Journal of Agricultural and Resource Economics 31(1):14–26

Do Inspection and Traceability Provide Incentives for Food Safety?

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One of the goals of inspection and traceability is to motivate suppliers to deliver safer food. The ability of these policies to motivate suppliers depends on the accuracy of the inspection, the cost of failing inspection, the cost of causing a foodborne illness, and the proportion of these costs paid by the supplier. We develop a model of the supplier's expected cost as a function of inspection accuracy, the cost of failure, and the proportion of the failure cost that is allocated to suppliers. The model is used to identify the conditions under which the supplier is motivated to deliver uncontaminated lots. Surprisingly, our results show that when safety failure costs can be allocated to suppliers, minimum levels of inspection error are required to motivate a supplier to deliver uncontaminated lots. This result does not hold when costs cannot be allocated to suppliers. As a case study, we use our results to analyze the technical requirements for suppliers of frozen beef to the USDA's Agricultural Marketing Service.

Key words: diagnostic error, food safety, inspection, sampling error, traceability

Introduction

One of the objectives of inspection and traceability systems is to improve the safety of the food supply. Inspection systems use sampling and testing to collect information about safety and quality. Buyers use the results of inspection to decide whether or not a supplier's product is safe enough to buy. Traceability systems accumulate information about product attributes, including safety and origin, as the product moves through the supply chain. Traceability systems are defined by the breadth, depth, and precision of the accumulated information. The breadth of the information refers to the variety of the product attributes that are monitored, the depth of the information refers to how far the accumulated information moves through the supply chain, and the precision of the information refers to its specificity and accuracy (Golan et al., 2004).

The information generated by inspection and traceability systems does not, by itself, lead to an improvement in food safety. To influence food safety, the information must be used to remove unsafe food that is already in the supply chain, or to prevent unsafe food from ever entering the supply chain. In this analysis, we focus on how these systems prevent unsafe food from entering the supply chain by motivating suppliers to produce and deliver safer food. Inspection systems motivate suppliers by generating a

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This research was partially supported by the Economic Research Service, USDA, under Cooperative Research Agreement No. 43-3AEM-4-80122. The views expressed are those of the authors and not necessarily those of the ERS or USDA.
Review coordinated by DeeVon Bailey.

significant cost when a lot fails inspection and must be scrapped. Traceability systems motivate suppliers by making it possible to allocate the cost of unsafe food to the source. Not every unsafe lot that passes inspection will cause an illness, but when it does, the cost of illness associated with contaminated food can be significant. Without inspection, unsafe food can enter the supply chain unhindered and, without traceability, the supplier responsible for unsafe food cannot be identified.

Improving food safety is only one of the reasons to employ a traceability system. Hobbs (2004) identifies three distinct functions for traceability in a food supply chain: (*a*) as a reactive traceback mechanism when contamination problems occur (externality cost-reduction function), (*b*) to strengthen liability incentives (liability function), and (*c*) to verify credence quality attributes (ex ante quality verification). Here, we consider only the liability function of the traceability system. As this analysis will show, the liability function of a traceability system is not always effective in providing incentives to supply safer food. Even if the liability function is ineffective, the traceability system's other functions may be performing adequately.

The power of inspection and traceability to motivate a supplier depends on inspection accuracy. Inspection is, unfortunately, subject to at least two kinds of error. Diagnostic error occurs when samples are incorrectly diagnosed, and sampling error occurs when a sample is not representative of the lot from which it is drawn. Inspection error can result in safe product failing inspection and unsafe product passing inspection. These errors affect supplier profit, and consequently the ability of inspection and traceability to motivate the supplier. The effect of inspection error on motivation is not entirely clear. Inspection is a powerful incentive only if safe product passes and unsafe product fails inspection, and these events are more probable when inspection error is low. Through its liability function, traceability provides a powerful incentive only if unsafe product passes inspection, and this event is more probable when inspection error is high.

The magnitude of inspection error, and therefore the incentive power of inspection and traceability, depend on the attributes of the inspection policy. Inspection policies can be negotiated directly between buyers and suppliers or they can be established by a third party such as a futures exchange or the government. Local governments are often responsible for the safety inspection of food service establishments, and federal and state governments are usually involved at the farm and first processor level. Contracts between food buyers and suppliers often require that, at a minimum, products pass all governmental safety inspections. It is not uncommon, however, for contracts to include additional provisions for ensuring food safety. Some of the possibilities include requiring the seller to maintain a buyer-approved safety program, requiring tests for pathogens or contaminants not covered by government regulations, allowing onsite inspections by buyer representatives, and using more accurate diagnostic or sampling procedures. Ollinger (2004) found that private incentives are responsible for almost as much investment in food safety as public incentives.

The goal of this research is to determine how inspection and the liability function of traceability influence the supplier's willingness to deliver safe food. The inspection system parameters examined include diagnostic error, sampling error, the cost of failing inspection, and the cost of an illness caused by contaminated food (i.e., the cost of a safety failure). The willingness to supply safe food depends on the magnitude and allocation of these costs, which depend, in turn, on inspection error and the depth and precision of the traceability system.

With a few notable exceptions, research addressing the influence of inspection on the supply chain is quite limited. Bogetoft and Olesen (2004) examine how the competitive environment influences investment in safety improvement in the pork supply chain. They demonstrate that improvements at different stages of the supply chain are substitutes for one another and specifically consider testing for *Salmonella*. Mayer, Nickerson, and Owan (2004) show how supply inspections and plant inspections are complements in some markets and substitutes in others, and they apply their results to a large biotechnology firm. Baiman, Fischer, and Rajan (2000) examine the influence of contractible information systems on the supplier's quality improvement effort, the buyer's inspection effort, and product quality. Finally, Hueth and Ligon (1999) explore how price provides quality information when quality measurement is imperfect.

The work on inspection is closely related to research addressing the influence of uncertainty on decisions involving product quality. As reported by Heinkel (1981), imperfect test technology can increase total surplus, and the total surplus is a function of the test accuracy. Chalfant et al. (1999) and Chalfant and Sexton (2002) examine the influence of grading error on adverse selection in the California prune industry. They conclude that while grading error can contribute to adverse selection, adverse selection can sometimes improve industrywide welfare.

Traceability is an increasingly common topic of research in economics. Hobbs et al. (2005) note that traceability systems must be combined with a quality assurance system for traceability to be of value to consumers. Winfree and McCluskey (2005) show that in the absence of traceability, firms choose quality levels which are suboptimal in terms of the collective reputation of a group. Meuwissen et al. (2003) analyze the interaction between certification schemes and traceability systems. Dickinson and Bailey (2002) report on experiments involving consumers' willingness to pay for traceability, transparency, and extra assurances regarding safety. Finally, Smyth and Phillips (2002) consider traceability, segregation, and identity preservation as strategies for product differentiation.

Over the last 25 years, renewed public interest in food safety has resulted in increasing research in this area. Recent food safety research has focused on consumer perceptions regarding food safety and on producer processes to enhance safety by controlling pathogens. Examples of research on consumer perceptions include Marsh, Schroeder, and Mintert (2004); Atsushi and Kikuchi (2004); Nayga, Poghosyan, and Nichols (2004); and Clayton, Griffith, and Price (2003). Research focusing on producer processes to control pathogens is more directly related to our work and includes van der Gaag et al. (2004) who use a simulation model to predict the spread of *Salmonella* throughout the pork supply chain. Patil and Frey (2004) use sensitivity analysis to identify critical control points related to food safety in a processing facility. Malcolm et al. (2004) evaluate the economic effectiveness of pathogen reduction technologies in cattle slaughter facilities. Finally, an analysis by Elbasha and Riggs (2003) is especially interesting in that it attempts to identify the appropriate allocation of preventative effort between consumers and producers.

In this study, we build upon the existing literature by showing how inspection and traceability systems interact to motivate the supplier to deliver safe food. Our findings suggest that greater supplier liability and more accurate inspection do not unambiguously lead to more powerful incentives or to safer food. The relationship between inspection and traceability systems influences the supply of safe food, and so understanding the relationship is vitally important for buyers, regulators, and consumers.

The Model

We assume that suppliers can exert effort to improve the safety of their product and that safety is measured by the contamination rate, $0 \leq q \leq 1$. We also assume safer food costs more to produce and the cost of production per lot is $c(q)$, where $c' < 0$ and $c'' > 0$. The cost of no detectable contamination is assumed to be finite, and we define $c^0 = c(0)$. In some supply chains, the market price is a function of quality, but here it is assumed that the price is zero for lots that fail inspection and w for lots that pass inspection. The supplier observes w and selects q in order to maximize expected utility.

The inspection can be performed by the buyer or a third party (the government or an independent laboratory, for example) and is paid for by the buyer. If a supplier's lot fails inspection, then no transaction occurs. The inspection procedure is imperfect, so some contaminated lots pass inspection and some uncontaminated lots fail inspection. If a contaminated lot passes inspection, it causes a food safety failure for the buyer or for the buyer's customers. We assume the origin of lots is traceable, and if a supplier's lot causes a food safety failure, the supplier is responsible for a portion of the cost of the failure.

Contamination influences the supplier's expected utility through the expected cost of an inspection failure and the expected cost of a food safety failure. The cost of failing inspection (r_t) includes the cost of disposal, scrap, and any fines levied by the government. The supplier's expected cost of inspection failure is a function of the probability of failing inspection, which is a function of the contamination rate, sampling error, and diagnostic error.

The cost of a food safety failure (r_e) includes the direct cost of liability, recalls, and fines levied due to safety failures. This cost includes the social cost of safety failures to the extent these costs are translated into direct economic sanctions. The responsibility for a food safety failure is shared by the supplier, the buyer, and other downstream users. The cost of a food safety failure (r_e) and the portion for which the supplier is responsible are functions of the traceability system. One of the functions of the traceability system is to reduce externality costs when a contamination problem occurs (Hobbs, 2004). If traceback information is precise, then the health impact of contamination can be restricted, and r_e will be reduced. Similarly, precise traceback information may affect the proportion of r_e that the supplier is obligated to pay. Precise traceback may reveal that a safety failure is due to errors made by the buyer instead of the supplier, for instance.

For the purposes of this analysis, both r_e and the proportion of r_e for which the supplier is responsible are assumed to be constant and known by the buyer and supplier. If the nature of the traceability system is changed (i.e., the depth, breadth, or precision of the traced information is changed), then the failure cost and failure cost allocation will also change.

We use π, denoted as the failure cost allocation factor, to represent the proportion of r_e for which the supplier is responsible when a food safety failure occurs. The supplier's expected failure cost depends on the probability of a food safety failure, which depends on the probability that a contaminated lot passes inspection, which in turn depends on the contamination rate, the diagnostic error, and the sampling error. Figure 1 illustrates the flow of product and cost in this stylized supply chain.

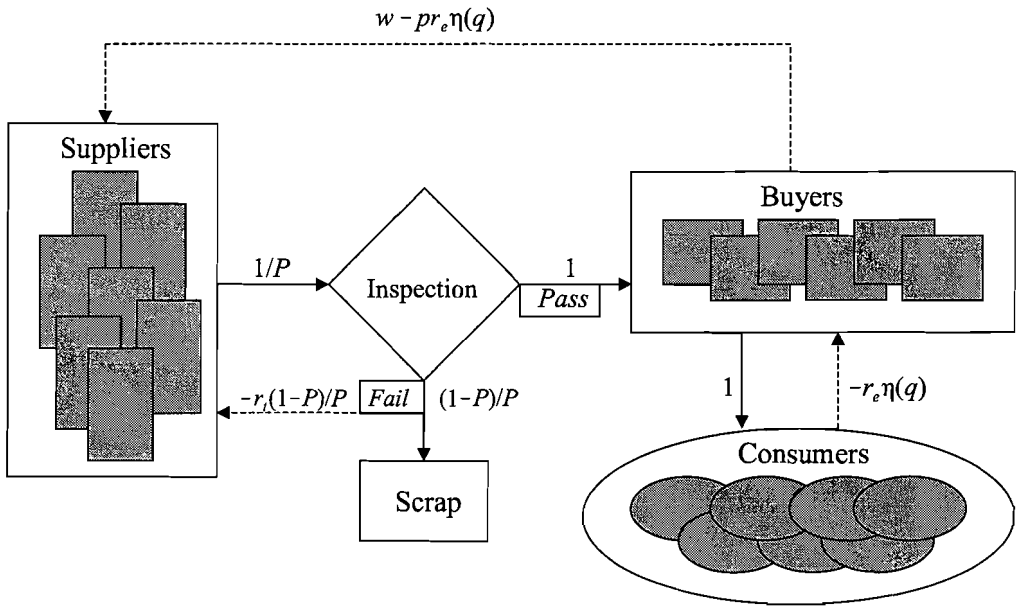

Figure 1. Flowchart of the food supply chain

The Probability of a Failure

Two failure probabilities influence the supplier's expected utility: the probability of failing inspection ($1 - P(q)$) and the probability of a food safety failure ($\eta(q)$). These probabilities depend on the inspection policy which is subject to both diagnostic and sampling error. Diagnostic error is a function of the sensitivity (α) of the test for contamination (the probability of a positive test for contamination given the sample is contaminated), and the specificity (β) of the test for contamination (the probability of a negative test for contamination given the sample is uncontaminated). Diagnostic errors are classified as false positives or false negatives, with probabilities $1 - \beta$ and $1 - \alpha$, respectively. Test sensitivity and specificity are different for different pathogens. For example, Qualicon, the division of Dupont that manufactures screening tests for *Salmonella*, *E. coli*, *Listeria*, and other pathogens, reports sensitivity and specificity of over 99% for its *E. coli* screening test and over 98% for its *Salmonella* screening test.

The other source of error in the inspection procedure is sampling error. Sampling error occurs when the characteristics of a sample are different than the characteristics of the lot from which it is drawn. For our purposes, sampling error is defined as the probability that an uncontaminated sample is drawn from a contaminated lot, and ε is used to represent this probability. It is assumed that the probability of a contaminated sample being drawn from an uncontaminated lot is zero, and the probability of an uncontaminated sample being drawn from an uncontaminated lot is one. The sampling error is more difficult to estimate than the diagnostic error because it depends on how lots are assembled, shipped, delivered, and sampled. Research on bulk sampling error in food safety is virtually nonexistent, even though good models for its estimation exist (Schilling, 1982).

Using these definitions of sensitivity, specificity, and sampling error, we can define the probability that a lot passes inspection as:

$$P(q) = \left[(1-\alpha)(1-\varepsilon) + \beta\varepsilon\right]q + \beta(1-q) \tag{1}$$

and the probability that a contaminated lot passes inspection as:

$$\eta(q) = \left[(1-\alpha)(1-\varepsilon) + \beta\varepsilon\right]q/P(q). \tag{2}$$

The probability of a lot passing inspection [equation (1)] is the sum of the probability that a lot is contaminated and passes inspection, $[(1-\alpha)(1-\varepsilon)+\beta\varepsilon]q$, and the probability that a lot is uncontaminated and passes inspection, $\beta(1-q)$. A contaminated lot can pass inspection if a contaminated sample is drawn but it is incorrectly diagnosed, or if an uncontaminated sample is drawn and it is correctly diagnosed. For notational ease, we define $\gamma = (1-\varepsilon)\alpha + \varepsilon(1-\beta)$, which is the probability of a positive test given a lot is contaminated. Thus, $P(q) = (1-\gamma)q + \beta(1-q)$, and $\eta(q) = (1-\gamma)q/P$. Some straightforward analysis shows that $P_q = 1-\gamma-\beta$, and $\eta_q = (1-\gamma)\beta/P^2$, where subscripts indicate partial derivatives.

The Supplier's Objective Function

If we assume the supplier is risk neutral, and recall the market price is fixed at w for all lots that pass inspection, the supplier's objective is simply to minimize expected cost:

$$\underset{q}{\text{Min}}\ G(q) = \frac{c(q)}{P(q)} + \frac{r_t\left(1-P(q)\right)}{P(q)} + \pi r_e \eta(q). \tag{3}$$

The first term in $G(q)$ is the expected cost of producing a deliverable lot. In order to sell one lot at w, the supplier must produce $1/P(q)$ lots to make up for the lots that fail inspection. The second term in $G(q)$ is the expected cost of an inspection failure and the third term in $G(q)$ is the expected cost of a food safety failure. Assuming risk neutrality allows us to ignore the size of the transaction and focus on the influence of inspection error on supplier behavior.

The necessary condition for an interior solution to (3) is:

$$G_q = \frac{c_q}{P} - \frac{(c+r_t)P_q}{P^2} + \pi r_e \eta_q = 0, \tag{4}$$

and the sufficient condition is

$$G_{qq} = \frac{c_{qq}}{P} - \frac{2c_q P_q}{P^2} - \frac{(c+r_t)}{P^2}\left(P_{qq} - \frac{2P_q^2}{P}\right) + \pi r_e \eta_{qq} > 0. \tag{5}$$

Rearranging (4), an interior extremum is found to exist if:

$$\frac{-c_q}{P} = \frac{-(c+r_t)P_q}{P^2} + \pi r_e \eta_q. \tag{6}$$

The left-hand side of (6) is the marginal reduction in production cost associated with increasing the contamination rate, and the right-hand side is the marginal increase in the expected cost of inspection and food safety failure associated with an increase in q. At an optimum, the marginal increase in failure costs must equal the marginal decline in the production cost. Otherwise, the supplier will benefit from either increasing or decreasing the contamination rate.

No Detectable Contamination

Equations (4) and (5) identify the necessary and sufficient conditions for an interior optimum, but our primary interest is the conditions under which a corner solution is optimal. In particular, we are interested in the influence of the inspection policy parameters (α, β, and ε), the failure costs (r_t and r_e), and the failure cost allocation factor (π) on the supplier's motivation to deliver no detectable contamination, $q = 0$. The supplier's optimal (local) solution is no detectable contamination ($q^* = 0$) when $G_q > 0$ at $q = 0$. If $G_q > 0$, then any increase in the supplier's contamination rate also increases the supplier's expected cost and decreases the supplier's expected utility.

At $q = 0$, we know that $P(0) = \beta$, $P_q = 1 - \gamma - \beta$, and $\eta_q = (1 - \gamma)/\beta$. Substituting these values into (6) gives the following condition for $q^* = 0$:

$$-c_q^0/\beta < -(c^0 + r_t)(1 - \gamma - \beta)/\beta^2 + \pi r_e(1 - \gamma)/\beta, \tag{7}$$

where $c^0 = c(0)$, $c_q^0 = c_q(0)$, and $\gamma = (1 - \varepsilon)\alpha + \varepsilon(1 - \beta)$. Equation (7) requires that the marginal reduction in cost associated with relaxing food safety efforts is less than the marginal increase in the failure costs associated with relaxing food safety efforts at $q = 0$.

Traceability, Failure Costs, and the Supply of Safe Food

Equation (7) can be rearranged to identify the values of π, r_e, and r_t that lead to $q^* = 0$:

$$\frac{-c_q^0 - (c^0 + r_t)}{r_e(1 - \gamma)} + \frac{(c^0 + r_t)}{r_e\beta} < \pi, \tag{8}$$

$$\frac{-c_q^0 - (c^0 + r_t)}{\pi(1 - \gamma)} + \frac{(c^0 + r_t)}{\pi\beta} < r_e, \tag{9}$$

$$\frac{\beta\left(-c_q^0 - \pi r_e(1 - \gamma)\right)}{\gamma + \beta - 1} - c^0 < r_t. \tag{10}$$

Conditions (8), (9), and (10) show the minimum values for the safety failure cost allocation factor, safety failure cost, and inspection failure required to ensure that $q^* = 0$. The failure cost allocation factor and the two failure costs are clearly substitutes for one another in motivating the supplier to deliver $q^* = 0$. The power of these incentives, however, is closely related to the accuracy of the inspection protocol.

Inspection Error and the Supply of Safe Food

We can also rearrange (7) to identify the values of $(1 - \alpha)$ and ε that are consistent with $q^* = 0$. The value $(1 - \alpha)$ is the probability that a contaminated sample is misdiagnosed, and ε is the probability that an uncontaminated sample is drawn from a contaminated lot. No detectable contamination is the supplier's optimal solution if:

$$\frac{-\beta(c_q^0 + c^0 + r_t)}{(1-\varepsilon)(\beta\pi r_e - (c^0 + r_t))} - \frac{\beta\varepsilon}{(1-\varepsilon)} < 1 - \alpha, \tag{11}$$

$$\frac{-\beta(c_q^0 + c^0 + r_t)}{(\alpha+\beta-1)(\beta\pi r_e - (c^0 + r_t))} - \frac{1-\alpha}{(\alpha+\beta-1)} < \varepsilon, \tag{12}$$

and $\pi r_e > (c^0 + r_t)/\beta$; i.e., the expected cost per contaminated lot that passes inspection is greater than the expected cost per lot that fails inspection [recall, $P(0) = \beta$]. Strangely, the left-hand sides of (11) and (12) represent the lower limits on these probabilities. If the error falls below these limits, then the supplier's optimal contamination rate is more than zero.

This result is counterintuitive but not inexplicable. The key is the requirement that $\pi r_e > (c^0 + r_t)/\beta$. If πr_e is greater than $(c^0 + r_t)/\beta$, then the supplier pays more for a contaminated lot that passes inspection than for a lot that fails inspection. Of course, contaminated lots pass inspection only if diagnostic error or sampling error exists. The higher the diagnostic and sampling error, the greater the probability of a contaminated lot passing inspection, the greater the probability the supplier pays πr_e, and the greater the motivation to reduce contamination. Conditions (11) and (12) identify the minimum sampling and diagnostic errors which make the safety failure cost significant enough to motivate the supplier to produce at $q^* = 0$.

If there is no diagnostic or sampling error, then the buyer is indifferent to the supplier's contamination rate because no contaminated lots will pass inspection. Unfortunately, inspection error, and especially sampling error, is likely to remain a problem in food safety inspection protocols. The conditions presented above provide guidelines for ensuring $q^* = 0$ even when inspection error exists.

Anonymity

Some parts of the food industry work under conditions of relative anonymity—i.e., no information about product origin moves through the supply chain. Under conditions of anonymity, the supplier cannot be held responsible for food safety failures. Usually this occurs when raw materials are commingled as a part of processing. When there is no traceability, then no failure costs can be allocated to the supplier ($\pi = 0$), and the supplier pays no penalties for food safety failures.

Recall, one of the conditions for (11) and (12) is that $\pi r_e > (c^0 + r_t)/\beta$. If π is close to zero, then this condition is not true, and therefore the inequalities in (11) and (12) are reversed. In this situation, we have a maximum level of inspection error which will motivate the supplier to achieve $q^* = 0$. The lower the diagnostic and sampling error, the lower the probability that a contaminated lot passes inspection, the greater the supplier's

cost of inspection failure, and the greater the supplier's motivation to reduce contamination to its minimum.

Our results show that the food safety failure cost (r_t) and inspection failure cost (r_e) are substitutes for each other in motivating the supplier to deliver $q^* = 0$. Further, the diagnostic error and the inspection error are substitutes for each other in motivating the supplier. Finally, a traceability system that allocates failure cost to suppliers is found to be an effective incentive only if the inspection error is nonzero. Stated another way, in traceability systems with a large π, increased accuracy can result in lower expected failure cost. Therefore, increased accuracy may become a disincentive to providing safer food. In the following section, these results are used to evaluate an existing contract for ground beef.

Case Study: The AMS Ground Beef Contract

The USDA's Agricultural Marketing Service (AMS) purchases food for the National School Lunch Program and other federal feeding programs. Frozen beef in fine, coarse, and ground form is one of the livestock products purchased by the AMS. In fiscal year 2004, the AMS purchased 135.12 million pounds of frozen beef from 23 vendors for $213.31 million. Quality specifications for frozen ground beef are published in the AMS's *Technical Requirements Schedule GB-2005*. The technical requirements specify product codes, domestic origin and slaughter requirements, traceability requirements, fat content, patty weight and thickness, and microbial testing requirements. The technical requirements associated with microbial pathogens are designed so that suppliers (or "contractors" in the AMS vernacular) are motivated to deliver uncontaminated lots. As we have shown, the strength of this motivation depends on inspection error and the cost of failure.

Under the AMS technical requirements, inspecting ground beef for microbial pathogens requires sampling from each lot. A lot is defined as the quantity produced between "clean-ups," but not less than 10,000 pounds. The sampling procedure requires that each lot is divided into approximately 2,000-pound increments, each increment is sampled, and the samples are combined to create a composite sample. For microbes other than *E. coli* O157:H7, the samples are analyzed using procedures published in the *Compendium of Methods for the Microbiological Examination of Foods* (Downes and Ito, 2001). For *E. coli* O157:H7, the ground beef samples are tested using the methods set forth in the *USDA Microbiology Laboratory Guidebook* (Dey and Lattuada, 1998). The *Guidebook* requires *E. coli* screening tests to have a sensitivity of at least 98% and a specificity of at least 90%.

The inspection failure cost for suppliers is difficult to quantify. The status of AMS frozen beef suppliers is either "process assessment status," "conditional status," or "ineligible." To move up the status hierarchy, a supplier must have an approved quality control plan and have 20 consecutive lots with no detectible *E. coli* O157:H7, among other things. The cost of failing a test for *E. coli* O157:H7 is a change in status to either conditional or ineligible, and subsequently, the cost of moving back up the hierarchy. The AMS controls the cost of moving up the hierarchy, and therefore the cost of failing inspection.

Table 1. Optimal Contamination Rates (q^*) for Different Combinations of Inspection Failure Cost (r_t) and Sampling Error (ε)

Inspection Failure Cost (r_t)	Sampling Error (ε)			
	0.0	0.005	0.015	0.02
	<---------- Optimal Contamination Rate (q^*) ---------->			
0.0	0.166	0.125	0.089	0.056
0.1	0.128	0.091	0.059	0.029
0.2	0.094	0.061	0.031	0.004
0.3	0.063	0.033	0.005	0.000
0.4	0.034	0.007	0.000	0.000
0.5	0.008	0.000	0.000	0.000

The food safety failure cost for frozen beef suppliers is also difficult to quantify. A food safety failure traced back to a supplier would result, at a minimum, in a loss of the current contract, and probably a loss of future contracts with the AMS. If a consumer develops an illness and sues the supplier (and the AMS), then the costs clearly increase. In a survey of court cases involving foodborne illnesses, Buzby, Frenzen, and Rasco (2001) found only a third of the cases resulted in payment to the plaintiff, with a mean award of about $133,000. If the victim of food poisoning originating from AMS-distributed ground beef wins a case, it seems likely the supplier would share the cost of the award with other firms and agencies in the supply chain. Consequently, we suspect that $\pi < 1$.

The AMS's objective is to design the technical requirements of the contract so that suppliers deliver only uncontaminated lots. The AMS has little control over the cost of a food safety failure, and we assume the minimum requirements for test sensitivity and specificity are defined by other governmental agencies (perhaps in consultation with AMS). Therefore, we concentrate on using the sampling error (ε) and inspection failure cost (r_t) to motivate suppliers. The sampling error is a function of the lot size, increment size, and compositing procedures (Schilling, 1982). The inspection failure cost is a function of the rules for change of status and the requirements for acquiring and reacquiring process assessment status. What levels of ε and r_t will motivate suppliers to deliver uncontaminated product?

Table 1 reports the optimal contamination rates (q^*) for a supplier facing different levels of r_t and ε. As expected, the supplier's optimal contamination rate falls as the inspection failure cost increases. The counterintuitive result is also evident: the optimal contamination rate falls as the sampling error increases. In constructing table 1, it is assumed that the AMS technical requirements are satisfied. The sensitivity of the diagnostic test must be at least 98%, so the probability of a false negative ($1 - \alpha$) is 2%. The specificity of the diagnostic test must be at least 90%, so we set $\beta = 0.90$. For simplicity, costs are assumed to be scaled so that the cost of producing a lot is $c(q) = \exp(-2q)$; i.e., the cost of producing an uncontaminated lot is $c^0 = \$1$, and $c_q^0 = -2$. The cost of a food safety failure has not been estimated for frozen ground beef specifically. However, given Buzby, Frenzen, and Rasco's (2001) findings, we are comfortable assuming that the food safety failure cost is 50 times the cost of production, so we set $r_e = \$50$. Finally, we assume the supplier is liable for half of this safety failure cost ($\pi = 0.50$).

Table 2. Minimum Safety Failure Cost Allocation (π) Required to Motivate a Supplier to Deliver Uncontaminated Lots, as a Function of Inspection Failure Cost (r_t) and Sampling Error (ε)

Inspection Failure Cost (r_t)	Sampling Error (ε)			
	0.0	0.005	0.015	0.02
	<--- Minimum Safety Failure Cost Allocation Factor (π) --->			
0.0	NF[a]	0.842	0.717	0.625
0.1	0.924	0.762	0.649	0.567
0.2	0.827	0.682	0.582	0.509
0.3	0.729	0.603	0.515	0.451
0.4	0.631	0.523	0.448	0.393
0.5	0.533	0.443	0.381	0.335

[a] NF = not feasible.

Next we consider how the safety failure cost allocation factor and sampling error interact in this contract. Table 2 shows the minimum safety failure cost allocation required to motivate the supplier to deliver uncontaminated lots as a function of r_t and ε. As the error increases, π declines, indicating these parameters are substitutes for each other in accomplishing the objective of safer food. One important implication of this relationship is that if sampling error declines—due to improved sampling procedures, for instance—then the cost allocation factor must be increased in order to maintain the incentive to deliver uncontaminated lots. The AMS can use this information to guide construction of the technical requirements for frozen ground beef. While the relationship between most parameters and the supplier's incentives is straightforward, the impact of sampling error on the optimal contamination rate is unexpected but not unpredictable.

Conclusions

Inspection and traceability are not unique food industry policies. Many different organizations and government agencies use inspection and traceability to encourage individuals and organizations to comply with behavioral standards. For example, the U.S. Internal Revenue Service uses the threat of audits to encourage taxpayers to complete accurate and truthful tax returns. The threat of an expensive citation, among other things, motivates drivers to comply with parking and traffic laws. The possibility of getting caught encourages students to refrain from plagiarism. The menace of legal action motivates companies to fulfill their contractual obligations. And teenagers are often motivated to follow established behavioral norms by the threat of "grounding." Getting caught, audited, or cited are incentives only if there is a chance of these events occurring, and if the cost of these events is significant. Anything that reduces the probability or the cost of getting caught, audited, or cited, also reduces the incentive power of these events.

In general, inspection and traceability provide the incentives we expect in the food supply chain. Specifically, there are minimum failure costs and failure cost allocations (π) that motivate a supplier to deliver uncontaminated lots. The relationship between

the traceability system and inspection error is less clear, however. The traceability system provides an incentive only if safety failures can occur, can generate cost, and the cost can be allocated to the responsible supplier. Safety failures occur only if contaminated lots pass inspection, and contaminated lots pass inspection only if there is inspection error. Counter to what one might expect, therefore, when the failure cost allocation factor is large, there is a minimum level of inspection error needed to motivate a supplier to deliver $q^* = 0$.

Our results do not imply that traceability can be used in place of inspection or that inspection can be used instead of traceability to motivate suppliers to deliver safer food. On the contrary, when inspection error exists, a traceability system which allocates safety failure costs to suppliers increases the incentive to supply safer food. This incentive increases with the inspection error and with the proportion of failure cost paid by the supplier. As the inspection error disappears, however, so does the incentive provided by the traceability system.

In order to design effective incentives, buyers and regulators who want uncontaminated lots need to understand the interaction between a supply chain's inspection and traceability system. The best incentive system will depend on the relative magnitude of inspection failure and safety failure costs. Indeed, the primary weakness in our case analysis of the AMS contract for ground beef is quantifying the cost of failing inspection and the cost of a safety failure. When the inspection failure cost is low and safety failure cost is high, then increasing accuracy is unlikely to provide a meaningful incentive. Increased accuracy will save little in inspection failure cost and will reduce the incentive provided by the safety failure cost. If inspection failure cost is high relative to the safety failure cost, however, then increased accuracy is likely to provide a significant incentive to suppliers. These conclusions are consistent with the hypotheses posed by Barzel (1982) regarding the cost of measuring quality (by inspection) and the willingness to pay for differentiated products.

One of the unrealistic assumptions in our analysis is that failure costs and inspection errors are known by the supplier. In some supply chains this is a reasonable assumption, but in others it is not. In some cases, suppliers will have better information about inspection failure costs than buyers, and buyers will have better information about inspection error than suppliers. Future research should address the influence of the asymmetric information about inspection parameters and costs on buyer and supplier behavior.

[*Received September 2005; final revision received February 2006.*]

References

Atsushi, M., and M. Kikuchi. "Risk-Learning Process in Forming Willingness to Pay for Egg Safety." *Agribus.: An Internat. J.* 20(2004):167–180.

Baiman, S., P. E. Fischer, and M. V. Rajan. "Information, Contracting, and Quality Costs." *Mgmt. Sci.* 46(2000):776–790.

Barzel, Y. "Measurement Cost and the Organization of Markets." *J. Law and Econ.* 25(1982):27–48.

Bogetoft, P., and H. B. Olesen. "Quality Incentives and Supply Chains: Managing Salmonella in Pork Production." *Amer. J. Agr. Econ.* 86(2004):829–834.

Buzby, J. C., P. D. Frenzen, and B. Rasco. "Product Liability and Microbial Foodborne Illness." Agr. Econ. Rep. No. 799, USDA/Economic Research Service, Food and Rural Economics Division, Washington, DC, 2001.

Chalfant, J. A., J. S. James, N. Lavoie, and R. Sexton. "Asymmetric Grading Error and Adverse Selection: Lemons in the California Prune Industry." *J. Agr. and Resour. Econ.* 24,1(1999):57–79.

Chalfant, J. A., and R. J. Sexton. "Marketing Orders, Grading Errors, and Price Discrimination." *Amer. J. Agr. Econ.* 82(2002):53–66.

Clayton, D. A., C. J. Griffith, and P. Price. "Consumers' Attitudes, Knowledge, Self-Reported and Actual Hand-Washing Behaviour: A Challenge for Designers of Intervention Materials." *Internat. J. Consumer Studies* 27(2003):233–235.

Dey, B. P., and C. P. Lattuada, eds. *USDA Microbiology Laboratory Guidebook.* USDA/Food Safety and Inspection Service, Washington, DC, 1998.

Dickinson, D. L., and D. Bailey. "Meat Traceability: Are U.S. Consumers Willing to Pay for It?" *J. Agr. and Resour. Econ.* 27,2(2002):348–364.

Downes, F. P., and K. Ito, eds. *Compendium of Methods for the Microbiological Examination of Foods*, 4th ed. Washington, DC: American Public Health Association, 2001.

Elbasha, E. H., and T. L. Riggs. "The Effects of Information on Producer and Consumer Incentives to Undertake Food Safety Efforts: A Theoretical Model and Policy Implications." *Agribus.: An Internat. J.* 19(2003):29–42.

Golan, E., B. Krissoff, F. Kuchler, L. Calvin, K. Nelson, and G. Price. "Traceability in the U.S. Food Supply: Economic Theory and Industry Studies." Agr. Econ. Rep. No. 830, USDA/Economic Research Service, Food and Rural Economics Division, Washington, DC, 2004.

Heinkel, R. "Uncertain Product Quality: The Market for Lemons with an Imperfect Testing Technology." *Bell J. Econ.* 12(1981):625–636.

Hobbs, J. E. "Information Asymmetry and the Role of Traceability Systems." *Agribus.: An Internat. J.* 20(2004):397–415.

Hobbs, J. E., D. Bailey, D. L. Dickinson, and H. Morteza. "Traceability in the Canadian Red Meat Sector: Do Consumers Care?" *Can. J. Agr. Econ.* 53(2005):47–65.

Hueth, B., and E. Ligon. "Producer Price Risk and Quality Measurement." *Amer. J. Agr. Econ.* 81(1999): 512–526.

Malcolm, S., C. Narrod, T. Roberts, and M. Ollinger. "Evaluating the Economic Effectiveness of Pathogen Reduction Technologies in Cattle Slaughter Plants." *Agribus.: An Internat. J.* 20(2004):109–123.

Marsh, T. L., T. C. Schroeder, and J. Mintert. "Impacts of Meat Product Recalls on Consumer Demand in the USA." *Applied Econ.* 36(2004):897–910.

Mayer, K. J., J. A. Nickerson, and H. Owan. "Are Supply and Plant Inspections Complements or Substitutes? A Strategic and Operational Assessment of Inspection Practices in Biotechnology." *Mgmt. Sci.* 50(2004):1064–1081.

Meuwissen, M. P. M, A. G. J. Velthuis, H. Hogeveen, and R. B. M. Huirne. "Traceability and Certification in Meat Supply Chains." *J. Agribus.* 21,2(Fall 2003):167–181.

Nayga, R. M., A. Poghosyan, and J. P. Nichols. "Will Consumers Accept Irradiated Food Products?" *Internat. J. Consumer Studies* 28(2004):178–186.

Ollinger, M. "Market Incentives Raise Food Safety Bar." *Amber Waves* (April 2004):7.

Patil, S. R., and H. C. Frey. "Comparison of Sensitivity Analysis Methods Based on Applications to a Food Safety Risk Assessment Model." *Risk Analysis: An Internat. J.* 24(2004):573–586.

Schilling, E. G. *Acceptance Sampling in Quality Control.* New York: Marcel Dekker, Inc., 1982.

Smyth, S., and P. W. B. Phillips. "Product Differentiation Alternatives: Identity Preservation, Segregation, and Traceability." *AgBioForum* 5(2002):30–42.

U.S. Department of Agriculture, Agricultural Marketing Service. *Technical Requirements Schedule GB-2005 for USDA Purchases of Ground Beef Items, Frozen.* USDA/AMS, Washington, DC, 2005.

van der Gaag, M. A., H. W. Saatkamp, M. van Boven, P. van Beek, and R. B. M. Huirne. "A State-Transition Simulation Model for the Spread of Salmonella in the Pork Supply Chain." *Euro. J. Operational Res.* 156(2004):782–799.

Winfree, J. A., and J. J. McCluskey. "Collective Reputation and Quality." *Amer. J. Agr. Econ.* 87(2005): 206–213.