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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 downstream food processor firm (principal) that sets traceability precision and contingent payments so to induce homogeneous upstream suppliers (agents) to exert the principal's preferred level of food safety effort. We focus on cases in which food safety crises originate from defects in raw material provided by upstream firms to analytically show that high precision can substitute for high intensive contingent payments and vice-versa, and thus traceability is not an unequivocal signal for safer food. Contrary to previous results in the literature, we also show that government regulation based on mandatory traceability with sanctions may not necessarily lead to safer food, while increasing the food processor's costs. Finally, we use our analytical results to give managerial feedbacks for firms adopting and considering traceability.



## 1. Introduction

Foodborne diseases are a major cause of illness and death. In 2011, one in six Americans (47.8 million people) got sick, 127,836 were hospitalized, and 3037 died from foodborne diseases (Morris, 2011). Around the world, widely publicized food safety crises have raised public concerns, putting food supply chains and governments under pressure. Examples include the 2011 *E. coli* contamination of bean sprouts in Germany with 37 deaths and 3000 ill (Marucheck et al., 2011); the 2008 Peanut Corporation of America salmonella outbreak that resulted in nine deaths, 637 ill and one of the largest food recalls in the U.S. history (Layton and Miroff, 2009); and the 2008 Chinese government recall of infant milk powder contaminated by melamine (a chemical used in plastic) that was linked to six deaths and 294,000 illnesses (Spencer, 2009). Other recent food safety episodes involved the contamination of pork, poultry and dairy products with dioxin in Europe (ElAmin, 2006; Marucheck et al., 2011).

Ensuring a safe food supply is a difficult task that extends beyond the boundary of a single firm. Food supply chains are often composed of a number of independent firms (e.g., farms, processors, packers, distributors, transporters, and retail stores) where materials move across these firms through market and other transactions. Many of these market transactions are anonymous, making it difficult for downstream firms to ascertain upstream firms' food safety efforts. Actions that can be taken to reduce this anonymity include traceability systems. Traceability systems create the ability to retrieve the history and location of a product through a registered identity (International Organization for Standardization, 2000), including procedures for identification, preparation, collection, storage, and verification of data (Starbird and Amanor-Boadu, 2006), which may serve as a mechanism to assure food safety (Alfaro and Rábade, 2009).

There are a variety of reasons why firms might voluntarily adopt traceability: identify better sources of raw materials, comply with international trade standards, and certify credence attributes[1] (Golan et al., 2004). But the extent to which firms might voluntarily adopt traceability to improve food safety is less clear. Traceability does not directly impact production systems to improve food safety like Pathogen Reduction[2] (PR) and Hazard Analysis and Critical Control Point[3] (HACCP) systems. Instead, it accumulates information about product attributes and processes as the product moves through the supply chain, which by itself does not reduce the probability of a food safety crisis. However, information generated by traceability systems could facilitate contractual arrangements between firms in the supply chain to promote food safety.

Regardless of any voluntarily incentives firms may have to adopt traceability, governments have begun to require traceability to

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

[2] Examples of PR are steam pasteurization, spray-washing, irradiation and chemical interventions (Vitiello and Thaler, 2001: p. 600).

[3] HACCP is a systematic approach to control potential hazards in food by identifying problems before they occur and establishing measures for control at the stages found to be critical in production (Notermans et al., 1994: p. 204).

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improve food safety. The General Food Law Regulation of the European Union which came into effect in January of 2005 requires all food firms to trace food, feed, and ingredients through all stages of production, processing and distribution to the final consumer (Alfaro and Rábade, 2009; Pinto et al., 2006). Since December 2006, the Food and Drug Administration (FDA) in the U.S. has required food facilities (e.g., retailers, manufactures, processor, and packers) to maintain records (e.g., names, addresses, phone numbers, country of origin, dates, type of food and its packaging) on the sources and recipients of food products.

The purpose of this paper is to explore how traceability could improve food safety by facilitating incentive based contracts that encourage upstream firms to exert effort into providing safer raw material. Specifically, we are interested in how voluntarily traceability might improve food safety. We are also interested in how government mandated traceability might improve food safety. To accomplish these objectives, we develop a principal–agent model taking into account two stages of a food supply chain. The upstream stage includes homogeneous producers (the agents) of raw material for a downstream food processor (the principal). In the model, each agent can invest effort into providing safer raw material, and the principal can invest in a traceability system and offer agents contingent payments based on having been found to provide safe material. A key assumption in the model is that the safety of the material is not precisely observed by the principal, though the principal can invest in improving the precision in which it observes the safety of the material.

The paper contributes to the literature by extending Resende-Filho and Buhr (2008) to the broader issue of food safety, while considering continuous food safety effort and traceability precision. The model improves on the seminal Polinsky and Shavell (1979) by explicitly modeling the conflict between producers and food processors with traceability. It relaxes the assumption of perfect precision in the observation of quality and safety employed by Dubois and Vukina (2004), Starbird (2005) and King et al. (2007). The analysis also offers a different perspective on how traceability can improve food safety when compared to the legal liability approaches explored by Hobbs (2004), Tonsor and Schroeder (2004), Starbird and Amanor-Boadu (2006, 2007), and Pouliot and Sumner (2008).

The results of our analysis show that 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. Our results also show that voluntary traceability and mandatory traceability do not necessarily improve food safety, which challenges Pouliot and Sumner's (2008) result that traceability always increases food safety.

The next section develops the details of the principal–agent model that provides the foundation for our analysis. Section 3 analyzes the decisions of agents and develops key results regarding how an agent will respond to the principal's choice of the precision of traceability and contract incentives. The results developed in Section 3 are then used in Section 4 to analyze the principal's optimal level of precision and choice of contract incentives when the principal can and cannot directly observe the agents food safety efforts. Section 5 analyzes the implications of mandated traceability standards and fines drawing on key results established in Section 4. Section 6 offers concluding remarks.

## 2. Modeling framework

Although food safety crises may have many different origins, we focus on problems that originate from defects in raw material provided by upstream firms. We assume the probability of raw material defects is under the control of upstream firms, at least to some extent. Examples of food safety problems originating from an upstream material provider include chemical residues on food (e.g., dioxin, 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). Note that it is estimated that each year 38.4 million episodes of domestically acquired foodborne illness in the U.S. are caused by unspecified agents like chemicals and other substances known to be in food but whose ability to cause illness is unproven, resulting in 71,878 hospitalizations and 1686 deaths (Scallan et al., 2011).

We recognize that the transportation and stocking stage is critical for food safety because time delays in actions and temperature changes affect food products (Bogataj et al., 2005). However, to focus our analysis, we abstract from these issues by assuming that it is possible to perfectly monitor and incentivize transporters with an enforceable first-best contract. The monitoring of temperature is possible because temperature is recorded during transportation, for instance, to comply with the European Community directive EN 92/1 CEE (Bogataj et al., 2005). Thus, as "cold traceability" is in place such that tools and equipment (e.g., thermometers, temperature recorders, temperature indicators and time-temperature integrators) for the quality control of perishable goods are used, the additional cooling to contract is just a solution obtained from the model of Bogataj et al. (2005).

Let $1 \geq F \geq 0$ be the probability that an upstream firm provides one unit of 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 one unit of defective material that is processed into unsafe food. Following Tirole (1988: p. 54), we 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 depth, breadth, and precision (Golan et al., 2004). Depth is how far forward and backward the traceability system extends in the supply chain. Breadth is the amount of information recorded by the system. Precision is the system's capability to pinpoint the source of a material defect if it occurs. Our interest is in the system's precision and incentives for a downstream firm to endogenously influence precision.

In general, once attributes worth tracking are identified, the depth of the system is essentially determined (Golan et al., 2004). We assume here that the attribute of interest for the downstream firm is the identity of raw material suppliers, which requires the traceability system to record suppliers' complete names, addresses, phone numbers, and received dates. This information fully characterizes the system's breadth. Thus, it will be enough for our conceptualized traceability system to extend back to the point where raw materials are received by the food processor.

Note that our system's precision depends only on the number of raw material batches from different suppliers used to produce a finished product batch (i.e., the upward batch dispersion as defined by Dupuy et al. (2005), which makes the system's precision independent of its depth and breadth. Therefore the cost of a certain system's precision in our model should be though as the solution to the problem of minimizing the cost of traceability such that the resulting manufacturing upward batch dispersion guarantees the system's precision.

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

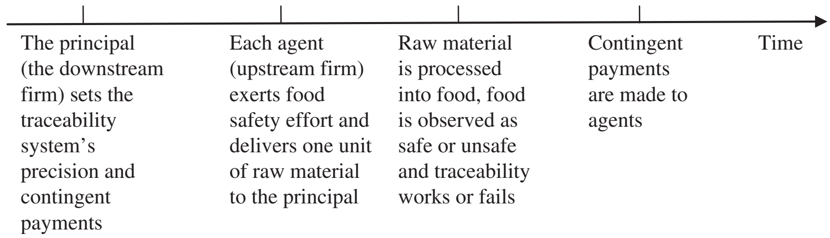


**Fig. 1.** Timing of the principal–agent game with traceability.

**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 | $F(a)$ | $F(a)s$ | $I_1$ | $(1-s)F(a)$ | $I_0$ |
| Raw material causes food to be unsafe (food is unsafe) | $(1-F(a))$ | $(1-F(a))s$ | $I_2$ | $(1-s)(1-F(a))$ | $I_0$ |

the traceability system fails. Thus, if $s=0$, there is no possibility of identifying the upstream material provider after delivery, meaning there is no traceability. In order to reduce complexity and tighten the focus of the model, we abstract from the possibility of false positives (i.e., an innocent upstream supplier be found guilty) or false negatives (i.e., a guilty farm be found innocent).

Given the above context, the principal (the food processor) and each of the $N>1$ homogeneous agents (raw material producers) plays the one-shot, three-stage sequential game illustrated in Fig. 1. The principal moves first, by setting the precision of the traceability system and offering agents a contract composed of contingent payments. Next, each agent who has accepted the principal's contract chooses the level of food safety effort to exert while producing and delivering one unit of raw material. Finally, nature determines whether the traceability system fails and whether each agent's raw material is defective so that the appropriate payments are made by the principal. Note that events out of the control of a raw material provider can create food safety problems. For instance, the behavior of a chemical (e.g., antibiotic or hormone) while in the body of animals is out of a farmer's control.

The types of contingent payment contracts we explore reward 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 the agent provided defective or defect free material (contingency denoted by $m=0$). Therefore, the principal's contract specifies three separate contingency payments, $I_m$ 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. Note that contingency payments may be positive, negative or zero. For instance, it is possible to set $I_2 < 0$ which would characterize the case where a penalty is paid by the agent to the principal for a defective supply, which frequently occurs in manufacturing (i.e., cost refunding plus penalty[4]).

[4] We thank one reviewer for bringing up this to us.

## 3. The agent's problem

We begin by analyzing the agent's problem, which yields four key results: (1) a traceability system must be able to identify at least some material defects if it is going to be able to improve food safety, (2) agents will invest more in food safety effort as the precision of traceability increases, (3) agents will invest more in food safety effort as payments for being found to have supplied defect free product increases, and (4) agents will invest less in food safety effort as payments for being found to have supplied defective product increases.

In our model each upstream supplier delivers one unit of raw material, and its preferences are represented by a utility function whose arguments are contingent payments ($I_m$) and food safety effort ($a$). Following Holmström (1979), Tirole (1988), Goodhue (2000), and Starbird (2005), an agent's contingent specific utility is additively separable in incentive payments and effort such that:

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

where $u(I_m)$ is a Bernoulli utility function as defined by Mas-Colell et al. (1996, p. 184), $c(a)$ is the cost of effort function, and

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

Note that Assumption 3 says nothing about an agent's risk aversion. Therefore, the results below hold for any type of risk preference (e.g., risk aversion, $u''(I_m) < 0$; risk neutrality, $u''(I_m) = 0$; or risk love, $u''(I_m) > 0$).

As the agent moves second in this game, it takes the principal's choice of traceability precision $s$ and contingency payments ($I_0$, $I_1$, $I_2$) as given and chooses the level of food safety effort that maximizes its expected utility:

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

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

$$sF'(a*)(u(I_1) - u(I_2)) - c'(a*) \leq 0 \tag{3a}$$

and

$$a*(sF'(a*)(u(I_1) - u(I_2)) - c'(a*)) = 0, \tag{3b}$$

which give us:

**Result 1.** A positive traceability precision ($s > 0$) is necessary and sufficient to induce positive food safety effort.

**Proof.** For $s=0$ Eqs. (3a) and (3b) imply $-c'(a*)\leq 0$ and $-c'(a*)a*=0$, which given Assumption 3 can only be fulfilled if $a*=0$. For $s>0$, Eq. (3b) jointly with Assumptions 1–3 imply that $a*>0$. **Q.E.D.**

The second-order sufficient condition for an interior solution at $a*$ is

$$sF''(a*)(u(I_1)-u(I_2))-c''(a*)<0 \tag{4}$$

which is fulfilled with $s>0$ because $u(I_1)-u(I_2)>0$ by Assumptions 2 and 3, and $F''(a)<0$ and $c''(a)>0$ by Assumptions 1 and 3. Also, the first-order conditions in (3a) and (3b) for an interior solution collapse to

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

where the left-hand-side of (5) is the marginal expected utility or marginal benefit of effort, while the right-hand-side is the marginal cost of effort. At the optimal level of food safety effort $a*$, the marginal benefit and marginal cost are equal. The results in (4) and (5) will prove useful in our subsequent analysis.

### 3.1. Traceability, contingent payments and food safety

We now investigate how the design of incentive based contracts affects food safety efforts. In so doing, we assume the agent's effort that maximizes problem (2) is a continuously differentiable function of the traceability system's precision and contingency payments, such that $a*=a*(s, I_0, I_1, I_2)$. Based on this, we analyze how a change in each component of the contract is expected to modify an agent's optimal food safety effort, while maintaining the other components of the contract. We obtain the following results:

**Result 2.** Increased precision of the traceability system induces more food safety effort by material suppliers: $(\partial a*/\partial s)>0$.

**Proof.** For $a*>0$, (3b) implies (3a) holds with equality. Using the implicit function theorem,

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

where the denominator of (6) is negative from inequality (4), and the numerator of (6) is also negative because $F'(a)>0$ by Assumption 1 and $u(I_1)-u(I_2)$ is positive by Assumptions 2 and 3. **Q.E.D.**

**Result 3.** Increasing the contingent payment when traceability works and the material is free from defect induces more food safety effort by agents: $(\partial a*/\partial I_1)>0$.

**Proof.** For $a*>0$, (3b) implies (3a) holds with equality. Using the implicit function theorem,

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

where the denominator of (7) is negative from inequality (4), and the numerator of (7) is also negative because $F'(a)>0$ by Assumption 1 and $u'(I_1)>0$ by Assumption 3. **Q.E.D.**

**Result 4.** Increasing the contingent payment when traceability works and the material is defective induces less food safety effort by agents: $(\partial a*(.)/\partial I_2)<0$.

**Proof.** For $a*>0$, (3b) implies (3a) holds with equality. Using the implicit function theorem,

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

where the denominator of (8) is negative from inequality (4), and the numerator of (8) is also positive because $F'(a)>0$ by Assumption 1 and $u'(I_2)>0$ by Assumption 3. **Q.E.D.**

Results 1–4 lead to the following general conclusions, which are summarized in Table 2:

First, Levison (2009) indicates that there is always some strictly positive traceability precision even when a traceability system is not in place such that Result 1 implies the implementation of a traceability system is neither a necessary nor a sufficient condition for inducing food safety effort.

Results 2–4 jointly imply that increasing incentives (i.e., $I_1-I_2>0$) for further food safety effort can substitute for increasing the precision of the traceability system. Thus, provided anonymity is not complete in the food supply chain (i.e., $s>0$), higher traceability precision must be used jointly with contingent payments to be sufficient for safer food. Also, increased incentives will be sufficient for safer food only if anonymity is not complete in the food supply chain. Finally, the level of food safety effort and, consequently, the safety of food should not be inferred by separately looking at the values of $s$, $I_1$ and $I_2$. It is possible for an imprecise traceability system coupled with high incentives to induce the same level of food safety effort as a highly precise

**Table 2**
Summary of conclusions based on analytical Results 1–4 and their managerial implications.

| Main conclusions | Managerial implications |
|---|---|
| The implementation of a traceability system is neither a necessary nor a sufficient condition for inducing further food safety effort, provided there is some strictly positive traceability precision before the adoption of a traceability system. | • A downstream firm should estimate the current traceability precision to evaluate the need for implementing a traceability system.<br>• A downstream firm should use contingent payments to make a traceability system capable of inducing further food safety efforts by raw material suppliers. |
| Increasing incentives (i.e., $I_1-I_2>0$) for further food safety effort can substitute for increasing a traceability system's precision ($s>0$). | • All types of traceability system (e.g., a pen and paper based or a technology of information based version) should be taken as candidates to be implemented because other reasons besides food safety (e.g., the cost of traceability) should drive the choice of the type of traceability system. For instance, Pinto et al. (2006) argues that pen and paper versions of traceability systems may be so time and resource consuming to make them economically feasible to be implemented in small and medium size companies.<br>• For a firm with a traceability system in place, the proper definition of contingent payments should be a crucial task to be performed when the object is to use all the potential incentive created with the adoption of a traceability system. For instance, Alfaro and Rábade (2009) conducted a longitudinal case study with a company in Spain that sells frozen vegetables in which they observed that the implementation of a traceability system allowed the company to audit raw material suppliers to calculate price-quality ratios and use this information to choose their suppliers. |

traceability system with low incentives. Ultimately, the level of food safety effort and the safety of food is a matter of choice by the downstream food processor as formalized by the principal–agent model in the following section.

## 4. The principal–agent model

We now consider how decisions on food safety effort and contingent payments are made, and explore how the cost of a food safety crisis affects the incentives the principal offers and the amount of effort agents invest in reducing the probability of defective materials. Our analysis yields four additional results: (5) increasing the cost of a food safety crisis to the principal increases the level of food safety effort it contracts when it can observe an agent's food safety effort, (6) the first and second-best levels of food safety effort are equal for risk neutral agents when the precision of traceability is positive, (7) the principal chooses the lowest possible positive level of traceability precision when agents are risk neutral, and (8) payments to risk neutral agents when traceability fails are irrelevant for determining the optimal level of food safety effort.

### 4.1. First-best setting with symmetric information

The first-best setting is characterized by the principal's ability to perfectly observe the agents' food safety efforts. In this idealized context, the principal is able to set the payment contingent $I$ on an agent's observed food safety effort, which makes the contract a pair $(I, a)$. We assume the principal chooses the contract that minimizes its cost of raw material plus the expected cost of resolving any resulting food safety crises, while making sure agents will be willing to accept the contract. The first-best principal's problem is formalized as:

$$\min_{a \geq 0, I} \quad I+(1-F(a))r_e \quad \text{subject to} \quad u(I)-c(a) \geq \underline{U} \tag{9}$$

where $r_e$ is the external cost of a food safety crisis including the direct cost of liability, product recalls, allowances, court or market-imposed penalties, and fines levied due to safety failures; and $U$ is the reservation utility or the lowest utility level a contract has to guarantee to get agents to accept it.

As the objective function and the left-hand side of constraint in (9) are strictly increasing in the payment, it is optimal to set $I$ such that the constraint holds with equality:

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

where $v(\cdot)$ is the inverse function of the Bernoulli utility function. Substituting (10) into the objective in (9) and solving for the first-best level of food safety effort $a_{FB}$ yields the first order necessary condition

$$v'(\underline{U}+c(a_{FB}))c'(a_{FB})-r_eF'(a_{FB})=0. \tag{11}$$

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

**Assumption 4.** $u''(\cdot) \leq 0$ (agents are either risk neutral or risk averse).

Eq. (11) then yields:

**Result 5.** Increasing the external cost of food safety crises leads the principal to contract for a higher level of food safety effort when it can observe this effort: $(\partial a_{FB}/\partial r_e) > 0$.

**Proof.** Applying the implicit function theorem to (11) yields

$$\frac{\partial a_{FB}}{\partial r_e} = \frac{F'(a_{FB})}{v''(\underline{U}+c(a_{FB}))c'(a_{FB})^2+v'(\underline{U}+c(a_{FB}))c''(a_{FB})-r_eF''(a_{FB})}. \tag{12}$$

The numerator of (12) is positive because $F'(\cdot)>0$ by Assumption 1. The denominator of (12), the second-order condition for (9), is positive because $v'(\cdot)>0$ by Assumption 3, $v''(\cdot) \leq 0$ by Assumption 4, $c''(\cdot)>0$ by Assumption 3, and $F''(\cdot)<0$ by Assumption 1. **Q.E.D.**

### 4.2. Second-best setting with asymmetric information

We now consider the second-best setting where the principal cannot observe agents' food safety efforts. The principal voluntarily implements a traceability system setting its precision and contingent payments ($s$, $I_0$, $I_1$, $I_2$) to induce its preferred food safety effort. Therefore, the principal chooses the contract and the effort induced from agents to minimize its expected cost of raw material plus the expected external cost of a food safety crisis, while making sure agents will be willing to accept the contract and exert the chosen level of effort. Formally, the problem is

$$\min_{a \geq 0, s \in [\underline{s},1], I_0, I_1, I_2} \quad (1-s)I_0+sF(a)I_1+s(1-F(a))I_2+(1-F(a))r_e+g(s) \text{ subject to}$$

$$(1-s)u(I_0)+sF(a)u(I_1)+s(1-F(a))u(I_2)-c(a) \geq \underline{U} \quad \text{and} \quad sF'(a)(u(I_1)-u(I_2))-c'(a)=0. \tag{13}$$

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

**Assumption 5.** $g'(s)>0$ and $g''(s)>0$ for $1 \geq s \geq \underline{s}$, where $\underline{s}$ is a strictly positive minimum level of traceability automatically created when a traceability system is implemented.

The sum of the first three terms in the objective of (13) gives the principal's expected cost of buying one unit of raw material. The fourth term gives the expected cost of a food crisis. The fifth term denotes the cost of the traceability system as a function of its precision. The first constraint in (13) is the participation constraint that ensures the agent will be willing to enter into the principal's contract. The second constraint in (13) is the incentive compatibility constraint that accounts for how an agent optimally invests in effort to reduce the probability of defects given the principal's contract and is obtained from (5).

Manipulation of incentive compatibility constraint gives

$$u(I_1) = \frac{c'(a)}{sF'(a)}+u(I_2). \tag{14}$$

In (14), $c'(a)/sF'(a)$ is positive for $s>0$ because $F'(a)>0$ by Assumption 1 and $c'(a)>0$ by Assumption 2. Combining $c'(a)/sF'(a)>0$ with $u'(\cdot)>0$ by Assumption 3 implies $I_1$ is always bigger than $I_2$. In other words, a contract will always pay agents more in the contingency preferred by the principal, which makes Assumption 2 redundant from this point on.

As the objective and participation constraint in (13) are strictly increasing in contingent payments, the participation constraint binds at an optimum. Using this fact to substitute $u(I_1)$ out of participation constraint using Eq. (14) gives

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

$I_1=I_1(a, s, I_0)$ and $I_2=I_2(a, s, I_0)$ then follows from (14) and (15). It is useful to note that Eqs. (14) and (15) imply (see Appendix for details):

$$F(a)\frac{\partial u(I_1)}{\partial I_1}\frac{\partial I_1}{\partial a}+(1-F(a))\frac{\partial u(I_2)}{\partial I_2}\frac{\partial I_2}{\partial a}=0 \tag{16}$$

and

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

Eqs. (14) and (15) also allow us to write (13) as the simpler unconstrained optimization problem:

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

with the interior first-order conditions:

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

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

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

and

$$(\underline{s}-s) \leq 0, \quad (\underline{s}-s)\mu = 0, \quad \mu \geq 0 \tag{22}$$

where $\mu$ is the Lagrange multiplier for the constraint $(\underline{s}-s) \leq 0$.

Comparative static results for Eqs. are generally intractable. To gain further insight, we assume agents are risk neutral (i.e., $u(I_m) = v(u(I_m)) = I_m$) such that:

$$F(a)\frac{\partial I_1(.)}{\partial a} + (1-F(a))\frac{\partial I_2(.)}{\partial a} = 0 \tag{16$'$}$$

and

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

**Result 6.** The first-best and second-best levels of food safety effort are equal for risk neutral agents when the traceability precision is positive.

**Proof.** Plugging (16′) into Eq. (19) results in

$$sF'(a)(I_1 - I_2) - r_e F'(a) = 0. \tag{19$'$}$$

Substituting (14) for risk neutral agents[5] into (19′) yields

$$c'(a) - F'(a)r_e = 0. \tag{19$''$}$$

which is exactly the same as (11) for the first-best problem in (9). **Q.E.D.**

**Result 7.** The principal sets the traceability system to its lowest level of precision $s$ when agents are risk neutral.

**Proof.** First, as agents are risk neutral, Eqs. (14) and (15) become

$$I_1 = \frac{F'(a)(\underline{U} + c(a) - (1-s)I_0) + c'(a)(1-F(a))}{sF'(a)} \quad \text{and}$$

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

implying

$$F(a)I_1 + (1-F(a))I_2 = s^{-1}(\underline{U} - I_0 + c(a) + sI_0). \tag{23}$$

Second, manipulating the derivative of (23) with respect to $s$ yields

$$s\left(F(a)\frac{\partial I_1}{\partial s} + (1-F(a))\frac{\partial I_2}{\partial s}\right) = -s^{-1}(\underline{U} - I_0 + c(a)). \tag{24}$$

Third, plugging (23) and (24) into (20) gives $g'(s) = \mu$. But $g'(\cdot) > 0$ by Assumption 5 such that $\mu > 0$. Finally, using this result with (22), $\mu(\underline{s}-s) = 0$, implies $(\underline{s}-s) = 0$. **Q.E.D.**

The fact is that when agents are risk neutral, more intensive incentives do not require the principal to pay higher risk-premium in order to get agents to participate in the contract. In fact, as the risk-premium is the difference between expected payment, $((1-s)I_0 + sF(a)I_1 + s(1-F(a))I_2)$, and the certainty equivalent, $v((1-s)u(I_0) + sF(a)u(I_1) + s(1-F(a))u(I_2))$, it is always zero in the case of risk neutral agents. On the other hand, the greater the precision of traceability, the more costly it will be for the principal by Assumption 5. Thus, the cheapest way to induce the first-best food safety effort is to substitute, as much as possible, incentives for precision. Note though that the lowest level of traceability $s$ must still be positive, otherwise no incentive scheme can be created according to Result 1.

Finally, the first-order condition in (21) is automatically fulfilled when agents are risk neutral. To see this, substitute (17′) into the left-hand-side of (21) to get $(1-s) + s(s^{-1}(s-1)) = 0$ for $s > 0$ such that

**Result 8.** $I_0$ is not unique when agents are risk neutral.

Results 5–8 are useful for our analysis of food safety regulation in the next section. Results 6 and 7 also have other important implications:

Results 6 and 7 make it clear that the difference between the first-best and second-best settings is the use of traceability in the later to guarantee the minimum degree of traceability $s$. Thus, it might not even be necessary to implement traceability in the case of risk neutral agents if the precision of traceability before its implementation is already positive as Levison (2009) suggests.

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

## 5. Food safety regulation

Having characterized the first and second-best level of food safety with voluntary adoption of traceability when agents are risk neutral, we now explore food safety regulation by government when there is voluntarily adopted traceability. First, we investigate the effect of increased fines levied due to food safety failures. Second, we investigate the effect of the imposition of traceability precision standards. The analysis adds two more key results: (9) increased fines will increase the first and second-best food safety effort when agents are risk neutral, and (10) traceability precision standards will have no effect on the first and second-best food safety effort when agents are risk neutral.

Government can increase fines levied due to food 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.** Food safety regulation based on increased fines due to food safety failures increases first and second-best food safety effort, increasing the safety of food when agents are risk neutral: $da/dr_e > 0$.

[5] Note that Eq. (13c)) under risk neutral agents becomes: $I_1 - I_2 = s^{-1}F'(a)^{-1}c'(a)$.

**Proof.** When agents are risk neutral, we know from Results 7 and 8 that $s$ and $I_0$ do not depend on $r_e$ such that $I_1=I_1(a(r_e),I_0,s)$ and $I_2=I_2(a(r_e),I_0,s)$. Using these facts to totally differentiate (19″) with respect to $r_e$ yields $(da/dr_e)=(F'(a))/c''(a)-F''(a)r_e$, which is positive by Assumptions 1 and 3. **Q.E.D.**

Note that Results 5 and 9 rely on the assumption that an interior solution for problem (18) holds even after increasing the external cost of food safety. Yet, if the external cost of food safety increases too much (e.g., due to higher fines for safety failures) it may become the principal's best choice to leave the market. The fact that higher fines for food safety failures could lead firms to leave the market implies that a government agency (e.g., the FDA) aiming to increase the food safety should use such an instrument with caution.

In terms of food safety regulation, the government may also impose a traceability standard, which in the context of our model translates into the imposition of a certain level of traceability precision. Under such regulation the following result holds:

**Result 10.** The exogenous imposition of a traceability standard will have no effect on the first and second-best food safety efforts when agents are risk neutral.

**Proof.** This result follows from Results 6–8. In the proof of Result 6, it is shown that condition (19) becomes condition (19″) implying $a$ does not depend on $s$. Also, the other first-order conditions to problem (18) are guaranteed to be fulfilled as shown in the proofs of Results 7 and 8. **Q.E.D.**

Result 10 implies that imposing a certain traceability standard may have no effect on food safety, while increasing the cost of traceability to firms. Indeed, when agents are risk neutral, the imposition of more precise traceability will lead the principal to reduce the incentives payments for improved food safety to keep inducing the first-best effort. To see this, note that when agents are risk neutral and $s>0$,

$$\left(\frac{\partial I_1(.)}{\partial s}-\frac{\partial I_2(.)}{\partial s}\right)=-s^{-2}F'(a)^{-1}c'(a)<0 \quad \text{Asssumptions 2 and 3}$$

Result 10 also implies that mandatory traceability with sanctions does not necessarily improve food safety, which challenges Pouliot and Sumner's (2008) result that traceability always increases food safety. We conjecture that this may also hold for the case where agents are risk averse, but leave it to be investigated in a future work.

## 6. Conclusions

Food safety crises have been common and the adoption of traceability has been proposed as a means to increase food safety. But traceability just accumulates information about product attributes and processes while the product moves through the supply chain, and is not expected to reduce the probability of food safety crisis by itself; though Dupuy et al. (2005) points out that traceability could still reduce the consequences of a crisis. To investigate this issue, we develop a principal–agent model where food safety crises can be caused by defects in raw material provided by upstream firms. We characterize traceability by its precision, which is the probability it keeps the identities of raw material producers linked to final food products. We conceptualize incentive based contracts in which payments are made contingent on whether traceability is precise or not, and food is safe or not for consumption. Therefore, the downstream food processor (the principal) specifies the traceability system's precision and contingent payments to induce material suppliers (the agents) to exert the desired food safety effort.

Our analysis of the raw material producers offers two major conclusions. First, the implementation of a traceability system by itself is neither a necessary nor sufficient condition for inducing further food safety effort when there is some traceability even without the explicit adoption of a traceability system. But if there is complete anonymity in the food supply chain, then traceability adoption is necessary and sufficient for safer food because, by eliminating complete anonymity, traceability will make it possible to use incentive contracts based on contingent payments. Second, to induce a certain level of food safety effort, more intensive contingent payments can substitute for higher traceability precision. This result implies that the precision of traceability should not be taken as an unequivocal signal for food safety. Low precision traceability systems may induce safer food than high precision systems.

We also derive some managerial implication for firms. For instance, firms should always estimate the current traceability precision and use this information to evaluate the need for the adoption of additional traceability. Furthermore, the trade-off between contingent payments and traceability precision implies that the proper definition of contingent payment incentives should be a crucial task when exploring the potential for traceability.

We simplify our principal–agent model by assuming agents are risk neutral. Under this condition, we analytically find that first and second-best levels of food safety effort are equal and that even a low precision traceability system can induce first-best food safety effort, confirming that low precision of traceability is not synonymous with unsafe food. Moreover, we show that an exogenously imposed traceability standard with sanctions has no effect on food safety efforts and thus on food safety, but is likely to increase costs to firms. This result offers a cautionary tale for food safety regulation by government. Our analytical results do not refute that increasing penalties for food safety crises may induce safer food. But they also do not confirm it because we have not analyzed the issue under the context with risk aversion. Finally, our model can serve as conceptual framework for empirical work in the economics of traceability because it generates results that can be tested.

One might also 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, our model could be extended to characterize the voluntary adoption of traceability when food safety problems can be caused by defects in raw material provided by upstream firms and by the care downstream firms when processing material into food (Roe, 2004). This context would be 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 safety effort exerted by a downstream firm would enter as an additional piece into the incentive mechanism. 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 can improve welfare when firms use the system to offer incentives.

## Appendix A. Details on the derivation of Eqs. (16) and (17)

To obtain Eq. (16), we first plug Eq. (15) into Eq. (14). We then take the derivative obtaining:

$$\frac{\partial u(I_1)}{\partial a}=s^{-1}\left(\frac{\partial F(a)}{\partial a}\right)^{-2}(1-F(a))\left(\frac{\partial F(a)}{\partial a}\frac{\partial^2 c(a)}{\partial a^2}-\frac{\partial^2 F(a)}{\partial a^2}\frac{\partial c(a)}{\partial a}\right) \tag{A1}$$

Second, we take the derivative of Eq. (15) with respect to $a$, obtaining:

$$\frac{du(I_2)}{da} = -s^{-1}\left(\frac{\partial F(a)}{\partial a}\right)^{-2} F(a)\left(\frac{\partial F(a)}{\partial a}\ \frac{\partial^2 c(a)}{\partial a^2} - \frac{\partial^2 F(a)}{\partial a^2}\ \frac{\partial c(a)}{\partial a}\right) \qquad (A2)$$

Finally, by comparison between (A1) and (A2) we arrive at Eq. (16).

To obtain Eq. (17), we first plug Eq. (15) into Eq. (14) and take its derivative with respect to $u(I_0)$. Second, we also take the derivative of (15) with respect to $u(I_0)$. Finally, combining those two results, we arrive at Eq. (17).

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