A Principal-Agent Model for Investigating Traceability Systems Incentives on Food Safety

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Summary

This article investigates the effects of contingent payments and a traceability system's expected traceback rate of success on the food safety effort exerted by raw material suppliers. This sheds light on when contingent payments and the reliability of a traceability system are substitutes and complements to each other in terms of inducing raw material suppliers to exert higher food safety effort. In addition, the effect of higher penalties and costs of food safety crisis on the effort to be induced by buyers (principal) on suppliers (agents) is investigated under a symmetric information setting. Finally, the asymmetric information setting is formalized as a principal-agent model and left to be explored in a future work. Some numerical exercises are carried out to illustrate main findings. It has been found that more reliable traceability systems might induce higher food safety efforts by suppliers. However, this same effect could be accomplished either with higher payments whenever no food safety crisis occurs or with lower payments whenever a food safety crisis occur both assuming the traceability system works. Finally, it is shown that without a traceability system in place no incentive scheme could be implemented.

KEYWORDS: Information Asymmetry, Identity Preservation, Food Traceability, Supply Chain Management.
JEL: D82, D86, C61.

1. Introduction

Following high profile food safety problems, worldwide public and private initiatives aiming at traceability system implementation have come to the forefront. The European Union and Japan made cattle traceability a public good by imposing mandatory systems after a series of mad cow disease outbreaks. Important exporters like Australia have started national mandatory traceability systems as a means of maintaining or enhancing export market shares.

In the US, private voluntary traceability systems have been the most common practice. Three primary objectives have motivated firms in the US food sector to develop, implement, and maintain traceability systems (i) to differentiate market foods with credence attributes, (ii) to improve supply chain management, and (iii) to facilitate tracing back for food safety and quality (Golan et al., 2004). Thus, to improve food safety is only one of the reasons motivating firms to voluntarily adopt a traceability system. Regarding this, Hobbs (2004) identifies that a traceability system may be used to strengthen liability incentives (liability function). This article will focus specifically on the liability function of a traceability system in the context of food safety.

In order to understand the liability function of a traceability system, it makes necessary to stress the differences between traceability systems and procedures such as Pathogen Reduction[1] (PR) and Hazard Analysis and Critical Control Point[2] (HACCP). Unlike PR and HACCP approaches, a traceability system does not aim at direct interventions in

[1]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).

[2]Notermans et al. (1994: p. 204) defines 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.

procedures and processes to improve quality and safety controls. Even if changes in a production line are necessary, for example to limit raw material mixing (Antle 2001, p: 1103), the ultimate goal of a traceability system is to accumulate information about product attributes, including safety and origin, as the product moves through the supply chain (Starbird and Amanor-Boadu, 2006). Thus, the information stored in a food traceability system is not expected, by itself, to lead to an improvement in food safety. To influence food safety, this information must be used either to remove unsafe food that is already in the supply chain, or to prevent unsafe food from ever entering the supply chain. For instance, in the event of a food product recall[3], the information stored in a traceability system may be used to backward trace to uncover the source of the problem, and to forward trace to find all other products and instances that have the same undesired properties (Jansen-Vuller et al. 2003). Thus, a more rapid and precise withdrawal of dangerous food products from the supply chain can be performed, ultimately reducing the probability by which consumers are exposed to contaminated food product.

Since traceability creates the opportunity of determining responsibilities whenever a food crisis event occurs, the effectiveness of tort liability law as an incentive for firms may be improved (Hobbs 2004). Indeed, most opponents of mandatory introduction of traceability (e.g. a national animal identification system) mention increased liability as a primary concern (Souza-Monteiro and Caswell 2004; Golan et al. 2004).

A traceability system might be used in a food supply chain as one of the pieces of incentive mechanisms, connecting the reward and punishment of raw material suppliers with observed safety of the food. It would be expected that by making incentive mechanisms feasible to be implemented, a traceability system can indirectly change the probability by which a food product is safe for consumption by enticing agents to exert more food safety efforts. In other words, it is hypothesized that a traceability system might be voluntarily employed by food processors to prevent unsafe food from entering the supply chain by motivating raw material suppliers to produce and deliver safer food. In this context, one of the issues addressed in the present article is whether a more reliable traceability system could be taken by the final consumer as a signal that a safer food has been produced.

This article objective is to shed light on the following issues: What is the relationship between traceability reliability and food safety? Are contingent payments and the reliability of a traceability system substitutes or complements? How do penalties and costs of food safety crisis affect the level of efforts on food safety?

2. Background

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

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

[3]A food recall is a voluntary action by a manufacturer or distributor to protect the public from products that may cause health problems or possible death . Teratanavat and Hooker (2004) present a broad review of the characteristics and trends of US meat and poultry recalls between 1994 and 2002.

Along this same line of reasoning, Chalfant et al. (1999) argue that imperfect verification of quality may be mitigated by grading. However, incentives based on an imperfect grade will not be strong enough to induce producers to incur first-best investments in higher value product. The reason for this is that incentives to produce high quality raw material are lowered because grading a lower quality product as being of higher quality (type II error in grading) is a feasible event.

Bogetoft and Olesen (2003) also study the effect of using a noisy grading technology to infer producers' behaviors regarding investing in product quality. They show that the results obtained by Hennessy (1996) and Chalfant et al. (1999) hold only for a perfectly competitive market structure where trade occurs after grading (a posteriori competition) but does not necessarily hold for a competitive setting where all trade occurs before grading (a priori competition).

As examples of the second group of works, Dubois and Vukina (2004) adapt the closed form solution for a principal-agent (PA) model with linear contracts, normally distributed measurement errors and agents’ exponential utility to econometrically estimate farmers' degree of risk aversion in contracting production of hogs. Their results give empirical evidence that agents’ degree of risk aversion constrain the set of possible incentive mechanisms to be offered by the principal to agents as predicted by the PA model. Starbird (2005) examines the effect of inspection policies set by the principal on the efforts exerted by producers (agents) concerning product safety. His findings support the idea that inspection policies are effective tools for improving food safety. King, Backus and Gaag (2007) develop and apply a dynamic principal-agent model for salmonella control in pork production in the Netherlands. In their model the principal offers a contract to the agent specifying the frequency at which the agent's hogs will be tested on delivery, the share of the expected testing cost paid by producer, and the level of penalty per hog for a salmonella prevalence test that exceeds a tolerance level pre-defined by the principal. The main contribution of this article is to show that reputation-based contracts affect agents' behavior.

A common characteristic of all previous studies is that at the time a signal correlated with an agent's action is observed, the principal knows the agent's identity. This is certainly the case when raw material is tested on delivery. However, once the processing of the raw material starts, unobservable characteristics of the raw material on delivery might become observable, but by this time the identity of the raw material supplier is likely to have been separated from the processed product.

3. Conceptual Framework

In general terms, a traceability system is composed of a series of procedures by which the identification, preparation, collection, storage, and verification of data are performed. A system like this accumulates information about product attributes, including safety and origin, as the product moves through the supply chain (Starbird and Amonor-Boadu 2006).

Like any other information system, a traceability system is expected to fail with some frequency. Therefore, a traceability system investigated in the present article is fully characterized by its expected traceback rate of success in preserving information about the supplier’s identity attached to the final food product. Hence, the unique information maintained by this traceability system is the identity of the supplier of the raw material, which gives the traceability system's breadth[4]. This information should be kept attached to the food product along its processing and packing. In other words, the identity of raw material suppliers should remain attached to the food product from the delivery of the raw materials up until the final product is sold to final consumers. Therefore, every traceability

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

system's depth[5] in the present article is assumed to be from delivery of raw materials to the consumption of the final food product. Moreover, in the context of the present article a traceability system's precision[6] will be 100% whenever it properly works in keeping the identity of a raw material supplier attached to the final food product, and zero otherwise.

It is hypothesized that a food processor, retailer, or wholesaler (the principal or buyer) purchases raw materials from a group of homogeneous growers or supplier (the agents or suppliers) to run a one-time project. Notice that, if the buyer were sourcing from only one supplier, a traceability system as conceptualized in the present article would be useless. But, because the buyer sources from many homogeneous suppliers, he/she is not able to keep track of suppliers' identity along food processing without using a traceability system. Thus, this traceability system in place will make it possible for the principal to associate, with a certain probability of success, the safety of the final food product to the safety of the raw material delivered by a supplier. This makes it feasible, with some probability of success, either to punish or to reward a raw material supplier based on the observed safety of the final food product, even after a transaction has occurred.

Given the above context, the principal and each agent play a two-stage sequential game that will run as shown in Figure 1. The buyer is the first mover, choosing and committing to the payment scheme and the traceability system's traceback rate of success. These two pieces together fully characterizes an incentive mechanism or contract. In sequence, each agent will be the second mover, choosing and then exerting the level of food safety effort as the best response to the contract offered by the principal. Finally the feasible contingencies are observed and income transfers will be made based on them.

[Figure 1, Here]

It is recognized that food safety problems occur due to many different causes. Despite this, I assume that a traceability system will never pinpoint a raw material supplier as the cause of a food safety crisis if this is not the case. Further, I take into account only food safety problems that might be originated at farm level. In other words, I assume that the principal's level of effort has no effect on the safety of the final product (e.g. the chances of observing excessive concentration of growth hormone in meat and broken syringe needles from health treatments depend only on the effort exerted by growers).

4. Probabilities in the Model

The traceability system is assumed to fail with certain frequency. Thus, if the identity of the raw material supplier will remain attached to the final food product is a random event. In addition, the safety of a food product will be also a random event. This is because there are other factors, out of agents' control, influencing the safety of the raw material supplied by them (e.g. human mistakes and failures in machinery can occur even in a context in which high effort has been exerted on food safety). Given all this, for the setting in which a traceability system is in place and the effort exerted by suppliers are not observable (asymmetric information), the sample space is composed of a collection of 2-tuples formalized as: $E = \{(z_1, z_2): z_1 = 0 \text{ or } 1, z_2 = 0 \text{ or } 1\}$, where z_1 equals 1 if the traceability system works in tracing back the identity of a raw material supplier, otherwise 0; and z_2 equals 1 if the raw material supplied by an agent does not cause a food product lot to be unsafe for consumption, otherwise 0.

I denote the expected frequency by which the traceability system will properly trace back the identity of an input supplier by s. Finally, the probability, $F(z_2=1|a)$, that the raw

[5] Depth defines how far backward and forward traceability is maintained (Golan et al. 2004).

[6] Precision represents the system's ability to pinpoint the original source of a problem (Golan et al. 2004).

material supplied by an agent will not cause a food product lot to be unsafe for consumption, given the supplier has exerted the level of effort a, is represented as $F(a)$. Given those definitions, the probabilities of every feasible contingency in the asymmetric information setting with traceability are summarized in table 1.

[Table 1 - Here]

5. The Supplier's Objective Function

As one of the steps in setting an incentive mechanism, the buyer should determine contingent income transfers to be offered to each agent. In doing so, the buyer knows that there is no means of making transfers contingent on the safety of the food product whenever the agent's identity is lost during food processing. Hence, let I_0 be the income to be transferred to a supplier whenever the traceability system does not work, regardless of the safety of the food product lot (contingency 0). However, whenever the traceability system works it will be possible for the principal to make income transfers, as dollar per delivered lot, contingent on the safety of the final product. Thus, let I_1 stand for the income transfer to an agent whenever the traceability system works and no food safety problem is observed (contingency 1). In addition, let I_2 be the income transfer to the Agent whenever the traceability system works and at least one food safety problem associated with the raw material is observed (contingency 2). To sum up, there will be an income transfer (I_m) to a supplier in dollars per lot delivered in each contingency $m \in M$ with $M = \{0, 1, 2\}$ as shown in Table 1.

I assume that a supplier's preferences can be represented by a utility function whose arguments are the contingent transfer (I_m) and the level of effort (a) exerted by supplier. Following Holmstrom (1979), Tirole (1988), Goodhue (2000), and Starbird (2005), it is assumed additive separability between the utility of income and the disutility of effort by letting the agent's utility function U: $\Re^2 \rightarrow \Re$ be of the functional form given as:

$$(1) \quad U(I_m, a)=u(I_m)-d(a)$$

where $U(.)$ is a *von Neuman* Morgenstern utility function and $u(.)$ is a Bernoulli utility function as defined by Mas-Collel, Whinston and Green (1996: p. 184), $d(.)$ is a utility function for effort[7]. This type of *von Neuman Morgenstern* utility functional form imposes independence of agent's preferences over income lotteries and perfectly certain actions (Haubrich, 1994).

Given equation (1), a supplier's expected utility for a given incentive mechanism (s, I_0, I_1, I_2) and level of effort (a) is given as:

$$(2) \quad U(s, I_0, I_1, I_2, a)= (1-s)u(I_0)+sF(a)u(I_1)+s(1-F(a))u(I_2)-d(a)$$

where s denotes the traceability system's expected rate of success in tracing back the source of the raw material; $F(a)$ is a continuously differentiable cumulative density function (CDF) in an agent's effort with its first and second derivatives following $F_a>0$ and $F_{aa}<0$. These assumptions assure that the probability of a safe food product is increasing and that the marginal probability of a safe food product is decreasing both on agent's effort (see Tirole 1988: p.54).

6. The Supplier's Problem

To deal with the question on the relationship between traceability system reliability and the degree of food safety, it suffices to look at the problem faced by the supplier of raw material. In the sequence, the problem of the principal will be formalized and investigated

[7] See Grossman and Hart (1983) for technical details.

in order to deal with the effect of increased costs with food safety crisis on the level of food safety to be induced by the principal on agents.
The supplier of raw material or agent wants to maximize his/her expected utility, choosing the level of effort to be exerted, taking as given the incentive mechanism (s, I_0, I_1, I_2) set by the principal. Therefore, the agent's problem is formalized as (4):

$$(4)\quad \max_{a}\ (1-s)u(I_0)+sF(a)u(I_1)+s(1-F(a))u(I_2)-d(a)$$

The necessary condition for an interior solution to (4) is:

$$(5)\quad sF_a(u(I_1)-u(I_2))-d_a=0$$

Notice that if the reliability of the traceability system is zero, then the best response for a supplier is to exert the level of effort that makes $d_a=0$. In other words, if a traceability system is not in place, a supplier's best response is to exert the level of effort that implies the lowest disutility for him/her.

The sufficient condition for an interior solution to (4) is:

$$(6)\quad sF_{aa}(u(I_1)-u(I_2))-d_{aa}<0$$

Let's say that the principal will pay more for preferable contingences, which implies that $u(I_1)-u(I_2)>0$. Moreover, if $s\in(0,1]$, $F_{aa}<0$, and $d_{aa}>0$ the sufficient condition is automatically fulfilled.
Rearranging (5), an interior maximum is found to exist if:

$$(7)\quad sF_a(u(I_1)-u(I_2))= d_a$$

The left-hand side of (7) gives the marginal utility of food safety effort for a supplier. This supplier's marginal benefit stems from the reduction in the probability of a food safety crisis as long as more food safety effort is exerted. The right-hand side of (7) gives the marginal disutility coming with more effort being exerted by a supplier. In other words, at an optimum level of effort (a^*) the marginal benefit of effort should equal its marginal cost.

7. Traceability, Incentive Scheme and the Supply of Safe Food

I assume that the maximizer for the problem (4) is a continuously differentiable function of traceability system's reliability, and the income transfers in contingencies 0, 1 and 2, such that $a^*=f(s, I_0, I_1, I_2)$. Given this, how will the optimal level of effort chosen by the supplier of raw material change with respect to the arguments of $f(.)$?
First, what is the effect on a^* of a more reliable traceability system?
Taking the derivative of (5) at the point $a^*=f(s, I_0, I_1, I_2)$ with respect to s results that $F_a(u(I_1)-u(I_2))+sF_{aa}(\partial a^*/\partial s)(u(I_1)-u(I_2))-d_{aa}(\partial a^*/\partial s)=0$, which implies that:

$$(8)\quad \partial a^*/\partial s=- F_a(u(I_1)-u(I_2))/(sF_{aa}(u(I_1)-u(I_2))-d_{aa})$$

It is known from (6) that the denominator in the right-hand side of (8) is negative. This fact implies that $\partial a^*/\partial s>0$. In other words, a more reliable traceability system induces more effort by the raw material suppliers, everything else remaining constant.
Second, what is the effect on a^* if an incentive scheme offers higher income transfers for the contingency wherein the traceability system works and no food safety crisis is observed?
To answer this question, I take the derivative of (5) with respect to I_1 at the point $a^*=f(s, I_0, I_1, I_2)$, which gives $sF_a(\partial u(I_1)/\partial I_1)+sF_{aa}(\partial a^*/\partial I_1)(u(I_1)-u(I_2))-d_{aa}(\partial a^*/\partial I_1)=0$. Rearranging terms, the following result is obtained:

(9) $\partial a^*/\partial I_1 = -sF_a(\partial u(I_1)/\partial I_1)/(sF_{aa}(u(I_1)-u(I_2))-d_{aa})$

A supplier's Bernoulli utility function is strictly increasing in income so that $\partial u(I_1)/\partial I_1>0$. Also, from (6) it is known that the denominator of (9) is negative. Therefore, it must be true that $\partial a^*/\partial I_1>0$. In other words, if everything else remains constant, an increase in the income to be transferred to suppliers under the contingency wherein the traceability system works and no food safety crisis is observed will induce more food safety effort by a supplier.

Third, what is the effect on a^* of higher income transfers under the contingency in which the traceability system works and a food safety crisis caused by the raw material supplied is observed?

Taking the derivative of (5) at the point $a^*=f(s, I_0, I_1, I_2)$ with respect to I_2 results that $-sF_a(\partial u(I_1)/\partial I_2)+sF_{aa}(\partial a^*/\partial I_2)(u(I_1)-u(I_2))-d_{aa}(\partial a^*/\partial I_2)=0$. After rearranging terms, the following result shows up:

(10) $\partial a^*/\partial I_2 = sF_a(\partial u(I_2)/\partial I_2)/(sF_{aa}(u(I_1)-u(I_2))-d_{aa})$

Again, since $\partial u(I_2)/\partial I_2>0$ and the denominator of (10) is negative, it will be true that $\partial a^*/\partial I_2<0$. In other words, if everything else remains constant, a reduction in the income to be transferred to suppliers under the contingency wherein the traceability system works and a food safety crisis is observed will induce more food safety effort by a supplier.

Summing up, $\partial a^*/\partial s>0$, $\partial a^*/\partial I_1>0$, $\partial a^*/\partial I_2<0$. Based on these results, higher income transfers under the contingency in which the traceability system works and no food safety crisis caused by the raw material supplied is observed (I_1) and lower income transfers under the contingency in which the traceability system works and a food safety crisis caused by the raw material supplied is observed (I_2) are substitutes one to each other and also to higher traceability system reliability (s). Despite this, it is important to mention that there would not be any incentive for exerting food safety effort to raw material suppliers if either s were set equal to zero or if I_1 were made equal to I_2. In this sense, s, I_1 and I_2 are in some degree complements too.

The role played by I_0 is to make $(1-s)u(I_0)+sF(a^*)u(I_1)+s(1-F(a^*))u(I_2)-d(a^*)>\underline{U}$. Where $\underline{U}$ denotes the reservation utility or the minimum expected utility a contract must offer to a supplier to assure that this same agent will accept the contract offered by the buyer. In other words, I_0 must be higher enough to assure that an interior solution ($a^*>0$) is feasible, otherwise the supplier will exert the lowest level of food safety effort available to him/her.

Despite the fact that $\partial a^*/\partial s>0$, which indicates that the more reliable a traceability system is the higher the food safety effort exerted by suppliers will be, it is wrong to infer the safety of a food product based on the reliability of a buyer's traceability system. This is because an incentive mechanism based on a traceability system with high reliability but that offers I_1 and I_2 such that $(u(I_1)-u(I_2))$ is low might be inducing low efforts by suppliers. In other words, a buyer could be inducing the same level of food safety efforts on suppliers by using a very reliable traceability system combined with low difference between I_1 and I_2. Putting another way, higher values for (I_1-I_2) might do the same job as making s closer to one.

7.1. A Numerical Illustration

To illustrate a supplier's best response as given by formula (7), let the Bernoulli utility function for a supplier be CRRA (Constant Relative Risk Aversion) with the coefficient of relative risk aversion very close to zero so that $u(I_m)=\ln(I_m)$. Assume that the probability of no food safety crisis caused by the raw material supplied by a supplier is given as $F(a)=0.5a^{1/2}$ with $a\in[0,4]$, and the disutility of effort is given as $d(a)=0.5a^2$. Parameterizing (4) with these functions and values results that the optimal food safety effort to be exerted by a supplier is given as $a^*=(s\ln(I_1/I_2)/2)^{2/3}$ which complies with $\boldsymbol{\partial a^*/\partial s>0}$, $\boldsymbol{\partial a^*/\partial I_1>0}$,

$\partial a^*/\partial I_2 < 0$. For instance, the case in which I_1=15, I_2=0.1, s=0.8 which implies $a^* \approx 1$ is illustrated with Figure 2.

[Figure 2 - Here]

8. Investigating the Effect of Penalties and Costs of Food Safety Crisis on Food Safety Efforts

I will star with the first-best or symmetric information setting characterized by agents' actions being freely verifiable by the principal. As discussed before, the principal should set a payment scheme such that each agent will want to exert the effort level chosen by the principal. Hence, the First-Best program is formalized as program (11).

(11a) $\min_{a,I} I+(1-F(a))r_e$

Subject to:
(11b) $u(I)-d(a) \geq \underline{U}$

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; $(1-F(a))r_e$ is the measure of the negative externality an agent can cause on the principal; Finally, $\underline{U}$ denotes the reservation utility or the minimum utility a contract must offer to an agent to assure that an agent will accept the contract (participation constraint).
Given a level of effort, for instance the first-best level of food safety effort (a_{FB}), the principal's cost will increase with higher income transfers. Thus, it must be true that any income transfer greater than I_{FB} will result in higher costs to the principal. As a consequence of this, the participation constraint (11b) has to bind in an optimal solution for (11), which implies that:

(12) $I_{FB}=v(\underline{U}+d(a_{FB}))$

where $v(.)$ denotes the inverse of the Bernoulli utility function $u(.)$.
By plugging (12) into (11a) and solving the unconstrained minimization problem for a_{FB}, results that the first order condition will be given as:

(13) $\partial v(\underline{U}+d(a_{FB}))/\partial(\underline{U}+d(a_{FB}))\ \partial d(a_{FB})/\partial a_{FB} - r_e \partial F(a_{FB})/\partial a_{FB}=0$

Notice that the first-best level of effort is a function of r_e, $a_{FB}=a_{FB}(r_e)$. Taking the derivative of equation (13) with respect to r_e gives that:

(14) $\partial a_{FB}/\partial r_e=F_a/(v^2(.))/\partial(\underline{U}+d(a_{FB}))^2+\partial v(.))/\partial(\underline{U}+d(a_{FB}))\partial^2 d(a_{FB})/\partial(a_{FB})^2-F_{aa}r_e)>0$

Since $v'(.)>0$, $v''(.)>0$, $d''(.)>0$, $F_a>0$, and $F_{aa}<0$, then it is possible to see from (14) that increased external cost of a food safety crisis will induce a buyer to contract higher level of effort under the first-best setting. Of course, this result holds assuming that an interior solution will still hold. In fact, if the cost of a food safety crisis becomes too high, a buyer could be better off producing nothing or even leaving the industry.

8.1. The Model for the Asymmetric Information Setting with Traceability

Having previously defined all the elements necessary to set the up the asymmetric information setting with traceability I will now set the principal-agent model with traceability as a mathematical programming problem.

The principal wants to minimize his/her expected cost incurred with the payment of raw material suppliers, with the costs of a traceability system and with the costs of a food safety crisis. In doing so, the principal chooses and offers to agents a contract (s, I_0, I_1, I_2) such that it will be in an agent's best interest to accept the contract and to exert an action a. Ultimately, the principal-agent problem can be formalized as the program (15).

(15a) $\min_{a,s\in[0,1],I_0,I_1,I_2} (1\text{-}s)I_0+sF(a)I_1+s(1\text{-}F(a))I_2+(1\text{-}F(a))r_e+g(s)$

Subject to:

(15b) $(1\text{-}s)u(I_0)+sF(a)u(I_1)+s(1\text{-}F(a))u(I_2)\text{-}d(a) \geq \underline{U}$

(15c) $sF_a(u(I_1)\text{-}u(I_2))\text{-}d_a=0$ (see Equation (7))

where $g(.)$ denotes the cost of tracing a lot of raw material as a strictly increasing, continuously differentiable and convex function in s. All other terms have previously been defined.

The first term in (15a) gives the expected cost of income transfers to a supplier (agent) per lot of food product or raw material whenever the food product is safe and the traceability system does not work. Without loss of generality I am assuming the one lot of raw material is necessary and sufficient to produce one lot of food product. The second term in (15a) stands for the expected cost of income transfers whenever a food safety crisis happens and the traceability system does not work. The third term in (15a) gives the expected cost of income transfers whenever the food product lot is safe and the traceability system works. The fourth term in (15a) gives the expected cost of a food safety crisis to the principal. Finally, the participation constraint is set as (15b) and the incentive compatibility constraint is given by (15c).

Analytically solving program (15) is very complex. Therefore, I leave the principal-agent model set to indicate what future works could be dealing with this in order to answer, in more general terms, how "penalties and costs of food safety crisis" will affect the level of food safety to be chosen by the principal to induce agents to exert.

9. Results

This article formalizes the problem of inducing food safety efforts on suppliers of raw material in a context of information asymmetry. It is hypothesized that by making it possible to pass the cost of unsafe food to the source with some chance of success, a traceability system will motivate raw material suppliers to deliver safer inputs to a food processor.

A principal-agent model is conceptually developed under the assumption that a buyer sources from many homogeneous suppliers in an information asymmetric word. Therefore, I first explore the supplier's problem by deriving his/her best response function. Using the best response function, it is investigated the relationship between traceability reliability and food safety and the complementarity and substitutability between contingent payments and the reliability of a traceability system. I found substitutability among higher income transfers under the contingency in which the traceability system works and no food safety crisis caused by the raw material supplied is observed, lower income transfers under the contingency in which the traceability system works and a food safety crisis caused by the raw material supplied is observed, and higher traceability system reliability. Despite this, it is important to mention that there would not be any feasible incentive scheme if a traceability system either is not in place or never works. This feature gives the complementarity between contingent payments and traceability system's reliability. It is defended that it is not reasonable to infer the safety of a food product on the basis of the reliability of a buyer's traceability system. This is because contingent payments properly set can do the same job as a very reliable traceability system.

Finally, I investigate how penalties and costs of food safety crisis are important to make buyer to demand from suppliers high levels of food safety efforts. At least under the symmetric information setting, it has been found that increased external cost of a food safety crisis will induce a buyer to contract higher food safety level of effort. This same investigation under the asymmetric information setting was properly formalized but left for a future work.

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Figures

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

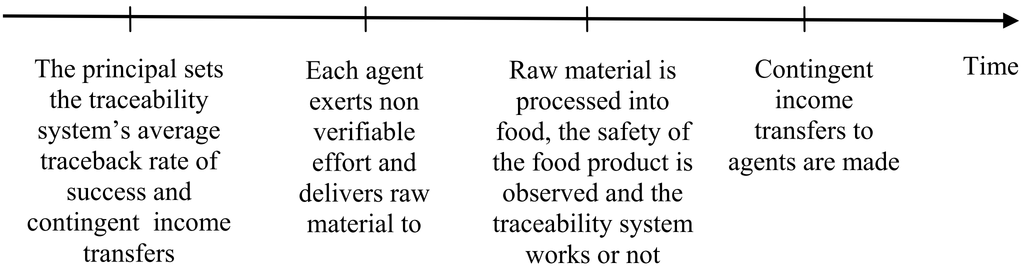

Figure 2. An illustration of the marginal utility function ($sF_a(u(I_1)-u(I_2))$) and marginal disutility function of food safety efforts (d_a) for the case wherein I_1=15, I_2=0.1, s=0.8, $u(I_m)=\ln(I_m)$, $F(a)=0.5a^{1/2}$ with $a\in[0,4]$ and $d(a)=0.5a^2$.

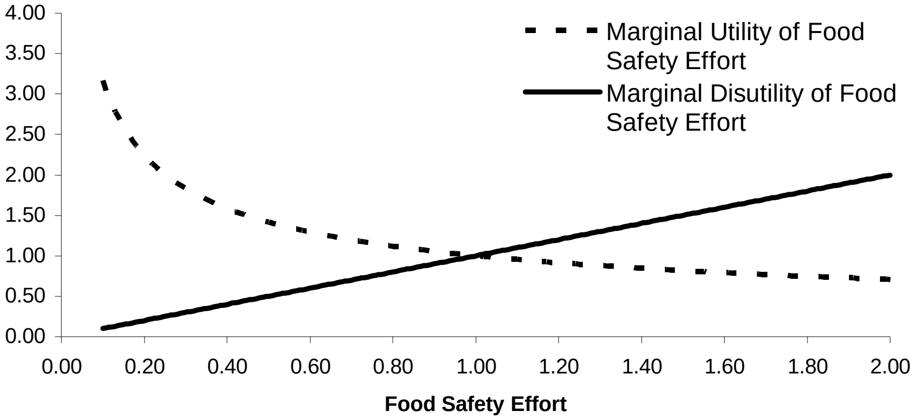

Table 1. Summary of Probabilities and Income Transfers in the Models

Event	Symmetric Information Setting	Asymmetric Information Setting with a Traceability System in Place			
		Traceability Works		Traceability does not Work	
	Probability	Probability	Income Transfer	Probability	Income Transfer
The raw material supplied by the agent does not cause any food product lot to be unsafe for consumption	$F(a)$	$F(a)s$	I_1	$(1-s)F(a)$	I_0
At least one lot of food product is found as unsafe for consumption due to problems originated from the raw material supplied by an agent	$(1-F(a))$	$(1-F(a))s$	I_2	$(1-s)(1-F(a))$	I_0

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