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Traceability, Liability, and Incentives for Food Safety and Quality

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Abstract
Recent food scares such as the discoveries of Bovine Spongiform Encephalopathy and *E. coli*-contaminated spinach have heightened interest in food traceability. Here, we show how exogenous increases in food traceability create incentives for farms and marketing firms to supply safer food by increasing liability costs. We model a stylized marketing chain composed of farms, marketers and consumers. Unsafe food for consumers can be caused by either marketers or farms. We show that food safety declines with the number of farms and marketers and imperfect traceability from consumers to marketers dampens liability incentives to supply safer food by farms.

Key words: foodborne illness, food safety, liability, traceability.

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Recent food safety concerns and well-publicized food scares have heightened interest in traceability in the U.S. food supply chain. When the first U.S. case of Bovine Spongiform Encephalopathy (BSE or "mad cow disease") was discovered in Washington state, federal authorities suggested that "it might take weeks, even months, to track the origins of the diseased cow" (Clemetson and Simon 2003, p.1). With the cooperation of herd owners, livestock dealers and market operators as well as detailed record searches between United States and Canadian agencies, the authorities were able to trace the origin of the infected cow to Canada after one week, but herd mates were never fully traced.

The December 2003 case of BSE in Washington State highlighted the demand for traceability to regain consumer confidence after the discovery of a food safety problem. Following the BSE event, marketing firms urged more traceability to the farms, but U.S. farm organizations resisted, which would be consistent with an effort to avoid potential liability. In addition, in the case of highly contagious disease or when multiple related dangers are suspected, traceability is important to reduce risk of further damage.

The interest in increased traceability is not unique to the red meat industry. The *E. coli* outbreak from tainted spinach in September 2006 illustrates the problems with traceability for fresh products. The contaminated spinach was rapidly traced to Natural Selection Foods as the packer but the farm of origin could not be identified without extensive further investigation. By matching the genetic fingerprints of the *E. coli* strain that sickened at least 200 people to the *E. coli* strain found in cattle feces, investigators were able to trace the contaminated spinach to one of four farms in San Benito or Monterey County in California (Food and Drug Administration 2006). The outbreak triggered many lawsuits (Marler Clark 2007) and proposals by the industry to legislate

best management practices (Western Growers 2007). The production of spinach and the price paid to growers recovered to their 2005 levels within two months. However, the consumption of bagged spinach was still below the previous year level six months after the outbreak while the consumption of bunched spinach had rebounded (Calvin 2007).

Firms' motivations for traceability back to the farms of origin include: a) protecting or regaining the general reputation of a product, a firm, an industry, or a country; b) differentiating products by suppliers who provide traceability; c) guaranteeing product origin when origin is an attribute of interest to consumers or others; d) improving supply management by firms; e) monitoring and assuring production or processing methods; f) improving the effectiveness of product recalls after the discovery of a food safety or product quality problem. Traceability can also be motivated by protectionism, as it may increase the relative costs of imported goods when firms in the home country have lower costs for supplying traceability. The adoption of traceability can also be stimulated by governments to correct market failures (Golan *et al.* 2004).[1]

Another motivation for traceability, and the focus of this article, is the use of traceability to improve food safety. For instance, new traceability systems provide added information about suppliers that allows application of liability for food safety or other product quality problems. The resulting increase in liability creates incentives for firms to supply safer food.

Food traceability has received growing recognition by policy makers and firms in the food industry. The European Union recently adopted *regulation 178/2002* which

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[1] Benefits from enhancing the general reputation of food system may be distributed differentially across marketing firms and farms in a country. Marketing firms may have more to lose if they are more liable because they have "deep-pockets" or simply have more economic rents at sake. Local farms have more to gain from the public perception that locally-supplied food is safer.

specifies mandatory traceability requirements in the European food industry with the stated objective of improving the safety of food (European Union 2002). Profit driven examples of traceability initiatives in the United States include those for California cantaloupes (California Department of Food and Agriculture 2003) and U.S. beef (U.S. Department of Agriculture 2006).

Food traceability has also received growing attention in the economic literature. For example, Souza-Monteiro and Caswell (2005) analyze the network externalities associated with traceability for multi-ingredient products. In their recent ERS report, Golan *et al.* (2004) discuss traceability as a solution to selected market failures. They describe the development of traceability systems in three food sectors: fresh produce, grains and oilseeds, and cattle and beef. Dickinson and Bailey (2002) and Hobbs *et al.* (2005) estimate the willingness to pay for traceability using laboratory auction markets. They both find that consumers are willing to pay a small premium for traceability but that consumers are willing to pay more for traceability attached to other valuable attributes such as enhanced food safety.

Hobbs (2004), Golan *et al.* (2003) and Meuwissen *et al.* (2003) link food traceability to product liability. For Hobbs (2004), one role of traceability systems is to provide *ex post* information that facilitates the allocation of liability and creates incentives for firms to improve their food safety practices. However, Hobbs (2004) provides no explicit model of this relationship. Golan *et al.* (2003) also recognize that traceability can help to establish the extent of liability of a firm and potentially shift liability to others. Finally, Meuwissen *et al.* (2003) list issues related to insurance for product recalls and liability as one item on the economic agenda on traceability.

In this article we focus specifically on the implications of additional traceability in the context of liability for food safety problems. We do not assess the costs of traceability or compare traceability to other means of improving food safety. Thus, we have no indication about whether traceability is an efficient tool to improve food safety practices. We also do not model the decision of firms to implement traceability. The choice to adopt traceability is complex and requires information regarding the cost of traceability, the possibility of vertical integration and strategic behavior. Here, traceability is either set exogenously by private firms or mandated by government regulation. We model formally the linkage between traceability and food safety and establish the implications of an increase in traceability-liability for food safety. In this context, liability is defined as the responsibility to pay compensation for damages such as caused by foodborne illnesses. The capacity to trace the origin of food increases the possibility of legal remedy and compensation in the case of a food safety incident. We show explicitly the mechanism through which traceability systems create incentives for firms to supply safer food. Traceability also allows parties to more easily document that they are not responsible for harm.

A large body of literature compares the effectiveness of liability relative to regulation in maximizing social welfare (e.g. Shavell 1984; Kolstad, Ulen and Johnson 1990; Roe 2004; and Boyer and Porrini 2004). Unlike Roe (2004) who compares the use of regulation and alternative liability rules to prevent foodborne illness, we focus specifically on how private or market traceability enhancements affect food safety by making liability feasible.

We show how traceability can increase the supply of safe food by allocating liability in a two-stage marketing channel with homogeneous farms that sell raw material to homogeneous marketers who sell food to consumers. Firms are anonymous when traceability is not available hence the supply of safe food is characterized by a free-rider problem. We show how liability incentives are dampened for upstream firms such as farms because information may be imperfectly transmitted through the marketing chain.

Cost of Foodborne Illness and Liability

Foodborne illnesses have important economic impacts. The Council for Agricultural Science and Technology (1994) estimates that each year in the United States, a total of 6.5 million to 33 million foodborne illnesses result in more than 9,000 deaths. The Economic Research Service estimates that the annual medical cost, productivity losses, and costs of premature deaths in the United States due to seven major foodborne pathogens range from $6.6 billion to $37.1 billion in 1996 dollars (Buzby and Roberts 1997). The implication is that there is considerable scope for liability if even a small share of those costs of foodborne illnesses could be traced back to their origin and those responsible could be held liable.

A very small proportion of consumers seeks monetary compensation for damages related to foodborne illnesses. Buzby and Frenzen (1999) calculate, conservatively, that foodborne poisoning results in only 0.9 to 4.5 legal actions per million foodborne illnesses. The Buzby and Frenzen (1999) data do not capture class action suits and thus underestimate the number of legal action per foodborne illness. Also, the Buzby and Frenzen (1999) numbers do not include out-of-court settlements. Firms generally prefer

to settle product liability claims to avoid public exposure and to keep the compensation awarded undisclosed. Viscusi (1991) calculates that 95% of the product liability claims (for all products, not just food) that are not dropped before going to court are finally resolved by an out-of-court settlement. We can calculate a conservative estimate of the number of food safety liability claims per year in the United States from the numbers presented above. Assuming mid-range values of 20 million foodborne illnesses per year and 3 legal actions per million illnesses and using Viscusi's (1991) finding that only 5% of product liability claims go to court, we obtain an annual average of 1,200 liability claims related to foodborne illnesses per year - a non-negligible number considering that class action suits are not taken into account.

Buzby, Frenzen and Rasco (2001) study the use of product liability law for injuries attributed to microbially contaminated foods. Using a sample of 175 foodborne illness lawsuits resolved in court from 1987-97, the authors examine the incentive to provide safe food under the threat of lawsuits by consumers in case of food safety problems. They find that 31.4% of the cases resulted in some compensation paid by the firms to the consumers. Similarly, Viscusi (1991) finds that when a case does go to court, the plaintiff success rate in court is 37%. When the plaintiff was favored, Buzby, Frenzen and Rasco (2001) find that the compensations awarded range from $2,256 to $2,368,858 with a median of $25,560 (1998 dollars).

Liability has been difficult to establish when food safety problems have occurred. First, it is often hard to link foodborne illness to a specific product because there is rarely a sample of suspect food remaining to test for contamination. Second, even if the contaminated product is identified, it is often difficult to discover its origin because

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contamination can occur at several stages of a marketing chain. Public health officials have recently made progress on these problems. For instance, regulation now requires health service providers to report an increased number of illnesses to public health agencies and public health investigations have become more sophisticated (Clark 2000).

The lack of traceability is not only a problem for consumers, but also for food firms in a food supply chain; without traceability upstream, firms are not able to transfer liability to their suppliers if a problem occurs at earlier stages. Vertically integrated firms may not be able to use the "proximate cause" defense because they are responsible for more stages of the production process.[2] That is, a vertically integrated firm cannot claim that an incident is not foreseeable to avoid liability and is therefore responsible for damages that are sourced at upstream production stages.[3]

Despite the difficulties in bringing and winning a case, the actual compensation allocated in food safety litigation is non-negligible. For example, Clark (2000) declares: "I have, for instance, been *personally* involved in the past 6 years in almost 200 *lawsuits* involving food claims, have resolved upwards of a *thousand* claims, involving more than $200 million dollars (words emphasized in original)." The importance of foodborne illness costs stresses how traceability, by making liability more feasible, could lead to large potential monetary compensations to consumers. Also, increased traceability to

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[2] There are two types of causation in law: cause-in-fact and proximate cause. Cause-in-fact is determined using the "but-for" test. The plaintiff must prove that in the absence of an action by the injurer, there would have been no harm. In proximate cause, the foreseeability of an event determines the scope of liability. The court must determine if the harm resulting from an action was reasonably predictable (Diamond 1974, Golan *et al.* 2004).

[3] Although firms cannot use the proximate cause defense, they have incentives to acquire information about the quality of their input. By monitoring and testing the product of their suppliers, downstream firms can reject defective products and avoid liability claims related to the activities of their suppliers. Nevertheless, monitoring and testing is costly. As discussed by Hobbs and Kerr (1992), vertical coordination can lead to increased efficiency in monitoring and testing as firms gain information about their input to reduce their liability burden. We do not consider this explicitly in our model.

early stages of production can shift liability to upstream firms. Liability costs and potential loss of reputation associated with publicized lawsuits also create significant incentives for firms and farms to supply safer food, thus reducing the societal costs of foodborne illnesses.

Definition and Model Specification

For the purpose of our model, we define traceability simply as the ability to trace the history of a product's origin including the identity of the farms and the marketing firms along a supply chain. Golan *et al.* (2004) refers to this as the traceback of food rather than food traceability.[4] We must also define the applicable liability rule. Strict liability is usually the applicable legal rule in the food industry in the United States (Clark 2000; Food and Drug Administration 2000).[5] Strict liability means that the seller of a product that causes injury to a consumer is legally responsible even in the absence of *ex ante* knowledge by the seller of the product's hazard (Cooter 1991).

In the liability literature, authors generally assume full traceability and only two types of entities: sellers and consumers.[6] In order to capture vital features of the food system, we model a two-stage marketing chain. We consider that farms sell raw material to marketers (any firms that provide services between farms and consumers) who sell food to consumers. There are *M* identical risk neutral marketers who each buy raw material from many farms and sell to many consumers. There are *N* identical risk neutral

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[4] Golan *et al.* (2004) define traceability as "*recordkeeping systems designed to track the flow of product or product attributes through the production process or supply chain*".
[5] Product liability claims in some states also include negligence and breach of warranty but strict liability is the dominant legal doctrine (Viscusi 1991; Clark 2000). We do not explore the impacts of alternative liability rules or the joint use or liability and regulation. For more details on these topics in the food industry context see Roe (2004).
[6] For a review of the literature on economic theory of liability, see Cooter (1991), or Polinsky and Shavell (2000) or Shavell (2007).

farms who each sell to many marketers. The homogeneity of firms allows us to highlight some key relationships. Extensions can be derived that focus on heterogeneous firms and product differentiation but those issues are not addressed here.

In our model, food safety problems derive either from the marketers or the farms. To focus on farms and marketing firms, we leave aside food safety problems originating with consumers. This assumption is directly applicable to cases such as BSE or *E. coli* in vegetables. We assume that the probability of a food safety problem perceived by consumers is a decreasing function of the effort, or level of care, exerted independently by marketers and farms.[7] This allows us to write the probability of a negative food safety incident as a function of the efforts to supply safe food by the marketers and the farms. Let e_m be the effort to provide safe food by the marketers and let e_f be the effort to provide safe raw material by the farms.[8] Throughout the article, we refer to the effort variables indexed by *m* as the optimal effort by marketers. When referring to a single marketing firm, we use the subscript *i*. Similarly, when the effort of farms is indexed by *f*, we refer to the optimal effort by all farms and when indexed by *j,* we refer to a single farm. Denote by $P(e_m, e_f)$ the probability of an unsafe food incident.

For simplicity and ease of exposition, we assume that efforts by marketers and farms to control contamination are independent, i.e. $\partial^2 P(e_m, e_f)/\partial e_m \partial e_f = 0$. We write the probability of a food safety event at the consumer level as

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[7] By "the probability of a food safety problem", we mean the probability that food is unsafe. We may also refer to this as a food safety event.
[8] Generic effort variables or level of care variables are common in the liability literature (e.g. Diamond 1974; Shavell 1984; Klostad *et al.* 1990; and Roe 2004). The literature on quality and regulation also commonly use similar effort variables (e.g. Tirole 1988).

(1)
$$P\left(e_m, e_f\right) = G_m + G_f = \frac{1}{M}\sum_{i=1}^{M} g_m\left(e_i\right) + \frac{1}{N}\sum_{j=1}^{N} g_f\left(e_j\right),$$

where G_m is the average probability that food delivered to consumers by marketers is

unsafe and G_f is the average probability that raw material delivered to marketers by

farms is unsafe. We assume that $g_m' \equiv \partial g_m\left(e_i\right)/\partial e_i < 0$, $g_f' \equiv \partial g_f\left(e_j\right)/\partial e_j < 0$,

$g_m'' \equiv \partial^2 g_m\left(e_i\right)/\partial e_i^2 \geq 0$ and $g_f'' \equiv \partial^2 g_f\left(e_j\right)/\partial e_j^2 \geq 0$.[9] That is, the probabilities of an

event decrease at a non-increasing rate with the level of care such that the marginal effect

of additional effort decreases with respect to effort.

The assumption of independence contrasts with the seminal work of Brown

(1973) and the recent model by Roe (2004). These authors do not consider raw material

suppliers and marketers separately, but only many suppliers and many consumers.

Nonetheless, they assume that consumers and suppliers each may be sources of product

safety problems. Brown (1973) and Roe (2004) assume that behavior by the suppliers

and the consumers are not independent so that any negative act by the supplier may be

offset by a positive act by the consumer and vice versa. The assumption of independence

means that marketers and farms cannot offset the actions of the other player or that

marketing firms and farms are not integrated such that there are no arrangements specific

to the safety of raw material. Assuming that the effort variables are independent

simplifies the analysis substantially by allowing us to assign liability conveniently.

In our model, as in reality, traceability is imperfect such that it is not always

possible to identify the source of the contamination. We measure the degree of

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[9] This assumption of a decreasing occurrence of accident at a decreasing rate with respect to the level of care is standard (e.g. Shavell 1984; or Shavell 2007). See Roe (2004) for the effects of relaxing this assumption on the choice of food safety supply or Brown (1973) for a discussion.

traceability as the probability of identifying the specific farm or marketer that is the source of contamination. Let $T_m \in [0,1]$ be the degree of traceability from the consumers to the marketers and let $T_f \in [0,1]$ be the degree of traceability from the marketers to the farms.[10] That is, T_m measures the probability that a food product is traced to a specific marketer and T_f measures the probability that raw material is traced from a marketer to a specific farm. We assume that the degrees of traceability to the marketers and to the farms are independent of each other. Thus, the probability that a product is traceable from the consumer to a farm is $T_m T_f$. We assume that the degrees of T_m and T_f are exogenous, independent of the number of marketing firms and farms and may be adjusted separately.[11] We will see later that even though these variables are independent, they do jointly affect the incentives for firms to supply safer food.

A change in the degree of traceability could, for example, be imposed by government policy or a change in the degree of traceability could be induced by a change in technology. For example, improved traceability of fresh spinach to the farms can be achieved by cleaning, packing and labeling the produce of each farm in separate batches. Even a higher degree of traceability would be achieved by field bagging each bunch of spinach and maintaining the identity of the produce through the retail product display. Smart tags such as radio frequency identification tags are more expensive but considered more reliable for improving traceability. In each case, a higher degree of traceability would be achieved when more care is devoted to assure that fewer mistakes are made.

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[10] In practice, even if no traceability technology is in place, minimum positive degrees of traceability may exist. We simplify by normalizing this minimum degree of traceability to zero.
[11] A model with endogenous traceability and number of firms would notably incorporate the causal relationship among the degrees of traceability and the numbers of firms.

We assume that full compensation is available when the source of contamination is identified. We do not consider cases where the firms are not able to compensate the consumers in case of an event. Shavell (1984) studies the effect of inefficiencies such as the possibility that parties would not be able to pay fully for harm done because of limited assets. Instead, we consider that, as in reality, marketers and farms may contract liability insurance (Clark 2000; Holland 2007).[12] Under this interpretation, we suppose that insurance is provided at a fair price and that the insurer knows the risk from marketers' and farms' activities. Therefore, the expected total liability cost is equal to the cost of insurance at a fair price. Any loss to a marketing firm or a farm is captured by compensation to consumers.

Consumers observe the average level of safety supplied by the marketers. Consumers are not able to differentiate the food safety attributes of different firms and all firms are identical except with respect to *ex post* food safety problems that occur randomly.[13] In this model, only traceability to the marketers matters to consumers because any possible compensation would be paid to consumers by the marketers.[14] We assume that consumers' willingness to pay for one unit of food is a decreasing function of the expected cost of foodborne illness. The price of food is denoted by

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[12] In practice, a few firms do not have liability or product recall insurance. However, most retailers require that liability insurance is attached to food products they carry (Holland 2007). Increased traceability encourages farms to contract insurance for liability because traceability allows claims to be pushed back into the chain. Moreover, increased traceability influences the design of insurance contracts to account for risks that would otherwise be ignored (Meuwissen *et al.* 2003).

[13] In our model, there are random food safety events and the frequency of these events affect willingness to pay for the food product. If certain marketing firms or farms have more to lose from perception that food safety problems are common, they have greater incentive to implement traceability and to urge industry-wide traceability. However, we do not deal with these differential incentives in this paper.

[14] A plaintiff can sue more than one defendant (Buzby, Frenzen and Rasco 2001). In this model, we simplify such that only one firm is liable for a food safety event. As long as any firm can fully cover the liability costs, this assumption is not restrictive because if a plaintiff sues multiple firms, the expected liability burden of a firm is unaffected. That is, the probability of a firm being sued rises but the total payout falls in the same proportion. Thus, our results for food safety are unaffected.

(2) $$\theta = W - (1 - T_m) P(e_m, e_f) A,$$

where W is willingness to pay for food that is surely safe and A is the size of the damage

in the case of a food safety event.[15] Oi (1973) derives a similar price assuming that

consumers' utility depends on the number of good units they consume and on a constant

damage per bad unit. In Oi (1973), θ is the *expected full price*, W is the *warranty price*

and $-(1 - T_m) P(e_m, e_f)$ is the *actuarially fair insurance premium rate*. Winfree and

McCluskey (2005) make the similar assumption that consumer's willingness to pay for

food depends on the average industry quality.

Our model recognizes that consumers are willing to pay for traceability to the

marketers for two traceability-related reasons.[16] To see this clearly, consider the partial

derivative of (2) with respect to traceability to the marketers

(3) $$\frac{\partial \theta}{\partial T_m} = P(e_m, e_f) A - (1 - T_m) \frac{\partial P(e_m, e_f)}{\partial T_m} A.$$

The first term, $P(e_m, e_f) A$, represents the consumers' willingness to pay for traceability

because traceability increases the probability of compensation in the case of a food safety

loss. The second term, $-(1 - T_m) \partial P(e_m, e_f) / \partial T_m A$, is the consumers' willingness to pay

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[15] In expected utility theory, risk aversion is related to the wealth in different contingencies. The expected utility is linear in probability. In our model, risk aversion is not central and we assume that A is constant and we analyze the effect of varying the probabilities T_m and $P(e_m, e_f)$. In practice, foodborne illnesses occur from a diversity of contaminants, some more likely to originate from farms and others more likely to originate from processors or retailers. Also, food contamination can result in illnesses with consequences ranging from small discomfort to death. A potential extension to this model would be to consider a large number of contaminants, each bearing a specific damage and a specific probability of illness function firms' control effort. Furthermore, the size of the damage may vary with the type of contaminant, the age of the individuals, access to a health care system, etc. For a discussion related to these issues, see Antle (2001).

[16] In this model, our attention is limited to liability and food safety. In practice, consumers may be willing to pay for traceability for other reasons. For more details, see for example Golan *et al.* (2004).

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for traceability because they know that with more traceability marketers and farms are likely to supply safer food.[17]

Increased traceability to the farms also affects consumers' willingness to pay more for food, but only for one reason. Taking the partial derivative of (2) with respect to traceability to the farms, we obtain

(4)
$$\frac{\partial \theta}{\partial T_f} = -\left(1-T_m\right)\frac{\partial P\left(e_m, e_f\right)}{\partial T_f}A\ .$$

Similar to the second term in (3), consumers recognize that with more traceback to the farms, farms are more likely to supply safer food. No term in (4) is analogous to the first term in (3) because consumers are compensated for direct loss from the marketers and cannot be compensated again by the farms. Traceability from the marketers to the farms does not increase the expected compensation to the consumers.

Each of the M marketers sells one unit of output.[18] Marketers maximize their profit by choosing an optimal effort under the constraint that effort is nonnegative, i.e. $e_i \geq 0$.[19] The expected profit of each marketer is

(5)
$$\Pi_i = \theta - \gamma\left(e_i\right) - T_m\left(g_m\left(e_i\right) + \left(1-T_f\right)G_f\right)A - \varphi,$$

where $\gamma\left(e_i\right)$ is the cost of supplying safe food and φ is the price paid to farms in terms of marketers' output. The cost of supplying safe food, $\gamma\left(e_i\right)$, increases at an increasing

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[17] Remember that all marketing firms and farms are identical in this model. The premium is not paid to a particular marketing firm but to all marketing firms who all supply the same level of food safety.
[18] It is standard in the literature on liability to assume that output is fixed (e.g. Shavell 1984; and Roe 2004). This is also true for the related literature on product quality (e.g. Tirole 1988). We normalize the output of each marketing firm to one. Later, we will normalize the farms' output using a proportion factor. By assuming fixed output, we ignore any issue related to market power.
[19] We normalize the minimum effort to zero. If we consider that the effort to supply safe food is regulated, we could consider cases where the minimum effort is greater than zero.

rate as a function of e_i, i.e. $\gamma' \equiv \partial\gamma(e_i)/\partial e_i > 0$ and $\gamma'' \equiv \partial^2\gamma(e_i)/\partial e_i^2 \geq 0$. Strict liability applies and the marketers are liable for any damages due either to their own activities or the activities of the farms from whom they buy raw materials. The total expected liability cost for each manufacturer is

$$T_m g_m(e_i) A + T_m (1 - T_f) G_f A \,.$$

The first term in this expression, $T_m g_m(e_i) A$, is the expected liability cost for damages that are due to marketers' practices. The second term, $T_m (1 - T_f) G_f A$, is the expected liability cost due to farms' activities. We assume that marketers cannot detect and remove tainted raw material to mitigate their liability cost for contamination originating at the farms.

Marketers observe the average safety of raw material supplied by the farm sector and not the level of safety supplied by each farm. The price paid to farms is

(6) $$\varphi = V - T_m (1 - T_f) G_f A \,,$$

where V is the price the marketers are willing to pay for perfectly safe product and $T_m (1 - T_f) G_f A$ is the expected liability costs that cannot be transferred to farms. That is, the price that marketers pay for raw material depends directly on their liability burden related to unsafe raw material. The expression $(-1) T_m (1 - T_f) G_f A$ can be interpreted as a reward paid to farms for supplying safe raw material. An increase in the safety of raw material, i.e. a decrease in G_f, results in an increase in the price paid for raw material. In this model, changes in the price paid to farms exactly equal changes in the marketers' expected liability cost related to problems originating from the farms.

Marketers benefit from increased traceability to the farms. Taking the derivative of (5) with respect to T_f, we find that $\partial \Pi_i / \partial T_f = \partial \theta / \partial T_f \geq 0$. That is, the expected profit of marketers increases because the consumers are willing to pay a premium for safer food. (Remember that T_f is exogenous, so the cost of T_f is not an issue.) Note that increased traceability to the farms does not affect marketers' liability cost related to farms' activities because they recover their liability cost from farms by paying a lower price to the farms.

For each identical and risk neutral farm the expected profit equation is

(7)
$$\Pi_j = \delta \left(\varphi - \xi(e_j) - T_m T_f g_f(e_j) A \right).$$

The parameter δ converts units of raw material supplied by farms into units of food. Recall that the *M* marketers produce one unit of food each. Because the number of farms, *N*, does not necessarily equal the number of marketers, we need to normalize each farm's output such that $\delta = M/N$. Each farm chooses an optimal effort under the constraint that effort is nonnegative, i.e. $e_j \geq 0$. We assume that the farms use a technology such that $\xi(e_j)$ increases at a non-decreasing rate, $\xi' \equiv \partial \xi(e_j) / \partial e_j > 0$ and $\xi'' \equiv \partial^2 \xi(e_j) / \partial e_j^2 \geq 0$. The expected liability cost of each farm is $T_m T_f g_f(e_j) A$, which is the expected total liability cost transferred from the marketers.

Recall that we do not model the choice of the degree of traceability. That is, we consider shifts in the degrees of traceability rather than in the cost of traceability. Assuming a shift in the degrees of traceability rather than a shift in cost of traceability does not affect the effort exerted by marketers or farms if the cost of traceability and the costs of supplying safe food are independent. The exogenous shift in the degrees of

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traceability in this model can either be interpreted as government mandated traceability or firms choosing to supply more traceability due to exogenous technology improvements.

Effects of traceability on food safety

In this section we derive how exogenous changes in the degrees of traceability and the number of marketing firms and farms influence the supply of food safety. Remember, the choice of supplying safe food by marketers and farms is determined by their cost of supplying safer food, their liability burden from unsafe food and the premium they receive from consumers to supply safer food.

Choice of effort to supply safety

First, let us consider the corner solutions for food safety effort. We can find the exogenous degrees of traceability such that the efforts to supply safe food by marketers and or farms, e_m and e_f, are zero from the first order condition for maximizing profit in (5) with respect to e_i. We use (1) and (2) in (5) to substitute for $P(e_m, e_f)$ and φ. The first order condition for the maximization of (5) is

(8)
$$-\frac{1}{M}(1-T_m)g'_m(e_i)A - \gamma'(e_i) - T_m g'_m(e_i)A < 0,$$

for the corner solution when $e_i = 0$. So effort by marketers is zero when

(9)
$$T_m < -\frac{M\gamma'(e_i) + g'_m(e_i)A}{(M-1)g'_m(e_i)A},$$

evaluated at $e_i = 0$. Expression (9) shows that effort by marketers is more likely to be zero when T_m is low, M is large, the marginal cost of safer food is large and the effect of

effort on the expected loss from unsafe food is small. Notice from (9) that traceability to

the farms plays no role in marketers' effort.

The condition for determining the corner solution when $e_j = 0$ is similar to that

derived for marketers except that traceability to downstream firms matters. We substitute

the expression for φ given by (6) in the expression for the farms' expected profit given

by (7). The first order condition for the maximization of (7) with respect to e_j is

$$(10) \qquad -\frac{1}{N}T_m\left(1-T_f\right)g_f'\left(e_j\right)A-\xi'\left(e_j\right)-T_fT_mg_f'\left(e_j\right)A<0,$$

for the corner solution when $e_j = 0$. From (10) we find that farms do not make additional

effort to supply food if

$$(11) \qquad T_m<\frac{-N\xi'\left(e_j\right)}{\left(1+T_f\left(N-1\right)\right)g_f'\left(e_j\right)A}$$

or

$$(12) \qquad T_f<-\frac{N\xi'\left(e_j\right)+T_mg_f'\left(e_j\right)A}{\left(N-1\right)T_mg_f'\left(e_j\right)A}.$$

In (11), notice that imperfect traceability to the farms, $T_f<1$, increases the minimum

degree of traceability to the marketers that is required for farms to supply a positive

effort. Nonetheless in (9), T_f plays no role. Expression (12), which gives the minimum

degree of traceability to the farms to supply positive effort by farms, is the exact analogue

to (9) when evaluated at $T_m=1$.

Assuming that T_m and T_f are sufficiently large so that conditions (9), (11) and

(12) are not satisfied, we can now analyze how traceability affects the efforts to supply

safe food when such efforts are positive. From the first order condition for the

maximization of (5), we find after some manipulation that the interior solution for

marketers' effort is implicitly given by

$$(13) \qquad\qquad \gamma' + T_m g'_m A = -\frac{1}{M}(1 - T_m) g'_m A.$$

Similarly, the farms' first order condition for an interior solution to the maximization of

(7) is

$$(14) \qquad\qquad \xi' + T_f T_m g'_f A = -\frac{1}{N} T_m (1 - T_f) g'_f A.$$

In expressions (13) and (14), the terms on the left-hand sides are the direct costs

of supplying safe food by marketers and farms plus the liability costs of supplying unsafe

food. The terms on the right-hand sides are the effect of the willingness to pay by

consumers and marketers for traceability because they value safe food. Clearly, when the

number of marketers in (13) and the number of farms in (14) tend to infinity, the right-

hand sides equal zero. In our model with identical marketing firms and farms,

willingness to pay by consumers and marketers is determined by the average level of

food safety. Further, marketers recognize that their ability to affect the average level of

food safety declines as the number of marketing firms increases. Similarly, farms know

they are less able to affect the average level of safety when the number of farms

increases. When the number of marketing firms or farms is infinite, the free-rider

problem eliminates the price incentive to supply safer food or safer raw material. In this

model with identical firms and no collusion, firms do not expect their behavior to influence the food safety supplied by other firms.[20]

When there is a single marketer and a single farm, or when the degrees of traceability are already equal to 1, the first order conditions are

$$\gamma' + g'_m A = 0$$

and

$$\xi' + g'_f A = 0.$$

In those cases, traceability is already assumed and the social cost of supplying safe food equals the social marginal benefit.

Comparative static

Next, use (13) and (14) to derive explicitly the effect of additional traceability on food safety. Define $S_m = 1 - g_m(e_m)$ as the level of safety supplied by the marketers and define $S_f = 1 - g_f(e_f)$ as the level of safety supplied by the farms. To examine the impact of additional traceability on the supply of food safety, take the total differential of (13) and (14), holding constant the degree of traceability to the farms T_f, the size of the damage A, and the number of marketers M and farms N. We obtain from (13)

$$\gamma''(de_m) + g'_m A(dT_m) + T_m g''_m A(de_m) = \frac{1}{M} g'_m A(dT_m) - \frac{1}{M}(1 - T_m) g''_m A(de_m)$$

and from (14)

$$\xi'(de_f) + T_f g'_f A(dT_m) + T_m T_f g''_f A(de_f) = \frac{1}{N} T_f g'_f A(dT_m) - \frac{1}{N} T_m (1 - T_f) g''_f A(de_f).$$

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[20] Some industries solve the free-rider problem by collective action to reduce food safety problems. For example, Alston *et al.* (2005) analyze collective action in the marketing order in the California pistachio industry. In the meat industry, many countries have adopted traceability to solve free-rider problems. However, some countries are more reluctant than others as discussed by Souza-Monteiro and Caswell (2004).

We can solve these two equations for de_m/dT_m and de_f/dT_m. Using the fact that

$dS_m/dT_m = -g'_m(de_m/dT_m)$ and $dS_f/dT_m = -g'_f(de_f/dT_m)$, we have

$$(15) \qquad \frac{dS_m}{dT_m} = \frac{(g'_m)^2(M-1)A}{M\gamma'' + (1 + T_m(M-1))g''_m A} \geq 0$$

and

$$(16) \qquad \frac{dS_f}{dT_m} = \frac{T_f(g'_f)^2(N-1)A}{N\xi'' + T_m(1 + T_f(N-1))g''_f A} \geq 0.$$

Thus, increased traceability to the marketers increases the supply of safer food from both the marketers and the farms.

We can proceed in the same way to find the effect of increasing traceability to the farms. Because the degree of traceability to the farms does not appear in (13), we obviously have that $de_m/dT_f = 0$. For the farms, holding the degree of traceability to the marketers and the size of the damage and the number of firms constant, we obtain

$$\xi''(de_f) + T_m g'_f A(dT_f) + T_m T_f g''_f A(de_f) = \frac{1}{N}T_m g'_f A(dT_f) - \frac{1}{N}T_m(1-T_f)g''_f A(de_f).$$

Solving for de_f/dT_f and using $dS_m/dT_f = -g'_m(de_m/dT_f)$ and

$dS_f/dT_f = -g'_f(de_f/dT_f)$, we find

$$(17) \qquad \frac{dS_m(e_m)}{dT_f} = 0$$

and

$$(18) \qquad \frac{dS_f}{dT_f} = \frac{T_m(g'_f)^2(N-1)A}{N\xi'' + T_m(1 + T_f(N-1))g''_f A} \geq 0.$$

Comparing (15) to (17), we see that additional traceability to the marketers or to the farms has different impacts on the supply of food safety by marketers. More traceability to the marketers or to the farms increases the incentives for farms to supply safe raw material as shown in inequalities (16) and (18). In (16), we see that additional traceability to the marketers increases the effort by farms to supply safe raw material because traceability to downstream firms matters. However, in (17), we see that an increase in the probability that raw material is traceable to the farms has no effect on the supply of food safety by the marketers because traceability upstream does not modify the incentives for the marketers to spend additional effort on safer food. This is due to the assumption of independence of the effort of marketers and farms and to the assumption that firms are not integrated in this model.

We can also examine how the number of marketing firms and the number of farms affect the supply of safe food. Take the total differential of (13) and (14) holding constant the degree of traceability to the marketers T_m and to the farms T_f, and the size of the damage A. We obtain from (13)

$$\gamma''(de_m) + T_m g_m'' A(de_m) = \frac{1}{M^2}(1-T_m) g_m' A(dM) - \frac{1}{M}(1-T_m) g_m'' A(de_m)$$

and from (14)

$$\xi''(de_f) + T_m T_f g_f'' A(de_f) = \frac{1}{N^2} T_m (1-T_f) g_f' A(dN) - \frac{1}{N} T_m (1-T_f) g_f'' A(de_f).$$

We can solve for de_m/dM and de_f/dN. Using $dS_m/dM = -g_m'(de_m/dM)$ and $dS_f/dN = -g_f'(de_f/dN)$, we find

(19)
$$\frac{dS_m}{dM} = -\left(\frac{1}{M}\right)\frac{(g_m')^2(1-T_m)A}{M\gamma'' + (1+T_m(M-1))g_m''A} \leq 0$$

and

$$(20) \qquad \frac{dS_f}{dN} = -\left(\frac{1}{N}\right) \frac{\left(g_f'\right)^2 T_m \left(1-T_f\right) A}{N\xi'' + T_m \left(1+T_f \left(N-1\right)\right) g_f'' A} \leq 0.$$

That is, for given cost functions and probability functions, the larger is the number of marketing firms, the less safe is food and the larger is the number of farms, the less safe is raw material and, ultimately, the lower is food safety for consumers.

Expressions (15) to (20) show the impacts of changes in the degrees of traceability and changes in the number of firms on the safety of raw material and the safety of food. Even though, as discussed previously, we assume that T_m is independent of M and T_f is independent of N, these variables jointly affect firms' incentives to supply safe food. Using our model, one can show that increased traceability has a larger effect on food safety when there are more marketers or farms. Using (15), assuming that $g_m''' = 0$ and $\gamma''' = 0$, we find

$$\frac{\partial \left(dS_m / dT_m\right)}{\partial M} = \frac{1}{\left(M-1\right)} \left(\frac{dS_m}{dT_m}\right) \left[1 + \left(\frac{M-1}{M}\right) \frac{2\left(1-T_m\right) g_m'' A - M\left(\gamma'' + T_m g_m'' A\right)}{M\gamma'' + \left(1+T_m \left(M-1\right)\right) g_m'' A}\right] \geq 0.$$

The larger is the number of marketing firms, the larger is the free-rider problem and the greater are the liability incentives to supply safer food provided by increased traceability. Assuming $g_f''' = 0$ and $\xi''' = 0$ we find from (16)

$$\frac{\partial \left(dS_f / dT_m\right)}{\partial N} = \frac{1}{\left(N-1\right)} \left(\frac{dS_f}{dT_m}\right) \left[1 + \left(\frac{N-1}{N}\right) \frac{2T_m \left(1-T_f\right) g_f'' A - N\left(\xi'' + T_m T_f g_f'' A\right)}{N\xi'' + T_m \left(1+T_f \left(N-1\right)\right) g_f'' A}\right] \geq 0$$

and from (18) we find

$$\frac{\partial\left(dS_f/dT_f\right)}{\partial N}=\frac{1}{\left(N-1\right)}\left(\frac{dS_f}{dT_f}\right)\left[1+\left(\frac{N-1}{N}\right)\frac{2T_m\left(1-T_f\right)g_f''A-N\left(\xi''+T_mT_fg_f''A\right)}{N\xi''+T_m\left(1+T_f\left(N-1\right)\right)g_f''A}\right]\geq0\,.$$

That is, increased traceability to the marketing firms and to the farms have stronger
impacts on the supply of safe raw material when the number of farms is large. The
intuition is the same as for the marketers. Because the free-rider problem is important
when the number of farms is large, the liability incentives from increased traceability
affect the supply of safe raw material by farms more strongly.

Conclusions

Many issues surround traceability of food products. Traceability may be a product
attribute demanded by consumers or traceability may be required to document some other
attribute that consumers value, such as specific production methods. Sometimes,
governments may impose mandatory traceability in order to enhance protection from
epidemics or invasive species to facilitate regulation. Here, we deal with one part of the
relationship between traceability and food safety.

This article is the first to explore in detail the relationships between traceability
and the provision of food safety when traceability facilitates attributing to individual
firms liability for lapses in food safety. The article develops a formal model of how, by
making liability feasible, traceability causes the degree of food safety to increase.

The improved food safety from increased traceability increases consumers'
willingness to pay for the (safer) product. This creates an additional incentive to improve
the food safety reputation of the industry. We show that as the number of marketers and
farms increases, industry reputation incentives for individual firms to supply safe food

decreases. Thus, holding other factors constant, for a given industry size, the larger are farms or processing and marketing firms are, the more likely food is safe.

Our model captures some important features of the creation of liability incentives through better traceability. Under U.S. laws, firms are directly liable for losses in welfare due to a food safety event. Consumers gain from increased traceability to the marketers by having better chances of receiving compensation in case of a food safety event and by consuming safer food. Additional traceability from the marketers to the farms does not increase consumers' compensation because it does not change the marketers' liability. However, additional traceability to the farms allows marketers to impose liability costs on farms and thus creates incentives for farms to supply safer food. In return, with more traceability, marketers and farms receive a premium for supplying safer food. This result documents a rationale for collective action in industries with many firms.

Our results suggest that downstream firms may require traceability back to the farms to shift liability upstream and reduce the chance of food safety problems. We do not discuss how such improved traceability would be accomplished. Nevertheless, the way firms achieve better traceability may have important consequences. For instance, vertical integration and exclusivity contracts can be substitutes to the implementation of traceability technology to keep separate raw material from many suppliers. Therefore, a potential consequence of the current trend in seeking better traceability is an increase in vertical coordination and integration.

Our general modeling approach is rich enough to accommodate investigation of several related topics that are not discussed thoroughly here. For example, we can consider that the liability burdens of the firms represent the cost of recall per unit of

product and that the negative of the liability burden of consumers represents their

willingness to pay for an industry with a good reputation regarding the safety of food.

Under this interpretation, the model can be use to illustrate the expected value of

traceability for improving the effectiveness of product recalls and preserving the

reputation of an industry. Further, by relaxing our assumption of homogeneous firms, we

can explore how differences in costs of providing traceability may provide strategic

advantages for some firms as the demand for traceability changes and explore how

traceability affects product differentiation.

Our model derives several propositions that can be tested empirically. Do more

concentrated industries supply safer food? Does traceability have a stronger impact on

the safety of food in industries where the number of firms is large? Is the role of

traceability in creating incentives for firms to supply safer food greater in industries with

a large number of firms and with a significant free-rider problem?   Our model clarifies

the relationship between traceability, liability and food safety and provides a framework

for empirical analysis.

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