

**INFORMATION ASYMMETRY
AND TRACEABILITY INCENTIVES
FOR FOOD SAFETY**

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Information Asymmetry and Traceability Incentives for Food Safety

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Abstract

We define traceability by its precision that is the probability of finding the source of a problem. We consider a food processor (principal) that sets the precision of traceability and contingent payments in order to entice homogeneous agents to exert the processor's desired level of food safety effort. We focus on cases in which food safety crises originate from defects in material provided by an upstream firm. We show that high precision can substitute for high intensive contingent payments and vice-versa, indicating that traceability is not an unequivocal signal for safer food. We also show that government regulation based on mandatory traceability with sanctions may not lead to safer food but is likely to increase the food processor's costs and that increased pecuniary penalties due to food safety failure can induce safer food.

Keywords: Moral Hazard, Identity Preservation, Food Traceability, Supply Chain Management.

JEL Classification: D82, D86, C61.

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There are many examples of widely publicized food safety crises. In 2002, nearly 19 million pounds of ground beef potentially contaminated with *E. coli* O157:H7 and 27.4 million pounds

of chicken and turkey potentially 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 Canada in 2003 (Centers for Disease Control and Prevention 2008). Also, poultry and dairy products were recently found contaminated with dioxin in European countries (Food Production Daily 2008) and dangerous levels of hormones and antibiotics in meat have been noticed in many places of the world.

Ensuring a safe food supply is a considerably difficult task because many food supply chains are composed of independent firms where material moves from one firm to the next frequently through open market transactions. Often downstream firms cannot observe the effort exerted by upstream firms to ensure product quality and safety. Therefore, quality and safety problems that originate in upstream firms may not manifest themselves until long after it is possible to identify the original source of the problem.

Traceability has been adopted to improve animal health and supply chain management (i.e. to improve the effectiveness of product recalls, to find better sources of raw materials); combat bio-terrorism; comply with international trade standards; and certify credence¹ attributes (Golan *et al.* 2004). Traceability has also been proposed as a strategy to improve food safety. According to the International Organization for Standardization (2000) 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 traceability includes procedures for identification, preparation, collection, storage, and verification of data. Unlike Pathogen Reduction² (PR) and Hazard Analysis and Critical Control Point³ (HACCP) approaches, traceability does not intervene directly into production processes in order to improve food safety. While it is clear how traceability systems can be used to mitigate harm in the event of a food safety crisis, the benefits of traceability in terms of actually improving food safety is not fully understood.

Studies exploring the potential benefits of using traceability to improve food safety have focused on liability issues. For example, Hobbs (2004) and Tonsor and Schroeder (2004) argue that traceability can strengthen incentives for firms to produce safer products by making it possible to assess *ex post* legal responsibility for any product failures. Pouliot and Sumner (2008) and Starbird and Amonor-Boadu (2006; 2007) further explore how traceability strengthens liability in supply chains and promotes food safety.

A variety of studies have also explored the possibility of using incentives to promote quality and safety in supply chains. For example, Dubois and Vukina (2004) and Starbird (2005), use principal-agent models to evaluate the impact of incentives offered by a principal on the effort of agents. King, Backus, and Gaag (2007) show how reputation can be an added incentive to induce performance. The fact is that in all of these studies, the principal knows the quality or safety of the product delivered by the agent, which is the case when the product is easily tested on delivery, but not when the product cannot be easily tested (e.g. meat). For example, it is easy to test for foreign objects in fluid milk, which is not true for meat.

The purpose of this paper is to explore the potential for traceability to improve product safety by providing a means to implement incentive based contracts that encourage upstream firms to exert more effort into providing safe material. We are also interested in the extent to which voluntarily adopted traceability systems will unequivocally improve product safety and the extent to which mandatory traceability systems with sanctions can be used to improve product safety. To accomplish this objective, we develop a principal agent model where the agent can invest effort into providing safer upstream material, and the principal can invest in a traceability system and offer the agent contingent payments based on whether it is identified as having provided safe material.

The model we develop contributes to the literature by generalizing Resende-Filho and Buhr's (2008) application to injection site lesions to the broader issues of food safety. Our study also improves upon the framework developed by Polinsky and Shavell (1979) by explicitly

modeling the conflict between a principal and agents while allowing agents to engage in a food safety activity at varying levels. Our model also contributes to the literature by allowing firms to voluntarily choose to adopt traceability. Other works have typically treated traceability systems exogenously (e.g. Pouliot and Sumner, 2008; and Starbird and Amonor-Boadu, 2006 and 2007). The results of our analysis contribute to the literature by showing firms can find it advantageous to voluntarily set up traceability systems in order to implement incentive based contracts and that the precision of a traceability system is not an unequivocal signal for safe food because downstream firms can substitute contracts with higher incentive payments for lower precision traceability systems and still ensure safe food. The results also show that voluntary traceability and mandatory traceability with sanctions do not necessarily improve food safety and that increased pecuniary penalties due to food safety crises can improve food safety.

The Model

Although food safety crises may have many different origins, this article focuses on the types of problems that originate from defects in material provided by an upstream firm. We will also assume that the probability of these material defects is under the control of the upstream firm, at least to some extent. Examples of food safety problems originating from an upstream material provider include chemical residues on food (e.g. dioxin, antibiotics, hormones and pesticides residues), physical residues on food (e.g. foreign objects such as broken needles from animal health treatments), and feeding of restricted ingredients (e.g. animal by-products in the case of BSE). Notice that we assume that events out of suppliers control can create food safety problems (i.e. the behavior of an antibiotic or hormone while in the body of animals is out of farmers' control).

Let $1 \geq F \geq 0$ be the probability that an upstream firm provides material that is free from defect, such that the food processed from this material is safe for human consumption.

Alternatively, $1 - F$ is the probability that an upstream firm provides defective material that is

processed into unsafe food. Following Tirole (1988, p.54), assume F increases at a decreasing rate with the upstream firm's effort, a :

Assumption 1. $F = F(a)$ with $F'(a) > 0$ and $F''(a) < 0$.

Traceability systems can be defined in terms of their breadth, depth, and precision (Golan *et al.*, 2004). Breadth is the amount of information recorded by the system. Depth is how far forward and backward traceability extends in the supply chain. Precision is the ability to pinpoint the source of a material defect if it occurs. Our interest is in the precision of the traceability system and the incentives for a down stream firm to endogenously influence this precision. Therefore, we abstract from the breadth and depth of the system. Let $1 \geq s \geq 0$ be the probability the traceability system successfully identifies the upstream source of material, which we refer to as the system's precision. Alternatively, let $1 - s$ be the probability the traceability system fails. Notice that if $s = 0$ there is no possibility of identifying the upstream material provider after delivery, meaning there is no traceability. We also abstract from the possibility of false positive or negatives with the traceability system when it works in order to reduce the complexity and tighten the focus of the model.

Given the above context, the principal and each agent play the one-shot, three-stage sequential game illustrated in Figure 1.

[Figure 1 here]

The principal moves first, by setting the precision of the traceability system and offering agents a contract composed of a contingent payment scheme. Next, homogeneous agents either accepted or reject the principal's contract knowing the precision of the traceability system, and if they accept the contract, choose how much effort to exert in order to reduce the probability of material defects. Finally, nature determines whether the traceability system fails and whether the agents' material is defective, and the appropriate payments to the agents are made by the principal.

The types of contingent payment contracts we explore rewards an agent if traceability shows it provided material free from defect (contingency denoted by $m = 1$) and penalizes an agent if traceability shows it provided defective material (contingency denoted by $m = 2$). A third alternative payment is made in the event that traceability fails such that the principal cannot verify whether an agent provided defective or defect free material (contingency denoted by $m = 0$). Thus, the principal's contract specifies three separate contingency payments, $I_m \geq 0$ for $m \in M = \{0, 1, 2\}$, where

Assumption 2. $I_1 > I_2$.

Table 1 summarizes the possible contingencies, their probabilities, and the corresponding payments to the agent from the principal.

[Table 1 here]

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). Like Holmström (1979), Tirole (1988), Goodhue (2000), and Starbird (2005), we assume an agent's contingent specific utility is additively separable in incentive payments and effort:

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

where $u(I_m)$ is a concave Bernoulli utility function as defined by Mas-Collel, Whinston and Green (1996, p. 184), and $c(a)$ is a convex effort cost function:

Assumption 3. $u'(I_m) > 0$, $u''(I_m) \leq 0$, $c'(a) > 0$, and $c''(a) > 0$.

Since the agent moves second in this game, it takes as given the principal's choice of precision (s) and incentive contract (I_0, I_1, I_2), and chooses a level of effort to maximize his/her expected utility as given by:

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

The first order necessary conditions for a maximum at a^* are:

$$sF'(a^*)(u(I_1) - u(I_2)) - c'(a^*) \leq 0 \text{ and} \quad (3a)$$

$$a^*(sF'(a^*)(u(I_1) - u(I_2)) - c'(a^*)) = 0. \quad (3b)$$

Notice that for $s = 0$ equations (3a) and (3b) imply $-c'(a^*) \leq 0$ and $-c'(a^*) a^* = 0$, which given **Assumption 3**, can only be true if $a^* = 0$. Effectively, this result says that agents will invest as little effort as possible into reducing the probability of producing defective material if there is no traceability.

Based on (3a) and (3b), the following result is formalized.

Result 1. The precision of traceability (s) must be strictly positive in order to induce food safety efforts higher than the lowest level of effort already exerted when there is no traceability.

The second-order sufficient condition for an interior solution to problem (2) at a^* is:

$$sF''(a^*)(u(I_1) - u(I_2)) - c''(a^*) < 0 \quad (4)$$

Notice that $u(I_1) - u(I_2) > 0$ by **Assumption 3** because $I_1 - I_2 > 0$ by **Assumption 2**.

Therefore, a traceability system ($s > 0$) together with $F''(a) < 0$ and $c''(a) > 0$ (**Assumptions 1 and 3**) are sufficient for the second-order sufficient condition in equation (4) to be fulfilled.

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

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

The left hand side of equation (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 improving his welfare by $u(I_1) - u(I_2) > 0$. On the other hand, the right hand side of equation (5) represents the marginal cost of higher food safety effort. Thus, the optimal effort, a^* , sets the marginal benefit of food safety equal to the marginal cost.

Traceability, Contingent Payments and Food Safety

In order to investigate the relationship between the contract and food safety it suffices to look at the problem an upstream raw material supplier faces. Suppose the level of effort that maximizes

problem (2) is a continuously differentiable function of the traceability system's precision and contingency payments, $a^*=a^*(s, I_0, I_1, I_2)$. Given this, we investigate how the optimal level of effort changes as precision and the alternative contingency payments change as follows.

Result 2. $\frac{\partial a^*}{\partial s} > 0$. Increased precision induces higher food safety efforts by raw material

suppliers, everything else remaining constant.

Proof: Assuming $a^*>0$ implies equation (3a) holds with equality, the use of implicit function theorem gives:

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

The denominator of (6) is negative from equation (4). The numerator is also negative because $F'(a)$ is positive from **Assumption 1**, and $u(I_1) - u(I_2)$ is positive by **Assumptions 2** and **3**.

Therefore, the equation (6) must be positive. Q.E.D.

Result 3. $\frac{\partial a^*}{\partial I_1} > 0$. Higher payments when traceability works properly and no food safety

crisis occurs induce more food safety effort by raw material suppliers, everything else remaining constant.

Proof: Assuming $a^*>0$ implies equation (3a) holds with equality, the implicit function theorem implies:

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

The denominator of (7) is negative from equation (4). The numerator is also negative because $F'(a)$ is positive from **Assumption 1**, and $u'(I_1)$ is positive by **Assumption 3**. Therefore, the equation (7) must be positive. Q.E.D.

Result 4. $\frac{\partial a^*(.)}{\partial I_2} < 0$. Higher payments when the traceability system works properly and

a food safety crisis occurs induce less food safety effort by suppliers, everything else remaining constant.

Proof: Assuming $a^* > 0$ implies equation (3a) holds with equality, the implicit function theorem implies:

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

The denominator of (8) is negative from equation (4). The numerator is also positive because $F'(a)$ is positive from **Assumption 1**, and $u'(I_2)$ is positive by **Assumption 3**. Therefore, the equation (7) must be negative. Q.E.D.

Results 1, 2, 3 and 4 lead to the following conclusions. First, 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 to be sufficient for safer food. Second, with $I_1 - I_2 > 0$ and $s > 0$, increasing incentives for a higher level of food safety (i.e. $I_1 - I_2$) can substitute for increasing the precision of a traceability system (i.e. s). Thus, one should not infer that 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 imprecise traceability system coupled with a high intensive incentive will induce the same level of food safety effort as a highly precise traceability system combined with a low intensive incentive. Moreover, notice that the food safety effort is a decision variable of the food processor as formalized with the principal-agent model that follows.

The Principal-Agent Framework

We now model how the decision on the food safety effort level is made and explore how the cost of a food safety crisis to the principal affects the incentives it offers to agents and the amount of effort agents invest in reducing the probability of providing defective materials. We also explore

how mandatory traceability systems with sanctions can be used to promote food safety. We accomplish this by comparing the results of our model under alternative assumptions regarding traceability regulations to a model with symmetric information and therefore, no need for traceability.

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) . We assume the principal chooses the contract that minimizes expected costs, raw material costs plus the expected cost of resolving any resulting food safety crises, while making sure agents will be willing to accept the contract:

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

Subject to:

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

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; and \underline{U} is the reservation utility or the lowest expected utility level a contract must guarantee in order to get an agent to accept it.

Notice that the objective function (9a) and the participation constraint (9b) are strictly increasing in the payments to agents, which means it is optimal for the principal to choose I such that equation (9b) holds with equality and the agent is indifferent between transacting with the principal or someone else:

$$I(a)=v(\underline{U} + c(a)) \quad (10)$$

where $v(\cdot)$ is the inverse function of the Bernoulli utility function. Notice that $u(I(a)) \equiv \underline{U} + c(a)$.

Substituting (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):

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

Condition (11) shows that the first-best level of effort is a function of r_e , $a_{FB} = a_{FB}(r_e)$.

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 for a higher level of effort that leads to safer food, everything else remaining constant.

Proof: Assuming equation (11) holds with equality, the implicit function theorem implies:

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

The denominator of equation (12) is positive because $v'(\cdot) > 0$, $v''(\cdot) \geq 0$, $c'(\cdot) > 0$, $c''(\cdot) > 0$, and $F''(\cdot) < 0$ by **Assumptions 1** and **3**. The numerator is positive by **Assumptions 1**. Therefore, equation (12) is positive. Q.E.D.

Result 5 assumes an interior solution for problem (9) will 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.

The Asymmetric Information with Traceability Setting

We now consider the case of asymmetric information where the principal voluntarily establishes traceability at some cost in order to implement incentive based contracts for improved food safety. Formally, the problem is

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

Such that:

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

$$sF'(a)(u(I_1) - u(I_2)) - c'(a) = 0 \quad (13c)$$

where $g(\cdot)$ denotes the convex cost of traceability as a function of precision:

Assumption 4. $g'(\cdot) \geq 0$ and $g''(\cdot) > 0$ for $1 \geq s \geq 0$.

The first three terms in equation (13a) are the principal's expected cost of material. The first term is associated with the cost of material when traceability fails. The second reflects costs when traceability works and there is no food crisis. The third reflects costs when traceability works and there is a food crisis. The fourth term is the expected cost of a food crisis. Finally, the fifth term is the cost of voluntarily providing traceability. The constraint in equation (13b) assures agents will be willing to enter into the principal's contract (i.e. the participation constraint), while equation (13c) accounts for how agents optimally invest in effort to reduce the probability of defects given the principal's contract offer (i.e. the incentive compatibility constraint derived in equation (3)).

Equations (13a) and (13b) are strictly increasing in I_0 , I_1 , and I_2 . Therefore, at an optimum, equation (13b) must bind. Substituting $u(I_1)$ out of equation (13b) using equation (13c), the left-hand-side of (13b) is increasing in I_0 and I_2 and independent of I_1 . Since equation (13b) and (13c) both hold with equality,

$$u(I_1) = \frac{c'(a)}{sF'(a)} + u(I_2) \quad \text{and} \quad (14)$$

$$u(I_2) = \frac{F'(a) \underline{U} + c(a) - (1-s)u(I_0) - F(a)c'(a)}{sF'(a)}, \quad (15)$$

such that at an optimum $I_1 = I_1(a, s, I_0)$ and $I_2 = I_2(a, s, I_0)$. Notice that when $s > 0$, $\frac{c'(a)}{sF'(a)}$ is

greater than zero by **Assumptions 1 and 2**, implying that I_1 is always set greater than I_2 . In

other words, a contract will pay agents better in the contingency that is preferred by the principal.

It will be useful later to also note that equations (14) and (15) imply

$$F(a) \frac{\partial u(I_1)}{\partial I_1} \frac{\partial I_1}{\partial a} + 1 - F(a) \frac{\partial u(I_2)}{\partial I_2} \frac{\partial I_2}{\partial a} = 0 \quad \text{and} \quad (16),$$

$$\frac{\partial u(I_1)}{\partial u(I_0)} = \frac{\partial u(I_2)}{\partial u(I_0)} = s^{-1} \quad s - 1. \quad (17)$$

Equations (14) and (15) also allow us to write the constrained optimization problem in equations (13a), (13b), and (13c) as the unconstrained optimization problem:

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

First-order conditions for an interior solution of problem (18) are:

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

$$-I_0 + (1-F(a))I_2(\cdot) + F(a)I_1(\cdot) + sF(a) \frac{\partial I_1(\cdot)}{\partial s} + s(1-F(a)) \frac{\partial I_2(\cdot)}{\partial s} + g'(s) = 0, \quad \text{and} \quad (20)$$

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

Comparative static results for equations (19) – (21) are generally intractable. Therefore, to gain further insight, we assume agents are risk neutral, such that $u(I_m) = I_m$ and equations (16) and (17) become

$$F(a) \frac{\partial I_1(\cdot)}{\partial a} = -1 - F(a) \frac{\partial I_2(\cdot)}{\partial a} \quad (16')$$

$$\frac{\partial I_1(\cdot)}{\partial I_0} = \frac{\partial I_2(\cdot)}{\partial I_0} = s^{-1} \quad s - 1 \quad (17')$$

Plugging (16') into equation (19) results in:

$$sF'(a)I_1 - I_2 - r_e F'(a) = 0 \quad (19')$$

Substituting equation (13c) for neutral risk agents⁴ into (19') then implies

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

Notice that (19'') is equal to the first-order condition for the first-best problem (11) which implies:

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

Thus, from 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.

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

Proof:

$$\text{Risk neutrality implies } I_1 = s^{-1} \frac{F'(a) \underline{U} + c(a) - 1 - s I_0 + c'(a) (1 - F(a))}{F'(a)} \text{ and}$$

$$I_2 = s^{-1} \frac{F'(a) \underline{U} + c(a) - 1 - s I_0 + c'(a) F(a)}{F'(a)}, \text{ or}$$

$$F(a)I_1 + (1 - F(a))I_2 = s^{-1} \underline{U} - I_0 + c(a) + sI_0, \text{ and} \quad (22)$$

$$s \left(F(a) \frac{\partial I_1}{\partial s} + (1 - F(a)) \frac{\partial I_2}{\partial s} \right) = -s^{-1} \underline{U} - I_0 + c(a). \quad (23)$$

Substituting equations (22) and (23) into equation (20) then yields $g'(s) = 0$, which implies $s = 0$ if the principal chooses not to use a contingent payment scheme or, by **Assumption 4**, s as small as possible if the principal chooses to use a contingent payment scheme. Q.E.D.

The fact is that when agents are risk neutral, more intensive incentive does not require the principal to pay higher risk-premium payment⁵ in order to get agents to participate in the contract. On the other hand, the greater the precision of traceability, the more costly it is for the

principal to induce the first-best food safety effort according to **Assumption 4**. Thus, the cheapest way to induce the first-best food safety effort is to substitute, as much as one can, the incentives for precision. Notice though that the lowest level of traceability must still be greater than zero, otherwise no incentive scheme would be created according to Result 1.

Results 6 and 7 imply that even a traceability system of low precision can induce first-best food safety effort, confirming that low precision of traceability is not synonymous with low food safety.

Finally, first-order condition (21) is automatically fulfilled when agents are risk neutral.

To see this, plug (17') into the left hand side of (21) to get $(1-s) + s \left(\frac{1}{s} s - 1 \right) = 0$ for $s > 0$:

Result 8. I_0 can assume any value at a solution for problem (18) when agents are risk neutral, provided that the resulting value function is greater than the product's unit price or alternatively, provided that profits are nonnegative.

Food Safety Regulation

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

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 :

Result 9. $\frac{da_{SB}}{dr_e} > 0$. Food safety regulation based on increased fines due to food safety

failures improves second-best and first-best food safety efforts, leading to food safety when agents are risk neutral.

Proof:

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

$I_2 = I_2(a(r_e), I_0(r_e), s(r_e))$ are simplified when agents are risk neutral to

$I_1 = I_1(a(r_e), I_0, s)$ and $I_2 = I_2(a(r_e), I_0, s)$. In other words, from Results 6 and 7 we know that I_0

and s do not depend on r_e . Using these facts and totally differentiating (19'') yields

$$c''(a_{SB}) \frac{da_{SB}}{dr_e} - F''(a_{SB}) \frac{da_{SB}}{dr_e} r_e - F'(a_{SB}) = 0 \text{ or } \frac{da_{SB}}{dr_e} = \frac{F'(a_{SB})}{c''(a_{SB}) - F''(a_{SB})r_e}. \text{ The numerator is}$$

positive by Assumption 1 and the denominator is positive by Assumptions 1 and 2, so the sign must be positive. Q.E.D.

In terms of food safety regulation, the government can impose a traceability standard that in the context of our model means the same as the imposition of a given level of traceability precision, s :

Result 10. $\frac{\partial a_{SB}}{\partial s} = 0$. An exogenous imposition of traceability standards has no effect on

second-best food safety efforts when agents are risk neutral.

Proof:

Notice that when agents are risk neutral, from results 7 and 8, the optimal food safety effort will only 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 these facts in taking the derivative of

condition (19') with respect to s using the implicit function theorem gives:

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

Notice that (19') can be modified to $sF'(a) I_1 - I_2 - s^{-1}r_e = 0$ that implies $I_1 - I_2 - s^{-1}r_e = 0$

for s and a_{SB} greater than zero. Also, (13c) implies that $(I_1 - I_2) = s^{-1}F'(a)^{-1}c'(a)$, (16') implies

that $\frac{\partial I_1(\cdot)}{\partial a} - \frac{\partial I_2(\cdot)}{\partial a} = -\frac{1-F(a)}{F(a)^{-1}}$, and it is possible to show that

$$\left(\frac{\partial I_1(\cdot)}{\partial s} - \frac{\partial I_2(\cdot)}{\partial s} \right) = -s^{-2} F'(a)^{-1} c'(a). \text{ Plugging all these results into (25) yields a zero numerator}$$

and positive denominator. Q.E.D.

Result 10 implies that to base food safety regulation on imposing a certain type of traceability system can result in no effect on food safety and will probably just increase costs for firms. When agents are risk neutral, an imposition of higher traceability precision will just lead the principal to reduce the intensity of incentives in order to keep inducing the first-best food safety effort on agents. To see this point notice that when agents are risk neutral,

$$\left(\frac{\partial I_1(\cdot)}{\partial s} - \frac{\partial I_2(\cdot)}{\partial s} \right) = -s^{-2} F'(a)^{-1} c'(a), \text{ which it is strictly negative by } \mathbf{Assumptions 1} \text{ and } \mathbf{3} \text{ for } s >$$

0.

Conclusions

Food safety crises have shown to be frequent. As a reaction to this, the adoption of traceability has been proposed as a means to increase food safety. But traceability just accumulates information about the product and processes as the product moves through its supply chain, implying that traceability adoption does not seem by itself to lead to safer food. Despite this, our results show that traceability can effectively improve food safety by reducing anonymity in food supply chains that makes it possible to create incentive mechanisms based on contingent payments. We develop a principal-agent model in which food safety can be caused only by defects in material provided by an upstream firm. We characterize a traceability system by its precision, that is, the probability by which it keeps the identities of raw material suppliers linked with final food products. Based on this, we conceptualize an incentive mechanism scheme in which payments are made contingent on whether traceability is precise or not and on whether food is safe or unsafe for consumption. Thus, the food processor (principal) sets a contract given by the precision of traceability and contingent payments in order to entice homogeneous agents

to exert the food safety effort chosen by the principal. Using this conceptual model, we first study a raw material supplier's best response function. In so doing we found that, for purpose of inducing a certain level of food safety effort, more intensive contingent payments can substitute for higher precision of traceability and vice-versa. This result indicates that the precision of a traceability system is not an unequivocal signal of food safety by itself. Yet, it is a necessary condition for safer food that the precision of traceability be bigger than zero in order to make the use of contingent payment incentives feasible.

We simplify our principal-agent model with traceability by assuming that agents are risk neutral and find that first-best and second-best levels of food safety effort are equal. Moreover, we show that when agents are risk neutral an exogenously imposed traceability standard with sanctions has no effect on food safety efforts and thus on food safety, but it is likely to increase costs for food processors. This result presents a clear alert for food safety regulation by government. Our results also confirm that increased penalties for food safety crises can be a means to induce higher food safety efforts and consequently food safety. Finally, our model can serve as conceptual framework for empirical work in the economics of traceability since it generates results that can be tested.

One might use our conceptual model as a starting point for further research regarding the positive and normative issues in the economics of food traceability. For instance, one might extend our model towards characterizing the voluntary adoption of traceability under a context in which food safety can be caused by defects in material provided by an upstream firm and by the care downstream firms have in processing material into food. This context is representative of a broad class of food safety issues in which microbial contamination is a food safety issue. In such a context of double-sided moral hazard, the food effort exerted by a downstream firm would enter as an additional piece into an incentive mechanism. The extension of our model might be applied for studying the effects of an exogenously imposed traceability standard with sanctions and increased penalties for food safety crises, in the same fashion we have pursued in the present

article. Alternatively, our model could be extended to explore cases where even a modest traceability system is too costly for individual firms to pursue on their own. In this instance, an interesting question to explore is under what conditions a publicly funded and administered traceability system that provides individual firms with the opportunity to offer incentives can improve welfare.

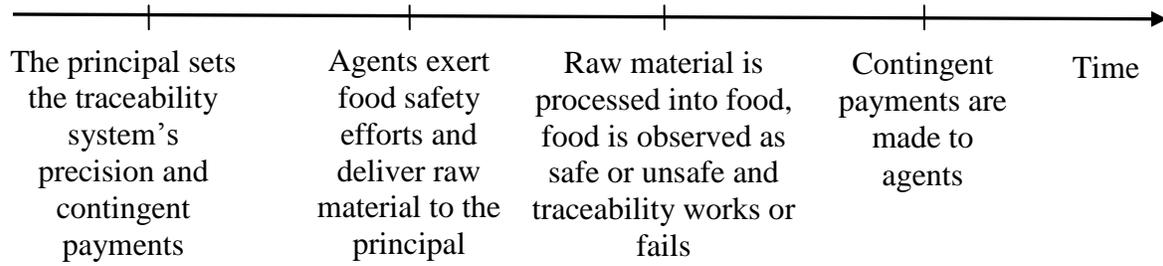


Figure 1. Timing of the principal-agent game with traceability

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

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

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Footnotes

¹A credence attribute cannot be verified even after the product is consumed or utilized.

²Examples 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).

³Notermans, 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.

⁴Notice that using (13c) for risk neutral agents implies that $(I_1 - I_2) = s^{-1}F'(a)^{-1}c'(a)$.

⁵ Using the definition of risk-premium \equiv Expected payment - certainty equivalent $\equiv ((1-s)I_0 + sF(a)I_1 + s(1-F(a))I_2) - v((1-s)u(I_0) + sF(a)u(I_1) + s(1 - F(a))u(I_2))$. But when agents are risk neutral $v((1-s)u(I_0) + sF(a)u(I_1) + s(1 - F(a))u(I_2)) = ((1-s)I_0 + sF(a)I_1 + s(1-F(a))I_2)$ that implies risk-premium=0.