IPRPD
International Journal of Business & Management Studies
ISSN 2694-1430 (Print), 2694-1449 (Online)
Volume 02; Issue no 06: June, 2021

Analysis of Food Inspection Policy

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Abstract

In recent years, food safety issues have emerged one after another. Even food firms with good reputation are inevitably exposed to food safety incidents related to them by the media. Hence, how the food regulator can develop a set of food inspection policies meeting the expectations of the society is an extraordinary issue that cannot be ignored. The paper creates an analytical model to examine the food regulator's inspection policies, taking into account the possible strategic responses of the food firms. The results show that the optimal food inspection policy includes heavily inspecting, moderately inspecting, slightly inspecting, and Laissez faire policy, depending on inspection cost. The food regulator, on behalf of consumers, is supposed to adopt an adequate inspection policy inducing food firms to enhance food quality and ensure food safety.

Keywords: Information Asymmetry, Inspection Policy, Strategy Response.

1. Introduction

In the position of all profit-making firms, how to continuously "reduce costs, increase revenue, and raise profits" seems to be an inevitable operating measure. It is no exception for those engaged in food processing and production. However, if the food firm is unscrupulous in pursuing cost reduction, it tends to cause food safety problems and result in serious damage to the health of the public. Whether the reduction of food production costs can endanger the food safety or not is the food firm's private information. It is impossible to judge and prevent the occurrence of illegality without proper intervention of public power. The situation essentially reflects the problem of information asymmetry discussed in agency theory.

Food firms engaged in food production are required to comply with relevant food safety laws and regulations. It is reasonably expected by consumers that the food they bought meet related food safety requirements completely. Nevertheless, due to the asymmetry of information between buyers and sellers, the food firm has an incentive to produce food that does not meet the food safety requirements at a lower cost in an attempt to obtain greater business benefits. This is so-called moral hazard problem mentioned in agency theory. If there is no appropriate incentive mechanism to restrict the agent (food firm), the interest of the principal (consumer) will be eroded.

Based on audit theory, the paper sets up an analytical model to deal with the issue related to the food regulator's inspection policy. As we know, there has been considerable discussion in the audit literature on reducing the moral hazard caused by information asymmetry. Generally, conventional audit policy analysis covers a three-tier agency structure, including the principal, auditor, and agent. Among them, the auditor can also be regarded as the second agent of the principal. The past related studies, such as Baiman, Evans & Noel (1987), Baiman, Evans & Nagarajan (1991), Baron & Besanko (1984), Demski & Sappington (1987), Kofman & Lawarree (1993 & 1996), Guo, Chen & Lee (2013), and Guo & Chen (2015), etc., can be classified as the analysis and application of the agency structure.

In this paper, we extend the research results of the past audit theory to the development of the food regulator's inspection policy. It is assumed that, the food regulator will serve as the principal (on behalf of the consumer) to develop an inspection policy. The food firm will act as an agent to respond to the policy and the independent inspection unit will play the role of an auditor. Furthermore, not only can food regulator assign an independent unit to conduct inspections, but also food firms are allowed to conduct similar inspections on basis of their own interests. Through the derivation and analysis of the model, we will clarify the timing of the application of various types of inspection policies to provide relevant research results for the food regulator's reference.

The basic structure of this paper is divided into four parts: The first is the introduction. The second explains the basic assumptions and settings of the model used in this research. The third describes the results of model derivation and related implications. The conclusion of the paper is summarized in the final part.

2. The Model

In the single-period analysis model, it is assumed that a food firm (denoted by A) is engaged in food processing and manufacturing, and its production cost (I) has two choices: high or low. Investment in high production costs $(I = \bar{I})$ will lead to a higher qualification rate of food $(\bar{g})$, while investment in low production costs $(I = \underline{I})$ will result in a lower qualification rate of food $(\underline{g})$. Whether the food is qualified or not can be confirmed through inspection. This study assumes that either the food firm or its regulator entrusts the same independent inspection unit to conduct inspection, the inspection method and cost can be consistent. After the food is inspected, it can be correctly judged whether it is qualified (no misjudgement), and the inspection cost related is C (the cost of complete inspection). In addition, if the food is not found to be unqualified, the total revenue that the firm can receive is R; but if it is unqualified, the relevant food must be destroyed and no revenue can be obtained.

After the food firm has invested in the relevant production cost, it immediately needs to face food inspection decision to confirm whether the food meets the relevant legal requirements. The firm investing in high production cost $(\bar{I})$ needs to determine an appropriate inspection rate $(\bar{\alpha})$ to maximize the related expected payoff $(E[\pi_A(\bar{I},\bar{\alpha})])$, where $0 \le \bar{\alpha} \le 1$. Similarly, the firm investing in low production cost $(\underline{I})$ also needs to determine an appropriate inspection rate $(\underline{\alpha})$ to maximize the related expected payoff $(E[\pi_A(\underline{I},\underline{\alpha})])$, where $0 \le \underline{\alpha} \le 1$. If the unqualified food is not inspected and destroyed by the firm, but is later inspected by the regulator, a penalty of T will be imposed. In maximizing the expected payoff, the food firm will takes into account relevant factors, such as food revenue, production cost, inspection cost, and possible penalty for unqualified food, to determine the optimal production cost input $(\bar{I} \text{ or } \underline{I})$ as well as food inspection decision $(\bar{\alpha} \text{ or } \underline{\alpha})$.

Under the asymmetry of information, the food regulator (denoted by P) cannot know the actual food production cost invested by the food firm. Nevertheless, the food firm has a choice of either high or low production cost $(\bar{I} \text{ or } \underline{I})$, corresponding to different food qualification rate $(\bar{g} \text{ or } \underline{g})$, which are all common information just as the inspection cost. According to these information, the food regulator can develop a food inspection policy (i.e. determine a food inspection rate β and $0 \le \beta \le 1$) that is in line with the maximal expected utility of society. It is assumed that the expected payoff function to be maximized by the regulator in policy development is $E(\pi_P(\beta))$, incorporating the relevant variables such as food revenue (R), production cost (I), inspection costs (C) borne by the food form or the regulator, and society's damage costs (s) caused by unqualified food. Since the paper assumes that the food firm will destroy all unqualified food, the regulator conducts sampling inspection on all "inspected as qualified" and "uninspected" food in the market.

To summarize, the timing on the relevant events is presented as follows:

1. Under the expected food revenue R, the food firm decides to invest in high production cost $\bar{I}$ or low production cost $\underline{I}$, where $0 < \underline{I} < \bar{I}$.
2. Due to the action of nature, high production cost $(\bar{I})$ will lead to a higher food qualification rate $(\bar{g})$, and low production cost (I) will result in a lower food qualification rate $(\underline{g})$, where $0 < \underline{g} < \bar{g} \le 1$.
3. The food firm determines an appropriate inspection rate for the food produced under the inspection cost (C) in order to maximize the relevant expected payoff. With high (low) production cost input, $\bar{I}\ (\underline{I})$, the firm's inspection rate is $\bar{\alpha}\ (\underline{\alpha})$, where $0 \le \bar{\alpha} \le 1$ and $0 \le \underline{\alpha} \le 1$. Food that fails the inspection will be destroyed and no revenue will be realized.
4. The food regulator determines an appropriate inspection rate β for all foods on the market (including uninspected and qualified foods) under the inspection cost C to maximize the society's expected payoff. Hence, the probability of inspection (t) is β, and the probability of no inspection (nt) is 1-β. For food that fails to pass the inspection, in addition to being destroyed, a related penalty T will be imposed. As for the unqualified food that has not been inspected, it will result in the related society's damage cost s.
5. Transfer takes place.

The following figure 1 is game tree diagram related to the model in this paper. Among them, $\hat{B}$ represents the food that is found to be unqualified after inspection and is destroyed; and $\hat{G}$ represents the food that has not been inspected or is qualified after inspection.

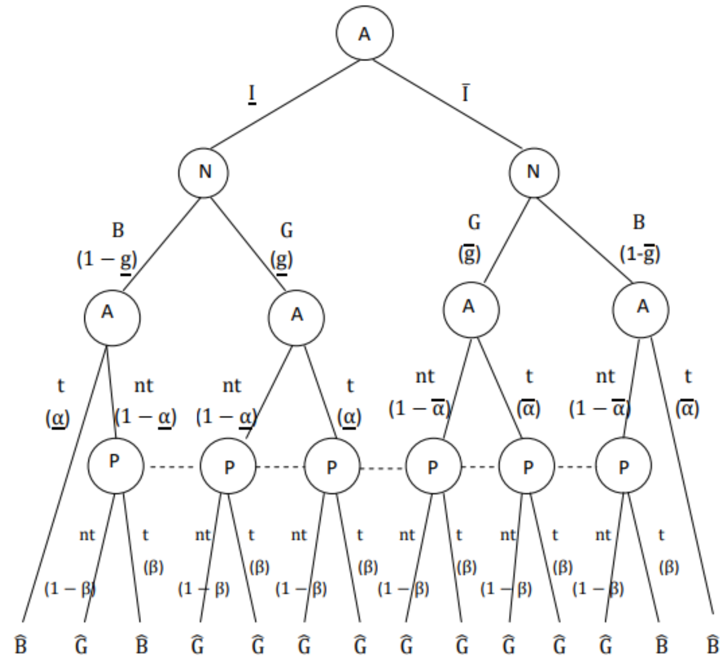

Figure 1: Game Tree

3. The Analysis

In this section, we explore the strategic interaction between the food firm and the regulator, and then obtain the optimal strategic choice in an equilibrium state. Basically, the analysis can be divided into two parts. The first part clarifies the influence of the regulator's food inspection policy on the food firm's self-inspection decision, while the second part discusses how the regulator develops the optimal food inspection policy as facing the possible strategic response from the food firm.

From the narration in the previous section, we learn that the inspection decision of the food firm is dependent on the production cost. Investing high production cost ($\bar{I}$) will lead to a higher food qualification rate ($\bar{g}$), and then the firm will determine a corresponding self-inspection rate ($\bar{\alpha}$) to maximize its expected return $E[\pi_A(\bar{I},\bar{\alpha})]$. By the same token, investing low production cost ($\underline{I}$) will lead to a lower food qualification rate ($\underline{g}$), and then the firm will determine a corresponding self-inspection rate ($\bar{\alpha}$) to maximize its expected return $E\left[\pi_A\left(\underline{I},\underline{\alpha}\right)\right]$. The related analysis results are summarized in lemma 1.

Lemma 1:

(1) $\bar{\alpha}^* = 1$ if $\bar{\beta} \leq \beta \leq 1$, but $\bar{\alpha}^* = 0$ if $0 \leq \beta < \bar{\beta}$.
(2) $\underline{\alpha}^* = 1$ if $\underline{\beta} \leq \beta \leq 1$, but $\underline{\alpha}^* = 0$ if $0 \leq \beta < \underline{\beta}$.

$\bar{\beta} \equiv [(1-\bar{g})R + C]/[(1-\bar{g})(R+T)]$, $\underline{\beta} \equiv \left[\left(1-\underline{g}\right)R + C\right]/\left[\left(1-\underline{g}\right)(R+T)\right]$, and $\underline{\beta} < \bar{\beta}$.

[Proof] See appendix A.

It is shown in lemma 1 that the food firm's self-inspection rate $\left(\bar{\alpha} \text{ or } \underline{\alpha}\right)$ is not only dependent on the production cost ($\bar{I}$ or $\underline{I}$), but also affected by the regulator's expected inspection rate ($\bar{\beta}$ or $\underline{\beta}$). Under the high (low) production cost invested by the firm, if the regulator's inspection rate is expected not less than $\bar{\beta}$ ($\underline{\beta}$), the firm's self-inspection rate will be 1; otherwise, the firm's self-inspection rate will be 0, where $\underline{\beta} < \bar{\beta}$.

After analysing the food firm's self-inspection decision, we further discuss its production cost input decision. According to lemma 1, $\bar{\alpha}^* = \underline{\alpha}^* = 0$ provided that the regulator's inspection rate is expected to be $\beta \in [0,\underline{\beta})$, and $\bar{\alpha}^* = 0$ but $\underline{\alpha}^* = 1$ if $\beta \in [\underline{\beta},\bar{\beta})$. Finally, $\bar{\alpha}^* = \underline{\alpha}^* = 1$ if $\beta \in [\bar{\beta},1]$. The following lemmas 2 to 4 are to evaluate the food firm's optimal production cost input decision, based on the three possible inspection rate ranges adopted by the regulator (β) as well as the corresponding three sets of optimal self-inspection rate combinations determined by the firm ($\bar{\alpha}^*,\underline{\alpha}^*$).

Lemma 2:

$I^* = \underline{I}$ and $\underline{\alpha}^* = 0$ if $0 \le \beta < \beta'$, but $I^* = \bar{I}$ and $\bar{\alpha}^* = 0$ if $\beta' \le \beta < \underline{\beta}$, where
$\beta' \equiv \Delta I/[\Delta g(R + T)]$, $\Delta I \equiv \bar{I} - \underline{I}$ and $\Delta g \equiv \bar{g} - \underline{g}$.
[Proof] See appendix B.

As shown in lemma 2, when $\beta \in [0, \underline{\beta})$, the food firm will choose to invest in low production costs (i.e. $I^* = \underline{I}$) without doing self-inspection (i.e. $\underline{\alpha}^* = 0$) if the regulator's inspection rate is relatively lower (i.e. $\beta < \beta'$). Nevertheless, the firm will choose to invest in high production costs (i.e. $I^* = \bar{I}$) and remain not doing self-inspection (i.e. $\bar{\alpha}^* = 0$) if the regulator's inspection rate is relatively higher (i.e. $\beta \ge \beta'$).

Lemma 3:

$I^* = \bar{I}$ and $\bar{\alpha}^* = 0$ if $\underline{\beta} \le \beta < \bar{\beta}$.
[Proof] See appendix C.

As shown in lemma 3, when $\beta \in [\underline{\beta}, \bar{\beta})$, the food firm will choose to invest in high production costs (i.e. $I^* = \bar{I}$) without doing self-inspection (i.e. $\bar{\alpha}^* = 0$).

Lemma 4:

$I^* = \bar{I}$ and $\bar{\alpha}^* = 1$ if $\bar{\beta} \le \beta \le 1$.
[Proof] See appendix D.

Expecting the regulator adopts highly inspection rate (i.e. $\bar{\beta} \le \beta \le 1$), the food firm will choose to invest in high production costs (i.e. $I^* = \bar{I}$) with conducting 100% self-inspection (i.e. $\bar{\alpha}^* = 1$). After analyzing the possible strategic response of the food firm to the inspection policy of the regulator, the latter can take it into consideration in the development of the inspection policy to meet the maximal expected utility of the society. According to the analysis results of lemmas 2 to 4, the regulator's inspection policies are classified as four types: laissez-faire, slightly, moderately, and heavily inspecting policy. The explanations related are as following:

The inspection rate for laissez-faire policy is assumed to be β_1 and $\beta_1 \in [0, \beta')$. The policy will result in the food firm not only choosing to invest in low production costs (i.e. $I^* = \underline{I}$) but not doing self-inspection (i.e. $\underline{\alpha}^* = 0$). Meanwhile, the maximal expected payoff of the society will be $\pi_1^* \equiv \max_{\beta_1} E(\pi_P(0 \le \beta_1 < \beta')) = E(\pi_P(0 \le \beta_1^* < \beta')) = R\underline{g} - \underline{I} - (1 - \underline{g})s + \beta_1^*[(1 - \underline{g})s - C]$.

The inspection rate for slightly inspecting policy is assumed to be β_2 and $\beta_2 \in [\beta', \underline{\beta})$. The policy will lead the food firm to invest in high production costs (i.e. $I^* = \bar{I}$) without doing self-inspection (i.e. $\bar{\alpha}^* = 0$). Meanwhile, the maximal expected payoff of the society will be $\pi_2^* \equiv \max_{\beta_2} E(\pi_P(\beta' \le \beta_2 < \underline{\beta})) = E(\pi_P(\beta' \le \beta_2^* < \underline{\beta})) = R\bar{g} - \bar{I} - (1 - \bar{g})s + \beta_2^*[(1 - \bar{g})s - C]$.

The inspection rate for moderately inspecting policy is assumed to be β_3 and $\beta_3 \in [\underline{\beta}, \bar{\beta})$. Under the policy, the firm will choose to invest in high production costs (i.e. $I^* = \bar{I}$) and remain not doing self-inspection (i.e. $\bar{\alpha}^* = 0$). Meanwhile, the maximal expected payoff of the society will be $\pi_3^* \equiv \max_{\beta_3} E(\pi_P(\underline{\beta} \le \beta_3 < \bar{\beta})) = E(\pi_P(\underline{\beta} \le \beta_3^* < \bar{\beta})) = R\bar{g} - \bar{I} - (1 - \bar{g})s + \beta_3^*[(1 - \bar{g})s - C]$.

Finally, the inspection rate for heavily inspecting policy is assumed to be β_4 and $\beta_4 \in [\bar{\beta}, 1]$. The policy will induce the food firm to invest in high production costs (i.e. $I^* = \bar{I}$) as well as undertake self-inspection (i.e. $\bar{\alpha}^* = 1$). Meanwhile, the maximal expected payoff of the society will be $\pi_4^* \equiv \max_{\beta_4} E(\pi_P(\bar{\beta} \le \beta_4 \le 1)) = E(\pi_P(\bar{\beta} \le \beta_4^* \le 1)) = R\bar{g} - \bar{I} - (1 + \bar{g}\beta_4^*)C$.

In the following lemmas 5 to 7, the four types of inspection policies will be compared and analyzed to confirm the relative advantages and disadvantages of each type of inspection policy under different conditions.

Lemma 5:

Let $\pi_1 \equiv E(\pi_P(0 \le \beta_1 < \beta'))$ and $\pi_2 \equiv E(\pi_P(\beta' \le \beta_2 < \underline{\beta}))$.
If $C \le C_1$, then $\pi_2^* \ge \pi_1^*$; but if $C > C_1$, then $\pi_1^* > \pi_2^*$, where
$\pi_1^* \equiv \max_{\beta_1} E(\pi_P(0 \le \beta_1 < \beta')) = E(\pi_P(0 \le \beta_1^* < \beta'))$,
$\pi_2^* \equiv \max_{\beta_2} E(\pi_P(\beta' \le \beta_2 < \underline{\beta})) = E(\pi_P(\beta' \le \beta_2^* < \underline{\beta}))$, and

$C_1 \equiv \left\{R\Delta g - \Delta I + \left[(1-\beta_1^*)\left(1-\underline{g}\right) - (1-\beta_2^*)(1-\overline{g})\right]s\right\}/(\beta_2^* - \beta_1^*)$.
[Proof] See appendix E.

As shown in lemma 5, $\pi_1^* > \pi_2^*$ as the inspection cost is higher than C_1. It implies that the laissez-faire inspecting policy will be better than the slightly inspecting policy. In contrast, the slightly inspecting policy will be better than the laissez-faire inspecting policy if the inspection cost is lower than (or equal to) C_1.

Lemma 6:

Let $\pi_3 \equiv E\left(\pi_P\left(\underline{\beta} \le \beta_3 < \overline{\beta}\right)\right)$ and $\pi_4 \equiv E\left(\pi_P(\overline{\beta} \le \beta_4 \le 1)\right)$.
If $C \le C_2$, then $\pi_4^* \ge \pi_3^*$; but if $C > C_2$, then $\pi_3^* > \pi_4^*$, where
$\pi_3^* \equiv \max_{\beta_3} E\left(\pi_P\left(\underline{\beta} \le \beta_3 < \overline{\beta}\right)\right) = E\left(\pi_P\left(\underline{\beta} \le \beta_3^* < \overline{\beta}\right)\right)$,
$\pi_4^* \equiv \max_{\beta_4} E\left(\pi_P(\overline{\beta} \le \beta_4 \le 1)\right) = E\left(\pi_P(\overline{\beta} \le \beta_4^* \le 1)\right)$,
$C_2 \equiv [(1-\beta_3^*)(1-\overline{g})s]/(1-\beta_3^* + \overline{g}\beta_4^*)$ and $C_2 < C_1$.
[Proof] See appendix F.

As shown in lemma 6, $\pi_3^* > \pi_4^*$ as the inspection cost is higher than C_2. It implies that the moderately inspecting policy will be better than the heavily inspecting policy. Conversely, the heavily inspecting policy will be better than the moderately inspecting policy if the inspection cost is lower than (or equal to) C_2.

Lemma 7:

Let $\pi_2 \equiv E\left(\pi_P\left(\beta' \le \beta_2 < \underline{\beta}\right)\right)$ and $\pi_3 \equiv E\left(\pi_P\left(\underline{\beta} \le \beta_3 < \overline{\beta}\right)\right)$.
If $C \le (1-\overline{g})s$, then $\pi_3^* \ge \pi_2^*$; but if $C > (1-\overline{g})s$, then $\pi_2^* > \pi_3^*$, where
$\pi_2^* \equiv \max_{\beta_2} E\left(\pi_P\left(\beta' \le \beta_2 < \underline{\beta}\right)\right) = E\left(\pi_P\left(\beta' \le \beta_2^* < \underline{\beta}\right)\right)$,
$\pi_3^* \equiv \max_{\beta_3} E\left(\pi_P\left(\underline{\beta} \le \beta_3 < \overline{\beta}\right)\right) = E\left(\pi_P\left(\underline{\beta} \le \beta_3^* < \overline{\beta}\right)\right)$, and
$C_2 < (1-\overline{g})s < \left(1-\underline{g}\right)s < C_1$.
[Proof] See appendix G.

As shown in lemma 7, $\pi_2^* > \pi_3^*$ as the inspection cost is higher than $(1-\overline{g})s$. Meanwhile, the slightly inspecting policy will be better than the moderately inspecting policy, and vice versa. Based on the results of Lemma 1 to Lemma 7, it is reasonable to further deduce the strategic equilibrium between the food firm and the regulator. The details are shown in Theorem 1 to Theorem 4.

Theorem 1:

If $C \le C_2$, then $\beta^* = \overline{\beta}, I^* = \overline{I}, \overline{\alpha}^* = 1$, and $\pi_P^* = R\overline{g} - \overline{I} - \left(1 + \overline{g}\overline{\beta}\right)C$, where
$C_2 \equiv [(1-\beta_3^*)(1-\overline{g})s]/(1-\beta_3^* + \overline{g}\beta_4^*)$ and $\overline{\beta} \equiv [(1-\overline{g})R + C]/[(1-\overline{g})(R+T)]$.
[Proof] See appendix H.
Theorem 1 points out that, when the inspection cost is relatively pretty low ($C \le C_2$), the regulator will adopt a heavily inspecting policy ($\beta = \overline{\beta}$) to induce the food firm to invest in high production cost ($I = \overline{I}$) and implement a complete inspection ($\overline{\alpha} = 1$).

Theorem 2:

If $C_2 < C \le (1-\overline{g})s$, then $\beta^* = \overline{\beta} - \varepsilon$ · $I^* = \overline{I}$ · $\overline{\alpha}^* = 0$, and $\pi_P^* = R\overline{g} - \overline{I} - (1-\overline{g})s + \left(\overline{\beta} - \varepsilon\right)[(1-\overline{g})s - C]$, where
$C_2 \equiv \left[\left(1-\overline{\beta}+\varepsilon\right)(1-\overline{g})s\right]/\left(1-\overline{\beta}+\varepsilon+\overline{g}\overline{\beta}\right) \cong \left[\left(1-\overline{\beta}\right)(1-\overline{g})s\right]/\left(1-\overline{\beta}+\overline{g}\overline{\beta}\right)$,
$\overline{\beta} \equiv [(1-\overline{g})R + C]/[(1-\overline{g})(R+T)]$, $\varepsilon > 0$ and $\varepsilon \to 0$ 。
[Proof] See appendix I.

Theorem 2 shows that when the inspection cost is relatively lower but not pretty low ($C_2 < C \le (1-\overline{g})s$), the regulator will adopt a moderate inspecting policy ($\beta = \overline{\beta} - \varepsilon < \overline{\beta}$) to induce the food firm to invest in high production cost ($I = \overline{I}$), but let it not perform any inspection ($\overline{\alpha} = 0$).

Theorem 3:

If $(1-\bar{g})s < C \le C_1$, then $\beta^* = \beta'$, $I^* = \bar{I}$, $\bar{\alpha}^* = 0$, and $\pi_P^* = R\bar{g} - \bar{I} - (1-\bar{g})s + \beta'[(1-\bar{g})s - C]$, where $C_1 \equiv [R\Delta g - \Delta I + \Delta gs + \beta'(1-\bar{g})s]/\beta'$ and $\beta' \equiv \Delta I/[\Delta g(R+T)]$.
[Proof] See appendix J.

According to the results of Theorem 3, when the inspection cost is relatively high but not pretty high ($(1-\bar{g})s < C \le C_1$), the regulator will adopt a slightly inspecting policy ($\beta = \beta'$). At this time, the food firm will respond by investing in high production cost ($I = \bar{I}$) instead of performing inspection ($\bar{\alpha} = 0$).

Theorem 4:

If $C > C_1$, then $\beta^* = 0, I^* = \underline{I}$, $\underline{\alpha}^* = 0$, and $\pi_P^* = R\underline{g} - \underline{I} - \left(1-\underline{g}\right)s$, where
$C_1 \equiv [R\Delta g - \Delta I + \Delta gs + \beta'(1-\bar{g})s]/\beta'$ and $\beta' \equiv \Delta I/[\Delta g(R+T)]$.
[Proof] See appendix K.
Based on the result of Theorem 4, when the inspection cost is significantly high ($C > C_1$), the regulator will tend to adopt a laissez-faire inspection policy ($\beta = 0$), resulting in the food firm responding with low production cost ($I = \underline{I}$) and not performing any inspection ($\underline{\alpha} = 0$).

4. Conclusion

The people will live in fear if food safety cannot be ensured. In the past decade, food safety problems have been not only widespread but getting worse and worse. Although the legislature, under the pressure of public opinion, has passed relevant food safety bills to impose much heavier penalties on illegal food firms, the effectiveness of the relevant laws and regulations remains dependent on the law enforcement of the food regulator. This study employs a model analysis method to examine how the regulator, facing the possible strategic responses of the food firms, develops a set of food inspection policies meeting the expectation of the society.

As shown in the paper, to maximize the expected utility of society, the optimal inspection policy of the food regulator will gradually shift from heavily inspecting to moderately inspecting, slightly inspecting, and Laissez faire policy, with the increase of inspection cost. Meanwhile, the food firms will respond by choosing to invest in high production costs coupled with complete inspections on its own, and finally to invest in low production costs without performing any inspections. The inspection policy and related strategic responses are essentially realistic results that conform to the cost-benefit principle of society as a whole.

Moreover, since the "heavily inspecting policy" tends to induce the food firms to make high investment in production costs and perform complete inspections, it is considered a better policy meeting the expectations of the society. However, the applicable condition of the heavily inspecting policy is when the inspection cost is relatively insignificant. The condition seems much easier to be satisfied when the uninspected unqualified food is relatively costlier to the society.

Appendix

Appendix A (*Proof of Lemma 1*)

Let $E[\pi_A(\bar{I},\bar{\alpha})] \equiv \bar{g}\bar{\alpha}(R-\bar{I}-C) + \bar{g}(1-\bar{\alpha})(R-\bar{I}) + (1-\bar{g})\bar{\alpha}(-\bar{I}-C) + (1-\bar{g})(1-\bar{\alpha})[\beta(-\bar{I}-T) + (1-\beta)(R-\bar{I})]$, and $dE[\pi_A(\bar{I},\bar{\alpha})]/d\,\bar{\alpha}$
$= \bar{g}(R-\bar{I}-C) - \bar{g}(R-\bar{I}) + (1-\bar{g})(-\bar{I}-C) - (1-\bar{g})[\beta(-\bar{I}-T) + (1-\beta)(R-\bar{I})]$
$= \beta(1-\bar{g})(R+T) - (1-\bar{g})R - C.$

If $\beta \ge [(1-\bar{g})R + C]/[(1-\bar{g})(R+T)] \equiv \bar{\beta}$, then $dE[\pi_A(\bar{I},\bar{\alpha})]/d\,\bar{\alpha} \ge 0$. $\bar{\alpha}^* = 1$ will maximize $E[\pi_A(\bar{I},\bar{\alpha})]$. Conversely, if $\beta < \bar{\beta}$, then $dE[\pi_A(\bar{I},\bar{\alpha})]/d\,\bar{\alpha} < 0$. *Thus*, $\bar{\alpha}^* = 0$ will maximize $E[\pi_A(\bar{I},\bar{\alpha})]$.

By the same token,
Let $E\left[\pi_A\left(\underline{I},\underline{\alpha}\right)\right] \equiv \underline{g}\underline{\alpha}\left(R-\underline{I}-C\right) + \underline{g}\left(1-\underline{\alpha}\right)\left(R-\underline{I}\right) + \left(1-\underline{g}\right)\underline{\alpha}\left(-\underline{I}-C\right)$
$+ \left(1-\underline{g}\right)\left(1-\underline{\alpha}\right)\left[\beta\left(-\underline{I}-T\right) + (1-\beta)\left(R-\underline{I}\right)\right]$,
and $dE\left[\pi_A\left(\underline{I},\underline{\alpha}\right)\right]/d\,\underline{\alpha} = \beta\left(1-\underline{g}\right)(R+T) - \left(1-\underline{g}\right)R - C.$
If $\beta \ge \left[\left(1-\underline{g}\right)R + C\right]/\left[\left(1-\underline{g}\right)(R+T)\right] \equiv \underline{\beta}$, then $dE\left[\pi_A\left(\underline{I},\underline{\alpha}\right)\right]/d\underline{\alpha} \ge 0$. $\underline{A}^* = 1$ will maximize $E\left[\pi_A\left(\underline{I},\underline{\alpha}\right)\right]$. Conversely, if $\beta < \underline{\beta}$, then $dE\left[\pi_A\left(\underline{I},\underline{\alpha}\right)\right]/d\underline{\alpha} < 0$.

Hence, $\underline{\alpha}^* = 0$ will maximize $E[\pi_A(\underline{I}, \underline{\alpha})]$.

Additionally, $\underline{\beta} < \overline{\beta} \Leftrightarrow (1-\overline{g})\left[\left(1-\underline{g}\right)R + C\right] < \left(1-\underline{g}\right)[(1-\overline{g})R + C] \Leftrightarrow (1-\overline{g})C < \left(1-\underline{g}\right)C \Leftrightarrow \underline{g} < \overline{g}$.

Q.E.D.

Appendix B (*Proof of Lemma 2*)

Based on Lemma 1, if $0 \leq \beta < \underline{\beta}$, then $\underline{\alpha}^* = \overline{\alpha}^* = 0$. Hence, when $0 \leq \beta < \underline{\beta}$,

$$E[\pi_A^*(I = \overline{I})] \geq E[\pi_A^*(I = \underline{I})]$$

$$\Leftrightarrow E[\pi_A(I = \overline{I}, \overline{\alpha} = 0)] \geq E[\pi_A(I = \underline{I}, \underline{\alpha} = 0)]$$

$$\Leftrightarrow \overline{g}(R - \overline{I}) + (1-\overline{g})[\beta(-\overline{I} - T) + (1-\beta)(R - \overline{I})] \geq$$

$$\underline{g}(R - \underline{I}) + \left(1-\underline{g}\right)[\beta(-\underline{I} - T) + (1-\beta)(R - \underline{I})]$$

$$\Leftrightarrow R - \overline{I} - \beta(1-\overline{g})(R + T) \geq R - \underline{I} - \beta\left(1-\underline{g}\right)(R + T)$$

$$\Leftrightarrow \beta\left(\overline{g} - \underline{g}\right)(R + T) \geq \overline{I} - \underline{I}$$

$$\Leftrightarrow \beta \geq [\overline{I} - \underline{I}]/\left[\left(\overline{g} - \underline{g}\right)(R + T)\right] = \Delta I/[\Delta g(R + T)] \equiv \beta'$$

Meanwhile, $\beta' < \underline{\beta}$

$$\Leftrightarrow \Delta I/[\Delta g(R + T)] < \left[\left(1-\underline{g}\right)R + C\right]/\left[\left(1-\underline{g}\right)(R + T)\right]$$

$$\Leftrightarrow \Delta I\left(1-\underline{g}\right)(R + T) < \Delta g(R + T)\left[\left(1-\underline{g}\right)R + C\right]$$

$$\Leftrightarrow \Delta I\left(1-\underline{g}\right)(R + T) < R\Delta g\left(1-\underline{g}\right)(R + T) + \Delta g(R + T)C$$

$\Leftrightarrow \Delta I\left(1-\underline{g}\right) < R\Delta g\left(1-\underline{g}\right) + \Delta gC$. (The paper assumes $\Delta I < R\Delta g$) Q.E.D.

Appendix C (*Proof of Lemma 3*)

Based on Lemma 1, if $\underline{\beta} \leq \beta < \bar{\beta}$, then $\overline{\alpha}^* = 0$ and $\underline{\alpha}^* = 1$. Hence, when $\underline{\beta} \leq \beta < \bar{\beta}$,

$$E[\pi_A^*(I = \overline{I})] \geq E[\pi_A^*(I = \underline{I})]$$

$$\Leftrightarrow E[\pi_A(I = \overline{I}, \overline{\alpha} = 0)] \geq E[\pi_A(I = \underline{I}, \underline{\alpha} = 1)]$$

$$\Leftrightarrow \overline{g}(R - \overline{I}) + (1-\overline{g})[\beta(-\overline{I} - T) + (1-\beta)(R - \overline{I})] \geq$$

$$\underline{g}(R - \underline{I} - C) + \left(1-\underline{g}\right)(-\underline{I} - C)$$

$$\Leftrightarrow R - \overline{I} - \beta(1-\overline{g})(R + T) \geq \underline{g}R - \underline{I} - C$$

$$\Leftrightarrow \beta \leq \left[\left(1-\underline{g}\right)R - \Delta I + C\right]/[(1-\overline{g})(R + T)] \equiv \beta''$$

Meanwhile, $\beta'' > \overline{\beta}$

$$\Leftrightarrow \left[\left(1-\underline{g}\right)R - \Delta I + C\right]/[(1-\overline{g})(R + T)] > [(1-\overline{g})R + C]/[(1-\overline{g})(R + T)]$$

$$\Leftrightarrow \left(1-\underline{g}\right)R - \Delta I + C > (1-\overline{g})R + C$$

$\Leftrightarrow R\Delta g > \Delta I$. Q.E.D.

Appendix D (*Proof of Lemma 4*)
Based on Lemma 1, if $\beta \geq \bar{\beta}$, then $\underline{\alpha}^* = \bar{\alpha}^* = 1$. Hence, when $\beta \geq \bar{\beta}$,
$E[\pi_A^*(I = \bar{I})] \geq E[\pi_A^*(I = \underline{I})]$
$\Leftrightarrow E[\pi_A(I = \bar{I}, \bar{\alpha} = 1)] \geq E[\pi_A(I = \underline{I}, \underline{\alpha} = 1)]$
$\Leftrightarrow \bar{g}(R - \bar{I} - C) + (1 - \bar{g})(-\bar{I} - C) \geq \underline{g}(R - \underline{I} - C) + (1 - \underline{g})(-\underline{I} - C)$
$\Leftrightarrow R\Delta g \geq \Delta I$. Q.E.D.

Appendix E (*Proof of Lemma 5*)
Based on Lemma 2, if $0 \leq \beta < \beta'$, then $I^* = \underline{I}$ and $\underline{\alpha}^* = 0$; but if $\beta' \leq \beta < \underline{\beta}$, then
$I^* = \bar{I}$ and $\bar{\alpha}^* = 0$.
Hence, $\pi_1^* \equiv \max_{\beta_1} E(\pi_P(0 \leq \beta_1 < \beta')) = E(\pi_P(0 \leq \beta_1^* < \beta')) = R\underline{g} - \underline{I} - (1 - \underline{g})s + \beta_1^*[(1 - \underline{g})s - C]$, and
$\pi_2^* \equiv \max_{\beta_2} E(\pi_P(\beta' \leq \beta_2 < \underline{\beta})) = E(\pi_P(\beta' \leq \beta_2^* < \underline{\beta})) = R\bar{g} - \bar{I} - (1 - \bar{g})s + \beta_2^*[(1 - \bar{g})s - C]$.
Moreover, $\pi_2^* \geq \pi_1^*$
$\Leftrightarrow R\bar{g} - \bar{I} - (1 - \bar{g})s + \beta_2^*[(1 - \bar{g})s - C] \geq R\underline{g} - \underline{I} - (1 - \underline{g})s + \beta_1^*[(1 - \underline{g})s - C]$
$\Leftrightarrow R\Delta g - \Delta I + [(1 - \beta_1^*)(1 - \underline{g}) - (1 - \beta_2^*)(1 - \bar{g})]s - (\beta_2^* - \beta_1^*)C \geq 0$
$\Leftrightarrow C \leq \{R\Delta g - \Delta I + [(1 - \beta_1^*)(1 - \underline{g}) - (1 - \beta_2^*)(1 - \bar{g})]s\}/(\beta_2^* - \beta_1^*) \equiv C_1$
Conversely, $\pi_1^* > \pi_2^* \Leftrightarrow C > C_1$. Q.E.D.

Appendix F (*Proof of Lemma 6*)
Based on Lemmas 3 & 4, if $\underline{\beta} \leq \beta < \bar{\beta}$, then $I^* = \bar{I}$ and $\bar{\alpha}^* = 0$; but if $\bar{\beta} \leq \beta \leq 1$, then $I^* = \bar{I}$ and $\bar{\alpha}^* = 1$. Hence,
$\pi_3^* \equiv \max_{\beta_3} E(\pi_P(\underline{\beta} \leq \beta_3 < \bar{\beta})) = E(\pi_P(\underline{\beta} \leq \beta_3^* < \bar{\beta})) = R\bar{g} - \bar{I} - (1 - \bar{g})s + \beta_3^*[(1 - \bar{g})s - C]$, and $\pi_4^* \equiv$
$\max_{\beta_4} E(\pi_P(\bar{\beta} \leq \beta_4 \leq 1)) = E(\pi_P(\bar{\beta} \leq \beta_4^* \leq 1)) = R\bar{g} - \bar{I} - (1 + \bar{g}\beta_4^*)C$. Moreover,
$\pi_4^* \geq \pi_3^*$
$\Leftrightarrow R\bar{g} - \bar{I} - (1 + \bar{g}\beta_4^*)C \geq R\bar{g} - \bar{I} - (1 - \bar{g})s + \beta_3^*[(1 - \bar{g})s - C]$
$\Leftrightarrow (1 - \beta_3^* + \bar{g}\beta_4^*)C \leq (1 - \bar{g})s - (1 - \bar{g})s\beta_3^*$

$$\Leftrightarrow \mathbf{C} \leq [(\mathbf{1} - \boldsymbol{\beta}_3^*)(\mathbf{1} - \bar{\mathbf{g}})\mathbf{s}]/(\mathbf{1} - \boldsymbol{\beta}_3^* + \bar{\mathbf{g}}\boldsymbol{\beta}_4^*) \equiv \mathbf{C_2}$$

Conversely, $\pi_3^* > \pi_4^* \Leftrightarrow C > C_2$. Q.E.D.

Appendix G (*Proof of Lemma 7*)
$\pi_2^* \equiv \max_{\beta_2} E(\pi_P(\beta' \leq \beta_2 < \underline{\beta})) = E(\pi_P(\beta' \leq \beta_2^* < \underline{\beta})) = R\bar{g} - \bar{I} - (1 - \bar{g})s + \beta_2^*[(1 - \bar{g})s - C]$, and
$\pi_3^* \equiv \max_{\beta_3} E(\pi_P(\underline{\beta} \leq \beta_3 < \bar{\beta})) = E(\pi_P(\underline{\beta} \leq \beta_3^* < \bar{\beta})) = R\bar{g} - \bar{I} - (1 - \bar{g})s +$
$\beta_3^*[(1 - \bar{g})s - C]$.
$\pi_3^* \geq \pi_2^*$
$\Leftrightarrow R\bar{g} - \bar{I} - (1 - \bar{g})s + \beta_3^*[(1 - \bar{g})s - C] \geq R\bar{g} - \bar{I} - (1 - \bar{g})s + \beta_2^*[(1 - \bar{g})s - C]$
$\Leftrightarrow \beta_3^*[(1 - \bar{g})s - C] \geq \beta_2^*[(1 - \bar{g})s - C]$
$\Leftrightarrow (\beta_3^* - \beta_2^*)[(1 - \bar{g})s - C] \geq 0$
Due to $\beta_3^* > \beta_2^*$, if $C \leq (1 - \bar{g})s$, then $\pi_3^* \geq \pi_2^*$; otherwise, $\pi_2^* > \pi_3^*$. Q.E.D.

Appendix H (*Proof of Theorem 1*)
According to Lemmas 5 & 6, if $C \leq C_2(< C_1)$, then $\pi_2^* > \pi_1^*$ and $\pi_4^* \geq \pi_3^*$. Besides, based on Lemma 7, if $C \leq C_2(< (1 - \bar{g})s)$, then $\pi_3^* \geq \pi_2^*$. Hence, if $C \leq C_2$, then $\pi_P^* = \pi_4^* = \max_{\beta_4} E(\pi_P(\bar{\beta} \leq \beta_4 \leq 1)) = R\bar{g} - \bar{I} - (1 + \bar{g}\bar{\beta})$.
Thus, $\beta^* = \bar{\beta}$ will lead to $I^* = \bar{I}$ and $\bar{\alpha}^* = 1$. Q.E.D.

Appendix I (*Proof of Theorem 2*)
According to Lemmas 5 & 6, if $C_2 < C \leq (1-\overline{g})s(< C_1)$, then $\pi_2^* \geq \pi_1^*$ and $\pi_3^* > \pi_4^*$. Also, based on Lemma 7, if $C \leq (1-\overline{g})s$, then $\pi_3^* \geq \pi_2^*$. Hence, if $C_2 < C \leq (1-\overline{g})s$, then $\pi_P^* = \pi_3^* \equiv \max_{\beta_3} E\left(\pi_P\left(\underline{\beta} \leq \beta_3 < \overline{\beta}\right)\right) = R\overline{g} - \overline{I} - (1-\overline{g})s + \left(\overline{\beta} - \varepsilon\right)[(1-\overline{g})s - C]$. Thus, $\beta^* = \overline{\beta} - \varepsilon$ will lead to $I^* = \overline{I}$ and $\overline{\alpha}^* = 0$, where $\varepsilon > 0$ and $\varepsilon \to 0$. Q.E.D.

Appendix J (*Proof of Theorem 3*)
According to Lemmas 5 & 6, if $C_2(< (1-\overline{g})s) < C \leq C_1$, then $\pi_2^* \geq \pi_1^*$ and $\pi_3^* > \pi_4^*$. Also, based on Lemma 7, if $(1-\overline{g})s < C(\leq C_1)$, then $\pi_2^* > \pi_3^*$. Hence, if $(1-\overline{g})s < C \leq C_1$, then $\pi_P^* = \pi_2^* = \max_{\beta_2} E\left(\pi_P\left(\beta' \leq \beta_2 < \underline{\beta}\right)\right) = R\overline{g} - \overline{I} - (1-\overline{g})s + \beta'[(1-\overline{g})s - C]$. Thus, $\beta^* = \beta'$ will lead to $I^* = \overline{I}$ and $\overline{\alpha}^* = 0$. Q.E.D.

Appendix K (*Proof of Theorem 4*)

According to Lemmas 5 & 7, if $\mathbf{C > C_1(> (1-\overline{g})s)}$, **then** $\boldsymbol{\pi_1^* > \pi_2^* > \pi_3^*}$. Also, based on Lemma 6, if $\mathbf{C(> C_1) > C_2}$, then $\boldsymbol{\pi_3^* > \pi_4^*}$. Hence, if $\mathbf{C > C_1}$, **then** $\boldsymbol{\pi_P^* = \pi_1^* = \max_{\beta_1} E\left(\pi_P(0 \leq \beta_1 < \beta')\right) = R\underline{g} - \underline{I} - \left(1-\underline{g}\right)s}$. Thus, $\boldsymbol{\beta^* = 0}$ **will lead to** $\mathbf{I^* = \underline{I}}$ and $\boldsymbol{\underline{\alpha}^* = 0}$. Q.E.D.

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