Reputation, Quality Observability, and the Choice of Quality Assurance Systems

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Abstract

Participants in a supply chain of agricultural value-added products face significant challenges. Many of the costly distinctive traits desired by consumers are difficult (if not impossible) to observe even after consumption. A complicating factor, addressed here, is that in some circumstances delivered quality can only be imperfectly learned and/or affected stochastically by producers. Hence, both symmetric and asymmetric informational imperfections may be present. In order for markets for these classes of goods to arise, firms touting the quality of the product need to be trusted. A repeated-purchases model is developed to explore the fundamental economic factors that lie behind the choice of different quality assurance systems and their associated degrees of stringency by firms. Differences in the quality discoverability of a sought-after attribute, attractiveness of a market, and the value placed in the future are among the factors contributing to the implementation of widely diverse systems across participants in different markets. Close attention is paid to the role of reputations in providing the incentives for firms to deliver high-quality goods in an environment of symmetrically imperfect information.

Keywords: imperfect information, product quality, quality assurance, repeated purchases, reputations, supply chain, value-added agriculture.

REPUTATION, QUALITY OBSERVABILITY, AND THE CHOICE OF QUALITY ASSURANCE SYSTEMS

The keys to success in commodity agricultural production are expansion to obtain scale economies, specialization, and adoption of cost-reducing technologies (Hennessy, Miranowski, and Babcock 2004). Producers and processors of commodities remain viable by following the prescribed strategy of producing and marketing their goods as inexpensively as possible. The sustained race for cost reductions leads to an adoption spiral of increasingly investment-intensive, high-volume production technologies. Some entrepreneurs see an alternative path to profits by producing and marketing differentiated agricultural products. The feasibility of this path has increased with the growth in consumer demand for specialty high-quality goods.[1] Rising standards of living and increasing health and environmental awareness are frequently cited as forces driving the demand for a variety of higher-quality products and information about on-farm activities. The availability of new production technologies and information systems make it possible to supply the differentiated products that consumers are increasingly demanding.

Participants in a supply chain of agricultural value-added products face significant challenges. Many of the costly distinctive traits desired by consumers are difficult (if not impossible) to observe even after consumption.[2] Quality may be difficult to appraise, even for producers or processors. Hence, both symmetric and asymmetric informational imperfections may be present (see Antle 2001). In order for markets for these classes of goods to arise, firms touting the quality of the product need to be trusted. Hence, maintaining an excellent reputation is essential for firm success. A complicating factor, addressed here, is that in some circumstances delivered quality can only be imperfectly learned and/or affected stochastically by producers. For example, even after using the best genetics available and following best management practices to obtain tender beef, it is possible that the resulting beef is not tender. Also, elevators cannot be absolutely certain that the grain they handle contains the claimed traits. The list of examples is long.

New quality assurance systems (QASs) are being put in place to facilitate the flow of information about agricultural and food products. Incentives for growers and food manufacturers to adopt QASs include (*a*) increased consumer demand for knowledge about where their food came from and how it was produced; (*b*) opportunities for producer groups to capture a greater share of the consumer dollar by differentiating their products; (*c*) greater protection for food manufacturers and retailers against food safety liability; and *(d)* increased chances that agreed upon specifications are met in a framework of imperfect information.

Various QASs have been developed in the United States and elsewhere to facilitate the flow of information about products (Bredahl et al. 2001; Reardon and Farina 2001; Lawrence 2002; Carriquiry, Babcock, and Carbone 2003). In the United States, some have been developed purely by the private sector, while others have relied on the U.S. Department of Agriculture (USDA) to set standards. But what constitutes a proper mix of public and private efforts in setting up QASs is an unsettled question. A better understanding of private sector incentives for setting up such systems will help clarify what role the public sector might have in establishing and enforcing standards. We contribute to this understanding by modeling the optimal degree of "stringency" or assurance in a processor's quality control system over procurement of agricultural output when uncertainty about quality exists. More specifically, we study the role of reputational mechanisms in providing incentives to implement QASs. We compare the resulting degrees of stringency across different levels of consumer awareness or quality discoverability.

The role of reputations as a deception-preventing device has been studied by Klein and Leffler (1981) and Shapiro (1983), among others. These authors examine a situation in which the resulting quality is completely determined by a producer's investments. The only study (we are aware of) that considers the case in which investments lead to higher expected quality (stochastically) in an environment of symmetrically imperfect information is by Rob and Sekiguchi (2001), who consider the producer-consumer interface. In their study, consumers "discipline" firms by switching to rival firms when quality is below certain tolerance levels and only one firm is able to make sales. We depart from that study by exploring the effects of different levels of quality discoverability on the choice of investments in quality assurance by a single firm that we model as a monopolist. The focus of this paper is on an arbitrary link of a supply chain.

Noelke and Caswell (2000) propose a model of quality management for credence attributes in a supply chain. Based on a literature review, the authors discuss benefits and costs of a voluntary, quasi-voluntary, and mandatory quality management system (QMS) for a firm within a supply chain. They then provide some comparative static results on how the behavior of the firm (given by the choice of a QMS) changes when other firms upstream or downstream modify their QMS under different tort laws. In our model, the firm under consideration is the one that has influence on the behavior of firms upstream in the supply chain. We also make the probability that a firm is punished dependent on the ability of consumers to discern when quality is substandard. Hence, our model accommodates credence, experience, and mixtures of the two types of goods.

We include both process control, where verification of certain production methods are to be followed, and control over a physical attribute of the input. The model developed here predicts that the degree of stringency and the output rate depend on (*a*) whether the sought-after attribute is discoverable by consumers; (*b*) the price premium paid for the attribute; and *(c)* the punishment capabilities of downstream customers, which are related to the value firms place in the future.

The next section provides an overview of the related literature, a detailed discussion of the situation studied, and the model presentation and analysis.

Modeling Quality Assurance

The two decisions modeled are the profit-maximizing rate of output and whether a buyer of an input should implement a QAS as a way to gain information about product quality that can be provided to its potential customers. If the buyer decides to implement a QAS, then the profit-maximizing level of assurance is determined.[3] We study a particular case that is becoming pervasive in the food industry (Caswell, Bredahl, and Hooker 1998; Reardon and Farina 2001; Northen 2001; Fearne, Hornibrook, and Dedman 2001), in which an input buyer requires its suppliers to implement a given system of assurance. To do so, the buyer has to be an important player in the market (Reardon and Farina 2001). This would be the case of a quasi-voluntary system (Caswell, Bredahl, and Hooker

1998; Noelke and Caswell 2000). To keep the framework general, we are not specifying the “type” of quality assurance strategy that an input processor will follow. For example, assurance potentially can come from a system run by the buyer, from reliance on certification by a private or public third party, or both. The information obtained through the implementation of the system allows the processing firm to better sort the input it buys, to gain a better idea of the actual quality of the inputs, and to be able to convey assurance to its customers about the quality of its product. The topic of this paper is especially relevant in an environment where it is difficult to assert the quality of a particular product (both before and after the input is processed and consumed). Clearly, if quality is readily observable by both input buyers and consumers, there is no need for a QAS in the procurement process.

Quality characteristics of agricultural products have an inherently high degree of heterogeneity (Ligon 2002). This variability stems mainly from the randomness of the production environment (e.g., weather and biological uncertainty) and/or the heterogeneity of the practices employed by farmers. We aim to capture this variability, and the fact that quality can be only imperfectly assessed, by assuming that the processor believes it can be represented by a random vector Q. Specifically, let Q denote the vector of the imperfectly observable array of quality attributes, and let $\mathbb{Q}$ denote the set of possible quality attributes of an input. In general, $\mathbb{Q}$ could be a set in many dimensions. However, for the sake of tractability, we will assume that only one quality attribute is of interest, is imperfectly observable, or differs across goods. In this case, the sample space of interest is one-dimensional (i.e., $\mathbb{Q} \subseteq \Re^1$). Further, we assume that the unconditional cumulative distribution function of Q is $F_Q(q) = \mathrm{P}_Q(Q \leq q)$ for all q.[4] This distribution of quality would prevail in the absence of a QAS or in the open market.

We define quality as meeting an agreed-upon standard. Every unit of the product meeting or surpassing this minimum standard will be considered of high quality. Caswell, Noelke, and Mojduszka (2002, p. 58) also define quality in a supply chain as consistently delivering a product that meets or exceeds “defined sets of standards for extrinsic indicators and cues.” The task of the processors is to decide which QAS to implement (if any) to better infer the nature of the product being certified. In particular, the QAS will inform the processor about the proportion of the input that is likely to deliver a product that meets the minimum standard. Note, however, that the processor will not be able to discern the difference in quality of any given unit it actually buys. We assume that the quality of the processed output has a direct relationship to its input counterpart, an assumption that is equivalent to claiming that the processing technology cannot be used as a substitute for input quality, or that it does so only at prohibitively high costs. We assume also that there is a one-to-one correspondence between the amount of input bought and output sold by a processor. Hence, the production technology works in a Leontief fashion, and the decision on the output rate essentially determines how much of the agricultural input is needed.

The proposed approach accommodates both the case in which the quality attribute or trait is the production method itself and the case in which the process alters the probability distribution of quality (i.e., the costlier process increases the probability of obtaining a high-quality product). The former has an analog to a discrete attribute (the good was produced using a desired process or it was not), whereas quality in the latter case is a continuous random variable whose distribution is altered by the process followed. The interpretation of the continuous case is straightforward. Let q^M be the minimum acceptable quality to be considered good quality (or with desirable properties for good performance at the processing stage, or to deliver a good eating experience). In this case, q^M divides the range of the random variable Q into two subsets defined in $\Re^1$, namely, $q^L = \{q \in \mathbb{Q} : q \le q^M\}$ and $q^H = \{q \in \mathbb{Q} : q \ge q^M\}$. Hence, $F(q^M) = P_Q(Q \in q^L)$ would be the unconditional probability that the product is inferior or unacceptable. A product that is deemed inferior receives a lower price than that certified as being high quality. This interpretation is akin to attributes such as the tenderness of a steak, where q^M would be some acceptable degree of tenderness, or to food safety, where q^M would be interpreted as the count of pathogens[5] that makes a particular food item unsafe.[6]

The discrete case can be analyzed in a similar way. Strictly speaking, here the input has or fails to have a particular attribute or was or was not produced following a value-adding (cost-increasing) production process. For example, milk used by some companies was produced with or without treating milking cows with genetically engineered hormones such as rBST (recombinant bovine somatotropin). Also, eggs can be produced using animal welfare[7] enhancing techniques (e.g., free-range production) or by conventional means. Poultry is or is not fed with animal protein. Crops can be grown conventionally or using environmentally friendly practices (e.g., minimum tillage).

However, to unify the analysis, we will differentiate by class of production practice. For example, in the case of animal welfare, we will consider a product to be of high quality if the production facilities meet a minimum set of amenities or if certain practices, such as forced molting of egg-laying hens, are avoided. Another example would be the intensity of the soil conservation practices employed. A different interpretation of Q is needed to tackle this type of attribute. Let $\mathbb{Q}$ be the set of all production practices "bought" by the input-processing firm. The natural variability here would come from the heterogeneity of farmers. Implicit here is the idea that the firms will buy from producers and certify the product if they believe the input was produced following a process that meets or surpasses some minimum standard (more on this to follow). Hence, $\mathbb{Q}$ would represent the set of all input procured from producers who have the capabilities needed to produce, and are believed to produce, following the desired processes. The clarification is important because having the capabilities does not necessarily mean that the process will be strictly followed under conditions of imperfect information.[8] A problem of moral hazard arises here. Because production of the high-quality input is costlier than production for a commodity market, and there is a strictly positive probability that deviant behavior will not be discovered and penalized, suppliers will find it rational to deviate from perfect compliance.[9,10] Hence, there is a strictly positive fraction of the output that will not be produced under the desired cost-increasing conditions. This fraction is again represented by $F_Q(q^M)$.

The preceding discussion suggests that there are two different types of uncertainties associated with the attribute under consideration. In the discrete case, the uncertainty is mainly about the opportunism of the suppliers, whereas the continuous case also entails the uncertainty derived from the randomness associated with agricultural processes that generate a distribution of qualities for any given set of production practices.

In terms of quality, the choice of the firm is on the QAS and the associated stringency of controls. Suppose there is a set of alternative systems denoted by

$S = \left\{ s \in \Re : 0 \le s \le s^U \right\}$, where $s = 0$ represents the absence of quality verification (reliance on claims made by suppliers), and $s = s^U$ is a situation in which the quality of the product is perfectly revealed (e.g., perfect monitoring, vertical integration, or a good system of incentives). In the absence of a QAS, the processor rationally expects to obtain an input of "average" quality from the market for raw materials. When $s = s^U$ is chosen, note that the actual quality of a given unit of input will be perfectly revealed only on the discrete case; in the continuous case, even the most stringent system available still leaves the uncertainty derived from the randomness of the production environment and attributable to scientific ignorance over biological processes. However, in the continuous case, a more stringent system potentially has the double effect of increasing the proportion of compliers and the probability of being in the set q^H.

In short, a processor procuring raw materials from certified suppliers (using the QAS indexed by *s*) expects to buy a fraction of good-quality input, denoted by $\lambda(s) = 1 - F\left(q^M \middle| s\right)$. Also, a fraction $1 - \lambda(s) = F_Q\left(q^M \middle| s\right)$ of the inferior input is expected because of the informational imperfections noted earlier. Here, we consider the QAS as aiding in the selection of which input to buy. All inputs bought (and hence certified) will be subjected to the production activity and sold to downstream customers as possessing the desired trait.[11] The case where $s = 0$ (absent an assurance effort) will result in the processor buying an input that is expected to have average market quality. To put it concisely, $\lambda(0) = 1 - F\left(q^M \middle| 0\right) = 1 - F\left(q^M\right)$. Alternatively, if the input were going to be bought anyway, the QAS would be functioning as a sorting device that allocates the input either to the commodity or to the high-quality market (or production process). In this case, the QAS tells the processor how much a unit of the input is worth to him, just as an imperfect test does (Hennessy 1996).

With this in place, we can focus on how to model the effects of a more stringent QAS on the overall quality of the product traded by the processor. For this purpose, we will use the concept of first-order stochastic dominance. Implementation of different levels of stringency switches the relevant distributions for quality as follows. For any $s^i, s^j \in S$ there is an associated conditional distribution for quality, namely, $F_Q\left(q \middle| s^i\right)$

and $F_Q\left(q\middle|s^j\right)$. In this context, increasing the level of stringency of the QAS, for example, by moving from s^i to s^j where $s^i \leq s^j$, leads to a first-order stochastically dominating shift on the distribution of quality. Therefore, we have that $F_Q\left(q\middle|s^i\right) \geq F_Q\left(q\middle|s^j\right)$ for all $q \in Q$. In particular, this implies that $\lambda\left(s^j\right) = 1 - F\left(q^M\middle|s^j\right) \geq 1 - F\left(q^M\middle|s^i\right) = \lambda\left(s^i\right)$. This can be interpreted as reducing the probability of incurring type I (rejecting an input that is of good quality[12]) and type II (certifying a product that is of low quality) errors. In short, systems that are more stringent increase the precision with which the actual quality of the input is asserted by processors. If we are willing to assume that $F_Q\left(q\middle|s\right)$ is differentiable with respect to *s*, the previous implies that $\partial\lambda\left(s\right)/\partial s \geq 0$.

However, the implementation of a QAS does not come without a cost. As noted before, the use of cost-increasing technologies has to be compensated for by processors. Complications arise, however, because the incentives of farmers and processors are not aligned, and the production practices used at the farm level are only imperfectly observed. Hence, processors may have to give up some information rent if they want to elicit production of high-quality inputs (or in the language of agency theory, a high level of effort from the principal's suppliers or agents). In other words, there are costs for monitoring and/or providing the incentives (e.g., premiums or discounts) to discourage dishonest performance on the part of input suppliers. We seek to capture those costs[13] through a cost function $C\left(s,y\right)$, which satisfies $\partial C\left(y,s\right)/\partial s > 0$, where y is the per period output rate.

The exposition from here on will be made in terms of processors and consumers. However, we could replace consumers by downstream firms to study issues within a supply chain. Consumers value both types of goods but value the high-quality good more and are willing to pay a premium for it. Because consumers can only assert the quality of a given product imperfectly, they must rely on the signals sent by the processors, in the form of quality certification.[14] Hence, we assume that consumers are willing to pay a price premium for a good that comes from a quality-assured process.

Putting all this together, the processor chooses the output rate, whether to participate in the market for quality-certified goods, and what level of certainty to obtain from the QAS or to direct its product toward the market for commodities. Clearly, the processor will implement a QAS as long as the benefits outweigh the costs of doing so.

Participation in the market for high-quality goods, using the QAS indexed by s, yields a per period profit of $\pi^{r}\left(y,s;a\right)=R\left(y;a\right)-C\left(y,s\right)$, where the revenue function $R\left(y;a\right)$ potentially depends on the firm's rate of output y and the strength of consumer preference for high-quality goods a. The superscript in the profit function represents the state of the world, where the processor has a reputation.

We could append a term to the profit function, representing the economic loss due to certifying a product that is of low quality. Several potential interpretations are possible for this loss. It could be the result of obtaining a bad reputation through some form of information dissemination or could occur just because the consumer will make future purchases from other processors. It also could be the result of legal action under the current tort law, applying mainly in the case of a food safety interpretation of the model. However, Caswell and Henson (1997) argue that this last effect is likely to be less important than the loss of reputation or market share. Therefore, the latter is the interpretation to which we adhere in this paper. The punishment for a processor that delivers a good of noticeable substandard quality is that it will lose consumers' trust and hence will be unable to sell its output in the market for value-added products in future periods. Note, however, that the processor obtains the price for the certified commodity no matter what the actual quality might be, because customers cannot assert a priori whether the claims made by the processor are false. In other words, processors will be trusted until proven wrong. Consumers' trust is what defines the states of the world in this model. For a given processor, demand is state contingent, where the states of the world reflect whether it is trusted by consumers or not. For this sort of punishment mechanism to have an impact on a firm's decisions, modeling more than one period is required (Klein and Leffler 1981).

Selling product into the market for commodities or non-differentiated products yields a quasi-rent of $\pi = 0$ independent of processors' reputations, since the market for the commodity is assumed perfectly competitive.

Optimal Choice of Quality Assurance Systems

We are now in a position to examine how fundamental characteristics of the economic environment influence decisions about the implementation of a QAS and the relative profitability of the competing markets or options, paying special attention to the discoverability of the sought-after quality attribute and the form of the punishment. Clearly, QASs will be observed if $E\left(\Pi^r\left(s,y\right)\right) \geq \pi = 0$ for some $s \in S$, and $y > 0$. That is, if there is a combination of output rate and QAS that makes the expected return of the value-added market to be positive, then the firm has an incentive to enter the value-added market. Throughout the analysis, we assume for mathematical convenience that there is a continuum of stringency levels from which to choose.

We introduce ω to parameterize the degree to which consumers can ascertain the actual quality of the good. It measures the ease with which quality is observed after consumption. For example, we could interpret $\omega \in [0,1]$ as the exogenous probability that a consumer discovers the true quality of the product. $\omega = 1$ implies that quality is perfectly observable after consumption, or the sought-after characteristic is an experience attribute. Credence attributes are represented by $\omega = 0$.

Recall that we assume processors will be trusted until proven wrong. Therefore, there are only two possible states of the world denoted by $r = 1, 2$. The first state denotes the periods where the processor has a good reputation, and hence faces a positive demand. In state two, the demand for the high quality product is zero. Since profits are zero in the second state of the world, the superscript of the per period profit function will be dropped here.

Let T denote the point in time where the processor loses its reputation (moves from the first to the second state). That is, T is the period in which consumers purchase a product that does not meet the standards promised and find out that this is the case. A processor that moves from state 1 to state 2 in period T has profits given by

$$\Pi\left(s,y\right) = \sum_{t=1}^{T} \beta^{t-1}\pi\left(y,s;a\right) = \pi\left(y,s;a\right)\sum_{t=1}^{T}\beta^{t-1} = \pi\left(y,s;a\right)\frac{1-\beta^T}{1-\beta}. \qquad (1)$$

As before, $\pi(\bullet)$ represents the per period profits of a processor that has a good reputation. Since it depends only on the state of the world, we can pull per period profits out of the summation. In equation (1), β is the relevant discount factor, a again denotes the size of the market for value-added products, and y and s represent the levels of output and QAS, respectively.[15] We assume that $\partial\pi / \partial a \geq 0$, i.e., per period profits increase as the demand for high-quality products strengthens. Again, profits are zero once the seller is forced out of the value-added market.

However, quality is random and the processor cannot exert perfect control over it. A processor can only affect the distribution of quality in the sense described earlier. Hence, it is not known when a processor will lose its reputation. The processor's expected profits are therefore

$$E\left(\Pi(y,s)\right) = E\left(\pi(y,s;a)\frac{1-\beta^T}{1-\beta}\middle| m(s,\omega)\right) = \pi(y,s;a)\frac{1-E\left(\beta^T \middle| m(s,\omega)\right)}{1-\beta},$$

where $m(s,\omega)$ denotes the probability that a processor with a QAS s in place will stay in the value-added market for a trait with discoverability ω. In particular, note that the probability of staying in the market or keeping a consumer's goodwill for two successive periods, $m(s,\omega) = \lambda(s) + \left(1-\lambda(s)\right)(1-\omega)$, combines the probability that resulting quality is high with the probability of type II error weighted by the consumer's level of awareness.[16] A processor will face a zero demand in the second period with probability $1-m(s,\omega)$.

To make further progress, we need an expression for $E\left(\beta^T \middle| m(s,\omega)\right)$. Note that *T* is just counting the number of periods until the first notorious (discovered) failure. Since the outcome in a given period is independent of the outcome of other periods, *T* is the number of Bernoulli trials required to get the first failure. This is just the description of a geometric random variable with "success" probability $1-m(s,\omega)$. The previous observation allows us to obtain the required expression as

$$E\left(\beta^{T}\left|m(s,\omega)\right.\right)=\sum_{t=1}^{\infty}\beta^{t}\Pr(T=t)=\sum_{t=1}^{\infty}\beta^{t}m(s,\omega)^{t-1}\left(1-m(s,\omega)\right)=\frac{\left(1-m(s,\omega)\right)\beta}{1-\beta m(s,\omega)}.$$

Substituting this back, we see that the processor expected profits are

$$E\left(\Pi(y,s)\right)=\frac{\pi(y,s;a)}{1-\beta m(s,\omega)}.$$

Suppose first that the choice of the output rate is independent of the optimal QAS. This may be the case where output and safety are nonjoint in inputs (see Chambers, 1989), or when investments in QAS do not depend on the rate of output. The choice of output in this case is the standard monopolist profit maximization problem. To focus on the selection of stringency of controls, we assume that processors only procure and sell one unit of the good (or the optimal and independently chosen y^*, which is fixed here). The problem then reduces to the choice of investments in QAS that maximizes profits as follows:

$$\max_{s\in S}E\left(\Pi(1,s)\right)=\max_{s\in S}\frac{\pi(1,s;a)}{1-\beta m(s,\omega)}.$$

A quick look at this problem reveals that the easier it is for a processor to acquire information about quality (i.e., the cheaper it is to implement a QAS that yields a given level of certainty about quality), the more likely it is that a QAS will be implemented. A rising price premium also would increase the likelihood that there exists a profitable QAS. The first-order condition with respect to s is

$$\frac{\partial E\left(\Pi(1,s)\right)}{\partial s}=\frac{\partial\pi(1,s;a)}{\partial s}\left(1-\beta m(s,\omega)\right)+\pi(1,s;a)\beta\frac{\partial m(s,\omega)}{\partial s}\leq 0 \qquad (2)$$

with equality if $s^*>0$. Note that $\frac{\partial\pi(1,s;a)}{\partial s}=-\frac{\partial C(1,s)}{\partial s}$. The second-order sufficient condition (*S.O.S.C.* presented in the appendix) is assumed to hold.

Equation (2) has the usual interpretation. It states that the level of stringency should be increased until the marginal benefits of increased stringency equal the marginal costs. Marginal benefits of an increase in s equals the change in the proportion of purchases that are of high quality multiplied by the probability that low-quality output will be discovered,[17] the per period profit rate, and a factor that takes into account the multi-period nature of the problem at hand. The marginal benefits of increased assurance rise as the quality of the good is more readily observable by the processor's customers, and as the potential punishments for false certification become more severe. Switching to the second state of the world is a harsher punishment when per period profits are high and the future is important to the processor. The marginal cost of an increase in *s* is simply the increase in costs that must be incurred to implement a more stringent QAS.

In this problem it is straightforward to show that the optimal level of investments in quality assurance is unambiguously increasing in the size of the market (or strength of the demand for value-added products) and the value processors place in the future. These comparative statics can be represented by

$$\frac{\partial s^*}{\partial a} = -\frac{\left(\dfrac{\partial \pi(1,s;a)}{\partial a}\beta\dfrac{\partial m(s,\omega)}{\partial s}\right)}{S.O.S.C.} > 0 \text{ and}$$

$$\frac{\partial s^*}{\partial \beta} = -\frac{\left(-\dfrac{\partial \pi(1,s;a)}{\partial s} m(s,\omega) + \pi(1,s;a)\dfrac{\partial m(s,\omega)}{\partial s}\right)}{S.O.S.C.} > 0 .$$

We next show that the ability of consumers to perceive quality also increases the optimal level of stringency of the QAS. This can be seen by implicit differentiation of equation (2) (assuming an interior solution and dropping the arguments of the functions to reduce notational clutter):

$$\left[\frac{\partial^2 \pi}{\partial s^2}(1-\beta m) + \pi\beta\frac{\partial^2 m}{\partial s^2}\right]\frac{\partial s^*}{\partial \omega} + \pi\beta\frac{\partial^2 m}{\partial s \partial \omega} - \beta\frac{\partial \pi}{\partial s}\frac{\partial m}{\partial \omega} \equiv 0 .$$

The term in square brackets denotes the usual second-order conditions of the maximization problem, and hence is negative. Therefore,

$\operatorname{sgn}\left(\partial s^* \big/ \partial \omega\right) = \operatorname{sgn}\left(\pi\beta\dfrac{\partial^2 m}{\partial s \partial \omega} - \beta\dfrac{\partial \pi}{\partial s}\dfrac{\partial m}{\partial \omega}\right)$. Note that $\dfrac{\partial^2 m}{\partial s \partial \omega}$ and $\beta\dfrac{\partial \pi}{\partial s}\dfrac{\partial m}{\partial \omega}$ are both positive and therefore we cannot determine this sign directly. To show that this difference is positive, add equation (2) to it (which is the first-order condition of the problem and hence zero), and multiply by $\beta\dfrac{\partial m}{\partial \omega}\dfrac{1}{(1-\beta m)}$ to obtain

$$\operatorname{sgn}\left(\frac{\partial s^*}{\partial \omega}\right)=\operatorname{sgn}\left(\pi\beta\frac{\partial^2 m}{\partial s\partial\omega}-\beta\frac{\partial \pi}{\partial s}\frac{\partial m}{\partial \omega}+\beta\frac{\partial m}{\partial \omega}\left(\frac{\partial \pi}{\partial s}+\pi\beta\frac{\partial m}{\partial s}\frac{1}{1-\beta m}\right)\right),$$

which simplifies to

$$\operatorname{sgn}\left(\frac{\partial s^*}{\partial \omega}\right)=\operatorname{sgn}\left(\frac{\pi\beta}{(1-\beta m)}\frac{\partial \lambda}{\partial s}(1-\beta)\right)\geq 0\,.$$

Thus, as consumers become more able to discern quality, processors find it optimal to increase their expenditures in reputation-preserving devices such as QASs. This reveals that as the economic loss from incurring a type II error and/or being discovered increases, processors will be more careful about the product they certify.

A more interesting and perhaps more realistic situation arises when the choice of the level of output is not independent of the investments in quality. Antle (2001) classifies quality control technologies for producing quality-differentiated goods as process control, inspection, testing, and identity preservation. He argues that all these technologies except testing affect the variable costs of production. However, the costs of the testing technologies are not independent of the rate of output, since sampling of a small proportion of the product is typically involved. Weaver and Kim (2002) also model quantity and quality as competing goals.[18]

In this case, we can write the processor's problem, which is to choose the optimal QAS and output level to maximize expected profits, as follows:

$$\max_{y\geq 0, s\in S} E\left(\Pi(y,s)\right)=\max_{y\geq 0, s\in S}\frac{\pi(y,s;a)}{1-\beta m(s,\omega)}\,.$$

Straightforward applications of the envelope theorem confirm the intuitive result that processors are better off when they face a larger demand in state 1 (higher a), when they are more "patient" (higher β), and when it is harder for consumers to determine true output quality (lower ω). In particular, the envelope theorem immediately indicates that

$$\frac{\partial E\left(\Pi(y,s)\right)}{\partial a}=\frac{\partial \pi}{\partial a}\frac{1}{\left(1-\beta m(s,\omega)\right)}\geq 0\,,\quad \frac{\partial E\left(\Pi(y,s)\right)}{\partial \beta}=\pi\frac{m(s,\omega)}{\left(1-\beta m(s,\omega)\right)^2}\geq 0\,,$$

and $\frac{\partial E\left(\Pi(y,s)\right)}{\partial \omega}=\pi\beta\frac{\partial m(s,\omega)}{\partial \omega}\frac{1}{\left(1-\beta m(s,\omega)\right)^2}\leq 0$. A direct implication of the last derivative is that as long as the certification system is imperfect, $\left(\lambda(s)=1-F\left(q^{M}\middle|s\right)<1\right)$, the profitability of participation in the market for quality-assured products is hindered by increased consumer awareness.

The first-order conditions for this problem are given by

$$\frac{\partial E(\Pi)}{\partial y}=\frac{\partial \pi(y,s;a)}{\partial y}\leq 0 \quad y\geq 0 \tag{3a}$$

$$\frac{\partial E(\Pi)}{\partial s}=\frac{\partial \pi^{1}(y,s;a)}{\partial s}+\pi^{1}(y,s;a)\frac{\beta\frac{\partial m(s,\omega)}{\partial s}}{\left(1-\beta m(s,\omega)\right)}\leq 0 \quad s\geq 0 \tag{3b}$$

and the corresponding complementary slackness conditions.

These first-order conditions can in principle be solved to obtain the optimal choices for output and stringency of controls represented by $y^{*}(\omega,\beta,a)$ and $s^{*}(\omega,\beta,a)$, respectively.

Second-order conditions (presented in the appendix) are assumed to hold. It is natural to ask what the optimal responses are in terms of output and choice of QAS as the parameters change. That is, what are the signs of $\partial y^{*}/\partial\omega$, $\partial s^{*}/\partial\omega$, $\partial y^{*}/\partial\beta$, $\partial s^{*}/\partial\beta$, $\partial y^{*}/\partial a$, and $\partial s^{*}/\partial a$? Some of these signs can be found by conducting comparative statics in the proposed model. However, the structure of the problem makes the signs of the last two derivatives inherently ambiguous.[19] The intuition is that as a increases, there is an incentive to increase the rate of output, which may in turn partially offset the gain in price. Increasing the output rate potentially has the double effect of reducing per unit price and increasing production costs (in a case of decreasing returns-to-scale technologies). Also, increases in the profitability of the market for value-added products provide incentives to monitor more closely product quality and to delay the transition to the second state. However, this has to be weighted against the costs incurred in doing so.[20]

We now tackle the question of the optimal choices of output and QAS as quality becomes more readily discernible. Differentiating system (3) partially with respect to ω using the chain rule, we get (after some rearrangement)

$$\begin{pmatrix} \dfrac{\partial^2 \pi(y,s;a)}{\partial y^2} & \dfrac{\partial^2 \pi(y,s;a)}{\partial y \partial s} \\ \dfrac{\partial^2 \pi(y,s;a)}{\partial y \partial s} & \dfrac{\partial^2 \pi(y,s;a)}{\partial s^2} + \pi(y,s;a)\dfrac{\beta \dfrac{\partial^2 m(s,\omega)}{\partial s^2}}{\left(1-\beta m(s,\omega)\right)} \end{pmatrix} \begin{pmatrix} \dfrac{\partial y^*}{\partial \omega} \\ \dfrac{\partial s^*}{\partial \omega} \end{pmatrix} =$$

$$\begin{pmatrix} 0 \\ -\dfrac{\pi(y,s;a)\beta}{\left(1-\beta m(s,\omega)\right)^2}\left(\dfrac{\partial^2 m(s,\omega)}{\partial s \partial \omega}\left(\left(1-\beta m(s,\omega)\right)\right)+\beta \dfrac{\partial m(s,\omega)}{\partial s}\dfrac{\partial m(s,\omega)}{\partial \omega}\right) \end{pmatrix} \tag{4}$$

Recalling that $m(s,\omega)=\lambda(s)+\left(1-\lambda(s)\right)(1-\omega)$ and applying the same technique used in the previous problem, the second element of the vector on the right-hand side of the system (4) can be written again as $-\dfrac{\pi\beta}{\left(1-\beta m(s,\omega)\right)^2}\dfrac{\partial \lambda(s)}{\partial s}(1-\beta)$, which makes its negative sign clear. Samuelson's (1947) conjugate pairs theorem immediately asserts $\dfrac{\partial s^*}{\partial \omega} > 0$. As consumers become more able to discern quality, processors will find it optimal to adopt more stringent controls. This result is similar in a sense to one of the findings of Darby and Karni (1973). These authors argued that it is very likely (albeit not necessarily true) that as consumers become more knowledgeable, the optimal amount of fraud is reduced.[21] In our paper, firms would have incentives to reduce the number of mistakes they make as consumers become increasingly able to discern qualities (or become more informed).

There exists a key trade-off between the benefits and costs of information acquisition on the part of processors. Having a more precise QAS, though costly, decreases the probability that firms will lose consumers trust. Furthermore, as the expected losses derived from consumer distrust increase, the payoff from the processor becoming better informed about actual quality increases.

Using Cramer's rule to solve for $\dfrac{\partial y^*}{\partial \omega}$, we find that the sign is ambiguous without imposing further structure, since ω enters by itself in the second equation of system (3).

Moreover, system (4) tells us that $\operatorname{sgn}\left({\partial y^*}/{\partial \omega}\right)=\operatorname{sgn}\left({\partial^2 \pi}/{\partial y \partial s}\right)$, which is not implied by the maximization hypothesis alone. Since it is reasonable to assume that raising the levels of controls increases the marginal costs of production, and noting that $\frac{\partial^2 \pi}{\partial y \partial s}=-\frac{\partial^2 C}{\partial y \partial s}$, we expect the optimal output rate to decrease as ω increases.

The question of how the value that producers place on the future affects the optimal choices of QAS and output levels can be explored through a similar exercise. The derivations are as follows:

$$\begin{pmatrix} \frac{\partial^2 \pi(y,s;a)}{\partial y^2} & \frac{\partial^2 \pi(y,s;a)}{\partial y \partial s} \\ \frac{\partial^2 \pi(y,s;a)}{\partial y \partial s} & \frac{\partial^2 \pi(y,s;a)}{\partial s^2}+\pi(y,s;a)\frac{\beta \frac{\partial^2 m(s,\omega)}{\partial s^2}}{(1-\beta m(s,\omega))} \end{pmatrix}\begin{pmatrix} \frac{\partial y^*}{\partial \beta} \\ \frac{\partial s^*}{\partial \beta} \end{pmatrix}=$$

$$\begin{pmatrix} 0 \\ -\frac{\partial m(s,\omega)}{\partial s}\frac{1}{(1-\beta m(s,\omega))}\left(\frac{\beta m(s,\omega)}{(1-\beta m(s,\omega))}+\pi(y,s;a)\right) \end{pmatrix}.$$

Solving the system by Cramer's rule, we obtain

$$\frac{\partial y^*}{\partial \beta}=\frac{\left[\frac{\partial m(s,\omega)}{\partial s}\frac{1}{(1-\beta m(s,\omega))}\left(\frac{\beta m(s,\omega)}{(1-\beta m(s,\omega))}+\pi(y,s;a)\right)\right]\frac{\partial^2 \pi(y,s;a)}{\partial y \partial s}}{|H|}$$

$$\frac{\partial s^*}{\partial \beta}=-\frac{\left[\frac{\partial m(s,\omega)}{\partial s}\frac{1}{(1-\beta m(s,\omega))}\left(\frac{\beta m(s,\omega)}{(1-\beta m(s,\omega))}+\pi(y,s;a)\right)\right]\frac{\partial^2 \pi(y,s;a)}{\partial y^2}}{|H|}.$$

Thus, we know that

$$\operatorname{sgn}\left(\frac{\partial y^*}{\partial \beta}\right)=\operatorname{sgn}\left(\frac{\partial^2 \pi(y,s;a)}{\partial y \partial s}\right)$$

$$\frac{\partial s^*}{\partial \beta} \geq 0.$$

As the future becomes more important, it is more valuable for processors to invest in QASs that give them a longer expected presence in the market. The sign of $\frac{\partial y^*}{\partial \beta}$ is ambiguous as before (and because of the exact same reasons). However, the previous discussion suggests it is negative. Increasing the expenses incurred to "learn" about the actual quality of the good increases variable costs of production, and hence it is optimal to cut back on the output rate.

Our findings are intuitively appealing and consistent with what we observe in reality. An earlier paper, Carriquiry, Babcock, and Carbone 2003, provides case studies of several QASs in use. Through a side-by-side comparison of the different QASs, we concluded that the cost and associated reliability of a system seem to be correlated with the expected economic damage that would result from false certification. Of the cases studied, the least stringent system was implemented for a trait with low discoverability such as rBST-free milk. There is no test capable of distinguishing rBST-free milk from milk obtained from rBST-treated cows. The most stringent (of the studied) QASs, implemented by Niman Ranch, is associated with the experience attribute of superior eating quality.

Conclusions

A repeated-purchases model is developed to explore the fundamental economic factors that lie behind the choice of different QASs and their associated degrees of stringency by firms. Differences in the quality discoverability of a sought-after attribute, attractiveness of a market, and the value placed in the future are among the factors contributing to the implementation of widely diverse systems across participants in different markets. Close attention is paid to the role of reputations in providing the incentives for firms to deliver high-quality goods in an environment of symmetrically imperfect information.

To summarize, we have modeled the decision of a monopolistic processor that chooses its per period output rate and the stringency of the QAS to implement in a potentially infinitely lived market. The duration of the market is unknown to the processor. However, it can influence the duration (stochastically) through its choices. In this setting, processors or firms implementing more stringent QASs are expected to keep their reputation for a larger number of time periods. Our main findings are that (*a*) the stringency of the QAS will be higher for more easily discoverable traits, more patient firms, and more attractive markets (only when the output rate is fixed); (*b*) firms are more likely to implement a QAS when the future is important, the quality trait is harder to observe, and, of course, when the demand for the differentiated product is stronger; and (*c*) the effect of both the discoverability of the quality trait and the value firms place on the future on the per period output rate is in general ambiguous, but we argue that an inverse relationship between both variables and the output rate is more likely.

Endnotes

1. For example, Dimitri and Greene (2002) reported that the retail industry for organic food has grown at a rate of 20 percent per year since 1990.

2. That is, they fall into what Nelson (1970) and Darby and Karni (1973) labeled as experience and credence attributes. The former refers to attributes that can be observed after consumption (for example, toughness of a steak), whereas for the latter, consumption does not provide information about the quality of the product (e.g., free-range eggs, dolphin-safe tuna, organic beef). Many food attributes can be thus classified (see, e.g., Caswell and Mojduszka 1996; Antle 1996; and Unnevehr and Jensen 1996).

3. Caswell, Bredahl, and Hooker (1998) provide an overview of the functions and effects of QMSs (or metasystems as they call them) on the food industry. See also Henson and Hooker 2001.

4. The quantity of Q is assumed to increase with the quality of the underlying input.

5. For this interpretation, we would need to reverse the claim that a larger Q represents a higher quality. Pathogen counts above q^M represent an unacceptable good.

6. Antle (2001) provides a literature review of the economics of food safety. Segerson (1999) discusses whether reliance on voluntary approaches to food safety will provide adequate levels of safety in a competitive framework that allows for consumers and firms to be imperfectly informed about potential damages. Marette, Bureau, and Gozlan (2000) explore the provision of product safety and possible public regulation for search, experience, and credence attributes when the supply sector competes imperfectly and hence can use prices as signals. However, in their model, and in Daughety and Reinganum 1995, sellers know the actual quality of the product they offer in each period.

7. See Blandford et al. 2002 for a classification of science-based definitions and measures of animal welfare.

8. Hayes and Lence (2002) provide the example of Parma Ham. They discuss that only ham produced within a certain region can be marketed as Parma Ham. The rationale for the restriction is that the weather in this region during the dry-curing process is what gives the ham its unique attributes. Nowadays, however, the dry-curing process is mainly carried on in modern, climate-controlled facilities.

9. There is ample literature that shows that when certification is imperfect, some producers of low quality will apply and obtain certification. See De and Nabar 1991; and Mason and Sterbenz 1994.

10. Hennessy (1996) and Chalfant et al. (1999) showed that imperfect testing and grading lead to under-investment in quality-enhancing techniques by farmers. This is because producers of low quality impose an externality on producers of high quality.

11. Firms would be participating in only one market.

12. Type I errors may be due to imperfections on the QAS (for example, because of incorrect monitoring). This would increase the costs of procuring the input the processor needs.

13. Note that we are being vague about what is being represented by this cost function. It could be modeling search costs, monitoring costs, or compensation given to farmers to induce high levels of effort.

14. This does not mean that their message to customers has to coincide with the assurance they get from the suppliers. For example, a restaurant that sources beef that is assured to be from a certain breed (e.g., Angus) may want to claim that the steaks they serve are tender. Another example would be a branded product. A customer of a well-known upscale restaurant expects to get a tender steak, and the restaurant will try to buy only beef it can certify to have been fed in a certain way or, again, from a certain breed.

15. The rightmost equality follows by recognizing that the summation term is a partial sum of a geometric series.

16. Note that $m(s,\omega)=\lambda(s)+(1-\lambda(s))(1-\omega)=(1-\omega)+\omega\lambda(s)$ is the convex combination between the true probability of having a product of high quality and 1. We see again that as $\omega \to 0$, $m(s,\omega)\to 1$, and the processors are expected to stay in state one for a large number of periods, even if they are offering a product that does not meet the promised standards.

17. Note that $\frac{\partial m(s,\omega)}{\partial s}=\omega\frac{\partial \lambda(s)}{\partial s}$.

18. They model quality as a product diversion process.

19. Note that the parameter a enters by itself in both equations of system (3). See Silberberg 1990.

20. For the commonly studied case of linear demand and constant marginal cost, both $\frac{\partial y^*}{\partial a}$ and $\frac{\partial s^*}{\partial a}$ are positive.

21. Note that in Darby and Karni's (1973) paper, supplying firms knew the actual quality of the product (repair services) they were offering.

Appendix

Second-Order Sufficient Conditions

Second-order sufficient conditions for the optimal choice of QAS for fixed y^* are

$$\frac{\partial^2 E\left(\prod(1,s)\right)}{\partial s^2}=\frac{\partial^2 \pi(1,s;a)}{\partial s^2}+\pi(1,s;a)\frac{\beta\frac{\partial^2 m(s,\omega)}{\partial s^2}}{\left(1-\beta m(s,\omega)\right)}\le 0$$

The Hessian for second-order sufficient conditions for the optimal QAS when both y and s are choice variables is

$$H=\begin{pmatrix}\frac{\partial^2 \pi(y,s;a)}{\partial y^2} & \frac{\partial^2 \pi(y,s;a)}{\partial y\partial s}\\ \frac{\partial^2 \pi(y,s;a)}{\partial y\partial s} & \frac{\partial^2 \pi(y,s;a)}{\partial s^2}+\pi(y,s;a)\frac{\beta\frac{\partial^2 m(s,\omega)}{\partial s^2}}{\left(1-\beta m(s,\omega)\right)}\end{pmatrix},$$

which implies that the second-order sufficient conditions will be satisfied when the following hold:

1. $\frac{\partial^2 \pi(y,s;a)}{\partial y^2}\le 0$;

2. $|H|=\frac{\partial^2 \pi(y,s;a)}{\partial y^2}\left(\frac{\partial^2 \pi(y,s;a)}{\partial s^2}+\pi(y,s;a)\frac{\beta\frac{\partial^2 m(s,\omega)}{\partial s^2}}{\left(1-\beta m(s,\omega)\right)}\right)-\left(\frac{\partial^2 \pi(y,s;a)}{\partial y\partial s}\right)^2\ge 0$;

and

3. $\left(\frac{\partial^2 \pi(y,s;a)}{\partial s^2}+\pi(y,s;a)\frac{\beta\frac{\partial^2 m(s,\omega)}{\partial s^2}}{\left(1-\beta m(s,\omega)\right)}\right)\le 0$, (implied by [1] and [2] together).

References

Antle, J. M. 1996. "Efficient Food Safety Regulation in the Food Manufacturing Sector." *American Journal of Agricultural Economics* 78(December): 1242-47.

———. 2001. "Economic Analysis of Food Safety." Chap. 19 in *Handbook of Agricultural Economics*, vol. 2. Edited by B. Gardner and G. Rausser. Amsterdam: North-Holland.

Blandford, D., J. C. Bureau, L. Fulponi, and S. Henson. 2002. "Potential Implications of Animal Welfare Concerns and Public Policies in Industrialized Countries for International Trade." Chap. 5 in *Global Food Trade and Consumer Demand for Quality*. Edited by B. Krissoff, M. Bohman, and J. A. Caswell. New York: Kluwer Academic Publishers.

Bredahl, M. E., J. R. Northen, A. Boecker, and M. A. Normille. 2001. "Consumer Demand Sparks the Growth of Quality Assurance Schemes in the European Food Sector. In *Changing Structure of the Global Food Consumption and Trade*. Edited by A. Regmi. Market and Trade Economics Division, Economic Research Service, U.S. Department of Agriculture, Agriculture and Trade Report WRS-01-1, May, pp. 90-102.

Carriquiry, M. A., B. A. Babcock, and R. Carbone. 2003. "Optimal Quality Assurance Systems for Agricultural Outputs." CARD Working Paper 03-WP 328. Center for Agricultural and Rural Development, Iowa State University.

Caswell, J. A., M. E. Bredahl, and N. H. Hooker. 1998. "How Quality Management Metasystems Are Affecting the Food Industry." *Review of Agricultural Economics* 20(2): 547-57.

Caswell, J. A., and S. J. Henson. 1997. "Interaction of Private and Public Food Quality Control Systems in Global Markets." In *Proceedings of the European Association of Agricultural Economists Conference on Globalization of the Food Industry: Policy Implications.* Edited by R. J. Loader, S. J. Henson, and W. B. Traill. Reading, UK: Department of Agricultural and Food Economics, University of Reading, pp. 217-36.

Caswell, J. A., and E. M. Mojduszka. 1996. "Using Informational Labeling to Influence the Market for Quality in Food Products." *American Journal of Agricultural Economics* 78(December): 1248-53.

Caswell, J. A., C. M. Noelke, and E. M. Mojduszka. 2002. "Unifying Two Frameworks for Analyzing Quality and Quality Assurance for Food Products." Chap. 3 in *Global Food Trade and Consumer Demand for Quality*. Edited by B. Krissoff, M. Bohman, and J. A. Caswell. New York: Kluwer Academic Publishers.

Chalfant, I. A., I. S. James, N. Lavoie, and R. I. Sexton. 1999. "Asymmetric Grading Error and Adverse Selection: Lemons in the California Prune Industry." *Journal of Agricultural and Resource Economics* 24: 57-79.

Chambers, R. G. 1989. *Applied Production Analysis: A Dual Approach*. New York: Cambridge University Press.

Darby, M., and E. Karni. 1973. "Free Competition and the Optimal Amount of Fraud." *Journal of Law and Economics* 16: 67-88.

Daughety, A. F., and J. F. Reinganum. 1995. "Product Safety: Liability, R&D, and Signaling. *American Economic Review* 85 (5): 1187-1206.

De, S., and P. Nabar. 1991. "Economic Implications of Imperfect Quality Certification." *Economics Letters* 37: 333-37.

Dimitri, C., and C. Greene. 2002. "Recent Growth Patterns in the U.S. Organic Foods Market." U.S. Department of Agriculture, Economic Research Service. Bulletin Number 777.

Fearne, A., S. Hornibrook, and S. Dedman. 2001. "The Management of Perceived Risk in the Food Supply Chain: A Comparative Study of Retailer-Led Beef Quality Assurance Schemes in Germany and Italy." *International Food and Agribusiness Management Review* 1(4): 19-36.

Hayes, D. J., and S. H. Lence. 2002. "A New Brand of Agriculture? Farmer Owned Brands Reward Innovation." *Iowa Ag Review* Vol. 8, No. 4 (Fall), pp. 4-5.

Hennessy, D. A. 1996. "Information Asymmetry as a Reason for Food Industry Vertical Integration." *American Journal of Agricultural Economics* 78(November): 1034-43.

Hennessy, D. A., J. A. Miranowski, and B. A. Babcock. 2004. "Genetic Information in Agricultural Productivity and Product Development." *American Journal of Agricultural Economics* 78(February): 73-87.

Henson, S. J., and N. H. Hooker. 2001. "Private Sector Management of Food Safety: Public Regulation and the Role of Private Controls." *International Food and Agribusiness Management Review* 1(4): 7-17.

Klein, B., and K. B. Leffler. 1981. "The Role of Market Forces in Assuring Contractual Performance." *Journal of Political Economy* 89: 615-41.

Lawrence, J. D. 2002. "Quality Assurance 'Down Under': Market Access and Product Differentiation." MATRIC Briefing Paper 02-MBP 1. Midwest Agribusiness Trade Research and Information Center, Iowa State University.

Ligon, E. 2002. "Quality and Grading Risk." Chap. 16 in *A Comprehensive Assessment of the Role of Risk in U.S. Agriculture*. Edited by R. E. Just and R. D. Pope. Boston: Kluwer Academic Publishers.

Marette, S., J. N. Bureau, and E. Gozlan. 2000. "Product Safety Provision and Consumers Information." *Australian Economic Papers* 39(4, December): 426-41.

Mason, C. F., and F. P. Sterbenz. 1994. "Imperfect Product Testing and Market Size." *International Economic Review* 35(1): 61-86.

Nelson, P. 1970. "Information and Consumer Behavior." *Journal of Political Economy* 78(2, March-April): 311-29.

Noelke, C. M., and J. A. Caswell. 2000. "A Model of the Implementation of Quality Management Systems for Credence Attributes." Paper presented at the American Agricultural Economics Association Annual Meeting, Tampa, FL, August 1.

Northen, J. R. 2001. "Using Farm Assurance Schemes to Signal Safety to Multiple Retailers in the U.K." *International Food and Agribusiness Management Review* 1(4): 37-50.

Reardon, T., and E. Farina. 2001. “The Rise of Private Food Quality and Safety Standards: Illustrations from Brazil.” *International Food and Agribusiness Management Review* 4(4): 413-21.

Rob, R., and T. Sekiguchi. 2001. “Product Quality, Reputation and Turnover.” Working paper, University of Pennsylvania. http://www.econ.upenn.edu/Centers/CARESS/CARESSpdf/01-11.pdf (accessed September 2004).

Samuelson, P. A. 1947. *Foundations of Economic Analysis*. Cambridge, MA: Harvard University Press.

Segerson, K. 1999. “Mandatory versus Voluntary Approaches to Food Safety.” *Agribusiness* 15(1): 53-70.

Shapiro, C. 1983. “Premiums for High Quality Products as Returns to Reputations.” *Quarterly Journal of Economics* 98(4): 659-80.

Silberberg, E. 1990. *The Structure of Economics: A Mathematical Analysis*, 2nd Edition. McGraw-Hill.

Unnevehr, L. J., and H. H. Jensen. 1996. “HACCP as a Regulatory Innovation to Improve Food Safety in the Meat Industry.” *American Journal of Agricultural Economics* 78(August): 764-69.

Weaver, R. D., and T. Kim. 2002. “Demand for Quality: Implications for Managing Food System Supply Chains.” In *Proceedings of the Fifth International Conference on Chain and Network Management in Agribusiness and the Food Industry.* Noordwijk, The Netherlands, 6-8 June. Edited by J. H. Trienekens, and S. W. F. Omta, pp. 274-85. Wageningen, The Netherlands: Wageningen Academic Publishers.