Optimal choice of Voluntary traceability as a food risk management tool

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Abstract— **Traceability systems are information tools implemented within and between firms in food chains to improve logistics and transparency or to reduce total food safety damage costs. Information about location and condition of products is critical when food safety incidents arise. This paper uses a principal-agent model to investigate the optimal choice of voluntary traceability in terms of precision of information on a given attribute at each link of a food chain. The results suggest that four scenarios may emerge for the supply chain depending on the costs of a system and whether or not the industry can internalize total food safety damages: no traceability, traceability for one link, equal traceability for all links, or different positive traceability levels across all links.**

Keywords— **Traceability, food safety, principal-agent model**

I. INTRODUCTION

Traceability systems were first and voluntarily introduced in food supply chains in the late 1980s when the international traceability standard NF EN ISO 8402 was issued [1]. Initially traceability was conceived as part of a quality assurance system and intended to facilitate effective information management. Traceability can also be envisioned as a food safety risk management tool [2], as it can record information on attributes of a product and may establish a relation between inputs and outputs, different agents in the food chain, and events in production processes. A critical issue is the appropriate level of information in traceability, who determines it, and who governs it.

This paper investigates optimal levels of traceability at different stages of food chains as endogenous choices. Previous literature has analyzed how exogenous levels of traceability impact liability and incentives for food quality and safety [3], incentives for anonymity [4], inspection policies [5], or total costs of a food recall [6].

Traceability is but one of many tools firms have to manage food safety. In its essence a traceability system is merely an information management tool and is only useful if data therein is relevant, reliable, and readily accessible. To develop and implement traceability requires leadership and coordination among partners in a supply chain. Special types of governance structures may have to be created to assure that the level of traceability provided by each firm corresponds to the optimal level of traceability for the whole supply chain. Failure to coordinate the amount of information in traceability systems may lead to disruptions and impede an effective response to a food safety incident.

Traceability systems can potentially be used as a tool to prevent food safety incidents (i.e., as an ex-ante food safety system). In practice, most systems only react to an existing occurrence and thus are ex-post means of mitigating the total potential damages of an accidental or intentional safety failure. This paper provides insight into the impact of traceability by analysing the choice of traceable information through a principal-agent model.

The paper is organized as follows: the next section reviews previous work on traceability systems and voluntary and mandatory approaches to the mitigation of food safety risks. The following section models the choice of traceability. The fourth section analysis and discusses the model. The final section concludes and suggests future research.

II. TRACEABILITY AND FOOD SAFETY

Information is a key element of competitiveness in food markets; it is also an element of food quality and its availability is vital to manage food crises. However information is an elusive concept, it must be related to something (for example, an attribute of a product, a production process, or a cost). Moreover it must be defined, it has to be identified, collected, analyzed and communicated if it is to have any impact. A number of tools (for example the internet) enable easy and almost instantaneous assess to all sorts of information, yet vital pieces of information may not be freely accessible. This includes information on safety attributes of foods such as the level of pathogens in milk entering a cheese manufacturing plant or the type of pesticides used to spray a vegetable crop.

Traceability systems are information management tools with a particular feature: they enable the identification of the path of a product along each stage of the supply chain [7],[8]. In recent years a number of studies analysed the supply and demand for traceability in food and feedstuffs. Golan *et al*. (2004) studied food traceability systems in the US, developing a framework to analyse whether existing systems deliver an efficient level of traceability and how a regulator may induce the socially optimum level [8]. They classify systems in terms of depth (how far back or forward the system tracks relevant information), breadth (how much information is available) and precision (the detail and accuracy of the information). Golan *et al.* (2004) found that each industry had a different efficient level of traceability. However, they could not assure that the system in place provided the socially optimal level of traceability in terms of quick response to food safety hazards. This paper draws on the framework proposed by Golan's *et al.* (2004) to classify traceability systems proposing a model for the choice of traceability in terms of depth and precision.

In a recent paper, Starbird and Amanor-Boadu (2007) propose a principal-agent model where traceability is an exogenous variable impacting the nature of contractual relations between agents in the supply chain [9]. More specifically a monopsonistic buyer, with imperfect information on its input safety levels, has to design a set of contracts for its heterogeneous potential suppliers. The contracts offer a bid price related to the contamination rate of food. Traceability is an exogenous factor that decreases the levels of information asymmetry and permits a shift of the costs of food safety damages to the source of contamination [9]. This paper relates to our approach in that it uses agency theory to model the governance of a food chain. However, rather than using traceability as a parameter we model it as an endogenous variable.

Pouliot and Sumner (2008) investigate traceability in the context of food safety [3]. They offer a stylized model of a supply chain composed of farmers, marketers and consumers, where traceability is not a choice variable but is linked to food safety and liability as it enables the identification of the source of system failures and improves liability attribution [3]. They conclude that when traceability is not available firms are anonymous and may free-ride on the producers of safer food. This work proposes a formal model of the supply of safe food by different players in a supply chain. In [3] the model treats traceability as an exogenous probability of identifying a source. Overall, previous research on the economics of food traceability has not analyzed the choice of optimal traceability levels by firms and/or regulators in food chains.

III. MODELLING VOLUNTARY ADOPTION OF TRACEABILITY

Traceability can be defined as a flow of information on product attributes and processes between players in a supply chain. One must distinguish a traceability system from traceable information; the former refers to the process and structure (for example computer hardware and software) through which information is shared along links between firms in a food chain. Traceable information is what is flowing through these links. Different factors determine the level of complexity of a traceability system: the number of existing nodes and links, traceability levels, traceable units, and the governance structures.

Following [8], we define traceable information in three dimensions: depth (the number of links for which it is available), breadth (the number of attributes covered), and precision (the detail and accuracy of the information). Denote γ_{ij} as the level of precise traceable information for attribute j on link i. Assume that precision varies between zero and one, the later being maximum precision. For example, a traceability system for pork may track information on Salmonella and E. coli ($j=2$), between farms, feedlots, slaughterhouses, and retailers (3 links, i=3), with a level of precision such that each cut of meat can be traced to an individual animal.

Consider the development of a voluntary traceability system for a food supply chain where three representative firms are linked vertically. Further suppose this stylized supply chain represents an entire industry, composed of farmers, processors and distributors. Following [10] and [11], retailers are supply chain leaders in the provision of food safety. We present a model in which a downstream principal (the retailer) defines the level of traceability each agent upstream in the chain will have to provide. An appropriate framework to analyse the design of voluntary or private traceability systems (and mandatory or regulatory systems, as well) is the principal-agent model.

A. Model

Suppose a monopsonist retailer aims to design a voluntary traceability system requiring its suppliers to provide a traceability level to mitigate *ex post* food safety damage costs. Assume further that only one of the product's attribute is traceable (say origin), thus it is not necessary to use the subscript (j) identifying the attribute. Both the principal (the retailer) and the agents (the farmer and the processor) are risk neutral. The problem of the decision maker is to induce the optimal level of traceability from each link in the food chain (γ_1 from farm to processor and γ_2 from processor to retailer). Figure 1 shows a representation of the supply chain. Where the dash arrows denote product flow and bold ones the information flow. Assume that if traceability is implemented information can flow up and downstream at the same cost, allowing the identification of origin and destiny of products to which it relates. Only the farm and processing plant provide information to the system. The retailer demands traceability to mitigate safety risks.

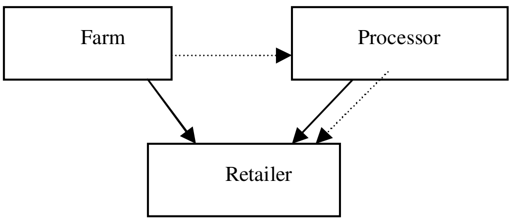

Figure 1: A stylized food chain traceability system

The retailer has perfect insight into the costs and actions of agents and contracts the levels of traceability from the farm or the processor independently. The task of the retailer is to design the least costly compensation scheme (b_i (i=1, 2)) to induce the farmer and the processor to provide a level of traceability (γ_i) that decreases the total damages (D) caused by a food contaminant (e.g., Salmonella), occurring with exogenous probability (ψ). The total damage cost of a food incident is a decreasing and convex function of upstream traceability levels. The subscript i is used throughout to identify the link between the farmer and the processor (i=1) or between the processor and the retailer (i=2). Assume that as precision decreases to zero, information becomes useless, i.e., when γ_i=0 there is no traceability. The problem of the retailer is to minimize its total expected costs (E[TCr]) written as:

$$\begin{aligned}
\underset{\gamma_1,\gamma_2\in[0,1];b_1(\cdot),b_2(\cdot)\geq 0}{E[TC^r]} &= \psi D(\bar{\gamma}_1,\bar{\gamma}_2)+\sum_{i=1}^{2} b_i(D(\bar{\gamma}_1,\bar{\gamma}_2)) \\
\text{s.t.:} & \; b_1(D(\bar{\gamma}_1,\bar{\gamma}_2))-c_1(\bar{\gamma}_1)\geq 0 \\
& \; b_2(D(\bar{\gamma}_1,\bar{\gamma}_2))-c_2(\bar{\gamma}_2)\geq 0 \qquad (1)\\
& \; b_1(D(\bar{\gamma}_1,\bar{\gamma}_2))-c_1(\bar{\gamma}_1)\geq b_1(D(\gamma_1,\gamma_2))-c_1(\gamma_1), \forall\gamma_1\in[0,1] \\
& \; b_2(D(\bar{\gamma}_1,\bar{\gamma}_2))-c_2(\bar{\gamma}_2)\geq b_2(D(\gamma_1,\gamma_2))-c_2(\gamma_2), \forall\gamma_2\in[0,1]
\end{aligned}$$

Where c_i*(*i=1,2*)* are the increasing and convex costs of traceability incurred by farmer and retailer. The first two constraints are the individual rationality or participation constraints: the farmer and processor accept a contract to provide traceability insofar as its payoff is it least as large as their respective reservation utilities, assumed to be zero. The third and fourth inequalities are the incentive compatibility constraints; they guarantee that both farmer and processor offer the level of traceability required by the retailer to minimize its total costs.

The retailer is better off the larger the savings from the compensation paid for having traceability. The participation constraints are binding as the principal has no motive to offer more compensation than is necessary for the agents to accept a contract. Focusing for now on the conditions to accept a contract and recalling the assumption of full information, we substitute the individual rationality constraints into the objective function in (1) to yield:

$$\underset{\gamma_1,\gamma_2\in[0,1]}{\mathrm{E}[\mathrm{TC}^r]} = \psi\, D(\overline{\gamma}_1, \overline{\gamma}_2) + c_1(\overline{\gamma}_1) + c_2(\overline{\gamma}_2) \qquad (2)$$

Differentiating with respect to γ_1 and γ_2 the retailer determines the optimal levels of traceability required from the farmer and processor.

$$\begin{cases} \dfrac{\partial E[TC]}{\partial \gamma_1} = 0 \Rightarrow D_{\gamma_1}(\bullet) = -c_1'(\bullet)/\psi \\ \dfrac{\partial E[TC]}{\partial \gamma_2} = 0 \Rightarrow D_{\gamma_2}(\bullet) = -c_1'(\bullet)/\psi \end{cases} \qquad (3)$$

Where D_{yi} is the partial first derivative of the damage function with respect to the traceability level of agent i, and c_i' denotes the marginal costs of traceability. Given the assumptions on food safety damage costs and traceability cost functions, the determinant of the Hessian matrix below is positive and therefore the sufficient condition is met:

$$H = \begin{bmatrix} \psi D_{\gamma_1\gamma_1}(\bullet) + c_1''(\bullet) & \psi D_{\gamma_1\gamma_2}(\bullet) \\ \psi D_{\gamma_1\gamma_2}(\bullet) & \psi D_{\gamma_2\gamma_2}(\bullet) + c_1''(\bullet) \end{bmatrix} \qquad (4)$$

By the implicit function theorem, the system of equations (3) defines the optimal levels of voluntary traceability required from the farmer and the processor. These are found where the marginal reduction of expected *ex post* food safety damages from traceability equals the marginal cost level.

Denote the optimal levels of traceability by y_i^* and the corresponding expected damages as $D^* = \psi D(y_1^*, y_2^*)$. The retailer must design a compensation scheme that guarantees the provision of these optimal levels of traceability by upstream agents. From the incentive compatibility constraints, we know that both farmer and processor will choose y_i^* if and only if it provides them more utility than they receive choosing any alternative traceability level. The payment scheme below is sufficient to assure both participation and that the optimal level of traceability requested by the retailer is chosen by both farmer and processor:

$$b_i(D^*) = \begin{cases} c_i(\gamma_i^*) & \text{if } \gamma_i = \gamma_i^* \\ 0 & \text{otherwise} \end{cases} \quad (\mathrm{i}=1,2) \qquad (5)$$

We note that there are many other alternative payment schemes, for example one with the residual claimancy solution, where the principal would assume a fixed amount of the damages and shift the remaining part upstream. This was the payment suggested in [9] though in a slightly different context.

IV. RESULTS AND DISCUSSION

A number of cases emerge when determining which level of traceability each agent upstream has to provide. We follow a benefit-cost analysis framework. Traceability will not be imposed if its costs are larger than the benefits from damage mitigation. Traceability is feasible if benefits outweigh costs for at least one link in the supply chain. Before proceeding with a detailed analysis, figure 2 provides initial intuition on the determinants of the decision. The figure is constructed fixing the level of traceability from the processor and focusing on the choice of voluntary traceability from the farm. Furthermore we assume a linear traceability and convex food safety damage functions. Since the objective of the principal downstream is to design a traceability system that reduces totals costs, if these are larger than the expected reduction of private damages the principal is better off without traceability.

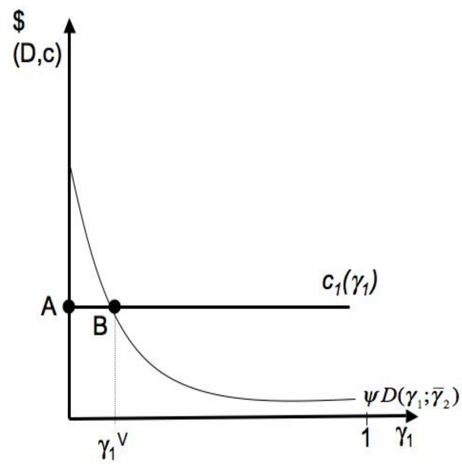

Figure 2: Illustration of the choice of the optimal levels of traceability

The analysis is further complicated when one considers other links in the supply chain. The more links involved and attributes that are traced, the more complex is the decision. Should the traceability level be the same regardless of the link or attribute to which it refers? Table 1 compares four different cases and provides insight into this question. The results are based on the first order conditions of the voluntary model of traceability.

Table 1: Cases of voluntary traceability

	Farm to Processor	Processor to Retailer
Case 1	$\psi D_{\gamma_1} < -c_1'$	$\psi D_{\gamma_2} < -c_2'$
Case 2	$\psi D_{\gamma_1} < -c_1'$	$\psi D_{\gamma_2} \geq -c_2'$
Case 3[§]	$\psi D_{\gamma_1} \geq -c_1'$	$\psi D_{\gamma_2} \geq -c_2'$
Case 4[§§]	$\psi D_{\gamma_1} \geq -c_1'$	$\psi D_{\gamma_2} \geq -c_2'$

[§] The levels of traceability will be positive and equal across links when marginal damage mitigation and cost of traceability are equal across links
[§§] The levels of traceability will be positive but different across links when both the marginal damages and costs are different across links.

Case 1 results in no traceability. It is based on analysis of the Kuhn-Tucker conditions and corresponds to the corner solution scenario in figure 1. In the voluntary case, if the marginal impact of extra levels of traceability in terms of expected damage mitigation is smaller than the marginal costs, then a rational principal should not implement traceability. For example, this could be the case where more detailed information on the presence of a contaminant does not contribute to the reduction of the food safety damages it causes.

In case 2, traceability is feasible for one of the links in the supply chain. This is the link for which the marginal costs of traceability equal the marginal partial expected damage mitigation costs. Suppose this is the link between the processor and the retailer. In this situation, the marginal costs of traceability for the farmer are larger than its marginal effect on the mitigation of expected food safety damages and it is not worth having traceability on this link.

In case 3, traceability is feasible at every link of the supply chain and the same levels of traceability emerge. This presumes that information is equally important, as it has the same costs and contributes in the same manner to the mitigation of damage costs, regardless of the link to which it refers. An example is traceability for a contaminant that persists along the supply chain (say a chemical component of food) and cannot be removed; the only way to assure its absence is by detecting it and keeping a record throughout the supply chain.

Finally, case 4 is perhaps the most realistic. It illustrates the case of a voluntary system that traces information for every link in the chain, but with differences in levels of traceability across links. For instance in beef supply chains each head of cattle may be traced from the feedlot to the slaughter house. In the next link, as animals are processed into beef cuts, precise traceability by the head may be replaced with lot traceability.

V. CONCLUSIONS AND FUTURE RESEARCH

This paper investigates the choice of voluntary traceability by firms in a food chain using a principal-agent model. The principal is the downstream retailer that designs two independent contracts for traceability from a farm and a processor upstream. Traceability reduces *ex post* damages of a food safety incident. Our results suggest that four cases may emerge. First no traceability will emerge if its marginal costs are larger than the benefits to the retailer. Partial traceability occurs when only one link of the chain is chosen to be traceable, i.e., only in one link are the marginal costs of traceability equal to the marginal benefits to the retailer. Third the same level of traceability will occur at each link of the food chain if the marginal costs of traceability and the partial marginal benefits are the same to each link of the chain. Finally, there will be different levels of traceability in each link if the marginal costs and partial marginal benefits are different for each upstream agent.

Understanding the conditions under which voluntary traceability will develop is important to companies and government agencies in making decisions on managing food safety risks. Traceability requirements by retailers and other downstream participants in food supply chains may be resisted by some suppliers as overly burdensome. In other cases, governmental authorities may conclude that private incentives to institute traceability are inadequate, for example where damages in the case of food safety failures do not fall fully on responsible companies. Future research focusing on *ex post* analysis of the development of voluntary traceability systems and on the *ex ante* conditions under which governments intervene to mandate traceability will lead to a better understanding of the economics of its adoption.

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REFERENCES

1. Gencod EAN France. 2001. Traceability in the Supply Chain From Strategy to Practice, April.
2. Standing Committee on the Food Chain and Animal Health (2004) Guidance on the Implementation of Articles 11, 12, 16, 17, 18, 19 and 20 of Regulation (EC) N° 178/2002 on General Food Law: Conclusions. at http://ec.europa.eu/food/food/foodlaw/guidance/guidance_rev_7_en.pdf
3. Pouliot S, Sumner D (2008) Traceability, Liability, and Incentives for Food Safety and Quality. Amer. J. Agr. Econ 90(1):15-27
4. Amanor-Boadu V, Starbird S A (2005) In Search of Anonymity in Supply Chains. Journal of Chain and Network Sciences 5:5-16.
5. Starbird S A, Amanor-Boadu V (2005) Do Inspection and Traceability Provide Incentives for Food Safety? Journal of Agricultural and Resource Economics 31:14-26
6. Resende-Filho M A, Buhr B L "A Principal-Agent Model for Evaluating the Economic Value of a Traceability System: A Case Study with Injection-site Lesion Control in Fed Cattle" Amer. J. Agr. Econ. Forthcoming
7. European Parliament and of the Council (2002) Regulation (EC) No 178/2002, laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety. Official Journal of the European Communities, L 31: 1-24.
8. Golan E, Krissoff , Kuchler F, Nelson K, Price G, Calvin L (2004) Traceability in the U.S. Food Supply: Economic Theory and Industry Studies. Economic Research Service, U.S. Department of Agriculture, Agricultural Economic Report No. 830. March 2004.
9. Starbird S A, Amanor-Boadu, V (2007) Contract selectivity, Food Safety and Traceability. Journal of Agricultural & Food Industrial Organization 5(1) at http://www.bepress.com/jafio/vol5/iss1/art2
10. Henessy D A, Roosen J, Miranowski J A (2001) Leadership and the Provision of Safe Food. Amer. J. Agr. Econ. 83(4):862-874
11. Henson S J, Reardon T (2005) Private Agri-Food Standards: Implications for Food Policy and the Agri-Food System. Food Pol. 30(3): 241-253

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