table 4 shows the probability of lesions occurring in a first-best situation. In the full information setting only the action of giving a needle free injection is relevant to the analysis. The meatpacker (principal) will clearly contract for the needle free injection eliminating the opportunity loss from lesions. The feedlot owner will comply with the contract because with full information, the meat packer observes whether the feedlot owner deviates from the contracted action and the meat packer will give the feedlot owner zero payment whenever the contracted action is not observed. 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 4. Probability of Injection Site Lesions Based on Agent's Injection Method

Agent's	Probability of Injection Site Lesion Occurrence (%)							
Injection	P_0	P_c	P_r	$P_{(c,r)}$	P_s	$P_{(c,s)}$	$P_{(r,s)}$	$P_{(c,r,s)}$
In Leg	82.699	3.784	10.536	0.482	2.121	0.097	0.270	0.012
In Neck	79.668	16.899	2.316	0.491	0.501	0.106	0.015	0.003
Ndl-free	**92.343**	**4.225**	**2.685**	**0.123**	**0.281**	**0.027**	**0.017**	**0.001**

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.

Although the relevant strategy is for needle free injections, the complete cost of injection site lesions to the principal and the income transfers made by the principal to the agent under various injection actions are shown in table 5. This 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. Hence, under full information 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.

Table 5. Expected Cost to Principal and Income Transfers to Agent Under Full Information

Agent's Injection	Expected Cost to the Principal, E_c^{FB} (\$/head)	Income Transfers, I_{FB} (\$/carcass side)
In Leg	963. 01	480. 00
In Neck	961. 91	480. 17
Needle-Free	**961. 32***	**480. 20**

Second-Best Scenarios - Injection Site Lesions Without Traceability

In reality, there is not full information and the current situation in the beef industry is such that there is information asymmetry and there is no 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 costs the principal 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 which is to inject in the leg.

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. Since the cost of giving all injections in the rear leg is zero, the expected costs for the first-best and for the second-best without traceability 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 5.

Results for the Second-Best with Traceability Setting

The final scenario is the second-best scenario of implementing traceability. The solution procedure is the same as in other scenarios. However, 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.

Results obtained by solving the first-step of the second-best PA model with traceability are presented in table 6. The expected costs presented in the third column of table 6 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 6. 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. 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.

Before proceeding with the second stage of the solution, it is necessary to ensure that the Monotone Likelihood Ratio Condition (MLRC) is satisfied (Salanié 1997, p. 118). The MLRC is satisfied if:

(11) $\frac{P_{n,m}}{P_{q,m}} \geq \frac{P_{n,-m}}{P_{q,-m}}$ 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 (11) showed that the Monotone Likelihood Ratio Conditions do not hold for the baseline scenario. To overcome this problem, eight additional constraints given as equation 12 are imposed on equations 4a-4c to guarantee that the more preferred the outcome is the higher the contingent income transfer ($I_{l,(j)}$) will be:

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

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 12. From table 6, \$961.47 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. Following this procedure and solving the model for possible lesion outcomes and methods of injection by the agent gives the income transfer results presented in table 7.

These results show that 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. If the traceability system works then \$480.26 will be transferred when no damage is observed ($I_{1,0}$), \$479.72 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 7. It is important to notice that by this incentive mechanism an agent will always be penalized when the traceability system works and damage is observed. In all these contingencies when traceability works, transfers are less than \$480 (market value of a carcass side). Agents will only be rewarded whenever the traceability system does not work and the traceability system works and no damage is observed. But even the low level of reliability (38.9%) is sufficient to induce agents to use needle free injection methods to avoid being penalized.

Table 7. Incentive Mechanisms from the First-Step Solution to the PA Model with Traceability

Agent's Action	Traceability System's Expected Traceback Rate of Success (%)	Income Transfers ($/carcass side)								
		$I_{0,0}$	$I_{1,0}$	$I_{1,c}$	$I_{1,r}$	$I_{1,(c,r)}$	$I_{1,s}$	$I_{1,(c,s)}$	$I_{1,(r,s)}$	$I_{1,(c,r,s)}$
(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. 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.

The probability of the income transfers shown in table 7 are shown in table 8. For the low level of traceback and the needle free injection method, the transfer $I_{0,0}$ = \$480.23 will occur 61.1% of time, $I_{1,0}$ = 480.26 will occur 35.92% of the time and so on for the rest of results. Using these values to calculate the expected transfer to agent *i* yield \$480.22 per carcass side. Hence, the principal will pay a price-premium of \$0.22 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 and to pay a risk-premium. Further, notice that the income transfers will vary little across contingencies. This is a sign that the principal should avoid imposing risk on agents in order to minimize the need for paying risk premiums to agents.

Table 8. Expected Frequency of Occurrence of Each Contingency

Agent's Action	Traceback Rate of Success (%)	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	32.17	1.47	4.10	0.19	0.82	0.04	0.105	0. 0048
(2)	38. 9	61.10	30.99	6.57	0.90	0.19	0.19	0.04	0.006	0. 0012
(3)	**38. 9**	**61.10**	**35.92**	**1.64**	**1.04**	**0.05**	**0.23**	**0.01**	**0.007**	**0. 0003**
(1)	43. 7	56.30	36.14	1.65	4.60	0.21	0.93	0.04	0.118	0. 0054
(2)	43. 7	56.30	34.82	7.39	1.01	0.21	0.22	0.05	0.006	0. 0014
(3)	43. 7	56.30	40.35	1.85	1.17	0.05	0.25	0.01	0.007	0. 0003
(1)	95. 0	5.00	78.56	3.59	10.01	0.46	2.01	0.09	0.257	0. 0117
(2)	95. 0	5.00	75.68	16.05	2.20	0.47	0.48	0.10	0.014	0. 0029
(3)	95. 0	5.00	87.72	4.01	2.55	0.12	0.55	0.03	0.016	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.

Having completed the three scenarios, it's now possible to draw comparisons between the first-best case of full information and the two second-best cases involving information asymmetry.

The first-best solution for the injection-site lesion case study is compared with the second-best solution by using equation 13.

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

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 result of equation 13 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 as is given by equation 14.

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

Plugging the costs of scenarios reported into equation 14, the cost of living in a second-best world is: $\min\{963.01, 961.47\} - 961.32$ = \$0.15 per head. The \$0.15 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. According to Agency Theory, such costs 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 14 is \$963.01 - \$961.47 = \$1.54 per head, or for an 800 head plant as assumed here would save approximately 800 head x \$1.54 per head = \$1,232 per day.

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.

Conclusions

The objectives of the present article 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. 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 injection site lesions 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 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.

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Footnotes

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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] It means that 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 the contingent payment scheme.

[4] Each carcass side is assumed to be independent of the other carcass side of 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.

[5] Inada condition (MacLeod 2003, p. 218-219) will guarantee that a solution for the PA's program will be interior. In other words, $I_{l,(j)}$ will be different from zero for all l and j.

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

[7] Agent i will not participate in a risky contract if this contract does not give this agent an expected utility as much as the utility of the best opportunity available to this Agent.

[8] The action space A_i is composed of three actions, so two compatibility constraints are set.