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Risk governance mechanism of food safety based on product reputation

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Abstract. Food matters in the public daily lives; it is both practically and theoretically imperative to enhance the governance of food safety risks. In this paper, a three-tier supply chain model involving government regulatory authorities, food producers, and customers is established for designing a risk governance mechanism of food safety based on a reputation updating model. Meanwhile, the study also explores the influence of reputation on product quality and sales price for food producers, as well as the accuracy in testing product quality of government and the effectiveness of governmental regulations. The results show that product price is positively correlated with reputation and negatively related to the government's rewards and punishments. When the government improves the accuracy of food sample testing and enhances rewards and strengthens punishments for food producers, product quality can be effectively controlled, sales prices can be balanced, and producer's profits can be improved. Finally, this paper provides insight into the risk governance of food safety through many observations. It is found that it is a relatively slow process for producers to improve their company's reputation by improving its product quality. Still, issues with food quality and safety afford a devastating blow to the company's reputation once this information is released.

1. Introduction

Food safety risk threatens public health and daily lives; almost 18 million people die from unsanitary food each year in recent decades. In recent years, many countries have also been plagued by food safety scandals, such as the "EHEC contaminated cucumber" in Germany, "*Salmonella* contaminated peanut butter" in the US, and a good deal of food safety incidents in China, including the "Fuxi incident", "clenbuterol", and "tainted stained buns", etc. According to the survey named "Comprehensive Well-off Index in China", which was recently completed by the Media Investigation Laboratory of Tsinghua University, people pay more attention to food safety issues (55.1%) than environmental protection (36.5%), price index (43.4%), medical reform (40.5%), housing prices (41.2%) and other issues, indicating public anxiety, helplessness and even extreme dissatisfaction with current food safety issues. Therefore, food safety has been becoming a major social problem worldwide, resulting in huge anxiety about food safety. However, food is a typical kind of credence product; its quality is hard to measure

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and quantify for the ordinary public. As well, health damages due to unsafe foods are hard to detect in real-time and *prohibitory* to figure out the source. The public eagerly expects effective and better governmental administration of food safety risks.

Food safety issues threaten public health every single day and evoke widespread social concern and panic. Sheltering residents from threats and risks is a key responsibility for governments, where governance mechanism is a pillar of food safety risk management. To mitigate food safety risks, government authorities develop food quality standards and take inspection on producers' productions. The lawful producers' output products strictly follow the food quality standards assigned by government authorities. However, some speculative producers obey regulations and output unqualified products to markets in practice. Although some of the unqualified products are detected in inspection, a proportion of them is outputted and consumed by consumers. The effectiveness of inspection mainly depends on the fiscal and manpower input, which are often limitations for huge administrative tasks. Considering the management problems of food safety in practice, this study tries to suggest a reputation-based food quality management mechanism and examine its effectiveness with a number of simulations.

To theoretically provide the governance mechanism, we consider a three-tier supply chain consisting of government regulatory authority (she), food producer (he), and customer. The suggested governance mechanism follows sequences. First, the government tests the products of food producers and publicizes the test results. The customer then builds perceptions of food based on the experienced product quality and the market price. In this paper, we specify the perceptions of product by product reputation. According to test results, government regulatory authority rewards or punishes the producer following regulations and rules. The food producer estimates the market demand affected by food quality reputation and decides its optimal selling prices. At the end of the trading period, customers establish a reputation updating model to update the products' reputation based on the actual product quality and sales price.

The contributions of this paper include the following: (1) Combining the previous government management system of food safety and the food producers' own quality contracts, this paper introduces the reputation factor to explore its regulatory role for decision-making parties in the food safety supply chain. (2) Based on market publicity information such as product quality and price, a reputation updating model is established to more accurately record the change in product reputation for several transaction periods. (3) The research results of this paper show that the influence of product reputation factors is a good complement to improving the traditional risk governance mechanism of food safety.

The rest of this paper is organized as follows: Section 2 is a literature review, and we summarize some existing problems and propose the innovation of this paper by analyzing the latest research on food safety supply chains. In Section 3, we design the reputation updating model, the market demand model, and the food producer profit model. Section 4 is the model derivation, and Section 5 reveals the results and performs an analysis by designing observation parameters. Section 6 summarizes the research results in this paper and proposes forward ideas for future research.

2. Literature review

Previous research on food supply chains and food safety risk management is not difficult to find. Den Ouden et al. [1] first proposed the concept of the food supply chain, considering it as a vertical integration operation model made by agricultural products as well as food production and sales organizations to lower logistics costs in food and agricultural products, improve product quality and safety, and provide better logistics services. Starbird [2] contended that food supply chain contracts can better identify food quality and safety producers, in which factors such as quality, cost, and punishments are involved. Van Asselt and Meuwissen [3] summarized the key factors affecting food safety risks in the dynamic food supply chain based on market demand for agricultural and food information. Lin and Yao [4] designed a product quality inspection method implemented by a government agency to find a balanced solution of quality and inspection strength based on publicized product quality information, which helps to identify disqualified companies. Martinez et al. [5] believed that in the different links of the food supply chain, the combination of government regulatory management and manufacturer contract management can improve food quality and safety at a lower cost and can realize the effective allocation of scarce resources.

As for the severe asymmetry of food supply information in the supply chain, Darby and Karni [6], based on the study of Nelson [7], divided the quality characteristic of goods into search quality, experience quality, and credence quality according to the degree of asymmetry in the quality of information between buyers and sellers. For search quality and experience quality in food, the appearance, taste, and other attributes can be obtained directly before or after purchase. It is difficult or nearly impossible to evaluate the health impact of chemical residues, food additives, and other attributes in credible food in the short term, even after purchase or use by the customer, so the customer can only make transactions based on product

credibility. Starbird and Amanorboadu [8] pointed out that product quality testing and product traceability have an impact on product safety. By establishing the seller's expected cost function, he studied the accuracy of product quality inspection, product traceability, cost of product failure to pass inspections, and the impact of product safety incidents on the qualification rate of the seller's product [9]. Souza Monteiro and Caswell [10] used a principal-agent model to study how a distributor can design a cost-compensation mechanism in a food supply chain system that includes a farmer, a processor, and a distributor to minimize cost. Saak [11] focused on the food supply chain of two upstream companies, one downstream company, and one customer group. Babich and Tang [12] researched the condition when the buyer could not fully understand and control the product quality from the seller; the buyer could prevent the seller from producing low-quality products through three mechanisms: quality inspection, trade credit, and a combination of the two.

In recent years, interdisciplinary research on risk management of food safety from perspectives of trust and word of mouth is gradually emerging [13]. Williams et al. [14] adopted research findings of risk cognition in sociology and psychology and studied food safety risk management based on theories in communication and politics. Katleen et al. [15] used statistical methods to obtain risk perception by customers and explained how trust in food safety information affects food purchase intention. Fu et al. [16] defined trust as the degree of reliance that retailers accept by using demand forecasting information provided by the agent and proposed a trust updating model to quantify the trustworthiness of decision-makers in the supply chain. Dania et al. [17] systematically reviewed the literature on sustainable agri-food supply chains based on resource reliance theory and content analysis. They summarized ten key behavioral factors such as sharing activities, trust, and commitment, thus forming an effective, sustainable management collaboration system for agricultural food supply chains.

In summary, research on the sources, formation, and risk levels of risk factors in food safety yielded fruitful results. However, based on a combination of government supervision and producers' contracts, this paper studies the impact of product reputation on product quality and sales price determined by food producers, as well as the accuracy of government testing and rewards and punishments, by establishing a game model to provide a new thought to explore food safety risk management.

3. Models in decisions

This paper aims at a three-tier supply chain model involving a government regulator, a food producer, and a customer. First, the food producer submits a product to the government regulatory department for inspection. The government department rewards or punishes the enterprise based on the quality of the detected product and later publicizes the test results. Then, the food producer predicts market demand based on previous reputation and the test results and sets a product price. Finally, the customer evaluates the product reputation based on the quality and price of the detected product and discloses the current reputation information. This decision process is shown in Figure 1.

The government decides the rewards and punishment, the food producer determines the selling price and food quality, and consumers update their perception of food products. The parameters and variables employed in the research are presented in Table A.1 in Appendix A.

3.1. Reputation updating model

By observing the government's test report on food quality and the product sales price, customers can obtain the reputation of the product in the market, and the reputation information could be disclosed at the end of each trading period, which means it is accessible to customers and businesses. The reputation value in each period is renewed based on the value in the previous period.

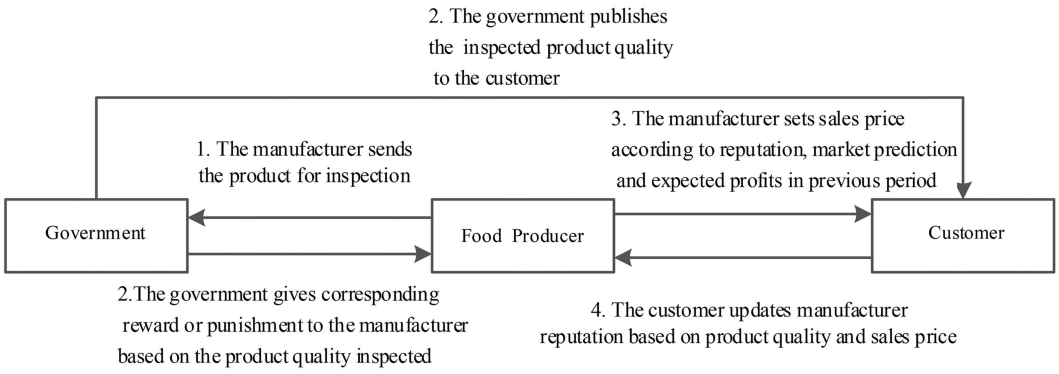

Figure 1. Flow chart of decision-making in the food supply chain after considering product reputation.

During period t, the true quality of the product is q_t, $q_t \in (0,1)$. The quality of the products inspected by the government is λq_t, $\lambda \in (1-\eta, 1+\eta)$. λ is the coefficient for government inspection of the product quality, while η is the fluctuation range for the inspected product quality. Factors that affect product reputation are known to be divided into two parts: one is the gap between the product quality inspected by the government λq_t, and the customer's expected quality $\bar{q}$, which also means the minimum quality that the customer can tolerate [18]; the other is the gap between product sales price p_t and the customer psychological price $\bar{p}$, which is also the customer expected price for the product and can only be known by the product producer at the end of the trading period [19]. Therefore, we determine reputation updating value Δ:

$$\Delta = \varepsilon \frac{\overline{q} - \lambda q_t}{\overline{q}} + (1-\varepsilon)\left(\frac{|\overline{p} - p_t|}{\overline{p}}\right). \quad (1)$$

The value of the sensitivity parameters ε in Eq. (1) means that if its value is larger, then the customers are more sensitive to product quality, and if its value is smaller, then the customers are more sensitive to product price. When the quality of the product inspected by the government is lower than the customer's expected quality, the reputation updating value is negative by Eq. (1), and the worse the product quality is, the more rapidly the reputation value decreases. The association can be explained as follows: when the sales price deviates from the customer's psychological price, customers suspect that the product is too expensive or is sold at a low price due to inferior quality, so the reputation updating value decreases faster; when the sales price approaches the customer psychological price, the product price is closer to the customers' psychological expectation, so the reputation updating value decreases slowly; and when the sales price is equal to the customer's psychological price, the product price is consistent with the customer's expectation, and the reputation updating is only subject to the impact of product quality. The reputation updating model can be designed as follows:

$$\begin{cases} R_0 = \mathrm{c}_0 \\ R_t = R_{\mathrm{t}-1}(1-\Delta) \end{cases} \quad (2)$$

In Eq. (2), R_0 is initial reputation, c_0 is a constant, and the product reputation during period t is $R_t \in (0,1)$. Since the reputation is determined by the customer, the actual product reputation for each period should be revealed after the product price is determined [20,21].

3.2. Market demand and food producer's profit model

This paper only considers the market linear demand for products [22]; then, the market demand for each trading period is:

$$D_{\mathrm{t}}(p_t, R_{t-1}) = D - \alpha p_t + \beta R_{t-1}. \quad (3)$$

D represents the overall market demand base, reflecting customers' inherent demand in the whole market. α and β represent the reaction coefficient for customer demand, which α represents the attraction of product price to the customer, and β represents the attraction of product reputation to the customer. During period t, the market demand predicted by the producer is R_{t-1} rather than R_t since the producer does not know the customers' evaluation of the reputation of the current product before selling and can only use the previous reputation as an alternative [23].

The total production cost of the product with quality q_t is $C = \frac{r}{2}{q_t}^2 + vq_t + c$, among which r and v indicate coefficients of product quality to total cost, while c represents the basic cost for a unit product. It is assumed that the production capacity of the producer can fully meet the market demand, and its profit can be obtained as [24]:

$$\Pi_M = (p_t - C)D_{\mathrm{t}}(p_t, R_{t-1}) + xp_tD_{\mathrm{t}}(p_t, R_{t-1}). \quad (4)$$

In Eq. (4), $x \in (-Pu, 0, Re)$, representing the government rewards and punishments for the food quality inspected. Re stands for the rewards, and Pu means the punishments, whose values are both positive. Since the government does not want unqualified food to flow into the market but it cannot guarantee its testing is accurate enough, an effective way to prevent unqualified food from being listed is to intensify the punishments for food producers that produce unqualified products, namely, $Pu >> Re$. However, companies manufacturing FMCG are unlikely to receive such heavy punishments. Moreover, there are always food producers whose unqualified products can escape government inspection and be found in the market. However, due to the evaluation of the product quality reputation model customers in this article, unqualified products ultimately affect food manufacturing, rapidly diminishing business profit to the negative, which can eventually cause company closure. This is also the significance of this paper, as the impact of product reputation is considered as it relates to food producers under the dual role of a governance system for food safety developed by the government and the food producers' own quality contracts.

In this manuscript, we focus on the producer's decision problems considering the influence of its reputation, where the current reputation of the product is partly affected by that in the previous period (namely periodical influence). Because a producer's reputation updates over periods, the study consists of two aspects. First, we consider the producer's optimization decision

problem considering periodical influence and conduct sensitive analysis to examine the relations among parameters. Second, we run simulations in multiple periods considering periodical influence and explore how producers' reputation updates in multiple periods.

4. Producer's decisions under government's policy of rewards and punishments

It can be found from Eq. (4) that product reputation is only related to the reputation value in the previous period, which is consistent with many existing studies [25,26]. Therefore, we denote the product reputation value in the $t-1$ period by variable R_{t-1}. We analyze the influence of product reputation on the government's and producer's decisions, i.e., product price, government rewards and punishment. The relations between product quality and market demand are also examined below.

Proposition 1. Product price is positively correlated with the product's reputation

We can simplify Eq. (4) as:

$$\prod_M = D_{\mathrm{t}}(p_t, R_{t-1})\left[(1+x)p_t - \left(\frac{r}{2}{q_t}^2 + vq_t + c\right)\right].$$

if $\frac{\partial \prod_M}{\partial p_t} = 0$; then:

$$\frac{\partial \prod_M}{\partial p_t} = -\alpha\left[(1+x)p_t - \left(\frac{r}{2}{q_t}^2 + vq_t + c\right)\right] + (1+x)(-\alpha p_t + \beta R_{t-1}) = 0.$$

Since $\frac{\partial^2 \prod_M}{\partial p_t^2} = -2\alpha(1+x)p_t < 0$, we determine the optimal sales price as:

$$p_t = \frac{(1+x)\beta R_{t-1} + \alpha\left(\frac{r}{2}{q_t}^2 + vq_t + c\right)}{2\alpha(1+x)} = \frac{\beta R_{\mathrm{t}-1}}{2\alpha} + \frac{C}{2(1+x)}. \quad (5)$$

We can find from Eq. (5) that the product price p_t increases by previous reputation R_{t-1} with a linear function, which means product sales price is subject to the previous product reputation. The contribution margins of selling price and reputation to market demand are specified by parameter α and β (Eq. (3)), respectively. Referring to some existing studies [27], we deem β/α as indicators of the contribution of reputation and selling price to market demand. When the value β/α equals 1, the selling price and reputation have the same contribution margin. Meanwhile, the situation that the value β/α is larger than 1 means the contribution margin of market demand by reputation is larger than that by selling price, and vice versa.

Corollary 1. Governmental rewards and punishments are negatively correlated with the product price

Take the derivative of government rewards and punishments x in Eq. (5), and determine $\frac{\partial P_{\mathrm{t}}}{\partial x} = -\frac{C}{2(1+x)^2}$.

Since $\frac{\partial P_{\mathrm{t}}}{\partial x}$ is always negative, as the government rewards and punishments increase, the optimal product price gradually decreases. This means, on the one hand, due to government subsidies, food companies tend to lower optimal product prices in order to expand market demand; on the other hand, due to the government punishment for poor quality products in food quality testing, food companies are afraid to be eliminated from the market, and the optimal product price also shows a downward trend.

Corollary 2. Market demand increases by product reputation

We introduce $p_t = \frac{\beta R_{\mathrm{t}-1}}{2\alpha} + \frac{C}{2(1+x)}$ (Eq. (5)) into Eq. (3); the expected market demand can be calculated by Eq. (6):

$$D_{\mathrm{t}}(p_t, R_{t-1}) = D - \frac{(1+x)\beta R_{t-1} + \alpha C}{2(1+x)} + \beta R_{t-1} = D + \frac{\beta}{2}R_{t-1} - \frac{\alpha C}{2(1+x)}. \quad (6)$$

Eq. (6) suggests that the producer's expected market demand positively correlates with previous reputation R_{t-1}. In other words, market demand volume is directly affected by the previous product's reputation.

Proposition 2 . Government rewards and punishments impact product reputation

Taking Eq. (5) into Eq. (2), we determine the optimal reputation value of the current period is:

$$R_{\mathrm{t}} = R_{t-1}\left[1 - \varepsilon\frac{\overline{q} - \lambda q_t}{\overline{q}} - (1-\varepsilon)\frac{\left|\overline{p} - \frac{(1+x)\beta R_{t-1} + \alpha C}{2\alpha(1+x)}\right|}{\overline{P}}\right].$$

We know from Corollary 1 that as the government increases its rewards and punishments x, the optimal product sales price p_t gradually decreases, which causes $|\overline{p} - p_t|/\overline{p}$ to gradually increase, and the reputation R_t gradually decreases. With a reduction of government rewards and punishments x, the optimal sales price of products p_t gradually increases, causing $|\overline{p} - p_t|/\overline{p}$ to gradually decrease and reputation R_t to gradually increase.

With the increase in governmental rewards and punishments as well as governmental supervision, customers tend to believe that the overall food quality is not good enough, which indirectly leads to a decline in reputation. Conversely, if the government cuts down on rewards and punishments, food producers inevitably improve product quality and satisfy customers' psychological expectations of product price and quality to earn long-term profit and maintain an optimal price, which helps to improve reputation. It is shown that the reputation updating model designed in this paper adopts the government food safety supervision system. It has supervision and compensation effects on food producers who control product quality according to the transaction contracts.

5. Simulations and observations

Since the equilibrium solution obtained above is very complicated or has no analytical expression, this section analyzes the influence of product reputation on the pricing behavior of food producers and the governmental reward and punishment mechanism through result observations. The supply chain partners determine their equilibrium decisions following the sequence presented in Figure 1. The analytical results suggest the influence of governmental punishments, rewards, and reputation. It is worthwhile to make more exploration and answer at least three further questions. How do exogenous variables affect the updating process of a producer's reputation? Does a producer's reputation influence its business decisions? Due to given governmental rewards and punishments degrees, what are the producer's optimal decisions? To answer the questions, we conduct six scenarios of simulations and try to provide some managerial insights to industries. The specific simulation observation content is as follows: Observation 1 studies the influence of sensitive factors on reputation updates. Observation 2 studies on the impact of the accuracy of government inspection of product quality on reputation update. Observation 3 studies the relationship between reputation and value for money. Observation 4 studies the influence of reputation in the previous period on the current corporate pricing and revenue. Observation 5 studies the impact of reputation in the previous period on corporate revenue when the government adopted different rewards and punishment mechanisms. Observation 6 studies the impact of product quality on corporate reputation when the government adopts different reward and punishment mechanisms.

The specific parameters are set as follows: q_t is subject to the normal distribution $N(\mu, \sigma^2)$, and μ and σ are both exogenous. In the results, standard quality is used, so $\mu = 0.5$ and $\sigma^2 = 0.004$. Since the product quality cannot be negative, an algorithm is used to correct the negative value. Since the standard quality cannot be greater than 1, an algorithm is used to set the maximum quality as 1. The market demand coefficient related to price is $\alpha = 10$, the market demand coefficient related to reputation is $\beta = 1000$, and the initial reputation value of goods entering the market is $R_0 = 0.5$. We can set the following parameters: the producer production efficiency $r = 0.3$, the fluctuation cost of the production unit product $v = 0.06$, the fixed cost of the production unit product $c = 10$, the customer psychological price $\bar{p} = 15$, and the customer's expected quality of the food $\overline{q} \in (0.25, 0.75)$.

Observation 1: Impact of sensitivity parameters and product quality on reputation ratio

The simulation results presented in Figure 2 show the relationship between sensitivity parameter ε, product quality q_t and reputation ratio R_t/R_{t-1} when $p = 18$, $\lambda = 1$. It can be seen from Figure 2 that when ε approaches 0.56, the slope is the largest, indicating that changes in product quality have the greatest impact on changes in reputation. Moreover, the reputation ratio is always greater than 1, indicating that the reputation gradually increases as the product quality increases. Therefore, the following observations use the optimal value of the sensitivity parameter $\varepsilon = 0.56$.

Observation 2: The impact of government inspection of product quality coefficient and product quality on reputation ratio

Figure 3 shows the relationship between the government's inspection of product quality coefficient λ, product quality q_t and reputation ratio R_t/R_{t-1} when $p = 18$, $\varepsilon = 0.56$. It can be seen from Figure 3 that when quality remains unchanged, the coefficient of government inspection of product quality λ is positively correlated with the reputation ratio. When λ is greater than 0.5, the reputation ratio is always

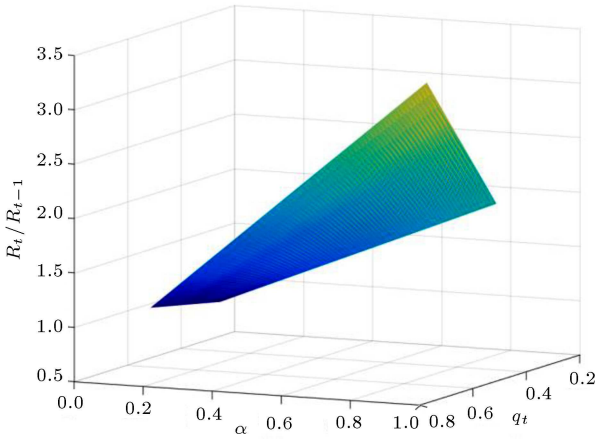

Figure 2. Relationship between sensitivity parameters, product quality, and reputation ratio.

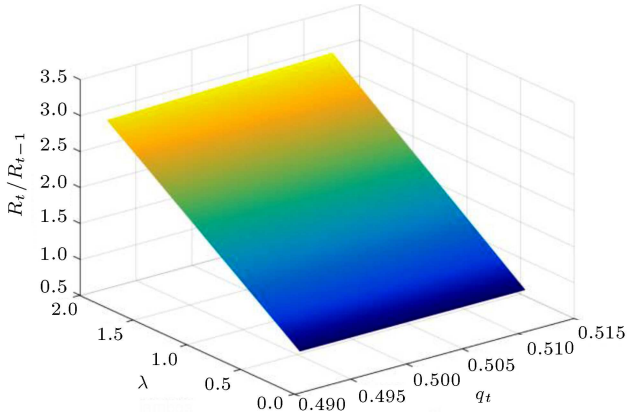

Figure 3. Relationship between government inspection of product quality coefficient, product quality and reputation ratio.

greater than 1, and the reputation grows faster as the government inspection of product quality coefficient increases. Conversely, reputation drops more quickly. This shows that when the government's inspection coefficient exceeds 0.5, the test results are reliable, and the reputation ratio increases with the increase in product quality. Otherwise, the reputation ratio drops rapidly due to unreliable test results. Another explanation is that λ can be understood as the accuracy when the government inspects the actual product quality, so producers expect that larger λ is better and that with larger λ, the company reputation will increase faster.

Observation 3: Impact of value for money on reputation

It is straightforward that consumers benefit from good food quality and suffer from high selling prices, which is consistent with the market demands function by Eq. (3). Because value for money shapes the decision-maker's decisions in transactions, it becomes to be a factor of gains and losses [28,29]. Differently from many other products, consumers can not fully quantitatively estimate foods' quality before and even after they consume the foods. Since it is both empirically and experientially known to people that food quality is good for health, people are willing to pay for high-quality foods at a reasonable price. The value for money is extremely important for consumers in the food industry, which explains the booming demand for expensive organic foods in the US and Europe [30,31]. When $\varepsilon = 0.56$, $\lambda = 1$, we determine the relationship between value for money q_t/p_t and reputation R_t (Figure 4). Figure 4 suggests that the product reputation increases by the value for money.

Observation 4: Impact of product reputation and sales price on the producer's profit

In the case of $\varepsilon = 0.56$, $\lambda = 1$, $Re = 0.2$, $Pu = 0.8$, we obtain Figure 5, in which the producer profit Π_M gradually increases with the increase of previous

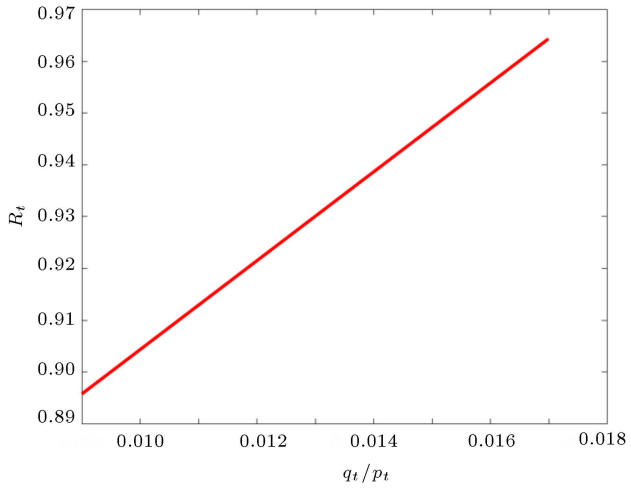

Figure 4. Relationship between value for money and reputation.

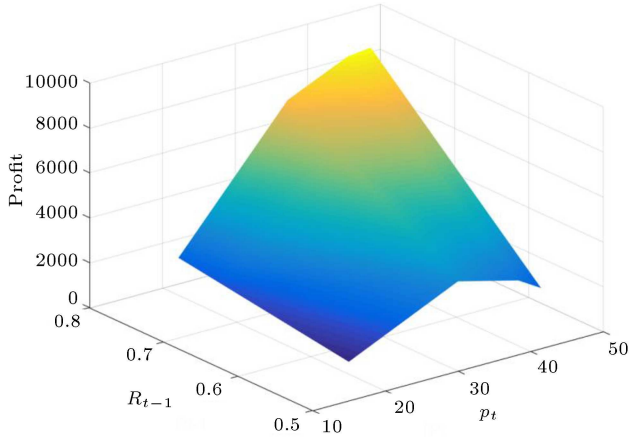

Figure 5. Relationship between previous reputation, sales price, and profit.

reputation R_{t-1}. Here, the reward parameter is set as $Re = 0.2$ and the punishment parameter as $Pu = 0.8$ because the reward and punishment mechanism featuring tiny rewards and very large punishments is more consistent with actual situations. When the product price p_t is near 40, the profit of the producer reaches the maximum. This indicates that the higher the previous reputation of the producer is, the higher the price that can be set in the current period, and the higher the profit of the producer profit will be.

Observation 5: The impact of the previous reputation of the producer on profit when the government adopts different reward and punishment mechanisms

As shown in Figure 6, when the government rewards the producer, the producer receives more profit than those with no reward and no punishment. With the increase in the previous reputation of the producer R_{t-1}, the profit Π_M gained in the current period gradually increases. When the government punishes the producer,

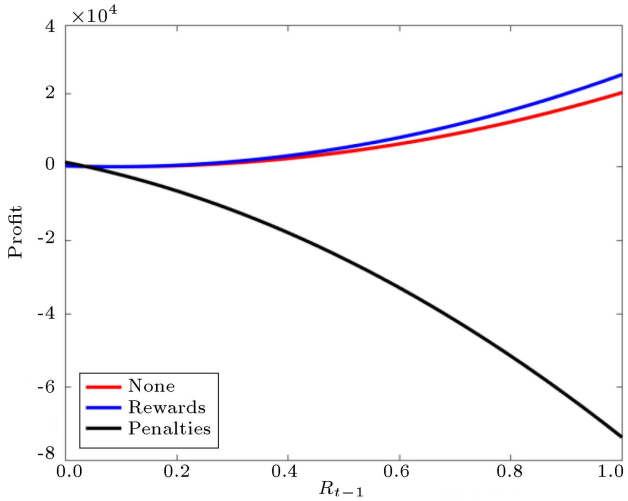

Figure 6. Relationship between previous reputation and profit when the government adopts different reward and punishment mechanisms.

the producer's profit is negative, indicating that the government's continuous increase in punishments leads the company to lose money. The higher the reputation is in the previous period, the greater the loss is in the current period. This is because the previous reputation and sales are relevant. The higher reputation in the previous period leads to a higher sales volume in the current period. Since the rewards and punishments are relevant to the sales volume, the higher sales volume leads to more punishments. Therefore, when there is a government reward and punishment mechanism, the previous reputation has a greater impact on the enterprise's profit in the current period.

Observation 6: The impact of product quality on profit when the government adopts different reward and punishment mechanisms

The following analyzes the impact of three different product quality on reputation:

- **Situation 1.** Reputation updating in regular production quality ranged from 0.25 to 0.75.

  When $\varepsilon = 0.56$, $\lambda = 1$, $Re = 0.2$, $Pu = 0.8$, the government has accurate test results on product quality and, at the same time, strictly supervises food producers through reward and punishment mechanisms. The above Figure 7 can be obtained, in which the producer reputation gradually increases in the first few periods and then levels off. Moreover, the highest reputation value when $\lambda = 1.1$ is greater than $\lambda = 0.9$, revealing that when the product quality inspected by the government is higher than the actual product quality, the producer's reputation greatly improves, benefiting the producer while damaging customer interests. Therefore, whether the government can verify the correct quality of the product has a large impact on reputation updating.

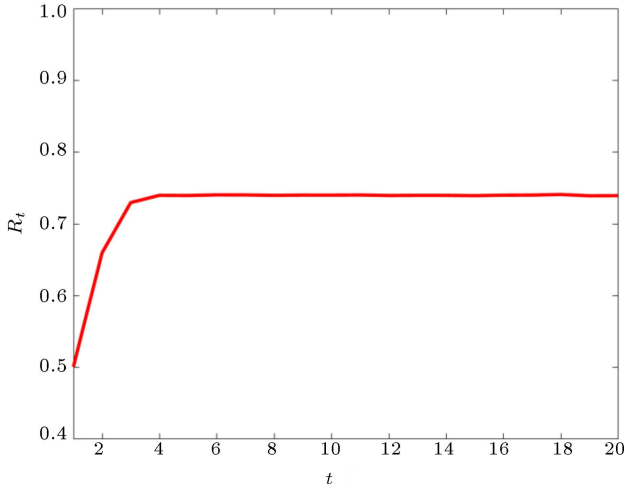

Figure 7. Reputation updating in regular production.

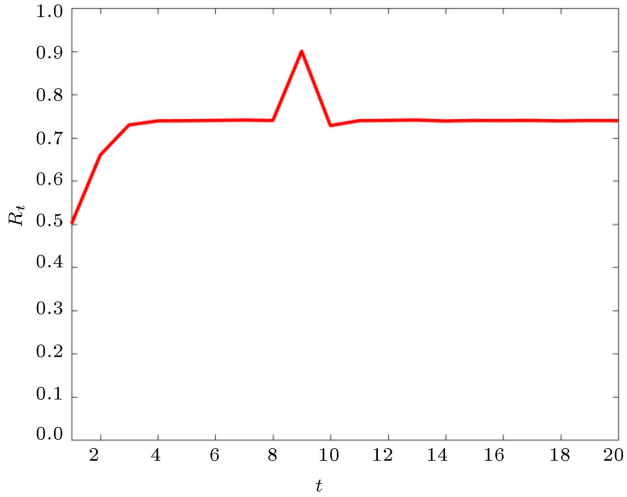

Figure 8. Reputation updating when product quality is higher than 0.75.

- **Situation 2.** Reputation updating when product quality is higher than 0.75.

  When the producer's reputation stabilizes, if the producer wants to improve its reputation by improving product quality, as shown in Figure 8, the producer's reputation significantly rises after the product quality increases, and even after the product quality returns to normal, the reputation is slightly higher than before.

- **Situation 3.** Reputation updating when product quality is lower than 0.25.

  When the producer's reputation stabilizes, if the producer wants to expand its own profit by lowering its product quality, a bad influence on the producer's reputation can result. As shown in Figure 9, after product quality is reduced, the producer's reputation plunges and the reputation recovery is slower than the reputation growth. Even when the product quality returns to normal, the reputation remains slightly lower than before.

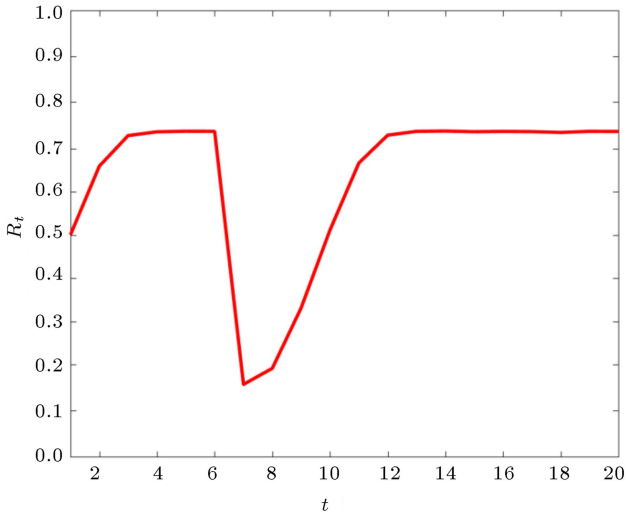

Figure 9. Reputation updating when product quality is lower than 0.25.

6. Conclusion

The research content of this paper first summarizes the research results of the previous two risk governance mechanisms of food safety, including the management system on food safety that was developed and whose implementation was supervised by the government, as well as product quality controlled by food producers according to the transaction contracts. Take the following as the foundation: a risk-management mechanism based on product reputation is proposed; then, the government inspects the product quality of food producers, gives rewards or punishments to the enterprise according to the test results, and publicizes the results. The food producer gives its optimal product pricing strategy by maximizing its expected profit based on previous "word of mouth". Finally, the customer renews their evaluation of the "word of mouth" status of the product based on the publicized product quality and price. In this paper, we define accumulated "word of mouth" of a product as reputation and mainly study the influence of reputation factors on food producers' product quality, sales price, government inspection accuracy, and rewards and punishments.

Although food quality and risk management have been studied for many decades, this study suggests a reputation-based food quality management mechanism. To conduct the study, a reputation-updating model is formulated and introduced in this study. The analytical and numeral study suggest some conclusions and managerial insights. For example, the product price is positively correlated with reputation and negatively correlated with government rewards and punishments. The government improves the accuracy of product quality inspection and strengthens the rewards and punishments for food producers with the reputation-based management mechanism. As a result, the food quality is effectively improved, thereby enlarging food producer's profits. As well, the reputation positively links with value for money. The results highlight that the producer's reputation grows continuously and slowly with the improvement of food quality. However, food safety accidents extremely damage the food producer's reputation, and the food producer's profit drops down rapidly in a short time.

The study suggests a reputation-based food quality management mechanism, which has proved to be effective in numerical studies. In this study, we consider the research problem to be a three-tier supply chain; extensive studies are able to consider the more industrial cases and provide some strategies in applications of theoretical results. Investigating the impact of reputation on food quality management offers a fertile avenue for future research. Another possible research direction is to explore how the government's reputation affects the consumers' willingness to pay and the corresponding producer's food quality decisions. Also, some producers have many competitors in industries, and future studies could explore the food quality issues considering the market competition of producers. Thus, there are many related research opportunities that potentially bring additional managerial insights.

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Table A.1. Main notations.

	Government	Food producer	Customer
Parameters	λ: Coefficient of government inspection of product quality η: Fluctuation range of government inspection product quality Pu: Government punished amount for unqualified food Re: Government rewarded amount for high-quality food	ε: Sensitive factors of producer's reputation R_0: Producer's initial reputation r: Coefficient of product quality to total product cost ν: Coefficient of product quality to total product cost c: Product cost for basic quality	α: The attractiveness of product prices to customers β: The attractiveness of product reputation to customers $\bar{q}$: Lowest quality that customers tolerated $\bar{p}$: Customer's expected product price
Variables	x: Government rewards (when $x > 0$) and punishments (when $x < 0$) for the food quality inspected	q_t: Product quality during t period Δ: The updated value of the product's reputation R_t: Product reputation during period t p_t: Product price during period t C: Total production cost Π_M: Producer's profit	D_t: The actual market demand during t period

Appendix A

The parameters and variables employed in the research and presented in Table A.1 in the appendix.

Biographies

Guanghua Han received his PhD degree in Management from Shanghai Jiao Tong University. Then, he joined the National University of Singapore as a Research Fellow. Currently, he is an Associate Professor at the School of International and Public Affairs at Shanghai Jiao Tong University. Dr. Han has more than ten years of research experience in the academic field of risk and safety management.

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Jiaxin Wang has served the School of Chinese Painting and Calligraphy, China Academy of Art, for several years. She has published several academic articles both in domestic and international journals. She has wide research interests; one of the research fields is risk management and communication theory.