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Welfare Effects of Mandatory Traceability When Firms are Heterogeneous

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Abstract
We develop a framework in which the cost of producing a quantity food and the cost of food safety differs across firms. We show that large firms may supply the safest food even though small firms have a cost advantage in producing safe food. The model shows that mandatory traceability can decrease the overall safety of food when small firms that supply the safest food exit the industry. Our model applies to food safety but can be applied to a wide range of issues related to regulation and product quality.

Keywords
Food safety, quality, traceability, regulation

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Welfare Effects of Mandatory Traceability When Firms are Heterogeneous*

Recent food safety incidents such as the discovery of bovine spongiform encephalopathy (BSE) in 2003 and the case of *E. coli* contaminated spinach in 2006 have raised the interest of consumers for the traceability of food in the United States. The California leafy-green industry required traceability in its marketing agreement less than a year after the discovery of *E. coli* in spinach in 2006. In March 2009, the President's Food Safety Group (2009) recommended a new national traceback and response system to deliver food safety alerts to consumers. Not all industries and governments are showing much interest in implementing traceability systems. For instance, the adoption of the National Animal Identification System (NAIS) in the United States is still limbo years after it was first proposed.

The lack of interest by some industries and government may stem from the lack of knowledge about the effects of traceability on consumers' welfare and on firms profit. This paper explores the effect of introducing traceability on the quantity of food and its safety when firms are heterogeneous. The paper shows the effect of traceability on consumers' welfare and on firms' profit. Our model differs from previous work that has analyzed the effects of traceability when firms are homogenous.

One role of traceability is to identify more specifically the origin of each product after the discovery of a food incident. Therefore, a traceability system enables more targeted recalls and protects the reputation of firms that supply a safe product. Both Winfree and McCluskey (2005) and Carriquiry and Babcock (2007) in their model of industry reputation have identified traceability as a prerequisite to induce firms to take more care to deliver safe food. The capacity to trace the origin of food removes the anonymity of firms, increases the possibility of legal remedy and compensation in the case of a food safety incident. Pouliot and Sumner (2008) formally model the linkage between traceability and the allocation of liability in a supply chain. The authors show the mechanism through which traceability systems create incentives for firms in a vertical supply chain to supply safer food products. The model shows that increased traceability to the processors increases the incentives for processors to deliver safe food and also increases the incentives for farms to deliver safe raw material. Increasing the traceability from

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the processors to the farms increases the incentives only to the farms to deliver safe raw material. The model also shows that the larger is the number of farms, the less safe raw material is because of public good problem in the safety of raw material. Likewise, the larger is the number of processors, the less safe food is because safe food has public good characteristics. One role of traceability is to privatize the safety of raw material and privatize the safety of food.

Previous literature on the economics of food traceability has relied on the assumptions that each firm delivers a fixed quantity of food and that all firms are identical. Here, we develop a model that relaxes the assumptions of fixed output and identical firms. We model heterogeneous firms that choose their output and their effort in supplying safe food. The heterogeneity of the cost function across firms is given exogenously. The zero profit condition determines the number of firms. Traceability is fixed exogenously by government regulation or imposed by collective industry action.

We show how the profit maximizing output and the profit maximizing food safety for individual firms relate. Under the assumption that firms all have access to the same technology to produce safe food, large firms will deliver food that is safer than the food supplied by small firms. If firms of different sizes do not have access to the same technology to produce safe food, the model shows that traceability may not always increase the safety food. Such case is possible when a traceability system is mandated for an industry that is characterized by many small firms that deliver very safe food and a few large firms that do not deliver food that is as safe.

Our model assumes that consumers are oblivious to the safety of food when making their consumption decisions. Still, consumers are affected by unsafe food through a loss in the income available for the purchase of products other than food. We show that traceability always increases consumers' welfare by decreasing the consumption of the unsafe food product, by increasing the safety of food and by increasing the potential for compensation when foodborne illnesses occur.

The framework that we develop can be applied to other issues related to the output and the quality of a product. Minimal changes to the objective function of firms can allow the model to consider the effect of regulation in a variety of settings.

Related literature

Our analysis applies to traceability but provide a general framework to analyze the interaction between output and a quality attribute when a market is characterized by heterogeneous competitive firms. This is different and not to be confused with the voluminous literature on market structure and the supply of quality. For instance, Spence (1975), Gabszewic and Thisse (1979), Mussa and Rosen (1978) study the supply of quality by monopolistic firms while Gal-Or (1983) studies the supply of quality by oligopolistic firms. Spence (1977) and Dixit and Stiglitz (1977) develop models of monopolistic competition. Dixit (1979) compares the choice of quality under competition and under various collusions settings. This is of course a very short list of papers that relate market structure to quality and much work has been done on the subject since it first attracted the interest of economists.

Recent empirical literature has attempted to estimate how concentration affects the supply of quality. For instance, Crespi and Marette (2009) estimate the effect of concentration on the supply of quality. The authors find that increase concentration leads to an increase both in the probability of observing a higher quality and an increase of the industry's average quality. However, the authors note that the relationship between concentration and quality should be taken as a stylized fact as their dataset includes only cross sectional data and therefore cannot yield full-blown structural estimation. Berry and Waldfogel (2010) document that in a market where quality is produced with variable cost, the range of quality increases with market size. For market where quality is produced with fixed costs, the average quality increases with market size but market size has little effect on variety.

Even though our model can accommodate the analysis of market structure and market concentration and the supply of quality, we will focus on the incentives for competitive firms of different size to deliver safe food. To our knowledge, the paper that most relate to ours is Cho and Hooker (2007) who consider how heterogeneous firms participate in voluntary food safety program. The authors find that firms with higher cost of food safety are less likely to participate in voluntary programs regardless of the financial incentives.

The model

Our model differs much from previous literature as we consider a population of competitive firms with cost efficiency parameters for the cost of output and the cost of food safety. That is, the cost of firms is determined by parameters are drawn in two spaces of a random distribution. This is unlike Cho and Hooker (2007) who consider that a firm's type is defined into a single parameter space.

We consider a population of N price taking and risk neutral firms. Each firm i maximizes its profit by choosing an output $q_i \geq 0$ and a level of food safety $s_i \in (0,1)$, which is measured as the probability that one unit of food does not cause illness. The profit of a firm i is given by

$$\Pi_i = P(Q)q_i - C(q_i, s_i : T, \alpha_i, \beta_i) - q_i(1-s_i)TA, \tag{1}$$

where $P(Q)$ is the inverse demand for food that is a function of the total quantity of food delivered given by Q. Our model assumes that consumers do not observe the firm of origin and that consumers are oblivious of food safety concerns when making their purchase decisions. This assumption is consistent with the nature of many types for food contaminants and the marketing of food products. In most cases, consumers cannot observe the safety of an individual food product because the safety of a food product cannot be detected by organoleptic inspection. Moreover, firms cannot make claims regarding the safety of a food product and will therefore not seek to differentiate their product with respect to safety. This does not mean that consumers do not value food safety. Consumers may value food safety and be willing to pay a premium for food safety. However, because consumers cannot observe the safety of food products and moreover because they cannot observe firms' effort to guarantee food safety, consumption decision of food product is done without regard for its safety.

The cost of producing food depends on the quantity of food delivered, q_i, the safety food s_i and the degree of traceability T. Traceability is measured as the probability that one unit of food can be traced from the consumer to the firm of origin. Output and food safety are choice variables to the firms while traceability is imposed by industry or government regulation. An individual firm does not benefit from increasing traceability because it cannot differentiate its product. We assume that the cost function is increasing and convex with respect to the output, food safety and traceability. The safety of food is measured as the *ex ante* probability that food is safe and therefore takes a value between zero and one. We assume that food can be made perfectly safe only at an infinite cost, $\partial C(\cdot)/\partial s_i\big|_{s_i \to 1} \to \infty$. Increasing food safety increases the marginal cost of food, $C_{q,s} \geq 0$, where each subscript denotes a partial derivative. Likewise, increasing traceability increases the marginal cost of food $C_{q,T} \geq 0$. Likewise, increasing traceability increases the marginal cost of food safety, $C_{s,T} \geq 0$.

The parameters α_i and β_i capture the efficiency of firm to produce food and to produce safe food. We assume that the parameter α_i is specific to the marginal cost of output. The larger α_i is, the larger is the marginal cost of producing one unit of food, $C_{q,\alpha} \geq 0$. However, α_i does not directly affect the marginal cost of food safety, $C_{s,\alpha} = 0$. Similarly, we assume that the parameter β_i is specific to the marginal cost of producing safe food. The larger β_i is, the larger is the cost of producing safe food, $C_{s,\beta} \geq 0$, but β_i does not affect the marginal cost of output, $C_{q,\beta} = 0$. The parameters α_i and β_i do not affect the marginal cost of traceability as the same traceability technology is used by all firms. The parameters α_i and β_i are jointly distributed following a distribution function $f = f(\alpha_i, \beta_i)$.

A low value of α could be associated with a firm located where the weather is ideal to the growth of an agricultural product, where land is inexpensive and where labor is also inexpensive. Likewise, a low value of β could mean that workers in an area are educated to the risk of foodborne illnesses and a firm does not have to spend much resources training its employees. However, it is possible that the conditions that favor the growth of a crop also favor the growth of undesirable mold or bacteria. Perhaps high moisture increases yield but may at the same time facilitates the growth of molds that are toxic for humans implying that α and β are negatively correlated. It is also possible that a region with the best soil for a crop is also isolated from pests that can cause the contamination. Thus, for firms in that region, α and β would be positively correlated.

The last term in expression (1) is the expected cost of liability or fines for delivering unsafe food. For each unit of food that is unsafe with probability $1-s_i$, firm i must pay compensation to consumers affected or pay a fine. Liability and fines can be imposed only when traceability is successful with probability T. We assume that for each unit of unsafe food that is delivered and traced to the firm of origin that the total of the costs imposed to firm i is given by A.

The first order conditions for the interior solution for profit maximization with respect to output and food safety are given by

$$P(Q) - C_q - (1 - s_i)TA \leq 0\,; \tag{2}$$

$$-C_s + q_i TA \leq 0\,. \tag{3}$$

The second order conditions are $-C_{q,q} < 0$, $-C_{s,s} < 0$, and

$$C_{q,q}C_{s,s} - \left(C_{q,s} - TA\right)^2 > 0 \tag{4}$$

Finally, a firm i produces only if delivering food yields a nonnegative profit

$$P(Q)q_i - C\left(q_i, s_i \middle| T, \alpha_i, \beta_i\right) - q_i(1 - s_i)TA \geq 0\,. \tag{5}$$

Equations (2) and (3) implicitly define the interior solutions for the quantity of food supplied, the safety of food for a single firm. We denote the solution for the quantity of food by a firm i by $q_i^*\left(\alpha_i, \beta_i, T, P\left(Q^*\right)\right)$ and the safety of the food delivered by firm i by $s_i^*\left(\alpha_i, \beta_i, T, P\left(Q^*\right)\right)$, where Q^* is the total quantity of food at equilibrium. In these solutions, we use the fact that the price is given exogenously to individual firms. We will show below the expression for the total quantity of food. Accounting for the market price at equilibrium, the quantity of food, the safety of food and the number of firms are defined by equations (2), (3) and (5). Let us note by $q_i^*\left(\alpha_i, \beta_i, T \middle| N, f\right)$ the quantity of food delivered by firm i and the safety of the food delivered by firm i as $s_i^*\left(\alpha_i, \beta_i, T \middle| N, f\right)$. In those solutions, we write that the equilibrium quantity and the safety of the food delivered by a firm also depend on the population of firms and the distribution of firms in the industry, which determines the total quantity of food and the its average safety. We can write for the interior solutions that $q_i^*\left(\alpha_i, \beta_i, T \middle| N, f\right) = q_i^*\left(\alpha_i, \beta_i, T, P\left(Q^*\right)\right)$ and $s_i^*\left(\alpha_i, \beta_i, T \middle| N, f\right) = s_i^*\left(\alpha_i, \beta_i, T, P\left(Q^*\right)\right)$.

Expression (5) determines whether a firm produces a positive quantity of food. We define by $\alpha^*\left(\beta, T\right)$ the limit between the firms that enter and those that choose not to enter the market. For $\alpha_i \geq \alpha^*\left(\beta_i, T\right)$ a firm i does not enter the market such that its output equals zero.[2]

[2] We could equivalently have written $\beta^*\left(\alpha_i, T\right)$, the inverse function of $\alpha^*\left(\beta, T\right)$. Results are of course not affected by which function we choose.

For $\alpha_i < \alpha^*(\beta_i, T)$, it is profit maximizing for a firm i to produce a positive quantity of food. We can write that the number of firms that enter the market is given by

$$N^*(T) = N\int_0^1 \int_0^{\alpha^*(\beta,T)} f(\alpha,\beta)\,d\alpha\,d\beta \,.$$

We assume that not all firms choose to enter the market such that $N^*(T) < N$. Following the expression for the number of firms participating in the market, we can write that the total quantity of food is given by

$$Q^*(T) = N^*(T)\int_0^1 \int_0^{\alpha^*(\beta,T)} q^*(\alpha,\beta,T)\, f\left(\alpha,\beta \middle| \alpha \le \alpha^*(\beta,T)\right) d\alpha\,d\beta \,, \qquad (6)$$

where

$$f\left(\alpha,\beta \middle| \alpha \le \alpha^*(\beta,T)\right) = \frac{f(\alpha,\beta)}{1-F\left(\alpha^*(\beta,T),\beta\right)}$$

is the density of the truncated distribution and $F(\cdot)$ is the cumulative distribution function. Expression (6) is the expected output of a firm participating in the market times the number of participants. Thus, we can write $Q^*(T) = N^*(T)\mu_q(T)$, where $\mu_q(T)$ is the expected output given traceability T.

Comparative static

Before turning to the analysis of the effects of traceability, let us first investigate how the profit maximizing output and the profit maximizing food safety pair is affected by the parameters α_i and β_i. To determine how output and food safety is affected by the parameters α_i and β_i, take the total derivatives of (2) and (3). The effects of a change an increase in α_i on the output and the safety of food are given by

$$\frac{dq_i^*}{d\alpha_i} = -\frac{C_{q,\alpha}C_{s,s}}{C_{q,q}C_{s,s} - \left(C_{q,s} - TA\right)^2} \le 0\,; \qquad (7)$$

$$\frac{ds_i^*}{d\alpha_i} = \frac{\left(C_{q,s} - TA\right)C_{q,\alpha}}{C_{q,q}C_{s,s} - \left(C_{q,s} - TA\right)^2}\,. \qquad (8)$$

The denominator in (7) and (8) is positive from the second order condition for profit maximization in (4). Expression (7) says that firms with a higher cost of output produce a smaller quantity, everything else being equal. The sign of the effect of α_i on the safety of food in (8) depends on the size of the shift in the marginal cost of output from an increase in the safety of food, $C_{q,s}$, and the expected cost associated with the delivery of one unit of unsafe food, TA. In the remainder of the paper, we assume that the penalty for delivering unsafe food is larger than the shift in the marginal cost of output from a change in food safety. We make this explicit in the following assumption.

<u>Assumption 1</u>: *The expected penalty associated with the delivery of unsafe food,* TA*, is very large such it is always larger than the cross partial derivative of the cost function with respect to the output and the safety of food when evaluated at the profit maximizing output and food safety. That is* $TA > C_{q,s}$.

Assumption 1 says that, for one unit of output, the increase in the marginal cost from an increase in the safety of food is smaller than the expected penalty from delivering unsafe food. In practice, the penalty imposed to a firm that delivers unsafe food can be very stiff as it can be legally kept from selling food, governmental authorities may impose fines and consumers may seek compensation for damages caused by unsafe food. Whether the penalties can be imposed to the firm responsible of a food safety incident depends on the capacity to trace the product to its origin. In most cases where a food safety incident occurs a large number of people are affected, health authorities conduct intensive investigations to find the origin of the contamination and the traceability to the firm of origin large. Thus, the expected cost to a firm to deliver unsafe food should be in practice large.

Given that assumption 1 holds, firms that have a lower cost of output, everything else being equal, also deliver safer food such that $ds_i^* / d\alpha_i \leq 0$. This implies that for a given β, larger firms deliver safer food.

The effects of an increase in β_i on the output and the safety of food are given by

$$\frac{dq_i^*}{d\beta_i} = \frac{\left(C_{q,s} - TA\right) C_{s,\beta}}{C_{q,q} C_{s,s} - \left(C_{q,s} - TA\right)^2}; \qquad (9)$$

$$\frac{ds_i^*}{d\beta_i} = \frac{-C_{q,q}C_{s,\beta}}{C_{q,q}C_{s,s} - \left(C_{q,s} - TA\right)^2} \leq 0 . \tag{10}$$

The effects of β_i on the output and the safety of food are analogous to the effects of α_i. When assumption 1 holds, expression (9) says that firms that have a lower cost of producing safe food also produce a larger output. Expression (10) says that firms with a lower cost of producing safe food produce, of course, safer food.

We now turn to analyze the effect of increased traceability on the output and the safety of food. Comparative static with respect to traceability yields

$$\frac{dq_i^*}{dT} = \frac{\left(C_{q,s} - TA\right)\left(C_{s,T} - q_i^* A\right) - C_{s,s}\left(C_{q,T} + \left(1 - s_i^*\right)A\right)}{C_{q,q}C_{s,s} - \left(C_{q,s} - TA\right)^2}, \tag{11}$$

$$\frac{ds_i^*}{dT} = \frac{\left(C_{q,s} - TA\right)\left(C_{q,T} + \left(1 - s_i^*\right)A\right) - C_{q,q}\left(C_{s,T} - q_i^* A\right)}{C_{q,q}C_{s,s} - \left(C_{q,s} - TA\right)^2}. \tag{12}$$

Let us first take a look at the effect of traceability on the safety of food in equation (12). Note that $C_{s,T}$ is likely to be small as traceability technology does not directly affect the cost of food safety unless a traceability system requires that a firm separates batches of products and cleans its equipment between batches. Pouliot and Sumner (2009) assume that this term equals zero. Thus, if $C_{s,T}$ is small, it implies that the second set of terms on the numerator of (12) is positive. The first set of terms on the numerator of (12) is negative from assumption 1. Thus, the effect of traceability on food safety is undetermined.

The result about the effect of traceability on food safety differs from the result of Pouliot and Sumner (2008) who find that increased traceability always increases the effort by firm to produce safe food. The model of Pouliot and Sumner (2008) assumes that the output of all firms is fixed to one unit and that the cost of food safety is independent of the cost of traceability. We can show that result by taking the total differential of (3), letting $dq_i^* = 0$, we can then write that

$$\frac{ds_i^*}{dT} = \frac{q_i^* A - C_{s,T}}{C_{s,s}}$$

That is, if $C_{s,T}$ is small and that the output is fixed, our model shows the same result as in Pouliot and Sumner (2008) that food safety always increases with increased traceability.

Equation (11) shows the effect of increased traceability on the output. Given that assumption 1 holds, the sign of the effect of increased traceability on the output is undetermined. For the remainder of the paper, we will assume that increased traceability causes firms to increase the safety of their food and decrease their output. This is formally stated in assumption 2.

Assumption 2: *Increased traceability causes firms to increase the safety of their food and decrease their output.*

For assumption 2 to hold, it requires that $\left(C_{q,T}+\left(1-s_i^*\right)A\right)$ is small and that $\left(C_{s,T}-q_i^*A\right)$ is large in absolute value. The term $\left(C_{q,T}+\left(1-s_i^*\right)A\right)$ is the total effect of traceability on the marginal cost of output. Empirically, this cost is likely to be small as the cost of traceability represents a small share of the marginal cost of output. Even though A is large, unsafe food is unlikely such that s_i^* is near one making $\left(1-s_i^*\right)A$ small. The term $\left(C_{s,T}-q_i^*A\right)$ is the effect of traceability on the total marginal cost of food safety. As mentioned earlier, $C_{s,T}$ is likely small unless traceability implies segregating batches of products. However, the product of the output and the penalty for delivering unsafe food is large unless the firm delivers a very small quantity of product. Overall, assuming that traceability increases food safety and reduces the output seems a reasonable assumption.

We can use expressions (11) and (12) to show how firms of different sizes respond to increased traceability. For simplicity, let us assume here that all third order derivatives of the cost function are equal to zero. Taking the partial derivatives of (11) and (12) with respect to α yields

$$\frac{\partial\left(dq_i^*/dT\right)}{\partial\alpha}=\frac{C_{s,s}A\dfrac{\partial s_i^*}{\partial\alpha}-\left(C_{q,s}-TA\right)A\dfrac{\partial q_i^*}{\partial\alpha}}{C_{q,q}C_{s,s}-\left(C_{q,s}-TA\right)^2}<0, \tag{13}$$

$$\frac{\partial\left(ds_i^*/dT\right)}{\partial\alpha}=\frac{C_{q,q}A\dfrac{\partial q_i^*}{\partial\alpha}-\left(C_{q,s}-TA\right)A\dfrac{\partial s_i^*}{\partial\alpha}}{C_{q,q}C_{s,s}-\left(C_{q,s}-TA\right)^2}<0. \tag{14}$$

Expression (13) and (14) say that larger firms, defined by a small α, are more responsive to increased traceability. Expression (13) shows that larger firms will decrease their output by more when traceability is increased (because $dq_i^* / dT < 0$) while expression (14) shows that larger firm will increase the safety of their food by more when traceability is increased. We do not show how firms supplying safer food are affected by increased traceability because the effect of β on output and food safety is analogous to the effect of α. That is, firms supplying safer food will decrease their output by more and making their food safer by more when traceability is increased.

We next look at the effect of an increase in the price that is exogenous to the firms on the output and the safety of food. Comparative static with respect to the price yields:

$$\frac{dq_i^*}{dP} = \frac{C_{s,s}}{C_{q,q}C_{s,s} - \left(C_{q,s} - TA\right)^2} \geq 0\,; \tag{15}$$

$$\frac{ds_i^*}{dP} = -\frac{C_{q,s} - TA}{C_{q,q}C_{s,s} - \left(C_{q,s} - TA\right)^2} \geq 0\,. \tag{16}$$

An increase in the price yield an increase in the output and, given that assumption 1 holds, an increase in the price also yields an increase in the safety of food.

The signs in (15) and (16) have implications beyond the comparative static of how firms respond to changes in price. Recall that the price of the food product is a function of the distributions of the firms in the market. The price will be lower in a market where most of the firms have a low α and a low β than the price in a market where α and β tend to be higher. This implies that the safety of the food delivered by two identical firms (same α and same β) in two separate markets will be different if the price in those two markets is different. Moreover, suppose that two markets with two different distributions for α and β open access to their markets causing the price in one market to increase and the other to decrease. This will cause the firms in the market where the price was initially high to reduce the safety of their food and the firms in the market where the price increases to improve the safety of their food.

The effects of increased traceability

In this model with heterogeneous firms, increased traceability does not have the same effect on all firms. In this section, we will consider that traceability is exogenously increased from T_0 to

T_1. The increase in the degree of traceability can be set by the industry organization, or mandated by the government or induced by a change in technology. We will not go into the detail of why a government or an industry organization may want to increase traceability other than noting that individual firms have no private incentives in this model to offer traceability. Thus, unless the socially optimal degree of traceability is coincidentally zero, we have a situation where traceability is under supplied with respect to the social optimum or the industry optimum. Thus, a government can improve social welfare by mandating traceability. Likewise, an industry organization can increase the total surplus of the industry by imposing a traceability system to its members.

Effect of traceability on total output

In the previous section we showed the effect of increased traceability on the output of individual firms. If assumption 2 holds, the direct effect of increased traceability is to cause individual firms to decrease their output. This however does not take into account the change in the price resulting from the entry or the exit of firms. Thus, the sign of the change in the total output may not be the same as the change in the output of all firms. In this section, we consider the total effects of traceability as firms potentially exit the market following an increase in traceability.

Comparative static is difficult because firms are heterogeneous. However, to facilitate the analysis we can start with basic economic theory to establish the effect of traceability on the entry or exit of firms. Recall that the function $\alpha^*\left(\beta_i, T\right)$ is determined by the zero profit condition in (5). The effects of traceability on the entry and the exit of firms are either through a change in the cost or a change in the revenues. On the cost side, traceability increases the minimum of the average cost curve. Only firms for which the minimum of the average cost curve is not above the price remain in the market. On the cost side again, traceability can contribute to reduce a public good problem related, for instance, to animal disease or industry reputation (see for example Gilbert, et al. (2005) and Pouliot and Sumner (2008)). However, our model does not consider the dynamic associated with such cost savings and therefore traceability cannot lower the minimum of the average cost curve. Finally, on the revenue side, our model ignores that consumers may be willing to pay a premium for traceability. Therefore, the direct effect of traceability on the price is zero. This assumption is supported by the findings of Dickinson and Bailey (2002) and Hobbs, et al. (2005). In summary, given our assumptions on the cost and the demand, increased traceability causes firms to exit the market through an increase in the minimum of the average cost curve.

We consider that all firms implement the same traceability system and that no firm benefits from a comparative advantage in the cost of adopting traceability. This does not mean, however, that traceability affects all firms the same. If the traceability technology requires paying a large fixed cost, then that cost can be better absorbed by large firms. If however, traceability requires mostly an increase in the marginal cost of output, the effect of mandatory traceability is more size neutral. We do not specify the traceability technology and rather adopt a general approach by modeling the effect of traceability on the entry and the exit of firms in the (α, β) space. The effect of increased traceability on the exit of firms is represented by a shift in $\alpha^*(\beta, T)$ with $\alpha^*(\beta, T_0) \geq \alpha^*(\beta, T_1) \forall i$. The shift of the function $\alpha^*(\beta, T)$ incorporates the effect of traceability on the cost of firms and on the price paid for food. Given the comparative static for increase in α or β and that all firms implement the same traceability system, increased traceability does not cause $\alpha^*(\beta, T_0)$ and $\alpha^*(\beta, T_1)$ to cross each other in the (α, β) space.

To analyze the effect of traceability on the total output, we will break down the effect of traceability on output at the intensive and the extensive margins. To this end, it is convenient to write the total output before the implementation of traceability as

$$\begin{aligned} Q_0 &= N_0 \int_0^1 \int_0^{\alpha_1} q_0 f\left(\alpha, \beta \middle| \alpha \leq \alpha_0\right) d\alpha d\beta + N_0 \int_0^1 \int_{\alpha_1}^{\alpha_0} q_0 f\left(\alpha, \beta \middle| \alpha \leq \alpha_0\right) d\alpha d\beta \\ &= \underline{N}_0 \underline{\mu}_0^q + \overline{N}_0 \overline{\mu}_0^q \end{aligned}, \qquad (17)$$

and the total output after increased traceability as

$$\begin{aligned} Q_1 &= \underline{N}_0 \int_0^1 \int_0^{\alpha_1} q_1 f\left(\alpha, \beta \middle| \alpha \leq \alpha_1\right) d\alpha d\beta + \overline{N}_0 \int_0^1 \int_{\alpha_1}^{\alpha_0} q_1 f\left(\alpha, \beta \middle| \alpha \leq \alpha_1\right) d\alpha d\beta \\ &= \underline{N}_0 \underline{\mu}_1^q + \overline{N}_0 \overline{\mu}_1^q = \underline{N}_0 \mu_1^q \end{aligned}, \qquad (18)$$

where we simplify the notation by writing $\alpha_0 \equiv \alpha^*(\beta, T_0)$, $\alpha_1 \equiv \alpha^*(\beta, T_1)$, $q_0 = q^*(\alpha, \beta, T_0)$, $q_1 = q^*(\alpha, \beta, T_1)$, and μ^q is the expected output. We also write the total quantity supplied by infra-marginal firms using an under-bar and the quantity supplied by extra-marginal firms with an over-bar. Note that $\overline{\mu}_1^q = 0$ because firms for which $\alpha_i \in (\alpha_1, \alpha_0]$ exit the market such that there output is zero after traceability is increased. The expected output of inframarginal firms is therefore equal to the expected output of firms still in the market after traceability is increased.

We can write from (17) and (18) that the change in total output is given by

$$dQ^* = \underline{N}_0 \left(\mu_1^q - \underline{\mu}_0^q \right) - \overline{N}_0 \overline{\mu}_0^q . \tag{19}$$

The first term on the right hand side of (19), in brackets, is the effect of traceability on the mean output of infra-marginal firms. That is, the effect of traceability on the output by firms who remain in the market. The second term on the right hand side of (19) is the effect of traceability at the extensive margin, which is always negative because firms exit the market.

To determine the effect of increased traceability on the output by firms at the intensive margin, take the total differential of the output by an infra-marginal firm i given by $q_i^* \left(\alpha_i, \beta_i, T, P\left(Q^*\right) \right)$

$$\frac{dq_i^*}{dT} = \frac{\partial q_i^*(.)}{\partial T} + \frac{\partial q_i^*(.)}{\partial P} \frac{\partial P}{\partial Q} \frac{\partial Q}{\partial T} . \tag{20}$$

The first term on the right side of (20) is the direct effect of traceability on the output caused by increased cost. This effect is always negative by assumption 1. The second term on the right side of (20) is the indirect effect of traceability on the output through a change in the price caused by a change in the total output. The price effect is positive if the total quantity, given by expression (19), goes down. The price effect is negative if the total quantity goes up.

Overall, the effect of traceability on the output of infra-marginal firms is undetermined. For some firms, increased traceability may cause them to increase their output because of the effect of increased price dominates the effect of increased cost. Other firms may choose to decrease their output following an increase in the degree of traceability.

Even though the effect of increased traceability on the output of individual firms in undetermined, the effect on the total output is always negative. We will not derive an expression for the change in the total output here but the following argument should suffice. Consider that the total output goes up following increased traceability. This implies that the price goes down. In such case, expression (20) is always negative meaning that all infra-marginal firms decrease their output: a contradiction. Thus, total output must go down and the price must go up after traceability is increased.

Effect of traceability on food safety

In assumption 2 we state that increased traceability increases the safety of food. Moreover, we have showed that a higher price causes firm to increase the safety of their food. These results apply only for infra-marginal firms. Whether food is made safer after traceability is increased is not as obvious as it first may seem. An analysis of the effect of traceability on food safety must take into account that the firms exiting the market might be those that delivered the safest food. Thus, even though infra-marginal deliver safer food after traceability is increased, the overall safety of food may decrease because of firms exiting the market.

Recall that the safety of food delivered by individual firms is measured as the probability that one unit of food is safe. The same probability applies to all the food delivered by a firm. However, the same probability does not apply to all food on the market because firms are not identical. Thus, we will measure the safety of all food as the expected probability that one unit of food is safe given that it is not possible to observe which firm delivered that unit of food. We denote the expected safety of a food product as the quantity weighted sum of the safety of food delivered by individual firms

$$E\left[s(T)\right]=\int_0^1\int_0^{\alpha^*(\beta_i,T)} s^*(\alpha,\beta,T)\frac{q^*(\alpha,\beta,T)}{\mu^q} f\left(\alpha,\beta\middle|\alpha\le\alpha^*(\beta,T)\right)d\alpha d\beta .$$

The expected safety of food depends on the quantity of food delivered by a firm relative to other firms, q^*/μ^q, and the density function f accounts for the likelihood of observing a pair (α,β). If f is a uniform distribution, it equals $1/N$ and the weight given to each firm food safety is its market share given by $q^*/N\mu^q$.

We can write that the change in the safety of food from increased traceability is given by

$$\begin{aligned} ds^*(T) &= E\left[s(T_1)\right]-E\left[s(T_0)\right] \\ &= \int_0^1\int_0^{\alpha_1}\left(\frac{s_1q_1}{\mu_1^q} f\left(\alpha,\beta\middle|\alpha\le\alpha_1\right)-\frac{s_0q_0}{\mu_0^q} f\left(\alpha,\beta\middle|\alpha\le\alpha_0\right)\right)d\alpha d\beta \qquad (21) \\ &\quad -\int_0^1\int_{\alpha_1}^{\alpha_0}\frac{s_0q_0}{\mu_0^q} f\left(\alpha,\beta\middle|\alpha\le\alpha_0\right)d\alpha d\beta, \end{aligned}$$

where $s_0=s^*(\alpha,\beta,T_0)$ and $s_1=s^*(\alpha,\beta,T_1)$. For convenience, we can rewrite (21) in terms of means and covariance. To this end, note that we can write

$$f\left(\alpha,\beta \middle| \alpha \le \alpha_0\right) = \frac{f\left(\alpha,\beta\right)}{F\left(\alpha \le \alpha_0\right)} = \frac{F\left(\alpha \le \alpha_1\right)}{F\left(\alpha \le \alpha_0\right)} \frac{f\left(\alpha,\beta\right)}{F\left(\alpha \le \alpha_1\right)} = \frac{\underline{N}_0}{N_0} f\left(\alpha,\beta \middle| \alpha \le \alpha_1\right).$$

Similarly, we can also write that

$$f\left(\alpha,\beta \middle| \alpha \le \alpha_0\right) = \frac{f\left(\alpha,\beta\right)}{F\left(\alpha \le \alpha_0\right)} = \frac{F\left(\alpha_1 \le \alpha \le \alpha_0\right)}{F\left(\alpha \le \alpha_0\right)} \frac{f\left(\alpha,\beta\right)}{F\left(\alpha_1 \le \alpha \le \alpha_0\right)} = \frac{\bar{N}_0}{N_0} f\left(\alpha,\beta \middle| \alpha_1 \le \alpha \le \alpha_0\right).$$

Making use of these two expressions, we can rewrite (21)

$$ds^*\left(T\right) = \frac{E\left[s_1 q_1 \middle| \alpha \le \alpha_1\right]}{\mu_1^q} - \frac{\underline{N}_0}{N_0} \frac{E\left[s_0 q_0 \middle| \alpha \le \alpha_0\right]}{\mu_0^q} - \frac{\bar{N}_0}{N_0} \frac{E\left[s_0 q_0 \middle| \alpha_1 \le \alpha \le \alpha_0\right]}{\mu_0^q}. \tag{22}$$

Finally, it is more instructive to write (22) using the fact that $E\left[sq\right] = \sigma^{q,s} + \mu^q \mu^s$

$$ds^*\left(T\right) = \mu_1^s - \frac{\underline{N}_0}{N_0} \underline{\mu}_0^s \frac{\underline{\mu}_0^q}{\mu_0^q} - \frac{\bar{N}_0}{N_0} \bar{\mu}_0^s \frac{\bar{\mu}_0^q}{\mu_0^q} + \frac{\sigma_1^{q,s}}{\mu_1^q} - \frac{\underline{N}_0 \underline{\sigma}_0^{q,s}}{N_0 \mu_0^q} - \frac{\bar{N}_0 \bar{\sigma}_0^{q,s}}{N_0 \mu_0^q}, \tag{23}$$

where $\sigma^{q,s}$ is the covariance between the output and the safety of food and μ^s is the expected safety of food. Again, we use over-bars and under-bars to identify infra-marginal and extra-marginal firms. For instance, in (23), $\underline{\mu}_0^q$ represents the expected safety of food by an infra-marginal firm before traceability is increased.

We can rearrange expression (23) to gain insights of the effect of traceability on the safety of food

$$ds^*\left(T\right) = \mu_1^s - \underline{\mu}_0^s + \frac{\bar{N}_0}{N_0} \frac{\bar{\mu}_0^q}{\mu_0^q}\left(\underline{\mu}_0^s - \bar{\mu}_0^s\right) + \frac{\sigma_1^{q,s}}{\mu_1^q} - \frac{\underline{N}_0 \underline{\sigma}_0^{q,s}}{N_0 \mu_0^q} - \frac{\bar{N}_0 \bar{\sigma}_0^{q,s}}{N_0 \mu_0^q},$$

where we simplify using the fact that $\mu_0^q = \frac{\underline{N}_0}{N_0} \underline{\mu}_0^q + \frac{\bar{N}_0}{N_0} \bar{\mu}_0^q$ and that $\frac{\underline{\mu}_0^q}{\mu_0^q} = \frac{N_0}{\underline{N}_0} - \frac{\bar{N}_0}{\underline{N}_0} \frac{\bar{\mu}_0^q}{\mu_0^q}$. Let us further simplify by assuming that the covariance between the output and the safety of food is the same before and after traceability is increased such that $\sigma^{q,s} = \sigma_1^{q,s} = \underline{\sigma}_0^{q,s} = \bar{\sigma}_0^{q,s}$. We can therefore write

$$ds^*\left(T\right) = \mu_1^s - \underline{\mu}_0^s + \frac{\bar{N}_0}{N_0} \frac{\bar{\mu}_0^q}{\mu_0^q}\left(\underline{\mu}_0^s - \bar{\mu}_0^s\right) + \frac{\sigma^{q,s}}{\mu_0^q \mu_1^q}\left(\mu_0^q - \mu_1^q\right) \tag{24}$$

Expression (24) shows that the change in food safety from increased traceability is explained by the effect of traceability on the mean food safety by infra-marginal firms, $\mu_1^s - \underline{\mu}_0^s$, the effect of extra-marginal firm quitting the market, $\left(\bar{N}_0\bar{\mu}_0^q / N_0\mu_0^q\right)\left(\underline{\mu}_0^s - \bar{\mu}_0^s\right)$, and a correction to account for the fact that firms are not the same size after traceability is increased, $\left(\sigma^{q,s} / \mu_0^q\mu_1^q\right)\left(\mu_0^q - \mu_1^q\right)$.

The direct effect of traceability on the safety of food by infra-marginal firms is given by the difference in the mean of the safety of food delivered by infra-marginal firms before and after traceability is increased, $\mu_1^s - \underline{\mu}_0^s$. We can find the sign of the difference between $\underline{\mu}_0^s$ and μ_1^s by taking the total differential of the safety of food supplied by infra-marginal firms given by $s_i^*\left(\alpha_i, \beta_i, T, P\left(Q^*\right)\right)$. The effect of traceability on the safety of food by infra-marginal firms is given by

$$\frac{ds_i^*}{dT} = \frac{\partial s_i^*(.)}{\partial T} + \frac{\partial s_i^*(.)}{\partial P}\frac{\partial P}{\partial Q}\frac{\partial Q}{\partial T} \geq 0, \tag{25}$$

where the sign follow from the signs in (12) and (16). Expression (25) says that all infra-marginal firms increase the safety of their food after traceability is increased. This implies that $\mu_1^s - \underline{\mu}_0^s > 0$.

Increased traceability also affects food safety because it causes firms to exit the market. In expression (24), this effect is given by $\left(\bar{N}_0\bar{\mu}_0^q / N_0\mu_0^q\right)\left(\underline{\mu}_0^s - \bar{\mu}_0^s\right)$. The firms that exit the market may be those that deliver the safest food. In such case, $\underline{\mu}_0^s - \bar{\mu}_0^s < 0$, and increased traceability causes the safest food supplier out of the market contributing to reduce the safety of food. On the opposite, traceability can make food safer by pushing unsafe food suppliers out of the market such that $\underline{\mu}_0^s - \bar{\mu}_0^s > 0$. Our model shows that large firms tend to deliver safer food such that it is likely that we would observe in practice that $\underline{\mu}_0^s - \bar{\mu}_0^s > 0$. But it is possible that we observe that $\underline{\mu}_0^s - \bar{\mu}_0^s < 0$ if α and β are (very) negatively correlated. However, the exit of firms will tend to have a small effect on the safety of food. The size of the effect depends on the share of total output by extra-marginal firms before traceability is increased, $\bar{N}_0\bar{\mu}_0^q / N_0\mu_0^q$. Given that firms that exit the market are small and that it is likely that a small share of firms quit the market following the increased in traceability, then the effect of firms exiting the market on the safety of food is small.

The third effect accounts for the fact that the mean size of firms changes following the increase in traceability. The term $\left(\sigma^{q,s}/\mu_0^q\mu_1^q\right)\left(\mu_0^q-\mu_1^q\right)$ in (24) corrects for firms mean size before and after traceability is increased. The sign of this effect depends on the change in the mean of quantity of food delivered by a firm and the sign of the covariance between the quantity supplied and food safety. We must consider four cases: 1) $\sigma^{q,s}>0$ and $\mu_0^q-\mu_1^q>0$; 2) $\sigma^{q,s}<0$ and $\mu_0^q-\mu_1^q>0$; 3) $\sigma^{q,s}>0$ and $\mu_0^q-\mu_1^q<0$; and 4) $\sigma^{q,s}<0$ and $\mu_0^q-\mu_1^q<0$. In case 1) and 4) the correction is positive while in cases 2) and 3) the correction is negative.

The sign of the change in the mean output by firms is undetermined. On one side, the mean output increases because small firms quit the market and the price increases. On the other side, traceability is costly and reduces the output of firms remaining in the market. The situation where $\mu_0^q-\mu_1^q>0$ is more likely when: 1) there is little variance in the size of firms such that increased traceability drives a few firms out of the market and 2) the cost of traceability affects the marginal cost of output by more than the effect of increased price. Conversely, $\mu_0^q-\mu_1^q<0$ is more likely when the firm size variance is large such that many small firms exit the market and only large firms remain despite that increased traceability affects marginal cost of output.

The sign of the covariance between the output and the safety of food is also undetermined. Recall that α is an efficiency parameter for the output and β is an efficiency parameter for the safety of food. Expression (8) shows that a smaller α is associated with safer food while expression (9) shows that smaller β is associated with a larger output. This implies that even if α and β are negatively correlated, q and s can still be positively correlated. If α and β are not negatively correlated, then q and s are always positively correlated. Output will be positively correlated with the safety of food only when correlation between α and β is very much negative.

Given that the covariance is likely to be greater than zero, case number 1 and number 3 above are the most likely. Moreover, the size of correction should be small given that the mean size of firms will not be affected by much by increased traceability.

Overall, the change in the weighted mean food safety will be dominated by the un-weighted change in the mean of food safety, which is positive. The effect of firms exiting the market and the correction can be negative but these two effects should be small compared to the un-weighted change in the mean of food safety. This is especially true if traceability drives only a few firms out of the market. We therefore conclude that in most cases, provided that assumption 1 and assumption 2 hold, increased traceability increases the safety of food.

Welfare effects of traceability

We showed above that food that the price of food increases and that food is likely made safer after traceability is increased. We ask in this section what are the effects of traceability on consumers' welfare and on firms' profits?

Consumers' welfare

In our model, consumers are oblivious of the consequences of unsafe food implying that the safety of food does not affect consumption. However, this does not means that consumers are not affected by tainted food. In the following calculations of consumers' welfare, we will take into account the effect of foodborne illness on consumers' foregone income.

Consider the following quasi-linear utility function

$$U\left(x, y\right) = y + h\left(x\right), \tag{26}$$

where x is the consumption of food and y is a numéraire good. The consumer budget constraint is given by

$$W = I - y - px - \tilde{x}\left(1-s\right)\left(TB_C + \left(1-T\right)B_{NC}\right), \tag{27}$$

where I is the available income and p is the price of x. Our assumption that consumers are oblivious to food safety when making their consumption decision does not imply that consumers are not affected by the consumption of unsafe food. In (27), we incorporate the assumption that consumers are oblivious to the safety of food but that they are financially affected by tainted food by distinguishing between x and $\tilde{x}$. The variable x is the actual consumption decision made by the consumers while the variable $\tilde{x}$ represents how the consumption of unsafe food affects the available income. Consumers are oblivious in the sense that they do not recognize that $x = \tilde{x}$ and that the consumption of food may lead to health related expenses.

One unit of food makes a consumer sick with probability $1-s$. In the event of foodborne illness, a consumer must incur costs for medical treatments or other costs related to pain and discomfort. The consumer may also loose income from missing time at work. If traceability allows the consumer to obtain compensation with probability T from the food supplier, the net cost to the consumer is B_C. However, if traceability to the firm of origin is not successful with probability $1-T$, the consumer incurs a cost B_{NC}. Of course, the cost to the consumer from unsafe food is larger when the consumer does not receive compensation, $B_{NC} > B_C$. It is possible that the compensation awarded to a consumer is larger than the actual cost to the consumer. In such case, the net cost to the consumer is negative, $B_C < 0$.

In the case of a quasi-linear utility function such as the one in (26), the consumption of x is implicitly given by

$$h'\left(x^*\right) = p,$$

where x^* denotes the consumption of food that maximizes the utility of the consumer. Given the assumption of a quasi-linear utility function, the consumption of food is not a function of the income. This is consistent with many food products for which the income elasticity is small. Here, income affects only the consumption of the numéraire good. One consequence of this is that the compensated and the uncompensated demand are the same such that we can write that $x(p,I) = h(p,U) = x(p)$. Also, note that the consumption of food is not a function of the expected cost associated to foodborne illness as consumers are oblivious to food safety.

The utility maximization problem of consumers in this model can be thought of as a two-stage process. In the first stage, consumers maximize their utility by equating the marginal utility of food to the price. Then in the second stage consumers allocate their remaining income, if any, net of expenses related to the consumption of unsafe food to the consumption of the numéraire good. We will assume that consumers always have an income sufficiently large to allocate resources to the consumption of goods other than food. Thus, given the solution for the consumption of food, we find that the consumption of the numéraire good is

$$y^* = I - x^*(1-s)\left(TB_C + (1-T)B_{NC}\right) - px^*. \tag{28}$$

We do not make the difference in (28) between x and $\tilde{x}$ as they are both equal x^* in the calculation of the income remaining for the consumption of y. The expected consumption of the numéraire good depends on the income I, the expected expenses related to unsafe food $x^*(1-s)\left(TB_C + (1-T)B_{NC}\right)$ and the expenses in food px^*.

Let us now consider how a change in the traceability of food affects consumers. We are interested in finding the change in the income that would yield the same utility as would a given increase in traceability and the related change in the safety of food. We therefore calculate the equivalent variation

$$EV = e\left(p_0, s_0, T_0, U_1 \right) - e\left(p_0, s_0, T_0, U_0 \right),$$

where $e(\ )$ is the expenditure function. Again, we use a subscript 0 to identify variables before traceability is increased and use a subscript 1 to identify variables after traceability is increased. The equivalent variation compares the expenditure at the price, food safety and traceability for the levels of utility before and after traceability is increased. The expression for the equivalent variation simplifies to

$$EV = y\left(p_0, s_0, T_0, U_1 \right) - y\left(p_0, s_0, T_0, U_0 \right).$$

From that expression, using (28) we can write

$$EV = x\left(p_1 \right)\left(1 - s_1\right)\left(T_1 B_C + \left(1 - T_1\right) B_{NC} \right) - x\left(p_0 \right)\left(1 - s_0\right)\left(T_0 B_C + \left(1 - T_0\right) B_{NC} \right). \qquad (29)$$

That is, the equivalent variation is given by the difference between the total expected expenses related to unsafe food.

Increased traceability will cause consumer welfare to increase most of the time given that food is made safer by increased traceability most of the time. First, the increase in price of food causes lower consumption of a food product that is potentially unsafe. Remember we showed that the effect of increased traceability on the total output is always negative causing the price of food to always increase when traceability is increased. This implies that $x\left(p^0\right) > x\left(p^1\right)$. Therefore, the increase in price causes consumers to substitute food for the numéraire good that is always safe. Second, the unsafe food product is made safer is most cases. Recall that it is possible that small firms that supply the safest food exit the market when traceability is increased causing the safety of food to go down. Let us consider for now the case where increased traceability increases food safety such that $\left(1 - s^0\right) > \left(1 - s^1\right)$. Third, consumers are more likely to be compensated in the event of foodborne illness. Because traceability increases, the expected cost to the consumer of an unsafe unit of food decreases such that $T^0 B_C + \left(1 - T^0\right) B_{NC} > T^1 B_C + \left(1 - T^1\right) B_{NC}$. Together, the results for the consumption of food, the safety of food and the expected compensation for eating unsafe food imply that the consumer welfare in (29) is always increases when traceability is increased make food safer.

Our model suggests that one driver of the increase in consumer's welfare is a result of the cost of traceability pressuring the price of food up. This result holds because of two assumptions. First, consumers are oblivious to food safety and therefore the demand does not shift up when food becomes safer. Because traceability is costly, then the price of food always goes up and the quantity demanded goes down. Second, our model assumes that the numéraire is perfectly safe. If consumers were to substitute for another food product that is less safe, then increased traceability would not always increase consumer's welfare.

In the case where traceability does not make food safer, then increased traceability can increase or decreased consumers' welfare. The sign of the change in consumer's welfare depends on the size of the change in the safety of food, which has a negative effect on welfare, compared to the changes in consumption and compensation when foodborne illness occurs, which have positive effects on welfare.

Firms' profit

The effect of traceability on the total profit of individual firms is undetermined. Some firms, by being driven out of the market are of course worse off after traceability is increased. Other firms that stay in the market are also worse off because traceability increases their average cost by more than the increase in the price of food. However, other firms benefit from increased traceability because the price increase dominates the effect of traceability on their average cost.

The sign of the change in the total of firms' profit from increased traceability is undetermined. The sum of all firms' profit may increase if increased traceability induces the total output closer to the output for the industry acting as a cartel. We do not derive in this paper the conditions for the total profit of the industry to increase and refer the reader to Pouliot and Sumner (2009).

Summary and conclusion

This paper analyses of the effects of increased traceability on the quantity and the safety of food using a new framework where firms' heterogeneity arises from differences in the cost of output and the cost of producing safe food. This contrasts with previous research where firms' heterogeneity is modeled in one parameter space. An advantage of our model is that it allows us to model the relationship between the cost of food safety and the cost of output. For instance, we can consider the cases where firms are distributed such that the cost of producing safe food is negatively, positively or non correlated with the cost of producing a lot of food. Our model shows that for a given cost efficiency of producing safe food, the food delivered by large firms is safer than the food delivered by small firms. Thus, even though the cost of producing safe food is negatively correlated with the cost of producing a large quantity of food, the quantity of food produced by a firm may be positively correlated with its safety. This means that even thought the marginal cost of food safety is safe is smaller for a small firm compared to a large firm, the large firm may still be the one that delivers the safest food.

We show the impacts of increased traceability on the output and the safety of food. Increased traceability causes some firms to exit the market through an increase in the minimum average cost. Under reasonable assumptions, the total quantity of food marketed goes down after traceability is increased. Firms that remain in the market increase the safety of their food. Still, the overall food safety, defined as the expected safety of one unit of food, may go down after traceability is increased. That case is possible if many small firms that produce the safest food exit the market after traceability is increased. However, we note that it is the most likely that the safety of food increases after traceability is increased.

Our model considers that consumers are oblivious to food safety and that they are not willing to pay a premium for traceability. We show that consumers' welfare is likely to increase when traceability is adopted in an industry where food is the least safe. Consumers' welfare always increases when traceability causes the safety of food to increase. In such case, consumers' welfare increases because: 1) the consumption of the unsafe food product goes down; 2) the food is made safer; 3) consumers are more likely to obtain compensation if they suffer from a foodborne illness. The total profit of firms is undetermined because traceability is costly but may cause the total output of the industry to move toward the cartel output.

The model in this paper offers potential to analyze many other questions. For instance, we will later verify if the theoretical results of Shaked and Sutton (1987) regarding market size and the supply of quality (food safety) hold in our framework. Moreover, our model has applications to the production of quality attributes other than food safety. Applications are particularly interesting when production costs differ for firms located in different areas. For example, our model could be applied to the market for grapes in California where high quality grapes are produced in region such as the Napa Valley and where low quality grapes are produced in Central Valley. Larger volume of grapes can be produced in Central Valley at a low cost while high quality grapes can be produced in Napa Valley. Other applications of our model include issues related to trade and the quality of products. The model could explain the quality differential between products from China and the United States and the quantity of products from those two countries.

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