Imperfect Food Certification, Opportunistic Behaviors and Detection

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Jing Liang and Helen H. Jensen[1]

Abstract: In response to the recent outbreaks of food-borne illness, the "Good Agricultural Practices" program has been widely adopted to ensure consistency of food safety. This paper presents a theoretical framework to analyze the performance of the program with respect to output quality based on the assumption of predetermined productive capacity (farm size), heterogeneous farms and exogenous detection. Our main results are: (i) farms respond to the monitoring and enforcement not only by reducing fraudulent output, but also by increasing truly high-safety output until the perfect compliance level is achieved. (ii) the monitoring agency takes farm strategies as given and its optimal inspection policies are: If the monitoring budget is not enough to cover the necessary inspection cost of achieving perfect high-safety output level, it will allocate resources to farms with larger size and lower costs; If the budget is enough to obtain perfect level of high-safety output but is not enough to eliminate fraudulent output completely, the monitoring agency will expend equal effort on all the farms.

Keywords: certification, food safety, fraud, GAPs, monitoring and detection rates

JEL Classification: Q12, Q13, Q18

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Recent outbreaks of food-borne illness have led to increased concerns about food safety and its effect on health. Contamination of E.coli O157:H7 on spinach in Fall 2006 killed three people and made more than 200 seriously ill. In the spinach cases, as in other recent outbreaks, the causes of the problems were not detected until after the crisis had occurred. As a consequence, consumers' confidence in the quality and safety of many food products has declined. Many food products are classified as credence goods or goods with attributes which can not be ascertained through inspection or use of the product (Darby and Karni, 1973). In this case, although consumers prefer a high-safety product to a low-safety one, they may not be able to tell the difference between the two. To the producer, or farmer, the level of effort used to deliver a safe food is private information and may not be perceived by the consumer. The farmer can shirk in his effort to supply the level of safety consumers would demand with full information.

To reduce food borne illness in fruits and vegetables, Good Agricultural Practices (GAPs) has been used as food safety guidance for growers and handlers to adopt on critical production steps to ensure the consistency of the food safety. The first generation of GAPs has been developed in "Guide to Minimize Microbial Food Safety Hazards for Fresh Fruits and Vegetables" which was issued in 1998. The recent outbreaks related to microbial risks such as E.coli O157:H7 led to a considerable push to develop more specific measures of identified best practices. The 2nd generation of GAPs has been published on March, 2007. Those practices are part of a voluntary food safety program – Fresh Produce Audit Verification Program which is developed by FDA and USDA. Farms can enroll the program voluntarily and be awarded a certification mark for implementing the GAPs which can be used to distinguish their output from others thereby enhancing their profit and market share. For retailers, the certification is useful for sourcing vegetable supply from quality farms. Moreover, origin and source information in certification ensures that consumers obtain safer foods through reliable sources.

The GAP certification program, however, is susceptible to opportunistic behaviors. Despite consumers' increasing demand for high-safety foods, farmers face the use of the GAPs as an increased cost. The existence of a cost gap between low and high-safety foods provides an incentive for the participants to attempt to sell some of their outputs produced with conventional producing practices instead with GAPs. Agricultural activities are space-consuming or area-occupying ones. A farmer may have several fields with varying soil and irrigation conditions. The production practices used on individual parcels may be different. Thus, fraudulent behaviors become possible when monitoring activity is imperfect and costly. Even with inspection in place, identifying food produced with conventional practices from ones produced with the "best practices" is difficult and the detection of fraudulent product is not likely to be 100% effective. A farmer who decides to shirk his care-taking effort faces a decision about the effort where the outcome of his decision depends on whether he is inspected (or caught) or not. Therefore, analysis of a GAP program should account for the possibility of opportunistic behaviors.

This paper explores a GAP program's performance on farmers and enforcement activities on food markets where there is potential for fraud. More specifically, our aim is to study the effects of the possibility of fraud on the production and how the optimal monitoring policy varies with different budget levels on heterogeneous farms.

There is a substantial body of literature that addresses the economic implications of food certification programs. Fields of application relate to food safety and to the environment. For instance, the role of labeling (Caswell and Padberg 1992; Golan, Kuchler and Mitchell 2001; Crespi and Marette 2003), the financing method of food safety certification (Crespi and Marette 2001), consumer response to food certification (Kim, Rodolfo and Oral. 2000; Tregear, Kuznesof and Moxey 1998; Govindasamy and Italia 1999), whether certification systems should be mandatory or voluntary (Segerson 1999), and the welfare impact of labeling policies (Zago and Pick 2004). These papers make the assumption of perfect certification. That is, the certification can differentiate completely between high-safety foods and low-safety ones. There are no low-safety foods in the high-safety market. Under this assumption, the monitoring and enforcement process is not considered. In contrast to these studies, our model allows for the existence of opportunistic behaviors. Monitoring effort plays an important role in detecting low-safety foods disguised as high safety ones, and its inclusion leads to rather different conclusions regarding the market outcomes.

Lack of information or asymmetric information in markets is major sources of market failure. Since the pioneering work of Akerlof (1970) and Klein and Leffler (1981), many studies investigate the causes and remedies to market failures caused by asymmetric information on product quality. A variety of mechanisms have been proposed to identify the characteristics of products and to obtain suboptimal equilibria resulting from information problems. The mechanisms used include identification of price differences (Shapiro 1983), signaling and reputation (Kreps and Robert 1982; Shapiro 1983), and advertising (Nelson 1970). These types of solutions, however, become problematic for goods, such as food products, which have credence qualities. In this case, it is difficult to measure the credence attribute except through a binary indicator. More recent studies have considered the relationship between food safety and asymmetric information. For example, Elbasha and Riggs (1999) investigate the double moral hazard problem present in food market. Fox and Hennessy (1999) examine the trade-off between regulation on food quality control and economic damage using a microeconomic model. Carriquiry and Babcock (2004) develop a repeated purchase model to investigate the different choices of quality assurance systems of producers and role of reputations.

Without full information, the ability to test becomes important to the functioning of markets. This gives rise to literature focusing on the problem of imperfect certification and the role of testing (e.g., Darby and Karni 1973; De and Nabar 1991; Polinsky and Shavell 1992; and Starbird 1997, 2000). Starbird (2005) looks at the impacts of inspection policies on the consumer and the producer’s strategies using a principle-agent model. Marette (2005) addresses the relationship of financing policy of enforcement and the market structure. Mason and Sterbenz (1994) study the effects of an imperfect test of product quality on the strategies of the producers and its interaction with adverse selection to affect market size. This paper leads some interesting and different comparative static results in the effects induced by changes in test cost and accuracy compared with those of a perfect test.

Especially relevant to our study are those that address how the possibility of fraud affects the producer’s behavior and choice of product. This includes whether mechanisms in markets may induce non fraudulent behaviors (Emons 1997; 2000), game-theoretic approaches to making false claims on product quality (McCluskey 2000 on organic markets), and consequences of mislabeling for consumer behavior and welfare (Giannakas 2002). The certifiers’ role as intermediaries between producers and consumers has also been explored in the certification problem (Biglaiser 1993; Lizzeri 1999; Nunez 2001).

We extend this work on the relationship between producer behavior and optimal monitoring policy. The crucial distinction between our paper and the extant literature is our attention to the constraint of productive capacity (maximum yield) which is the feature of agricultural activities. The different monitoring policies on different budget levels have been ignored by many previous studies. The main findings of the paper can be summarized as follows: farmers respond to monitoring and enforcement not only by reducing fraudulent output, but also by increasing truly high-safety output up until the perfect compliance level is achieved. Without monitoring, farmers will not use GAPs at all. When monitoring pressure is positive but small, farmers begin to reduce fraudulent output and increase truly high-safety output until the full compliance level of high-safety output is achieved. With increasing monitoring effort, the farmers continue reducing fraudulent production until zero. Second, when the budget cannot cover the necessary monitoring cost of achieving maximum level of high-safety output, the optimal monitoring policy is to allocate resources on the farms with larger size and lower cost of adopting GAPs; when the budget of achieving optimal high-safety output is met, the monitoring agency will expend equal monitoring efforts on all farms.

The remainder of this paper is organized as follows: Section 2 sets up the bench-mark model with perfect monitoring and full compliance. Section 3 presents the results of the monitoring policy's effect on farmers' behaviors under an exogenous detection rate. In Section 4 we develop the optimal monitoring policy for farmers with different size. . The optimal policy is developed in Section 5 for farms with different costs of adopting

GAPs. Section 6 provides model extensions on endogenous detection. Conclusions are given in Section 7.

Benchmark Model-Perfect Monitoring

Our analysis is built around the case of a perfectly competitive market framework which consists of a continuum of farms with a single food product. The assumption of a single food product is not essential to the arguments presented here, however is included in order not to introduce unnecessary analytical complications. Food can be of two safety-qualities, *high* or *low.* We call the food produced with GAPs as high safety and food produced with conventional practices as low safety. For simplicity, safety is assumed to be one-dimensional and fixed for now. Farmers operate in an environment with an audit-based GAPs program. The farmers participate in the program voluntarily and can be certified by official monitoring agency (e.g. AMS certification service or) as confirmation that they have successfully applied the required GAPs.

To start, farms are assumed to be homogenous here; a more complex and realistic case that the farms are heterogeneous will be discussed later. Let $\bar{y}$ denote the farm size in terms of its productive capacity. Although the traditional way to measure farm size is a spatial measure, in acres. We use the most useful farm size concept in this paper, which is the measure of the productive capacity of the land. Therefore, $\bar{y}$ implies the maximum yield of the farm and is predetermined by nature. Although the safety quality can be improved by using GAPs, $\bar{y}$ does not change. The farm production cost with conventional practices does not depend on quantity. For simplicity, we normalize the cost of using conventional practices to be zero. However, it costs more to produce high-safety output by using GAPs than by using conventional practices. Let $c(\cdot)$ represent the minimum cost of using GAPs where $c(\cdot)$ satisfies $c^{'} > 0$ and $c^{''} \geq 0$. In order to obtain price premium and contribute less effort, the certified farmer can choose to adopt GAPs on only some parcels and invest less on the rest. Throughout, output produced with GAPs is denoted y_h and output produced under conventional practices but disguised as high-safety is denoted y_f , where $y_h, y_f \in [0, \overline{y}]$.

To understand the impact of fraudulent activities and enforcement policy on market outcomes, it is instructive to construct a framework in which fraudulent activities are excluded from the market completely, i.e., perfect monitoring of production. In this case, consumers are provided with a full guarantee that if the food is sold as being of high safety it is, in fact, of high safety quality. This means that the certification provides consumers with a prefect substitute for the trust they cannot develop and for the information they cannot access to. Let p_h and t denote the market price of high-safety product and per unit certification fee, respectively. The profit of a farm is given by:

(1)
$$\max_{y_h} \pi = (p_h - t) y_h - c(y_h)$$
$$\text{s.t. } y_h \leq \overline{y}$$

The farmer chooses the level of high-safety output so as to maximize his profit. The first order necessary condition for an interior maximum is:

(2)
$$(p - t) = c^{'}(y_h^*)$$

where y_h^* is the optimal level of high-safety output under perfect compliance . The marginal benefit is equal to the increment in marginal production cost. We assume the farm is large enough to support efficient production, i.e., $y_h^* \leq \overline{y}$.

If there is no fraud, the monitoring effort plays a minor role and the monitoring agency is just a mechanistic provider. The detection effort becomes more important when fraudulent behaviors are in place.

Imperfect Monitoring and Noncompliance

Next we turn to discuss the case in which the monitoring is imperfect and fraudulent activities occur in the market. The GAPs program is credible only if farms are monitored by the monitoring agency that conducts on the ground inspections and initiates verification processes. Trying to implement higher and stricter standards that entail added costs to producers may result in increased fraudulent behavior if the agency cannot control farmers' activities and enforce compliance. Thus, establishing the relationship between monitoring policy and farmer's strategies will guide the monitoring agency to implement policy efficiently.

We assume that safety control is not error-free, which means if a farm is selected for testing, whether GAPs are adopted or how much the farmer sells fraudulently may not become known for sure. Let $\bar{\rho}\left(0<\bar{\rho}\leq 1\right)$ denote an exogenous detection rate and it is assumed to be the same for all the farms. $\bar{\rho}$ is the conditional probability of detection given that a monitoring events occurs, it can be looked at as the difficulty of detecting fraudulent output. Higher $\bar{\rho}$ means easier detection. The more complicated and realistic situation under an endogenous detection scenario will be discussed as an extension. The monitoring agency monitors the behavior of farmers by investing in monitoring effort and collecting a fine for fraudulent output. However, the monitoring and fines may not ensure perfect compliance. We denote $\omega\in\left[0,1\right]$ as the monitoring probability selected by the monitoring agency and it is assumed exogenous to the farmers. Therefore, $\bar{\rho}\omega$ is the true probability that the fraudulent behavior is detected.

If fraud is detected, penalties are assessed on the fraudulent units and fraudulent output will be banned for sale in the region. Following the assumptions of previous literature, $f\left(y_f\right)$ is assumed to be increasing and convex in y_f with $f\left(0\right)=0$, $f^{'}\left(y_f\right)>0$, and $f^{"}\left(y_f\right)>0$ so that a larger level of fraudulent goods implies a higher penalty.

The farmer perceives the probability of being inspected is ω. His problem is to choose y_h and y_f to maximize his expected profit,

(3) $$\max E\pi=\left(p_h-t\right)\left(y_h+y_f\right)-c\left(y_h\right)-\bar{\rho}\omega\left(f\left(y_f\right)+p_h\cdot y_f\right)$$

$$\text{s.t. } y_h+y_f\leq\bar{y}$$

The first-order necessary conditions for a maximum can be written

(4) $$\Phi_h\equiv\left(p-t\right)-c^{'}\left(y_h\right)-\lambda\leq 0,\ \ y_h\Phi_h=0$$

(5) $$\Phi_f\equiv\left(p-t\right)-\bar{\rho}\omega\left(p+f^{'}\left(y_f\right)\right)-\lambda\leq 0,\ y_f\Phi_f=0$$

(6) $$\Phi_\lambda\equiv y_h+y_f-\bar{y}\leq 0,\ \lambda\Phi_\lambda=0$$

Expression (4) provides the optimal condition for production of high-safety output. Expression (5) gives the optimal condition on the level of fraud. The increasing marginal cost of fraud implies that additional fraud on the margin increases convictions, and this raises fines.

Different from the production of most other goods, the maximum yield of a farm is predetermined by nature. Without this constraint, the representative farm produces truly high safety output as long as the marginal private benefit p_h-t exceeds the marginal cost of using GAPs, $c^{'}\left(y_h\right)$, and the representative farmer engages in fraud as long the marginal benefit $p_h - t$ exceeds its marginal cost $\bar{\rho}\omega\left(f\left(y_f\right)+p_h \cdot y_f\right)$. Monitoring and enforcement serve only to deter fraud and have no impact on truly high-safety production. One important feature of farm output is that the productive capacity (farm size) is predetermined by nature and will not change in a short period of time. That is, the reduction of fraudulent output may be useful for increasing high-safety production. This has interesting implications for the design of efficient monitoring policy. The following proposition describes the optimal strategies of a farmer given exogenous monitoring policy when one considers the constraint of productive capacity.

Proposition 1. The homogeneous farmer's strategies $\left(y_h, y_l\right)$ are as follows:

(a) If $\omega = 0$, then $y_h = 0$ and $y_f = \bar{y}$.

(b) If $\omega \in \left(0, \omega_1\right)$, then $y_h \in \left(0, y_h^*\right)$ and $y_f \in \left(\bar{y} - y_h^*, \bar{y}\right)$.

where $\omega_1 = \left(0, \dfrac{p_h - t}{\bar{\rho}\left(p + f^{'}\left(\bar{y} - y_h^*\right)\right)}\right)$

(c) If $\omega \in \left(\omega_1, \omega_2\right)$, then $y_h = y_h^*$ and $y_f \in \left(0, \bar{y} - y_h^*\right)$.

where $\omega_2 = \dfrac{p_h - t}{\bar{\rho} \cdot p_h}$

(d) If $\omega \geq \omega_2$, then $y_h = y_h^*$ and $y_f = 0$.

Proof: see Appendix.

Suppose for the moment that the monitoring agency does not engage in monitoring and enforcement activities $\left(\omega = 0\right)$. The farmer is not afraid of being caught and attempts at fraudulent sales always succeed. Thus, adverse selection will drive truly high-safety production away. Because the marginal benefit of the high-safety output is higher than that of the low-safety output, he will produce his entire crop by using conventional practices but claim all his output to be high safety, i.e., $y_h = 0$ and $y_f = \bar{y}$.

When the monitoring rate becomes positive but not very large ($\omega \in (0, \omega_1)$), the farmer increases his high-safety output and decreases his fraudulent output. However, the monitoring pressure is not high enough to guide the farmer to produce the perfect compliance level of high-safety output y_h^* until $\omega = \omega_1$. An additional unit of truly high-safety output reduces an additional unit of the fraudulent output. The total output is still the maximum yield of the crop, i.e., $y_h + y_f = \bar{y}$ .Thus enforcement activity has a deterrence effect on both high-safety output and fraudulent output.

When the monitoring rate is high enough ($\omega \in (\omega_1, \omega_2)$), the farmer chooses the full compliance level of high-safety output y_h^* and continues reducing fraudulent output due to the increased monitoring pressure. After $\omega > \omega_2$, fraudulent output is eliminated completely. In this stage, y_h cannot be increased anymore and the total output is less than the farmer's productive capacity $\bar{y}$. After $\omega > \omega_2$, the farmer's decision is the same as under perfect monitoring; that is, $y_h = y_h^*$ and $y_f = 0$.

What we should mention here is that the farmer keeps his maximum yield until y_h^* is achieved. At output levels less than y_h^*, the perfect level of high-safety output, the farmer will not decrease his fraudulent sales without increasing his high-safety output at the same time. Decreases in fraudulent output are offset by increases in high-safety output. This is very good news for policy makers and has important implications for the design of efficient inspecting policies. Because if the monitoring activities only serve to reduce fraudulent output and have no influence on high-safety production, the objective of the GAPs program cannot be fulfilled and the consumers cannot benefit from the program.

Proposition 2. Full compliance production can be obtained under exogenous detection when $\bar{\rho} \geq \bar{\rho}^c = \frac{p_h - t}{p_h}$. A ban on sales of detected fraudulent output is sufficient to support the result.

The full compliance production level can be supported by the exogenous detection rate if and only if $\omega \geq \omega_2$. Note that $\omega \in [0,1]$, if $\bar{\rho}_h < \bar{\rho}^c$, the necessary inspection probability to achieve full compliance production is higher than 1, which is not possible. In addition, fraudulent output cannot be eliminated completely although the maximum high-safety output can be achieved if the following condition is satisfied:

(7)
$$\frac{p_h - t}{p_h + f^{'}\left(\bar{y} - y_h^*\right)} \leq \bar{\rho} < \frac{p_h - t}{p_h}$$

Obviously, when $\bar{\rho} < \frac{p_h - t}{p_h + f^{'}\left(\bar{y} - y_h^*\right)}$, y_h^* cannot be obtained either.

From equation (4) and (5), we know the convexity of the cost function and penalty function can always guarantee satisfaction of the second order conditions. Thus, a penalty is necessary to support the interior solution. Obviously, if the detected output is not discarded in the market, fraud cannot be precluded completely. Thus, the ban on sales of the detected units is sufficient to support the result.

Now we address the effect of the parameters on the boundaries between regions.

From (b) and (c) of Proposition 1, the penalty function can reduce the necessary monitoring rate to achieve the maximum high-safety production but has no effect on the necessary monitoring effort to eliminate fraudulent output; the unit assessment fee will reduce both ω_1 and ω_2.

Farms are Heterogeneous with respect to Size

In this section we consider the optimal type-specific monitoring policy with exogenous detection on a fixed set of farms which differ in their size. Let $\alpha\bar{y}$ denote the volume of the crop. Parameter α reflects differences in size and is assumed to be a continuous index and distributed over the interval $\left[\underline{\alpha},\bar{\alpha}\right]$ according to density function $g\left(\alpha\right)$ and distribution function $G\left(\alpha\right)$, with $G\left(\underline{\alpha}\right)=0$ and $G\left(\bar{\alpha}\right)=1$.We denote the highest level of high-safety output that the monitoring agency can achieve through its monitoring strategy by $y_h^*\left(\alpha\right)$. From equation (2), we find $y_h^*\left(\alpha\right)=y_h^*$, In order to guarantee that all farmers can produce efficiently, we assume $y_h^*<\alpha\bar{y}$ for $\alpha\in\left[\underline{\alpha},\bar{\alpha}\right]$.If there is no constraint on the budget, the maximum high-safety production in the whole market is $Y_h\left(\alpha\right)=y_h^*$. From proposition 1, we know that the farmer with parameter α will produce y_h^* if and only if the monitoring probability is higher or equal to

(8) $$\omega_1\left(\alpha\right)=\frac{p_h-t}{\bar{\rho}\left(p_h+f^{'}\left(\alpha\bar{y}-y_h^*\right)\right)}$$

As $\omega_1\left(\alpha\right)$ should be less or equal to one, y_h^* can be achieved if and only if $\omega_1\left(\alpha\right)\leq 1$ for $\alpha\in\left(\underline{\alpha},\bar{\alpha}\right)$. We normalize the unit cost of inspection to be one, and thus the necessary budget to achieve $Y_h(\alpha)$ is

(9) $$R_h(\alpha) = \int_{\underline{\alpha}}^{\bar{\alpha}} \omega_1(\alpha) g(\alpha) d\alpha$$

When $\omega_1(\alpha) > 1$ for all $\alpha \in (\underline{\alpha}, \bar{\alpha})$, the full compliance level y_h^* can not be obtained from any farmer even if the monitoring agency inspects the farm with probability one. Thus the maximum high-safety output $y_h^0(\alpha)$ that can be achieved for a farm with α is implicitly defined as

(10) $$c'\left(y_h^0(\alpha)\right) = \bar{\rho}\left(p_h + f'\left(\alpha\bar{y} - y_h^0(\alpha)\right)\right), \alpha \in (\underline{\alpha}, \bar{\alpha}) \ .$$

Accordingly, $Y_h(\alpha) = \int_{\underline{\alpha}}^{\bar{\alpha}} y_h^0(\alpha) g(\alpha) d\alpha$. Every farmer sells fraudulently and the total output is $\alpha\bar{y}$.

If there exists an $\tilde{\alpha}$ which satisfies $\omega_1(\tilde{\alpha}) = 1$, then those farms with $\alpha > \tilde{\alpha}$ will be inspected with probability $\omega_1(\alpha)$ and y_h^* can be achieved. Those farms with $\alpha \le \tilde{\alpha}$ will be inspected with probability one and the highest high-safety output level is $y_h^0(\alpha)$. Thus, the total high-safety production on the market is

(11) $$Y_h(\alpha) = \left(\int_{\underline{\alpha}}^{\tilde{\alpha}} y_h^0(\alpha) g(\alpha) d\alpha + \left(1 - G(\tilde{\alpha})\right) y_h^*\right)$$

The necessary resources to obtain $Y_h(\alpha)$ should be

(12) $$R_h(\alpha) = G(\tilde{\alpha}) + \left(\int_{\tilde{\alpha}}^{\bar{\alpha}} \omega_1(\alpha) g(\alpha) d\alpha\right)$$

The results of the previous discussion are summarized in table 1.

Table 1. Monitoring budget and high-safety production decisions

	$\omega_1(\alpha)\le 1$	$\omega_1(\alpha)>1$	$\omega_1(\tilde{\alpha})=1 \quad \tilde{\alpha}\in(\underline{\alpha},\bar{\alpha})$
$R_h(\alpha)$	$\int_{\underline{\alpha}}^{\bar{\alpha}} \omega_1(\alpha)g(\alpha)d\alpha$	1	$G(\tilde{\alpha})+\int_{\tilde{\alpha}}^{\bar{\alpha}} \omega_1(\alpha)g(\alpha)d\alpha$
$Y_h(\alpha)$	y_h^*	$\int_{\underline{\alpha}}^{\bar{\alpha}} y_h^0(\alpha)g(\alpha)d\alpha$	$\int_{\underline{\alpha}}^{\tilde{\alpha}} y_h^0(\alpha)g(\alpha)d\alpha+(1-G(\tilde{\alpha}))y_h^*$

In reality, the budget is not always large enough to cover the necessary monitoring cost to get $Y_h(\alpha)$. The allocated budget is always less than what is necessary. Thus, in addition to the relationship of monitoring effort and the production strategies discussed above, we are also interested in the question of how the monitoring agency should distribute monitoring effort among heterogeneous farms when the budget is constrained. Taking the farmer's production strategies into account, we examine how the monitoring agency allocates the constrained enforcement budget efficiently among the farms.

Again, we need to highlight the fact that our analysis relies on the assumption that the monitoring agency is concerned more with increasing true high-safety production than decreasing fraudulent production, i.e., it will not set an extra monitoring effort to decrease one farmer's fraudulent production after his y_h^* is attained while the other farms y_h^* has not yet been achieved. Without heterogeneity in farm size, there is no advantage to discriminate among the farms in monitoring effort and it is meaningfulness to study efficient strategies to allocate resources. It is intuitive that two identical farms should be inspected with the same probability. From proposition 1, when $\omega(\alpha)<\omega_1(\alpha)$, y_h is implicitly defined as $c'(y_h)=\bar{\rho}\omega\left(p+f\left(\alpha\bar{y}-y_h\right)\right)$, this suggests that a difference in the choice of y_h for the farmers depends on differences in their size parameters. If two farms of different size are audited with the same probability and the same enforcement effort is applied to each, the amounts of the high-safety level they choose are different. Then the agency has incentive to discriminate among farms.

For simplicity, we only discuss the optimal policy for the case $\omega_1(\alpha) \le 1$. The results are robust if we consider the other two situations. Moreover, we give the penalty function an explicit form to simplify the notation. Define $f(y_f) = fy_f^2/2$, and $c(y_h) = cy_h^2/2$ which satisfies the assumptions in Section 2. If the monitoring agency's budget is large enough to obtain the full compliance level of high-safety output, i.e., $R \ge R_h(\alpha)$,then all farms will be audited with probability $\omega_1(\alpha)$ or even larger. If the monitoring resources are not enough to cover $R_h(\alpha)$, given that the monitoring agency's budget is just exhausted, the rule for distributing the monitoring effort is given in next proposition.

Proposition 3: When $R < R_h(\alpha)$, the monitoring agency first targets those farms with large size. The optimal monitoring policy must satisfy:

(13)
$$\frac{p_h + \alpha_k \bar{y} f}{(\omega_{1k}\bar{\rho} f + c)^2} = \frac{p_h + \alpha_j \bar{y} f}{(\omega_{1j}\bar{\rho} f + c)^2} \quad k \ne j$$

Proof: see Appendix.

The result has a very strong policy implication: when the monitoring agency does not have the necessary resources to achieve the maximum high-safety output, it should use size differences among the farms to guide the decision about distributing monitoring efforts among them. We assume producing costs of using GAPs are same for all the farms in this case. Obviously, whether the agency invests monitoring effort on one farm at a level higher than for another farm or not depends on the relationship between $\alpha_k \bar{y} f$ and $\alpha_j \bar{y} f$ .Thus, the monitoring agency applies more intense monitoring effort to farms with larger size. Intuitively, this happens because the full compliance level of high-safety output is same for all the farms, large farms produce more fraudulent products than small farms and can be easily deterred with stricter monitoring. Thus, the necessary monitoring rate to obtain y_h^* for larger farms is lower than for small farms. The monitoring rate increases with α , some farms with large α may be monitored with $\omega_1(\alpha)$, i.e., the allocated monitoring rate is high enough to direct the farmer to produce y_h^* . While the farms with small α may be monitored with a probability less than $\omega_1(\alpha)$ and the farms with very small α may not be monitored at all. Whether a farm will be inspected or not and the level of inspection rate depend on the total budget $R_h(\alpha)$. Because all farmers' allocated monitoring rate is less or equal to $\omega_1(\alpha)$, all of them will produce low-safety product and sell them fraudulently as high-safety. In addition, the total output is the maximum yield $\alpha\bar{y}$.

Now we consider the optimal monitoring policy if the monitoring budget is enough to achieve full compliance level of high-safety output but is still less than the necessary amount to eliminate fraudulent sales. The farmer will continue decreasing fraudulent sales with stronger monitoring pressure. The total output now is less than the maximum yield. First, consider the case with $\omega_1(\alpha) \le 1$; recall the necessary monitoring effort to eliminate fraudulent output is $\omega_2(\alpha)$ which should be less or equal to one.

Similar to the previous analysis, three possible situations are examined.

If $\omega_2(\alpha) \le 1$ for all $\alpha \in (\underline{\alpha}, \bar{\alpha})$, the total necessary monitoring effort to exclude fraud from the market is $R_f(\alpha) = \int_{\underline{\alpha}}^{\bar{\alpha}} \omega_2(\alpha) g(\alpha) d\alpha$; If $\omega_2(\alpha) > 1$ for all $\alpha \in (\underline{\alpha}, \bar{\alpha})$, the fraudulent behaviors cannot be eliminated even if all the farms are inspected with probability one. The minimum level of total fraudulent sale on the market is $Y_f(\alpha) = \int_{\underline{\alpha}}^{\bar{\alpha}} y_f^0(\alpha) g(\alpha) d\alpha$, where $y_f^0(\alpha)$ is defined as $p_h - t = \bar{\rho}\left(p_h + f y_f^0(\alpha)\right)$. Obviously, $y_f^0(\alpha)$ does not depend on the size parameter. For simplification, we denote it as y_f^0. Thus, $Y_f(\alpha) = y_f^0$. If there exist an $\hat{\alpha}$ which satisfies $\omega_2(\hat{\alpha}) = 1$ with $\hat{\alpha} \in (\underline{\alpha}, \bar{\alpha})$, the monitoring agency will monitor those farms with $\alpha > \hat{\alpha}$ with probability $\omega_2(\alpha)$ and the other farms with probability one. Then the necessary budget and total fraudulent sales can be derived. We summarize the results in table 2.

Second, consider the case with $\omega_1(\alpha) > 1$; fraudulent sales cannot be reduced anymore because the monitoring probability has been already increased to one. The total fraudulent output on the market is $\int_{\underline{\alpha}}^{\bar{\alpha}} \left(\alpha \bar{y} - y_h^0(\alpha)\right) g(\alpha) d\alpha$. Similar analysis can be applied to a third case with $\omega_1(\tilde{\alpha}) = 1$ for a specific α.

Table 2. Monitoring budget and fraudulent production decisions ($\omega_2(\alpha) \le 1$)

	$\omega_2(\alpha) \le 1$	$\omega_2(\alpha) > 1$	$\omega_2(\hat{\alpha}) = 1, \ \alpha \in (\underline{\alpha}, \bar{\alpha})$
$R_f(\alpha)$	$\int_{\underline{\alpha}}^{\bar{\alpha}} \omega_2(\alpha) g(\alpha) d\alpha$	1	$G(\hat{\alpha}) + \int_{\hat{\alpha}}^{\bar{\alpha}} \omega_1(\alpha) g(\alpha) d\alpha$
$Y_f(\alpha)$	0	y_f^0	$y_f^0 G(\hat{\alpha})$

The following question is how to allocate monitoring resources to achieve minimum fraudulent sales when $R_h(\alpha) \le R < R_f(\alpha)$. To provide representative results and avoid complex calculation, we assume $\omega_2(\alpha) \le 1$ for all $\alpha \in (\underline{\alpha}, \bar{\alpha})$. The results are robust when the assumption is relaxed to the other cases.

Recall proposition 1, y_f is defined as:

(14) $$p_h - t = \bar{\rho}\omega\left(p_h + fy_f\right)$$

which means the farmer's choice of fraudulent production is also independent of its size parameter. This has interesting implications for efficient monitoring policy design.

Proposition 4: When $R_h(\alpha) \le R < R_f(\alpha)$, the monitoring policy is independent of the exogenous size parameter, the monitoring agency applies the same effort on two different farms, i.e., $\omega_{2k} = \omega_{2j}\ k \ne j$.

Proof: see Appendix.

Actually, ω_2 can be written as $\omega_1 + \Delta\omega$, because $\omega_{1i} < \omega_{1j}$ for $\alpha_i > \alpha_j$; the effort on deterring fraudulent output satisfies $\Delta\omega_i > \Delta\omega_j$. This is because the fraudulent output of the i farm is more than that of the j farm.

Farms are Heterogeneous with respect to Cost

In this section, we examine the optimal type-specific monitoring policy when farms differ in the cost of adopting GAPs. Because the analysis here is similar to the one in the previous section, we focus on the main results and intuition and avoid the repeated description. If the two farms differ in adopting cost and are the same in other parameters, let $\theta c(\cdot)$ represent the minimum cost of using GAPs, parameter α reflects the difference of cost and is assumed to be continuous and distributed over the interval $\left[\underline{\theta},\bar{\theta}\right]$ with probability $h(\theta)$.As in previous section, we denote by $y_h^*(\theta)$ the maximum level of high-safety output that can be induced by the monitoring agency. Obviously, $y_h^*(\theta)=y_h^*/\theta$.Moreover, the farmer will produce $y_h^*(\theta)$ if and only if the monitoring rate is higher or equal to $\omega_1(\theta)$

(15) $$\omega_1(\theta)=\frac{p_h-t}{\bar{\rho}\left(p_h+f\left(\bar{y}-y_h^*(\theta)\right)\right)}$$

And the necessary effort to eliminate fraudulent sales is the same as in the previous case

(16) $$\omega_2(\theta)=\frac{p_h-t}{\bar{\rho}p_h}$$

Let $R_h(\theta)$ and $R_f(\theta)$ denote the necessary budget to obtain the maximum high-safety level and minimum fraudulent level, respectively. The next proposition characterizes the optimal auditing policy when the budget can not cover all the inspection cost.

Proposition 5: The optimal monitoring policy on farms with different adoption cost is:

(a) When $R<R_h(\theta)$, the inspection of the monitoring agency starts with the farm with lower cost.

(b) When $R_h(\theta)\le R<R_f(\theta)$, the monitoring rate should be same for all farms.

Proof: see Appendix.

The intuition behind (a) is that the farmers with lower adoption cost can change their production practices easily comparing to the farmers with higher cost and their behaviors are easily be guided by monitoring activities. Hence inspection activities have a stronger effect on those farms with lower cost and the monitoring agency prefers not to devote resources to farms that have greater difficulty in using GAPs. The marginal deterrence effect of the inspection is smaller for the farms with higher cost than the farms with lower cost. Result (b) implies that there is no point to applying different monitoring effort to farms with different cost. This is due to the nature of the fraudulent production. The farmer's decision on y_f is independent on the exogenous cost parameter when $y_h^*(\theta)$ is attained.

Extension-Endogenous Detection Rate

The previous assumption that the detection rate is exogenous is a simplification applied for defining the analytical framework. A more realistic direction is to assume that the detection rate is to some extent influenced by the farmer's actions. It would be reasonable to think that the probability depends positively on the ratio of fraudulent output to the productive capacity. Let $\rho = \bar{\rho} y_f / \bar{y}$ denote the detection rate of a farm. It depends on both the fixed detection rate $\bar{\rho}$ and the impurity level $y_f / \bar{y}$.

With endogenous detection rate, the first order condition with respect to y_f becomes

(17) $$\Phi_f \equiv (p_h - t) - \frac{\bar{\rho}}{\bar{y}} \omega \left(2 p_h \cdot y_f + f(y_f) + y_f f'(y_f) \right) - \lambda \leq 0, \quad y_f \Phi_f = 0$$

A marginal unit of fraudulent output now increases the detection rate, which raises the penalty, i.e., expected marginal cost increases due to the fraudulent sales. This gives less incentive for the farmers to sell fraudulently. When the fraudulent output equals zero, if the marginal benefit of fraud is greater than the marginal cost, then it will be profitable for a farmer to attempt to sell output fraudulently. In the model, this condition would be

(18) $$\Phi_f \equiv \left(p_h - t\right) - \frac{\bar{\rho}}{\bar{y}}\omega\left(2p_h \cdot y_f + f\left(y_f\right)\right) \geq 0 \Leftrightarrow y_f \geq 0$$

Thus, there is always some fraud in the market regardless of the penalty. The full compliance production cannot be obtained with endogenous detection. This is because with decreasing of fraudulent output, the deterrence effect of monitoring becomes weak. In the perfectly competitive equilibrium, a fixed fine can be used to solve the problem of reducing the fraud completely. If there is a fixed fine F imposed on the fraudulent output in additional to the per unit penalty rate, the farmer will sell fraudulent output only if the following condition is satisfied,

(19) $$\left(p_h - t\right) - \frac{\bar{\rho}}{\bar{y}}\omega\left(2p_h \cdot y_f + f\left(y_f\right) + F\right) \geq 0$$

Therefore, we can find the fixed penalty has an *ex ante* deterrence effect. However, such a big fine usually cannot be enforced in reality.

Proposition 6. With endogenous detection rate and a given monitoring rate ω, the homogenous farmers' strategies $\left(y_h, y_l\right)$ are as follows:

(a) If $\omega = 0$, then $y_h = 0$ and $y_f = \bar{y}$.

(b) If $\omega \in \left(0, \omega_1\right)$, then $y_h \in \left(0, y_h^*\right)$ and $y_f \in \left(\bar{y} - y_h^*, \bar{y}\right)$.

where $\omega_1 = \dfrac{\left(p_h - t\right)\bar{y}}{2p_h \cdot y_f^* + f\left(y_f^*\right) + y_f f'\left(y_f^*\right)}$ and $y_f^* = \bar{y} - y_h^*$

(c) If $\omega \in \left(\omega_1, 1\right)$, then $y_h = y_h^*$ and $y_f \in \left(y_f^0, \bar{y} - y_h^*\right)$.

y_f^0 is implicitly defined as: $\left(p_h - t\right) - \frac{\bar{\rho}}{\bar{y}}\left(2p_h \cdot y_f^0 + f\left(y_f^0\right) + y_f f'\left(y_f^0\right)\right) = 0$

Proof: see Appendix.

Because fraudulent output cannot be excluded completely due to the endogenous detection rate, region (d) does not exist in this case. At region (c), the minimum level of fraudulent output y_f^0 can be attained only when the monitoring rate is one. An interesting possibility for future research is to examine the optimal policy design under endogenous detection.

Conclusions

We have built a model which illustrates how, and under what conditions, monitoring and enforcement activities might mitigate the fraudulent activities of food growers under a voluntary GAPs program. Our analysis brings out the following results:

First, the farms respond to the monitoring and enforcement not only on reducing fraudulent output, but also on increasing truly high-safety output till the perfect compliance level is achieved. Second, optimal monitoring policy depends on the exogenous parameters of the farms. If the monitoring budget is not enough to cover the necessary inspection cost of achieving perfect high-safety output level, it will allocate resources to farms with larger size and lower costs; If the budget is enough to obtain perfect level of high-safety output but is not enough to preclude fraudulent output, the monitoring agency will expend equal effort on all the farms. Third, fraudulent behaviors can be eliminated using the combination policies of penalty, sale ban and monitoring activities while cannot be excluded completely under an endogenous detection rate.

There are also several possible extensions for future work. First, we analyze the optimal monitoring policy when the farms are heterogeneous with respect to different parameters separately. For completeness, a more general case should be considered for the farms differing along two dimensions. A more complicated analysis could be developed when the parameters are dependent. Second, the monitoring budget is assumed to be exogenous in our model and we do not address the question of how the budget is decided. Actually, the voluntary program is always funded by a certification fee raised using inspection on each pound of output. On one hand, if the certification fee is too high, farms are forced to exit the industry; on the other hand, if it is too low, the monitoring cost cannot be covered and noncompliance increases. This leads to implications for the design of efficient monitoring programs in second-best policy settings.

References

Akerlof,G. 1970. "The Market for 'Lemons': Qualitative Uncertainty and the Market Mechanism." *Quarterly Journal of Economics* 84: 488-500.

Biglaiser, G. 1993. "Middlemen as Experts." *Rand Journal of Economics* 24: 212-224.

Darby, M.R. and E. Karni. 1973. "Free Competition and the Optimal Amount of Fraud." *Journal of Law and Economics* 16 (1): 67-88.

Hueth, B.and P. Marcoul. 2006. "Information Sharing and Oligopoly in Agricultural Markets: The Role of the Cooperative Bargaining Association." *American Journal of Agricultural Economics* 88: 866-881.

Caswell, J. and M. Mojduszka. 1996. "Using Informational Labeling to Influence the Market for Quality in Food Products." *American Journal of Agricultural Economics* 78: 1248-1253.

Caswell, J. and D. Padberg 1992. "Toward a More Comprehensive Theory of Food Labels." *American Journal of Agricultural Economics* 74(2): 460-468.

Carriquiry, M.A.and B. A. Babcock. 2004. "Reputations, Market Structure, and the Choice of Quality Assurance Systems in the Food Industry." Working Paper, Dept of Economics, Iowa State University

Crespi, J. M. and S. Marette. 2001. "How Should Food Safety Certification be Financed?" *American Journal of Agricultural Economics* 83: 852-861.

Crespi J.M. and S.Marette. 2003. "Some Economic Implications of Public Labeling." *Journal of Food Distribution Research* 34 (3): 83-94.

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

De, S. and P. Nabar 1991. “Economic Implications of Imperfect Quality Certification.” *Economic Letters* 37: 333-337.

Elbasha, E.H. and T.L. Riggs 1999. “The Effects of Information on Producer and Consumer Incentives to Undertake Food Safety Efforts: A Theoretical Model and Policy Implications.” *Agribusiness: An International Journal* 19: 29-42.

Emons, W. 1997. “Credence Goods and Fraudulent Experts.” *Rand Journal of Economics* 28: 107–119.

Emons, W. 2000. “Expertise, Contingent Fees, and Insufficient Attorney Effort.” *International Review of Law and Economics* 20 (1): 21–33.

Fox, J.A. and D.A. Hennessy 1999. “Cost-effective Hazard Control in Food Handling.” *American Journal of Agricultural Economics* 81: 359-72.

Govindasamy, R.and J. Italia. 1999. “Evaluating Consumer Usage of Nutritional Labeling: The Influence of Socio-Economic Characteristics.” *Journal of Nutritional Education* 4:370-375.

Golan, E., F. Kuchler and L. Mitchell. 2001. “Economics of Food Labeling.” *Journal of Consumer Policy* 24 (4): 117-184.

Kim, S-Y, R, N.M. Rodolfo and C. Oral. 2000. “The Effect of Food Label Use on Nutrient Intakes: An Endogenous Switching Regression Analysis.” *Journal of Agricultural and Resource Economics* 25:215-231.

Klein, B. and K. Leffler. 1981. “The Role of Market Forces in Assuring Contractual Performance.” *Journal of Political Economy* 89(4): 615-641.

Kreps, M. and W. Robert. 1982. “Reputation and Imperfect Information.” *Journal of Economic Theory* 27: 253-279.

Lizzeri, A. 1999. "Information Revelation and Certification Intermediaries." *Rand Journal of Economics* 30, 214-231.

Mason, C. and F. Sterbentz. 1994. "Imperfect Product Testing and Market Size." *International Economic Review* 35(2) 61-86.

Marette, S. 2005. "Inspection Intensity and Market Structure." CARD Working Paper 05-WP 412, Dept. of Economics, Iowa State University.

McCluskey, J.J. 2000. "A Game Theoretic Approach to Organic Foods: An Analysis of Asymmetric Information and Policy." *Agricultural and Resource Economics Review* 29 (1), 1-9.

Nelson, P. 1970. "Information and Consumer Behavior." *Journal of political Economy* 78: 311-329.

Nunez, J. 2001. "A Model of Self-Regualtion." *Economics Letters* 74: 91-97

Polinsky, A. M. and S. Shavell 1992. "Enforcement Cost and the Optimal Magnitude and Probability of Fines." *Journal of Law and Economics* 35(1): 133-148.

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: 659-679.

Starbird, S.A. 1997. "Acceptance Sampling, Imperfect Production, and the Optimality of Zero Defects." *Naval Research Logistics Quarterly* 44: 515-530.

Starbird, S.A. 2000. "Designing Food Safety Regulations: the Effect of Inspection Policy and Penalties for Noncompliance on Food Processor Behavior." *Journal of Agricultural and Resource Economics* 25(2): 616-635.

Starbird, S.A. 2005. “Moral Hazard, Inspection Policy, and Food Safety.” *American Journal of Agricultural Economics* 87(1): 15-27.

Tregear, A., S.Kuznesof and A.Moxey. 1998. “Policy Initiatives for Regional Foods: Some Insights from Consumer Research.” *Food Policy* 23: 383-94.

Giannakas, K. 2002. “Information Asymmetries and Consumption Decisions in Organic Food Product Markets.” *Canadian Journal of Agricultural Economics* 50, 35-50.

Yee. J. and M.C. Ahearn. 2005. “Government Policies and Farm Size: Does the Size Concept Matter.” *Applied Economic*, 37: 2231-2238.

Zago, A.M. and D. Pick. 2004. “Labeling Policies in Food Markets: Private Incentives, Public Intervention, and Welfare Effects.” *Journal of Agricultural and Resources Economics* 29 (1): 150-165.

Appendix

Proof of Proposition 1.

When $\omega = 0$, all farmers can sell fraudulent output freely, so they do not produce high-safety output at all. If $\lambda > 0$, the equality condition of equation (6) must be met, i.e., $y_h + y_f = \bar{y}$. From (4) and (5), we get $c^{'}(y_h) = \bar{\rho}\omega\left(p_h + f^{'}(y_f)\right)$. The monitoring rate can be expressed as $\omega = \dfrac{c^{'}(y_h)}{\bar{\rho}\left(p_h + f^{'}(y_f)\right)}$. Because the equality is met, y_f cannot be decreased without increasing y_h. The minimum monitoring effort necessary to achieve y_h^* is $\dfrac{p_h - t}{\bar{\rho}\left(p_h + f^{'}(\bar{y} - y_h^*)\right)} = \omega_1$. When $y_h = y_h^*$, then from (4) get $\lambda = 0$ and $y_h + y_f \le \bar{y}$ should be satisfied, thus equation (5) is reduced to $p_h - t = \bar{\rho}\omega\left(p_h + f^{'}(y_f)\right)$. With the increasing of ω, y_f decreases and the total output decreases. The fraudulent output level is interior of and only if $0 \le \omega < \dfrac{p_h - t}{\bar{\rho} p_h} = \omega_2$. The full compliance level can be obtained when $\omega \ge \omega_2$.

Proof of Proposition 3.

If $R < R_h(\alpha)$, y_h^* cannot be obtained. The monitoring rate is

$$\omega_1(\alpha) = \frac{c y_h(\alpha)}{\bar{\rho}\left(p_h + f^{'}\left(\alpha\bar{y} - y_h\right)\right)}$$

then $y_h(\alpha)$ is derived as

$$y_h(\alpha) = \frac{\omega_1 \bar{\rho}\left(p_h + f\alpha\bar{y}\right)}{\omega_1 \bar{\rho} f + c}$$

Let us now consider two farms, *k* and *j*, such that $\alpha_k > \alpha_j$. With limited resources the agency seeks to maximize aggregate equilibrium true high-safety production

$$\max_{\omega_i} \sum_i y_{hi} \text{ s.t. } \sum_i \omega_i \le R$$

We simplify the analysis by restricting our attention to interior solutions that exhaust resources. The first order necessary conditions reduce to

$$\frac{p_h + \alpha_k \bar{y} f}{\left(\omega_{1k} \bar{\rho} f + c\right)^2} = \frac{p_h + \alpha_j \bar{y} f}{\left(\omega_{1j} \bar{\rho} f + c\right)^2}$$

Proof of Proposition 4.

When $R_h(\alpha) \le R < 1$, the following condition should be satisfied:

$$\omega_2(\alpha) = \frac{p_h - t}{\bar{\rho}\left(p_h + f y_f\right)}$$

The maximum level of high-safety production can be achieved, the monitoring agency's problem is to minimize the noncompliance, and it should solve:

$$\min_{\omega_i} \sum_i y_{fi} \text{ s.t. } \sum_i \omega_i \le R$$

The first necessary conditions reduce to

$$\frac{1}{\left(\omega_{1k}\right)^2} = \frac{1}{\left(\omega_{2j}\right)^2}.$$

Proof of Proposition 5.

If $R < R_h(\theta)$, y_h^* cannot be obtained. The monitoring rate is

$$\omega_1(\theta) = \frac{\theta c y_h}{\bar{\rho}\left(p_h + f^{'}\left(\bar{y} - y_h\right)\right)}$$

then $y_h(\theta)$ is derived as

$$y_h(\theta) = \frac{(\omega_1 / \theta)}{(\omega_1 / \theta)\bar{\rho} f + c}\bar{\rho}\left(p_h + \bar{y}f\right)$$

Let us now consider two farms, *k* and *j*, such that $\theta_k > \theta_j$. With limited resources the agency seeks to maximize aggregate equilibrium true high-safety production

$$\max_{\omega_i / \theta_i} \sum_i y_{hi} \text{ s.t. } \sum_i \omega_i \le R$$

We simplify the analysis by restricting our attention to interior solutions that exhaust resources. The first order necessary conditions reduce to

$$\frac{\theta_j}{\left(f\omega_{1k} / \theta_k + c\right)^2} = \frac{\theta_k}{\left(f\omega_{1j} / \theta_j + c\right)^2}$$

When $R_h(\theta) \le R < 1$, the following condition should be satisfied:

$$\omega_2(\alpha) = \frac{p_h - t}{\bar{\rho}\left(p_h + f y_f\right)}$$

The maximum level of high-safety production can be achieved, the monitoring agency's problem is to minimize the noncompliance, it should solve:

$$\min_{\omega_i} \sum_i y_{fi} \text{ s.t. } \sum_i \omega_i \le R$$

The first necessary conditions reduce to

$$\frac{1}{\left(\omega_{1k}\right)^2} = \frac{1}{\left(\omega_{2j}\right)^2}.$$

When $R < R_h(\theta)$, the inspection of the monitoring agency starts with the farm with lower cost.

Proof of Proposition 6.

From equation (17), the monitoring rate under endogenous detection rate can be written as

$$\omega_1 = \frac{c y_h \bar{y}}{2 p_h \cdot y_f + f(y_f) + y_f f'(y_f)} \text{ and } y_f = \bar{y} - y_h$$

Similar to the exogenous detection case, the minimum effort necessary to achieve y_h^* is

$$\frac{(p_h - t)\bar{y}}{2 p_h \cdot y_f^* + f(y_f^*) + y_f f'(y_f^*)} = \omega_1 \text{ and } y_f^* = \bar{y} - y_h^*$$

Recall that the fraudulent output cannot be reduced to zero because the highest monitoring rate is one. Thus the minimum fraudulent output y_f^0 can be achieved if and only if $\omega = 1$ and the following condition satisfies

$$(p_h - t) - \frac{\bar{\rho}}{\bar{y}}\left(2 p_h \cdot y_f^0 + f(y_f^0) + y_f f'(y_f^0)\right) = 0$$