**Information Asymmetry and Traceability Incentives for Food Safety**[1]

Moises A. Resende-Filho, FEA/UFJF, Martelos, Juiz de Fora, MG 36036-330. Brazil. E-mail: moises.resende@ufjf.edu.br.

**Abstract**
I define traceability by its reliability that is the probability by which the identity of raw material suppliers (agents) is preserved linked with food. I consider a food processor (principal) that buys from many homogeneous agents. The food processor chooses the level of food safety effort, the reliability of traceability and the value of contingent payments so to entice agents to exert the chosen level of food safety effort, minimizing costs. The focus is on cases in which food safety crises can be caused only by misspecification of raw material. I show that very reliable traceability can be a substitute for high intensive contingent payments schemes and vice-versa, indicating that traceability is not an unequivocal signal for safer food. I also show that government regulation based on the imposition of traceability's reliability may not lead to safer food but increased pecuniary penalties due to food safety failure can induce safer food.
**Keywords**: Moral Hazard, Identity Preservation, Traceability, Food Safety.
**JEL Classification**: D82, D86, C61.

**Resumo**
Define-se rastreabilidade com base em sua confiabilidade que é a probabilidade de que a identidade dos fornecedores de matérias-primas (agentes) seja preservada atrelada ao produto final. Considera-se o caso de um processador de alimentos (principal) que compra de vários fornecedores (agentes) homogêneos. O principal escolhe o nível de esforço a ser induzido, a confiabilidade do seu sistema de rastreabilidade e os valores dos pagamentos contingentes, de modo a induzir os agentes a exercerem o nível de esforço escolhido, minimizando custos. O foco é sobre casos em que crises de segurança do alimento são causadas apenas por problemas na matéria-prima utilizada. Mostra-se que sistemas de rastreabilidade de elevada confiabilidade podem substituir esquemas de pagamentos contingentes intensivos e vice-versa, indicando que a confiabilidade de um sistema de rastreabilidade não é um sinal inequívoco de maior segurança do alimento. Mostra-se ainda que a regulação governamental via a imposição de um nível pré-determinado de confiabilidade dos sistemas de rastreabilidade pode ser inócua e que a imposição de multas mais severas em caso de crises de segurança do alimento podem aumentar a segurança do alimento.
**Palavras-chave**: Perigo Moral, Preservação da Identidade, Rastreabilidade, Segurança do Alimento.
**Classificação JEL**: D82, D86, C61.

**Área Anpec**: Área 7 - Microeconomia, Métodos Quantitativos e Finanças.

[1] The author thanks Nori Tarui, S. Adrew Starbird, Sébastien Pouliot and Terrance Hurley for helpful comments and suggestions on early versions of this article. All remain errors are author's.

## Introduction

There are many examples of widely publicized episodes of food borne diseases resulting in food safety crises. Cases of botulism (*Clostridium botulinum*) due to the ingestion of canned hearth-of-palms were reported between years 1997 and 1999 in Brazil. In 2002, nearly 19 million pounds of ground beef possibly contaminated with *E. coli* O157:H7 and 27.4 million pounds of chicken and turkey products that might be contaminated with *Listeria monocytogenes* were recalled (Teratanavat and Hooker 2004). Other recent examples of food safety crises are the first case of an animal testing positive for Bovine Spongiform Encephalopathy (BSE) in the United States and in Canada in 2003. Also, poultry and dairy products were recently found contaminated with dioxin in European countries and dangerous to the health levels of hormones and antibiotics in meat have been noticed in many places of the world.

High profile food safety crises have created a desire to identify strategies to improve quality-control systems in world food supply chain. In this context, traceability has been proposed as a potential instrument for safer food. Traceability has been also adopted to improve supply chain management and animal health, to combat bio-terrorism, to comply with international trade standards, and to certify credence[2] attributes (Golan *et al.* 2004). This article focuses on the relation between traceability and food safety.

The International Organization for Standardization (2000) states that traceability systems create the ability to retrieve the history and location of a product through a registered identity. Starbird and Amonor-Boadu (2006) point out that a traceability system is composed of a series of procedures by which the identification, preparation, collection, storage, and verification of data are performed. This includes implementing computer systems and databases, identification technologies such as bar codes or tags, and improved supply chain management protocols. Thus, traceability just accumulates information about product attributes, including safety and origin, as the product moves through the supply chain.

Unlike Pathogen Reduction[3] (PR) and Hazard Analysis and Critical Control Point[4] (HACCP), traceability does not aim at direct interventions in procedures and processes in the production so to improve safety and quality controls already in place. Therefore, traceability adoption does not seem by itself to imply safer food.

Food supply chains are traditionally composed of independent firms where product moves from a firm to the next through open market transactions wherein qualities, quantities and prices are established through observation and negotiation. In general, downstream firms do not observe food safety and food quality efforts exerted by upstream firms and the direct monitoring of upstream production processes is often prohibitively expensive. Moreover, downstream firms cannot directly observe the safety of upstream firms' product because food safety is a credence attribute (Golan et al. 2004). Thus, quality and safety problems originated at farm level often manifest themselves in downstream stages of production at which point the farmer identity was already lost.

Once traceability allows for tracing inputs used in the production of food back to their origin at various levels in the supply chain, it may reduce anonymity. In fact, traceability can

---

[2]A credence attribute cannot be verified even after the product is consumed or utilized.

[3]Examples of innovative and effective technologies for limiting carcass contamination and pathogen reduction are carcass steam pasteurization, spray-washing, irradiation and chemical interventions (Vitiello and Thaler 2001, p. 600).

[4]Notermans, Zwietering and Mead (1994, p. 204) define HACCP as a systematic approach to the control of potential hazards in a food by identifying problems before they occur, and establishing measures for their control at the stages in production that are found to be critical.

strengthen liability incentives (Hobbs 2004) by providing useful information in accessing *ex post* legal responsibility by those involved in the food production chain (Tonsor and Schroeder 2004). This is exactly the primary concern of most opponents of mandatory introduction of traceability (e.g. national animal identification systems) (Souza-Monteiro and Caswell 2004). Notice that neither of these authors provide explicit model of the relationship between traceability and incentives. But Pouliot and Sumner (2008) and Starbird and Amonor-Boadu (2006; 2007) studies the effect of traceability on strength liability along supply chains.

There are many studies addressing the issue of how to increase producers' efforts so to improve product quality and safety via incentives. Dubois and Vukina (2004), Starbird (2005), and King, Backus and Gaag (2007) use principal-agent models to evaluate the impacts of incentives offered by a principal on the effort of agents. King, Backus and Gage further show that reputation can be an added incentive to induce performance under a contract. In these previous studies, the principal knows the agent's identity at the time an event influenced by the agent' effort is observed that is certainly the case when raw material is tested on delivery. However, there are many cases in which the product defect caused by the agent can be discovered only after processing has begun. By this time the identity of the raw material supplier is likely to have been separated from the processed product. The model in this article formalizes this idea and unlike Pouliot and Sumner (2008) and Starbird and Amonor-Boadu (2006; 2007), considers and explicitly shows how traceability can be endogenously set by private firms. The model developed in this article follows close the framework used by Resende-Filho and Buhr (2008) for studying injection-site lesion control in beef, but differs from them by looking at the more general issue of food safety.

This article studies traceability under the perspective that although it does not directly act on food safety, it can do so indirectly. This is because traceability makes it possible to identify the source of food safety problems with some chance of success, reducing anonymity. Hence, traceability may mitigate suboptimal results due to asymmetric information amongst buyers and suppliers by allowing for the use of explicit and implicit incentives along food supply chains. Based on this premise, I pursue three objectives in this article. First, I aim at modeling and showing that voluntary use of traceability allows for the creation of incentives mechanisms that induce higher food safety efforts by raw material suppliers, leading to safer food. Second, I want to show that the adoption of traceability may not be an unequivocal signal of safer food. Third, I want to investigate how exogenously mandated traceability and fines levied in case of food safety crises can affect food safety.

## The Model

Although food safety crises may have many different origins, this article focuses only on problems originated at farm level. In other words, the focus is on cases in which food processor's effort has no effect on the safety of the final product but suppliers' effort has. Examples of problems originated only at farm level include chemical residues in food (e.g. dioxin, antibiotics, hormones and pesticides residues), physical residues in food (e.g. due to foreign objects such as broken syringe needles from health treatments) and feeding of restricted ingredients (e.g., animal by-products in the case of BSE).

Consider that food safety is a binary random variable, $\omega$. Food is safe to human consumption or, equivalently, the raw material does not cause food to be unsafe with probability $F$. Moreover, $F$ depends only on supplier's effort, $F$=$F(a)$, such that:

**Assumption 1.** $F'(.) > 0,\ F''(.) < 0$, where $F(a)$ is a cumulative density function.

Assumption 1 assures that food safety probability increases in effort but at decreasing rates (see Tirole 1988, p.54).

Golan *et al.* (2004) suggest that traceability systems should be characterized by their breadth[5], depth[6]and precision[7]. Following them, this article studies traceability systems that just store information about the identity of the raw material supplier (traceability's breadth) and keep this information from the delivery of the raw material up to the consumption of the food product (traceability's depth). Like any information system, a traceability system fails with some frequency as a consequence of hardware and software failures and human mistakes. Therefore, when food is unsafe and traceability works the source of problem is automatically pinpointed because food can be unsafe in the model only due to problems caused by raw material misspecification. Furthermore, it is assumed that there are no false positives. The consequence of this is that when food is unsafe, and traceability works properly the precision of a traceability system, as defined by Golan *et al.* (2004), is 100% and zero if traceability fails.

The reliability of a traceability system follows a binary random variable, $\phi$ such that the frequency by which the system works properly is $s$ and the probability by which it fails is (1-$s$). Notice that a traceability system is fully characterized by its reliability, $s$.

Given the above context, the principal and each agent play a one-shot, two-stage sequential game that runs as shown in Figure 1.

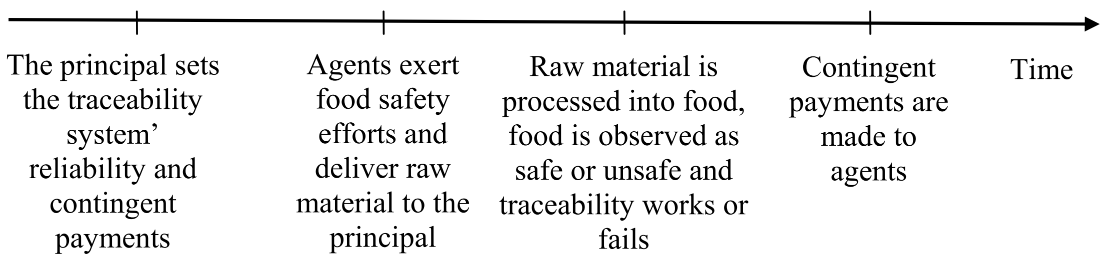


Figure 1. Timing of the principal-agent game with traceability

According to figure 1, the principal is the first mover, setting and offering to agents a contract composed of a contingent payment scheme and the traceability system's reliability. In sequence, homogeneous agents exert food safety efforts as their best response to the contract offered by the principal. Finally, payments are made to agents on the basis of observed states of nature.

A failure of the traceability system means that suppliers' identity was lost during food processing. In such contingency, it is impossible to reward or punish agents based on if food is found safe or unsafe. Thus, $I_0$ denotes the income transfer to agents when traceability fails regardless of the safety of food (contingency 0). On the other hand, when the traceability system works properly, $I_1$ is the payment to agents if food is safe (contingency 1), and $I_2$

[5] Breadth is the amount of information recorded by the system (Golan *et al.* 2004).

[6] Depth defines how far forward and backward in the supply chain traceability extends (Golan *et al.* 2004).

[7] Precision represents the ability to pinpoint the source of a product defect (Golan *et al.* 2004).

otherwise (contingency 2). Summing up, $I_m$ is the payment per raw material lot that is contingent on $m \in M$, with $M$={0, 1, and 2}. For convenience, table 1 summarizes probabilities and contingencies in the model.

Table 1. Summary of Events, their Probabilities and Contingent Payments in the Model

| Event | Symmetric Information Setting | Asymmetric Information with Traceability Setting | | | |
|---|---|---|---|---|---|
| | | Traceability Works | | Traceability Fails | |
| | Probability | Probability | Payment | Probability | Payment |
| Food is safe | $F(a)$ | $F(a)s$ | $I_1$ | $(1\text{-}s)F(a)$ | $I_0$ |
| Raw material causes food to be unsafe (food is unsafe) | $(1\text{-}F(a))$ | $(1\text{-}F(a))s$ | $I_2$ | $(1\text{-}s)(1\text{-}F(a))$ | $I_0$ |

**The Agent's Problem**

Each raw material supplier's preferences are represented by a utility function whose arguments are contingent transfers ($I_m$) and food safety effort ($a$). Following Holmström (1979), Tirole (1988), Goodhue (2000), and Starbird (2005), I assume additive separability between income utility and disutility of effort so that an agent's utility function $U$: $\Re^2 \rightarrow \Re$ is:

$$U(I_m, a)=u(I_m)\text{-}c(a) \qquad (1)$$

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

**Assumption 2.** $u'(.)>0$, $u''(.)\leq 0$, $c'(.)>0$, and $c''(.)>0$.

Being an agent the second mover in the game, he/she takes as given the contract ($s$, $I_0$, $I_1$, $I_2$) previously established by the principal and chooses the level of food safety effort so to maximize his/her expected utility as given by problem (2).

$$\max_{a\geq 0}\ (1\text{-}s)u(I_0)+sF(a)u(I_1)+s(1\text{-}F(a))u(I_2)\text{-}c(a) \qquad (2)$$

The first order necessary condition for problem (2) so to attain a maximum at the interior point, $a^*$, is:

$$sF'(a^*)(u(I_1)\text{-}u(I_2))\text{-}c'(a^*)=0 \qquad (3)$$

Notice from (3) that when $s$ is zero an agent's best response is given as the solution for $c'(a^*)=0$. Being $c(a)$ strictly convex by assumption 2, $c'(a^*)=0$ implies that the lowest level of food safety effort will be exert when traceability is not in place ($s$=0). Obviously, the lowest level of food safety effort must not imply that the probability of food being safe is zero ($F(a)$=0), otherwise the level of effort exerted by the population of homogeneous agents would be fully revealed and the principal could pay based on it. In other words, there must be some safe food in the market so to agents remain anonymous even if no traceability exists. I assume that the lowest level of effort is the one already exerted in the market wherein no traceability system is adopted by food processors.

Based on (3) the following result is formalized.

**Result 1.** It is necessary that a traceability is in place ($s$ must be strictly positive) so to induce food safety efforts higher than the lowest level of effort already exerted when no traceability system is adopted.

The second-order sufficient condition for problem (2) so to attain a maximum at the interior point, $a^*$, is:

$sF''(a^*)(u(I_1)-u(I_2))-c''(a^*)<0$

(4)

The characteristics of the principal-agent with traceability problem that are presented later in this article will guarantee that $(u(I_1)-u(I_2))>0$. Regarding this point, see discussion about equation (15). Notice that $(u(I_1)-u(I_2))>0$ implies, by assumption 2, that $(I_1-I_2)>0$. To sum up, a traceability system in place ($s>0$) together with $F''(a)<0$ and $c''(a)>0$ (assumptions 1 and 2) are sufficient for the second-order sufficient condition (4) to be fulfilled.

Rearranging the first-order condition (3) results in:

$$sF'(a^*)(u(I_1)-u(I_2))=c'(a^*) \tag{5}$$

Notice that the left hand side of (5) gives the marginal expected utility of higher food safety effort. The marginal benefit of higher effort stems from the reduction of the probability of food safety crises occurring, which increases the chance of an agent improve her/his welfare by $(u(I_1)-u(I_2))>0$. On the other hand, the right hand side of (5) represents the marginal disutility of higher food safety effort for an agent. Thus, the optimal level of effort, $a^*$, is attained when the marginal benefit and the marginal disutility of food safety effort equals.

### Traceability, Contingent Payments and Food Safety

To investigate the relationship between the pieces of the contract and food safety it suffices to look at the problem faced by raw material suppliers. In this way, let the level of effort that maximizes problem (3) be a continuously differentiable function of traceability system's reliability and payments in contingencies 0, 1 and 2, such that $a^*=a^*(s, I_0, I_1, I_2)$. Given this, I investigate in following how the optimal level of an agent's effort alter with changes in the arguments of $a^*(.)$.

First, to investigate the effect on $a^*$ of increased reliability of traceability, I take the derivative of (3) with respect to $s$ at point $a^*= a^*(s, I_0, I_1, I_2)$ that results in:

$$\frac{\partial a^*}{\partial s}=\frac{-F'(a^*)(u(I_1)-u(I_2))}{sF''(a^*)(u(I_1)-u(I_2))-c''(a^*)} \tag{6}$$

The denominator of (6) is strictly negative from equation (4), $(u(I_1)-u(I_2))$ is strictly positive (see discussion about equation (15)), and $F'(a)$ is positive from assumption 1, which implies the following result:

**Result 2.** $\frac{\partial a^*}{\partial s} > 0$. Increased reliability of traceability induces higher food safety efforts by raw material suppliers, everything else remaining constant.

To investigate the effect on $a^*$ of higher payments in the contingency in which traceability works properly and no food safety crisis is observed (contingency 1), I take the derivative of (3) with respect to $I_1$ at point $a^*=a^*(s, I_0, I_1, I_2)$, resulting in:

$$\frac{\partial a^*}{\partial I_1} = \frac{-sF'(a^*)u'(I_1)}{sF''(a^*)(u(I_1)-u(I_2))-c''(a^*)} \quad (7)$$

Adding the fact that $u'(.) > 0$ (by assumption 2) to the explanation of result 2 implies result 3 as follows.

**Result 3.** $\frac{\partial a^*}{\partial I_1} > 0$. Higher payment when traceability works properly and no food safety crisis occurs induces more food safety effort by raw material suppliers, everything else remaining constant.

Finally, to investigate the effect of increasing payment in the contingency in which the traceability system works properly and a food safety crisis occurs, I take the derivative of (3) with respect to $I_2$ at point $a^*= a^*(s, I_0, I_1, I_2)$, resulting in:

$$\frac{\partial a^*}{\partial I_2} = \frac{sF'(a^*)u'(I_2)}{sF''(a^*)(u(I_1)-u(I_2))-c''(a^*)} \quad (8)$$

Using similar reasoning to that used in obtaining results 2 and 3 generates result 4.

**Result 4.** $\frac{\partial a^*(.)}{\partial I_2} < 0$. Higher payment when the traceability system works properly and food safety crisis occurs induces less food safety effort by suppliers, everything else remaining constant.

Notice that the role played by payment $I_0$ is just to make $(1-s)u(I_0)+sF(a^*)u(I_1)+s(1-F(a^*))u(I_2)-d(a^*)\geq \underline{U}$, where $\underline{U}$ denotes the reservation utility or the lowest expected utility level a contract must guarantee so to get an agent to accept the contract.

Based on results 1, 2, 3 and 4 the following conclusions can be obtained: (i) The implementation of a traceability system is a necessary but not a sufficient condition for inducing higher food safety effort than the effort exerted by agents when traceability is not in place. Indeed, traceability must be used jointly with contingent payments so to be sufficient for safer food; (ii) Assuming both conditions $(u(I_1)-u(I_2))>0$ and $s>0$ hold it is also true that increased intensity of incentive, $(I_1-I_2)$, can substitute $s$ in inducing a given level of food safety effort. Thus, one should not infer the level of food safety effort and consequently food safety by separately looking at $s$, $I_1$ and $I_2$. For example, it is possible that an unreliable traceability system coupled with a high intensive incentive will induce the same level of food safety effort as a high reliable traceability system combined with a low intensive incentive.

It should be noticed though that the level of effort to be enticed is ultimately a decision variable of the food processor as is discussed later in the article. Thus, it is possible that low levels of food safety can coexist with traceability and contingent payments in place.

**The Principal-Agent Framework**

This section aims at answering the following questions: How does the cost of food safety crisis ($r_e$) affect the level of food safety efforts, and therefore food safety? And how can traceability regulation affect food safety? To answer these questions I will first formalize the settings with symmetric information and asymmetric information with traceability using principal-agent models as follows.

*The Symmetric Information Setting*

The symmetric information or first-best setting is characterized by agents' food safety effort being freely observed by the principal. In such a context the principal is able to set payments contingent on the level of exerted food safety effort, which makes the contract a pair ($I$, $a$). Under the assumption that the profit maximization problem of the food processor can be simplified so to minimize the cost incurred with the payment of raw material suppliers plus expenses with food safety crises, the principal sets a contract by solving problem (9).

$$\min_{a,I} I+(1-F(a))r_e \qquad (9a)$$

Subject to:

$$u(I)-c(a) \geq \underline{U} \qquad (9b)$$

where $r_e$ is the external cost of a food safety crisis which includes the direct cost of liability, product recalls, allowances, court or market-imposed penalties and fines levied due to safety failures.

Notice that the objective function (9a) is strictly increasing in the payment of agents, which implies that the participation constraint (9b) binds at a solution of problem (9). Using this fact, the first-best payment is given by:

$$I_{FB}=v(\underline{U}+c(a_{FB})) \qquad (10)$$

where $v(.)$ is the inverse function of the Bernoulli utility function, $u(.)$. Notice that $u(I_{FB})\equiv(\underline{U}+c(a_{FB})$.

Plugging (10) into (9a) and solving for the first-best level of food safety effort ($a_{FB}$) gives the following first order necessary condition for problem (9):

$$\frac{\partial v(u(I_{FB}))}{\partial u(I_{FB})}c'(a_{FB})-r_e F'(a_{FB})=0 \qquad (11)$$

Condition (11) shows that the first-best level of effort ($a_{FB}$) is a function of $r_e$, $a_{FB}=a_{FB}(r_e)$. Notice that if the agent is risk neutral, condition (11) becomes:

$$c'(a_{FB})-r_e F'(a_{FB})=0. \qquad (11')$$

To see the effect of higher costs of food safety crisis, for example as a consequence of increased fines levied due to safety failures, I take the derivative of equation (11) with respect to $r_e$ obtaining:

$$\frac{\partial a_{FB}}{\partial r_e}=\frac{F'(a_{FB})}{v''(u(I_{FB}))c'(a_{FB})+v'(u(I_{FB}))c''(a_{FB})-r_eF''(a_{FB})} \tag{12}$$

From equation (12) and based on the assumptions that $v'(.)>0$, $v''(.)\geq 0$, $c'(.)>0, c''(.)>0$, $F'(.)>0$ and $F''(.)<0$, result 5 is obtained.

**Result 5.** $\frac{\partial a_{FB}}{\partial r_e}>0$. Under symmetric information, increased external cost of food safety crises induces the principal to contract higher level of effort that leads to safer food, everything else remaining constant.

Result 5 obviously relies on the assumption that an interior solution for problem (9) will still hold even after increasing fines for safety failures. In fact, if the cost of food safety crisis increases too much it can become the principal's best choice not to produce (inactivation) or even to leave definitively the industry.

*The Asymmetric Information with Traceability Setting*

Consider that a food processor's profit maximization problem can be simplified so to minimize the expected cost incurred with the payment of raw material suppliers, with the operation of a traceability system and with damages caused by food safety crisis. Given this, the principal should choose the second-best level of food safety efforts ($a_{SB}$) and the contract ($s$, $I_0$, $I_1$, $I_2$) such that it will be each agent's best interest to accept the contract and to exert $a_{SB}$. The principal-agent with traceability setting is formalized as problem (13).

$$\min_{a,s\in(0,1],I_0,I_1,I_2} (1-s)I_0+sF(a)I_1+s(1-F(a))I_2+(1-F(a))r_e+g(s) \tag{13a}$$

Such that:

$$(1-s)u(I_0)+sF(a)u(I_1)+s(1-F(a))u(I_2)-c(a)\geq \underline{U} \tag{13b}$$

$$sF'(a)(u(I_1)-u(I_2))-c'(a)=0 \text{ (Equation (3))} \tag{13c}$$

where $g(.)$ denotes the cost of tracing a lot of raw material back to its suppliers as a function of $s$.

**Assumption 3.** $g(.)$ is a strictly increasing function ($g'(.)>0$), continuously differentiable and convex ($g''(.)>0$) in its entire domain, $s\in[0,1]$.

Assumption 3 is necessary for the objective function (13a) to be strictly convex so that problem (13) is a convex programming problem. Therefore, a solution for (13) will be a global minimum.

The objective function (13a) is set assuming that one lot of raw material produces one lot of food product so that (13a) is defined as the sum of five terms as follows: The first term denotes the expected payment per lot of food when traceability fails. The second term gives the expected payment per lot food when food is safe and traceability works properly. The third term is the expected payments per lot of food when a food safety crisis occurs and traceability works. The fourth term gives the expected cost of food safety crises. Finally, the last term is the cost of using a traceability system of reliability $s$.

The participation constraint (13b) assures that the contract will be accepted by agents, and the incentive compatibility constraint (13c) guarantees that it will be an agent's best interest to exert the food safety effort chosen by the principal.

Constraint (13b) binds at a solution because the higher is the expected utility assured to agents by the contract; the more expensive the incentive scheme will be to the principal. Thus, a contract should just guarantee the reservation utility so to minimize costs for the principal. Given this, I manipulate equations (13b) and (13c) so to put $u(I_1)$ and $u(I_2)$ as functions of $a$, $s$ and $I_0$ as given by equations (16) and (17). In doing so, I take the following steps.

First, I manipulate condition (13b) so to obtain:

$$u(I_1) = \frac{\underline{U} + c(a) - s(1-F(a))u(I_2) - (1-s)u(I_0)}{sF(a)} \tag{14}$$

Second, I modify incentive compatibility constraint (13c) to obtain:

$$u\left(I_1\right) = \frac{c'(a)}{sF'(a)} + u\left(I_2\right) \tag{15}$$

Using the fact that $\frac{c'(a)}{sF'(a)}$ is greater than zero in equation (15) proves that $u(I_1)$ will be set greater than $u(I_2)$. Moreover, because $u'(.)>0$ by Assumption 2, it is also true that $I_1$ will be set greater than $I_2$. In other words, any contract will be set so to better pay agents in the contingence that is preferred by the principal.

Third, by plugging (14) into (15) and after some manipulation result in:

$$u(I_2(a,s,I_0)) = \frac{F'(a)\left(U + c(a) - (1-s)u(I_0)\right) - c'(a)F(a)}{sF'(a)} \tag{16}$$

Finally, plugging (16) into (15) gives:

$$u(I_1(a,s,I_0)) = \frac{F'(a)\left(U + c(a) - (1-s)u(I_0)\right) + c'(a)\left(1-F(a)\right)}{sF'(a)} \tag{17}$$

Using the inverse Bernoulli utility function, it is possible to define the following two identities: $I_1(a, s, I_0) \equiv v(u(I_1(a, s, I_0)))$ and $I_1(a, s, I_0) \equiv v(u(I_1(a, s, I_0)))$. Plugging these identities into (13a) makes it possible to reset the principal's problem as an unconstrained one in which $I_0$, $s$ and $a$ are the decision variables, as shown in problem (18).

$$\min_{a,s\in(0,1],I_0} (1-s)I_0+sF(a)I_1(a,s,I_0)+s(1-F(a))I_2(a,s,I_0)+(1-F(a))r_e+g(s) \tag{18}$$

First-order conditions for an interior solution of problem (18) are presented as follows.

First-order condition with respect to the food safety effort is:

$$sF'(a)\left(I_1(.) - I_2(.)\right) + s\left(F(a)\frac{\partial I_1(.)}{\partial a} + (1-F(a))\frac{\partial I_2(.)}{\partial a}\right) - r_e F'(a) = 0 \tag{19}$$

First-order condition with respect to the reliability of traceability is:

$$-I_0 + (1-F(a))I_2(.) + F(a)I_1(.) + sF(a)\frac{\partial I_1(.)}{\partial s} + s(1-F(a))\frac{\partial I_2(.)}{\partial s} - g'(s) = 0 \qquad (20)$$

First-order condition with respect to $I_0$ is:

$$(1-s) + sF(a)\frac{\partial I_1(.)}{\partial I_0} + s(1-F(a))\frac{\partial I_2(.)}{\partial I_0} = 0 \qquad (21)$$

It is not possible to find conclusive comparative statics results for the model when agents are risk averse, thus problem (18) is used to study the particular case in which agents are risk neutral. In other words, I set the Bernoulli utility function as $u(I_m)=I_m$. In so doing, I first derive some intermediate results so to make it possible to manipulate equations (19), (20) and (21) in a reasonable way. Using equations (16) and (17) it is possible to show that:

$$F(a)\frac{\partial u(I_1(.))}{\partial a} + \left(1-F(a)\right)\frac{\partial u(I_2(.))}{\partial a} = 0 \qquad (22),$$

and

$$\frac{\partial u(I_1)}{\partial u(I_0)} = \frac{\partial u(I_2)}{\partial u(I_0)} = s^{-1}\left(s-1\right) \qquad (23).$$

Notice that when agents are risk neutral equations (22) and (23) become:

$$F(a)\frac{\partial I_1(.)}{\partial a} = -\left(1-F(a)\right)\frac{\partial I_2(.)}{\partial a} \qquad (22')$$

$$\frac{\partial I_1(.)}{\partial I_0} = \frac{\partial I_2(.)}{\partial I_0} = s^{-1}\left(s-1\right) \qquad (23')$$

Plugging (22′) in the first-order condition (19) results in:

$$sF'(a)\left(I_1 - I_2\right) - r_e F'(a) = 0 \qquad (19')$$

Plugging the risk neutral agent's best response $sF'(a)(I_1 - I_2) = c'(a)$ (see equation (5)) into (19′) and assuming that $s$>0, makes condition (19) equal:

$$c'(a) - F'(a)r_e = 0 \qquad (19'')$$

Notice that (19″) is equal to the first-order condition of the first-best problem (11′) that implies result 6.

**Result 6**. When agents are risk neutral, the first-best and second-best levels of food safety effort equal, provided that a traceability system is in place ($s$>0).

Thus, form Result 6 it is possible to see that what differs between the symmetric and asymmetric information settings is just the need for using a traceability system in the later.

It is possible to show that the first-order conditions (20) for the case wherein agents are risk neutral becomes:

$$g'(s) = 0 \tag{24}$$

Once $g(s)$ is strictly convex by assumption 3, condition (24) implies result 7.

**Result 7**. If agents are risk neutral, the principal chooses the lowest level of traceability so to make it possible to use a contingent payment scheme.

Notice that the lowest level of traceability must be greater than zero otherwise no incentive scheme can be created. The fact is that when agents are risk neutral, increased variability of contingent payment does not require higher risk-premiums payment to agents so to get them to participate in the contract. In other words, when agents are risk neutral there is no cost of using high variability contingent payments schemes, but the greater the reliability of a traceability system is the more costly will be for the principal to induce the first-best food safety effort.

Results 6 and 7 imply that even a traceability system of low reliability can induce first-best level of food safety effort, confirming that low reliability of traceability is not synonymous of low food safety. In fact, when agents are risk averse, it is cheaper to substitute reliability of traceability by more intensive incentive payments. This is because more reliable traceability costs more by assumption, whereas higher intensive incentive payments do not cost more to the principal because risk neutral agents do not require risk premium for incurring more risk.

Finally, first-order condition (21) is automatically fulfilled when agents are risk neutral. To see this, by plugging (23′) into the left hand side of (21) gives $(1-s)+s\left(\frac{1}{s}(s-1)\right)$ that is zero provided that $s$>0. The consequence of this is result 8.

**Result 8**. $I_0$ can assume any value at a solution for problem (18) when agents are risk neutral.

*Food Safety Regulation*

Having derived and studied the first-order conditions of problem (18) for the case wherein agents are risk neutral; it is possible now to finally study food safety regulation by government. In following, I investigate first the effect of increased fines levied due to safety failures on food safety. Second, I investigate the effect of the imposition of traceability standards based on its reliability on food safety.

Government can increase fines levied due to safety failures as a policy to improve food safety. The effect of this type of policy on food safety is investigated as an increase in $r_e$. From results 7 and 8 one sees that only the optimal food safety level of effort will depend on $r_e$ when agents are risk neutral. The consequence of this is that $I_1 = I_1(a(r_e), I_0(r_e), s(r_e))$ and $I_2 = I_2(a(r_e), I_0(r_e), s(r_e))$ can be simplified when agents are risk neutral to $I_1 = I_1(a(r_e))$ and $I_2 = I_2(a(r_e))$. Using these simplifications in taking the derivative of condition (19′) with respect to $r_e$ results in $\frac{\partial a_{SB}}{\partial r_e}\left((s(I_1 - I_2) - r_e)F''(a) + sF'(a)\left(\frac{\partial I_1(.)}{\partial a} - \frac{\partial I_2(.)}{\partial a}\right)\right) - F'(a) = 0$.

By plugging $s(I_1 - I_2) - r_e = 0$, obtained from condition (19′), into this gives result 9.

**Result 9**. $\frac{\partial a_{SB}}{\partial r_e} = s^{-1}\left(\frac{\partial I_1(.)}{\partial a} - \frac{\partial I_2(.)}{\partial a}\right)^{-1} > 0$. Food safety regulation based on increased fines due to food safety failures improves second-best food safety efforts, leading to food safety when agents are risk neutral.

In terms of food safety regulation, government can impose traceability standards that means in the context of this article's model the same as the imposition of a given level of traceability's reliability, $s$. Notice that when agents are risk neutral, from results 7 and 8, only the optimal food safety level of effort will depend on $s$. The consequence of this is that $I_1 = I_1(a(s), I_0(s), s)$ and $I_2 = I_2(a(s), I_0(s), s)$ become $I_1 = I_1(a(s), s)$ and $I_2 = I_2(a(s), s)$. Using this result in taking the derivative of condition (19′) with respect to $s$ gives:

$$\frac{\partial a}{\partial s} = -\frac{F'(a)\left(\left(I_1 - I_2\right) + s\left(\frac{\partial I_1}{\partial s} - \frac{\partial I_2}{\partial s}\right)\right) + F(a)\left(\frac{\partial I_1}{\partial a} + s\frac{\partial^2 I_1}{\partial a \partial s}\right) + (1 - F(a))\left(\frac{\partial I_2}{\partial a} + s\frac{\partial^2 I_2}{\partial a \partial s}\right)}{s\left(F''(a)\left(\left(I_1 - I_2\right) - s^{-1} r_e\right) + 2sF'(a)\left(\frac{\partial I_1}{\partial a} - \frac{\partial I_2}{\partial a}\right) + F(a)\frac{\partial^2 I_1}{\partial a \partial a} + (1 - F(a))\frac{\partial^2 I_2}{\partial a \partial a}\right)} \quad (25)$$

Using the fact that $\frac{\partial I_1}{\partial s} - \frac{\partial I_2}{\partial s} = -s^{-2}\frac{\partial F(a)}{\partial a}^{-1}\frac{\partial c(a)}{\partial a}$, $\frac{\partial^2 I_1}{\partial a \partial s} = -s^{-1}\frac{\partial I_1}{\partial a}$ and $\frac{\partial^2 I_2}{\partial a \partial s} = -s^{-1}\frac{\partial I_2}{\partial a}$ results in $F(a)\left(\frac{\partial I_1}{\partial a} + s\frac{\partial^2 I_1}{\partial a \partial s}\right) + (1 - F(a))\left(\frac{\partial I_2}{\partial a} + s\frac{\partial^2 I_2}{\partial a \partial s}\right) = 0$. Plugging this result into (25) gives:

$$\frac{\partial a}{\partial s} = -\frac{F'(a)\left(\left(I_1 - I_2\right) + s\left(-s^{-2}F'(a)^{-1}c'(a)\right)\right)}{s\left(F''(a)\left(\left(I_1 - I_2\right) - s^{-1} r_e\right) + 2sF'(a)\left(\frac{\partial I_1}{\partial a} - \frac{\partial I_2}{\partial a}\right) + F(a)\frac{\partial^2 I_1}{\partial a \partial a} + (1 - F(a))\frac{\partial^2 I_2}{\partial a \partial a}\right)} \quad (25')$$

Plugging $I_1 - I_2 = s^{-1}c'(a)F'(a)^{-1}$ and $\frac{\partial I_1}{\partial a} - \frac{\partial I_2}{\partial a} = F(a)\frac{\partial^2 I_1}{\partial a \partial a} + (1 - F(a))\frac{\partial^2 I_2}{\partial a \partial a}$ into (25′) gives:

$$\frac{\partial a}{\partial s} = -\frac{F'(a)\left(s^{-1}c'(a)F'(a)^{-1} - s^{-1}F'(a)^{-1}c'(a)\right)}{s\left(F''(a)\left(s\left(I_1 - I_2\right) - r_e\right) + (2F'(a) + 1)\left(\frac{\partial I_1}{\partial a} - \frac{\partial I_2}{\partial a}\right)\right)} \quad (25'')$$

Equation (19′) implies that $s\left(I_1 - I_2\right) - r_e = 0$ that plugged into (26″) gives:

$$\frac{\partial a}{\partial s} = -\frac{0}{s(2\frac{\partial F(a)}{\partial a} + 1)\left(\frac{\partial I_1}{\partial a} - \frac{\partial I_2}{\partial a}\right)} \quad (25''')$$

Result 10 is obtained on the basis of equation (26‴) as follows.

**Result 10.** $\frac{\partial a}{\partial s} = 0$. An exogenous imposition of traceability standards has no effect on second-best food safety efforts when agents are risk averse**.**

Result 10 implies that to base food safety regulation on imposing a certain type of traceability system can have no effect on food safety.

**Conclusions**

Food safety crises have shown to be frequent. As a reaction to this, the adoption of traceability has been proposed as a means of increasing food safety. However, traceability just accumulates information about the product and processes as the product moves through its supply chain. Therefore, traceability adoption does not imply by itself safer food. Despite this, this article shows that traceability can be an effective means of improving food safety because it reduces anonymity in food supply chains and thus makes it possible to use incentives via contingent payment schemes. In doing so, I use a principal-agent model in which food safety can be caused only by the misspecification of raw materials and traceability denotes the probability of keeping the identities of homogeneous raw material suppliers linked with final food products. Thus, traceability allows for using payments that are contingent on whether food is or is not safe for consumption. In this moral hazard context, the food processor (principal) sets a contract based on the reliability of traceability and contingent payments so to entice agents to exert the food safety effort chosen by him/her.

I subdivide the principal-agent problem by first studying the problem faced by an individual raw material supplier, deriving his/her best response function. Doing comparative statics of his/her best response showed that high intensive payment incentives can substitute more reliable traceability and vice-versa. This result indicates that one should not infer food safety just on the basis of the reliability of a traceability system. Despite this, a traceability system must be in place so to make incentives via contingent payment feasible. In other words, it is a necessary condition for safer food that the reliability of traceability is greater than zero but the reliability of traceability system is not an unequivocal signal of food safety.

The complete principal-agent model with traceability is set and used to study the ultimate level of food safety. This is because the level of food safety effort to be induced on agents is a food processor's decision variable. I simplify the model by assuming agents are risk neutral and found that first-best and second-best food safety levels of effort equal in this particular case. Moreover, I showed that when agents are risk neutral neither the intensity of the contingent payment scheme nor the reliability of traceability affect the food safety effort level chosen by the principal. This result has a direct implication for food safety regulation by government since it is possible that the imposition of a certain level of traceability's reliability can have no effect on food safety. Finally, this article shows that increased penalties for food safety crises can induce higher food safety efforts that ultimately will imply safer food.

**References**


Dubois, P. , and T. Vukina. 2004. "Grower Risk Aversion and the Cost of Moral Hazard in Livestock Production Contracts." *American Journal of Agricultural Economics* 86:835-841.

Golan, E. , B. Krissoff, F. Kuchler, K. Nelson, and G. Price. 2004. "*Traceability in the U. S. Food Supply: Economic Theory and Industry Studies*." Washington DC: U. S. Department of Agriculture, Agricultural Economic Report No. 830, March.

Goodhue, R.E. 2000. "Broiler Production Contracts as a Multi-Agent Problem: Common Risk, Incentives and Heterogeneity." *American Journal of Agricultural Economics* 82: 606–22.

Hobbs, J.E. (2004). "Information Asymmetry and the Role of Traceability Systems." *Agribusiness: An International Journal* 20: 397-415.

Holmström, B. (1979). "Moral Hazard and Observability." *Bell Journal of Economics* 10: 74–91.

International Organization for Standardization. 2000. ISO 9000:2000. *Quality management systems: Fundamentals and vocabulary*. Brussels, Belgium . European Standard, Committee for Standardization, EN ISO 9000:2000, Point 3.5.4.

King, R.P., G.B.C. Backus, and M. A. Gaag. 2007. "Incentive Systems for Food Quality Control with Repeated Deliveries: *Salmonella* Control in Pork Production." *European Review of Agricultural Economics* 34:81-104.

Mas-Collel, A., M.D. Whinston, and J.R. Green. 1996. *Microeconomic Theory*. New York: Oxford University Press.

Notermans, S., M.H. Zwietering, and G.C. Mead. 1994. "The HACCP concept: identification of potentially hazardous micro-organisms." *Food Microbiology* 11:203-14.

Pouliot, S., and D.A. Sumner. 2008. "Traceability, Liability, and Incentives for Food Safety and Quality." *American Journal of Agricultural Economics* 90: 15–27.

Resende-Filho, M. and B.L. Buhr. "A Principal Agent Model for Evaluating the Economic Value of a Traceability System: A Case Study with Injection-Site Lesion Control in Fed Cattle." *American Journal of Agricultural Economics* (forthcoming) doi:10.1111/j.1467-8276.2008.01150.x

Souza-Monteiro, D.M., and J.A. Caswell. 2004. "The Economic of Implementing Traceability in Beef Supply Chains: Trends in Major Producing and Trading Countries." Working Paper No. 2004-6. University of Massachusetts Amherst, Department of Resource Economics. Amherst, MA: University of Massachusetts Amherst.

Starbird, S. A. 2005. "Moral Hazard, Inspection Policy, and Food Safety." American Journal of *Agricultural Economics* 87:15-27.

Starbird, S.A., and V. Amanor-Boadu. 2006. "Do Inspection and Traceability Provide Incentives for Food Safety?" *Journal of Agricultural and Resource Economics* 31:14-26.

Starbird, S.A., and V. Amanor-Boadu. 2007. " Contract Selectivity, Food Safety, and Traceability" *Journal of Agricultural and Food Industrial Organization* 5:1-20.

Teratanavat, R., and N.H. Hooker. 2004. "Understanding the Characteristics of US Meat and Poultry Recalls: 1994-2002." *Food Control* 15:359-67.

Tirole, J. 1988. *The theory of industrial organization*. Cambridge, MA: The MIT Press.

Tonsor, G. T., and T. C. Schroeder. 2004. "Australia's Livestock Identification Systems: Implications for United States Programs." Selected paper presented at Risk & Profit conference, Manhattan, Kansas,USA, August. Available at http://www.agmanager.info/events/risk_profit/2004/Schroeder.pdf. Accessed June 18, 2008.

Vitiello, D.J., and A.M. Thaler. (2001). "Animal Identification: Links to Food Safety." *Scientific and Technical Review* 20:598-604.