Journal of Food Quality

Improving Food Quality and Safety with Big Data

Lead Guest Editor: Yong He
Guest Editors: Henry Xu and Chunming (Victor) Shi

Improving Food Quality and Safety with Big Data

Journal of Food Quality

Improving Food Quality and Safety with Big Data

Lead Guest Editor: Yong He
Guest Editors: Henry Xu and Chunming (Victor) Shi

Contents

Hindawi
Journal of Food Quality
Volume 2021, Article ID 5525691, 15 pages
https://doi.org/10.1155/2021/5525691

Research Article

Pricing and Ordering Strategies for Fresh Food Based on Quality Grading

Yong He,[1] **Yongmei Xie**,[1] **Xiaoli Zhou**,[1] **Henry Xu**,[2] **and Yanan Yu**[1]

[1]*School of Economics and Management, Southeast University, Sipailou 2, Nanjing 210096, China*
[2]*UQ Business School, The University of Queensland, Brisbane, Queensland (QLD) 4072, Australia*

Correspondence should be addressed to Yong He; hy@seu.edu.cn

Received 16 January 2021; Accepted 14 May 2021; Published 27 May 2021

Academic Editor: Rafik Balti

Fresh food quality grading is the basis of fresh food marketization. On the one hand, it can effectively improve the market efficiency of fresh food and improve the earnings of retailers. On the other hand, it can alleviate the incompleteness of market information and help consumers better identify the quality characteristics of fresh food. To address the issue of quality grading for fresh food, this study constructs a retailer profit model for selling fresh food with two quality grades. Considering the quality level distribution of fresh food and based on the quality selection model, the retailer's optimal grading, pricing, and ordering of fresh food are studied. Through numerical simulation and sensitivity analysis, some conclusions with managerial implications are drawn. We find that the retailer has the optimal quality grading strategy for fresh food, which is influenced by the minimum quality level and the unit cost of fresh food. Raising the quality standard at the lowest level or reducing the unit cost can help the retailer increase the profits.

1. Introduction

Food quality is becoming an increasingly important issue in our lives. Fresh food differs in appearance, size, color, defect degree, and other quality characteristics. For example, apples have different diameters. If a retailer adopts mixed packaging and mixed sales of fresh food, it is not beneficial to his sales nor can it meet the needs of consumers with different quality preferences. Moreover, shoddy products will directly affect consumers' satisfaction with fresh food and their purchase decisions in the mixed sales mode. Consequently, the retailer needs to consider making pricing decisions based on certain quality standards.

Consumers are willing to pay higher prices for higher quality products [1]. Big data provide companies the means of tracking customers' preferences to make a business more efficient and determines what future promotions, sales, and inventory should be brought to the fore (https://techgyo.com/using-big-data-track-customer-preferences). In the big data era, some enterprises have successfully used the grading management strategy of fresh food in real commercial operations and realized income growth. For example, Pagoda and Yonghui Superstores in China have practiced fresh food gradation. For the same batch of cherries, Pagoda first divides cherries into three grades based on fruit diameter and then further separates each of the three grades based on three quality characteristics (hardness, sugar acidity, and freshness), leading to nine grades in total. Similarly, Yonghui supermarkets sell high quality goods at high prices and low quality goods at average prices. In Western countries, more than 70% of fresh food is sold according to national or industry standards [2]. Agriproduct grading can meet the diverse needs of consumers and can bring additional benefits to supply chain members [3, 4].

However, many retailers have not realized the importance of quality grading for fresh food. They adopt a mixed sales approach and rely on low prices to attract users. These retailers are lagging behind the current trend of the fresh food market and thus may result in a small profit or even loss. For example, at the B2B website of "Yimutian" (a fresh food information service platform), fresh food from many suppliers (farmers) is in mixed sales at a low wholesale price.

Meanwhile, little research has been performed on modeling how to determine the optimal quality grading and how the quality grading standard influences the pricing strategy for fresh food. Quality grading based on objective quality standards of fresh food is a key step for standardization. For example, enterprises can use quality standards based on product characteristics such as appearance and freshness to properly grade the quality of fresh food and quantify the corresponding consumer experience. These quality standards also have certain rules to follow. For example, the diameter of an apple tends to have a normal distribution distributed [5]. The distribution of a specific quality variable has a certain influence on the optimal quality grading standards, thus affecting retailers' purchase and pricing strategies. Based on this understanding, we study how to determine the optimal quality grading standard, pricing, and ordering strategies of fresh food based on consumers' quality preference and the quality distribution characteristics of fresh food.

This article mainly has the following contributions. First, the quality grading standard of fresh food is taken as an endogenous decision-making variable by retailers based on consumers' quality preference for fresh food. Second, we further study the retailer's pricing and ordering decisions based on quality grading standards.

Our research aims to address the following questions:

(1) How to present the demand function according to consumers' quality preference
(2) How to establish the quality grading standard of fresh food
(3) How does the optimal quality grading standard affect the retailer's decision
(4) How do the parameters and variables in the model affect the retailer's optimal pricing and ordering strategies

The rest of the study is arranged as follows. Section 2 analyzes the relevant literature. We introduce the problem description and model assumptions in Section 3, and the utility model based on quality selection describes the market demand for fresh food. Section 4 obtains the retailer's optimal decisions for pricing, inventory, and quality grading. Section 5 presents a numerical simulation. In Section 6, we draw conclusions from our findings and indicate future research directions.

2. Literature Review

This study is mainly related to three streams of literature: (1) quality grading of fresh food, (2) consumers' purchase preference, and (3) pricing and inventory strategies of fresh food.

Several researchers have studied the effects of quality grading. It is important to grade fresh food as it meets consumers' demand and preferences of different quality levels and improves the marketing efficiency of fresh food [6]. Zusman [7] proposed that fresh food quality grading is beneficial for retailers as they can use product quality grading to implement price discrimination and product differentiation and obtain monopoly profits. Zago and Pick [8] established a vertical difference model based on quality selection behavior and analyzed the impacts of the optimal production quantity, pricing, and quality grading of fresh food on producers and consumers. Some researchers studied various methods for grading product quality. Lee et al. [9] developed a machine vision system based on digital reflective near-infrared imaging that is used to detect fruit size. Hong et al. [10] used machine vision to measure the size, shape, and color of aquatic products. Baigvand et al. [11] applied an image processing algorithm to develop the machine vision for grading figs. According to the volume and maturity feature, Jadhav et al. [12] proposed a fruit grading system to reconstruct fruit volume. Deplomo et al. [13] employed image processing methods to classify the size, color, and texture of onions.

Most of the studies in this direction take the quality grading standard of fresh food as an exogenous variable for decision-making and do not explore the optimal quality grading standard. This study aims to determine the optimal quality grading standard of fresh agricultural products, which is the main contribution of this study.

With the help of the Internet and big data, companies can better understand customer behaviors and extract consumer preferences [14, 15]. Mishra et al. used data from social media (Twitter) to find consumers' purchasing preferences such as quality, taste, carbon footprint, organic/inorganic, and nutrition while purchasing beef [16]. Retailers can also predict consumers' demand preferences for fresh food of different quality grades based on past sales experience [17, 18]. In the food industry, Ma [19] established demand functions for fresh food with different quality grades based on consumers' preferences. He found that the retailer's profit is only related to the factors at the high quality level as well as ordering and preservation costs, but not to those at a low quality level. Transchel [20] analyzed the substitution situation between products of different quality levels. Chen et al. [21] suggested that managers should use consumers' preference information carefully to formulate policies. Wongprawmas and Canavari [22] used the discrete choice experiment to study the preferences of Thai consumers for food safety labels and brands of fresh food. Taking the tomato industry, for example, Yin et al. [23] studied consumers' preferences for brand, price, and safety labels based on a mixed logit model. Considering consumers' service preference, Liu et al. [24] built a three-stage dynamic game model considering the online and offline distribution of fresh food. Wang et al. [25] confirmed that the online channel has advantages of keeping the consumers loyal than the offline channel.

Customers' quality preference drives the quality grading and pricing strategy of fresh food. Although the customers' quality preference can be well captured in the big data era, little is known about how the decision of quality grading standard is related to customers' quality preference. This study contributes to the extant literature by considering customers' quality preferences when making quality grading and pricing decisions. Furthermore, we analyze the effect of the lowest product quality on the retailer's optimal decisions.

Due to the perishability of fresh food, pricing and inventory strategies are important to the retailer's profits. Akcay et al. [26] studied the joint dynamic pricing of multiple fresh products and showed that the markup of the products depends only on the total inventory. Wang and Li [27] proposed a dynamic pricing model to evaluate the quality of fresh food. Sainathan [28] considered consumer utility affected by freshness and studied the two-stage dynamic pricing and optimal replenishment strategies of fresh food. Adenso-Díaz et al. [29] proved that dynamic pricing can significantly reduce the waste of resources caused by the deterioration of fresh food. Duan and Liu [30] analyzed the effects of fresh food quality and reference price effects. The preservation technology investment and ordering policy also affect optimal dynamic pricing [31, 32]. Transchel [20] studied the inventory and pricing issues of multiquality agricultural products. Fan et al. [33] solved the dynamic pricing and replenishment problem of multibatch fresh food by using a heuristic method.

Pricing and ordering strategies for agriproducts have been extensively studied, but little has been done on modeling how the retailer determines the optimal quality grading standards and makes pricing and ordering decisions based on grading standards. Furthermore, we incorporated the consumers' quality preference for fresh food into the model, which makes this research more realistic.

3. Model Setting

3.1. Problem Description and Notations. Due to different planting conditions and growing environments, the same batch of fresh food may differ in defect degree, maturity, and appearance quality. If a retailer sells fresh food at the same price, consumers tend to buy the products with higher quality, leaving lower quality fresh food unsellable, making the retailer suffer profit loss. Therefore, the retailer needs to organise its fresh food into two or more quality grades according to a certain quality level and sell them separately to obtain higher profits [6, 7].

Before sales, the retailer purchases fresh food with quantity Q and quality level R, $R \in [r_L, 1], r_L > 0$, where r_L is the minimum quality level of fresh food, while 1 is the highest quality level. The quality level R follows a continuous random function, whose probability density function is $f(x)$ and the cumulative distribution function is $F(x)$. When sales begin, to meet consumers' different quality demands and preferences, the retailer divides fresh food into two quality grades (i.e., high and low) based on the grading standard r. When $R \in [r_L, r]$, the product is of low quality; otherwise, it is of high quality $R \in (r, 1]$. The retailer prices high and low quality fresh products at $P_i (i \in \{H, L\})$, respectively. To simplify the problem, we do not consider the residual value and the shortage cost after the end of the sales period. The quality grading model of fresh food is shown in Figure 1.

Table 1 provides the variables and parameters involved in this study.

Since consumers have a certain preference in purchasing products of different quality levels, we study the overall consumer demand by referring to the quality selection model according to Tirole [34]. The function of consumers' utility can be expressed as follows:

$$U_i = q_i\theta - P_i, \quad i \in \{H, L\}. \tag{1}$$

Due to the natural characteristics of fresh food, it is difficult to have a unified quality level. In addition, market information is incomplete, and consumers can only know the lowest and highest quality levels of products through part of the information disclosed by the retailer. Therefore, it is assumed that consumers use average quality levels to estimate the quality levels of high and low quality grades, i.e., $q_H = ((1 + r)/2)$ and $q_L = ((r + r_L)/2)$. According to equation (1), consumer utility can be represented by

$$\begin{cases} U_H = \dfrac{r+1}{2}\theta - P_H, \\ U_L = \dfrac{r+r_L}{2}\theta - P_L. \end{cases} \tag{2}$$

3.2. Quality Grading and Profit Functions. Retailers are usually aware of the quality of the products they have purchased and can describe the product quality distribution through specific functions. According to the above problem description and hypothesis, the actual supply quantity of products with different quality grades is

$$\begin{cases} Q_H = Q\displaystyle\int_r^1 f(x)\mathrm{d}x, \\ Q_L = Q\displaystyle\int_{r_L}^r f(x)\mathrm{d}x. \end{cases} \tag{3}$$

In this study, we assume that consumers buy products with only one quality grade during the sales period, and every rational consumer will choose a product that maximizes utility. Therefore, the probability of consumers buying high quality fresh food is

$$\alpha_H = P\{U_H > U_L, U_H \geq 0\} = P\left\{\theta > \frac{2(P_H - P_L)}{1 - r_L}, \theta \geq \frac{2P_H}{r+1}\right\}. \tag{4}$$

The probability of consumers buying low quality fresh food is

$$\alpha_L = P\{U_L > U_H, U_L \geq 0\} = P\left\{\frac{2P_L}{r + r_L} \leq \theta < \frac{2(P_H - P_L)}{1 - r_L}\right\}. \tag{5}$$

The retailer makes price decisions based on the actual quantity of the two quality grades by maximizing its profit, i.e.,

$$\max \Pi = P_H \min\{Q_H, D_H\} + P_L \min\{Q_L, D_L\} - CQ. \tag{6}$$

Lemma 1. *According to the potential demand size of fresh food above, the actual demand of consumers for the two*

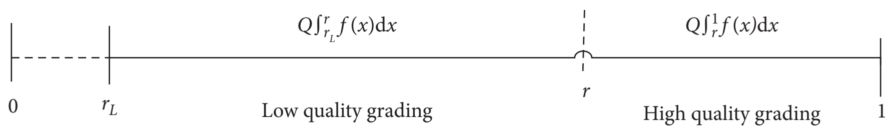

Figure 1: The quality grading model of fresh food.

Table 1: Notations description.

Notations	Description
D	Potential total demand for fresh food
r_L	The minimum quality level of fresh food
C	The unit cost of fresh food
Q	The total supply of fresh food from the retailer
r	The fresh food quality grading standard, $r \in [r_L, 1]$
P_H	Price of high quality fresh food
P_L	Price of low quality fresh food
D_i	Actual demand for fresh food with quality level i, $i \in \{\mathrm{H, L}\}$
Q_i	Actual supply for fresh food with quality level i, $i \in \{H, L\}$
α_i	The probability that consumers buy fresh food with quality level i, $i \in \{H, L\}$
R	The quality level of fresh food, $R \in [r_L, 1]$
Π	Profit of the retailer

quality grades can be obtained, respectively, based on the quality selection model. Table 2 provides the actual demand for fresh food of high and low quality grades.

In Table 2, consumers' actual demand for fresh food is mainly divided into the following three situations as shown in Figure 2. They are as follows: (i) all consumers choose to buy high quality products, (ii) some consumers choose to buy high quality products and others choose to buy low quality products, and (iii) all consumers choose to buy low quality products.

4. Model Analysis

To make the research more practical, we mainly consider the situation of market demand in scenario II in Figure 2. The demand with two quality grades coexists when $(P_L/(r + r_L)) \leq (P_H/(1 + r)) \leq ((P_H - P_L)/(1 - r_L)) \leq (1/2)$.

4.1. Optimal Pricing Decision. In this situation, all consumers who choose to buy products are divided into two groups: one group chooses to buy high quality products and the other chooses to buy low quality products. Consumers' demands for high and low grade products are as follows:

$$\begin{cases} D_H = D\left[1 - \dfrac{2(P_H - P_L)}{1 - r_L}\right], \\ \\ D_L = D\left[\dfrac{2(P_H - P_L)}{1 - r_L} - \dfrac{2P_L}{r + r_L}\right]. \end{cases} \tag{7}$$

The retailer's profit function can be expressed as follows:

$$\max \Pi = P_H \min\left\{D\left[1 - \frac{2(P_H - P_L)}{1 - r_L}\right], Q\int_r^1 f(x)\mathrm{d}x\right\} + P_L \min\left\{D\left[\frac{2(P_H - P_L)}{1 - r_L} - \frac{2P_L}{r + r_L}\right], Q\int_{r_L}^r f(x)\mathrm{d}x\right\} - \mathrm{CQ}. \tag{8}$$

According to equation (8), there are four types of supply and demand relations as shown in Figure 3 for fresh food of high and low quality grades.

According to Figure 3, in part 1, there is an oversupply of both high and low quality products, i.e., $Q_H \geq D_H$, $Q_L \geq D_L$. In part 2, the supply of high quality products exceeds their demand, and the supply of low quality products falls short of their demand, i.e., $Q_H > D_H$,$Q_L < D_L$. Part 3 shows the opposite of part 2. The supply of high quality products falls short of demand, and the supply of low quality products exceeds demand, i.e., $Q_H < D_H$,$Q_L > D_L$. In part 4, both high quality and low quality products are short of supply, i.e., $Q_H < D_H$ and $Q_L < D_L$.

For the convenience of analysis, we assume that the quality level of products follows the uniform distribution of $[r_L, 1]$. We find that the supply of high and low quality products can be expressed as follows:

Table 2: Actual demand for fresh food of high and low quality grades.

Conditions	D_H	D_L
$(P_L/(r+r_L)) \leq (P_H/(1+r)) \leq (P_H-P_L)/(1-r_L), 2(P_H-P_L)/(1-r_L) \geq 1$	0	$D[1-2P_L/(r+r_L)]$
$(p_L/(r+r_L)) \leq (p_H/(1+r)) \leq (P_H-P_L)/(1-r_L) \leq 1/2$	$D[1-(2(P_H-P_L)/(1-r_L))]$	$D[((2(P_H-P_L))/(1-r_L))-(2P_L/(r+r_L))]$
$(P_H-P_L)/(1-r_L) < (P_H/(r+1)) < (P_L/(r+r_L)), (P_H/(r+1)) < (1/2)$	$D[1-2P_H/(r+1)]$	0

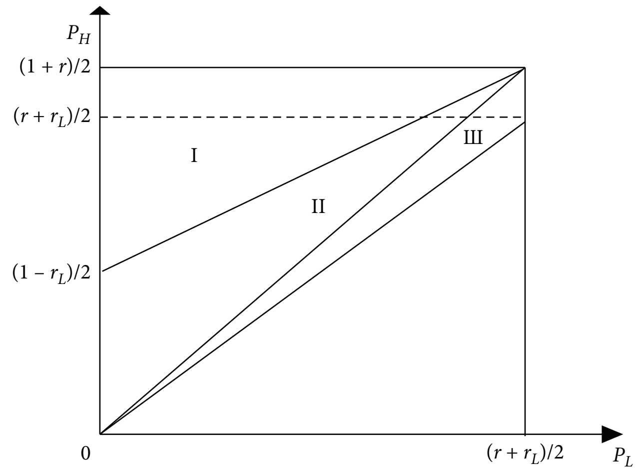

Figure 2: Actual market demand for fresh food.

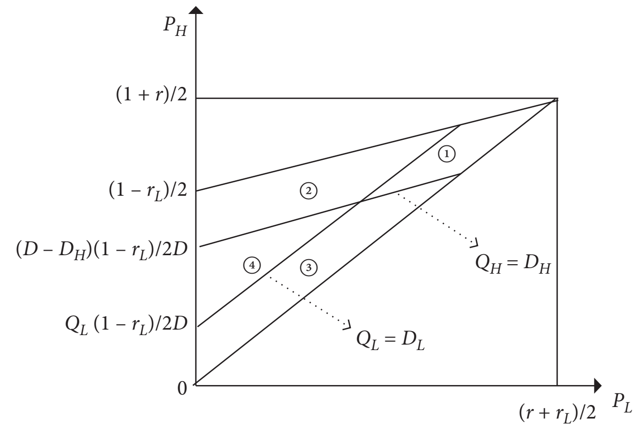

Figure 3: Supply and demand relations for fresh food.

$$\begin{cases} Q_H = \dfrac{1-r}{1-r_L}Q, \\ \\ Q_L = \dfrac{r-r_L}{1-r_L}Q. \end{cases} \tag{9}$$

Proposition 1. *When the total purchase quantity Q, potential demand size D, and grading standard R are given, the optimal pricing strategy of the retailer is presented in Table 3 and Figure 4.*

The proof of Proposition 1 is in Appendix A.

We analyze how the retailer makes pricing decisions when the demand for fresh food with both high and low quality levels coexists. According to Proposition 1, there are three optimal solutions for the retailer's optimal prices of fresh food with high and low quality grades, which are affected by the relationship between supply and demand. The prices of fresh food with high and low quality grades are positively correlated with the quality grading standard. A higher quality grading standard leads to a higher price of the product.

4.2. Optimal Ordering and Grading Decisions. The retailer needs to determine the total order quantity Q and the quality grading standard R before pricing the product. According to the above analysis, the retailer's profit function is

$$\Pi(Q,r) = \begin{cases} \dfrac{1+r}{8}D - CQ, & \dfrac{D}{2} \le Q_H \le Q, r_L \le r \le 1, \\ \dfrac{DQ(1-r_L)(1-r) - Q^2(1-r)^2}{2D(1-r_L)} + \dfrac{(r+r_L)D}{8} - CQ, & Q_H \le \dfrac{D}{2} \le Q, r_L \le r \le 1, \\ \dfrac{DQ\left(1-r_L^2\right) - \left[(1+r_L)(1-r) + \left(r^2 - r_L^2\right)\right]Q^2}{2D(1-r_L)} - CQ, & 0 < Q \le \dfrac{D}{2}, r_L \le r \le 1. \end{cases} \tag{10}$$

Proposition 2. *When the potential demand size D, minimum quality level r_L, and unit cost of fresh food C are given, the retailer's optimal quality grading standard, optimal order quantity, and profit can be expressed as follows:*

(1) When $C \le ((1-r_L)/8)$, the optimal quality grading standard and the optimal order quantity of fresh food are $r^* = \delta, Q^* = ((1-\delta)D/8C)$, respectively, and the retailer's optimal profit is $\Pi^* = ((1-\delta)^2 D/16C) - (((1-\delta)^4 D)/16C(1-r_L)) + (((2\delta + r_L - 1)D)/8)$.

(2) When $((1-r_L)/8) < C < ((1+r_L)/2)$, the optimal quality grading standard and the optimal order quantity are $r^* = ((1+r_L)/2), Q^* = ((2D(1-2C+r_L))/(3+5r_L))$, respectively, and the retailer's optimal profit is $\Pi^* = ((D(1-2C+r_L)^2)/(6+10r_L))$;

(3) When $C \ge ((1+r_L)/2)$, the optimal order quantity is $Q^* = 0$, where δ satisfies $\begin{cases} (1-\delta)^3 - 4C(1-r_L)(1-\delta) + 8C^2(1-r_L) = 0, \\ r_L \le r \le 1-4C. \end{cases}$

The proof of Proposition 2 is in Appendix B.

According to Proposition 2, we mainly obtain the retailer's optimal quality grading, optimal order quantity, and profit. Under different supply and demand relations, the retailer's optimal grading standard and optimal order

Table 3: The retailer's optimal pricing decision.

Conditions	P_H^*	P_L^*
$((D/2) \le Q_H \le Q)$, $(r_L \le r \le 1)$	$((1+r)/4)$	$((r+r_L)/4)$
$(Q_H < (D/2) \le Q)$, $(r_L \le r \le 1)$	$((r+r_L)/4) + ((D-Q_H)(1-r_L)/2D)$	$((r+r_L)/4)$
$(0 < Q \le (D/2))$, $(r_L \le r \le 1)$	$((D(1+r) - (1-r_L)Q)/2D)$	$((D-Q)/2D)(r+r_L)$

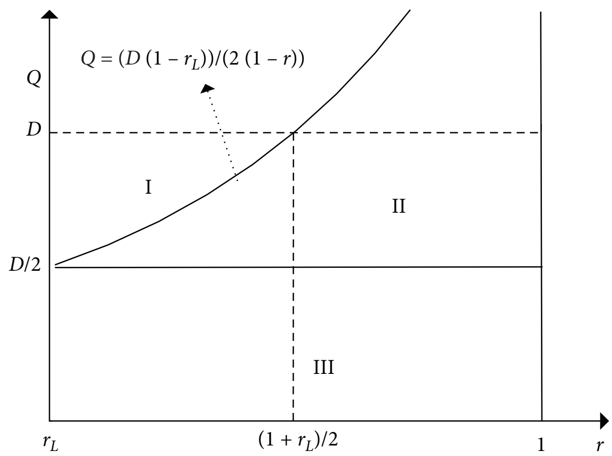

Figure 4: Retailer's optimal pricing strategy under the influence of Q and R.

quantity are affected by the unit cost of fresh food. Under different unit costs, the retailer will adjust his optimal decisions to increase profit.

Corollary 1. *(1) When $0 < C \le ((1+r_L)/2)$, the optimal quality grading standard r^* of fresh food increases with the lowest quality level r_L. (2) When $0 < C \le ((1-r_L)/8)$, the optimal grading standard r^* for fresh food decreases with the unit cost of fresh food. And when $((1-r_L)/8) < C \le ((1+r_L)/2)$, the optimal grading standard remains unchanged, regardless of the unit cost of fresh food.*

The proof of Corollary 1 is in Appendix C.

To ensure that high quality fresh food is sold at high prices and to reduce the quantity of low quality fresh food, the retailer will increase the quality grading standard as the minimum quality level of fresh food increases. However, as the unit cost of fresh food increases, the retailer will gradually reduce the optimal quality grading standard for fresh food to avoid the profit loss caused by an excessive quantity of low quality products and to ensure the profit of high quality products. When the unit cost of fresh food is high, the retailer will keep the quality grading standard unchanged to achieve a balance between the supply and demand of both high and low quality products.

Corollary 2. *When $((1-r_L)/8) < C \le ((1+r_L)/2)$, the retailer's profit π^* is positively correlated with the lowest quality level of fresh food and negatively correlated with the cost of fresh food.*

The proof of Corollary 2 is in Appendix D.

When the unit cost of fresh food is moderate, the increase of the minimum quality level of fresh food raises its price, further increasing the retailer's profit. As the unit cost of fresh food increases, the retailer will decrease the order quantity and quality grading standard to keep a balance between the supply and demand of both high and low quality fresh food. The retailer's profit falls as the unit cost rises because the increase of revenue from a higher price cannot compensate for the decrease of revenue from reduced demand.

Corollary 3. *(1) The optimal purchase quantity Q^* of fresh food is negatively correlated with the cost of fresh food. When the cost of fresh food is too high, the retailer will give up selling products with two quality grades. (2) When $0 < C \le (1/5)$, the optimal purchase quantity Q^* of fresh food decreases with the minimum quality level r_L. (3) When $(1/5) < C < ((1+r_L)/2)$, the optimal purchase quantity Q^* of fresh food increases with the minimum quality level r_L.*

The proof of Corollary 3 is in Appendix E.

Corollary 3 indicates that the unit cost of fresh food and the minimum level of quality affect the retailer's order quantity. When the unit cost of fresh food is low, with the increase of the minimum quality level, high and low quality products are more competitive and substitutable. To prevent profit loss caused by an excessive surplus of products, the retailer will reduce the purchase quantity. When the unit cost of fresh food is high, the retailer will raise its price, leading to the increase of quality grading standard. Meanwhile, the supply of high quality fresh food will decrease as the quality grading standard increases. Therefore, the retailer will gradually increase the supply of fresh food to ensure that all fresh foods can be sold at relatively higher prices.

5. Numerical Simulation

5.1. Numerical Example. To better analyze how relevant parameters affect the retailer's optimal decisions, this section assumes that the value of parameters satisfies $r_L = 0.5$, $D = 10$, and $C = 0.02$, and the product quality obeys the uniform distribution on $(r_L, 1)$. The influences of quality grading standard and order quantity on the retailer's profit are shown in Figure 5.

Figure 5 shows that the retailer's profit is a concave function of the quality grading standard and order quantity, and there is a unique and optimal solution to maximize the retailer's profit. The retailer's profit first increases and then decreases with the increase of order quantity, and the speed of increase is greater than that of decrease. When the purchase quantity is larger than the potential market demand, the retailer's profit will gradually decrease or even suffer a loss due to the increase of surplus of high and low quality fresh foods. When the purchase quantity is low, although it can avoid the profit reduction caused by the surplus, it cannot compensate for the profit reduction caused by unmet consumer demand.

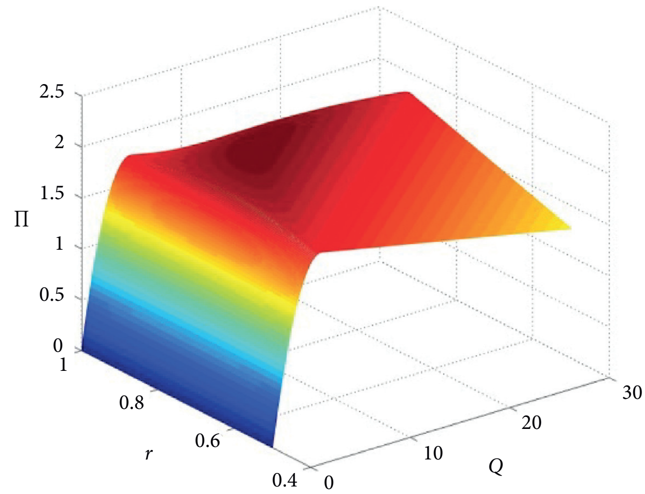

FIGURE 5: The influences of r and Q on the retailer's profit.

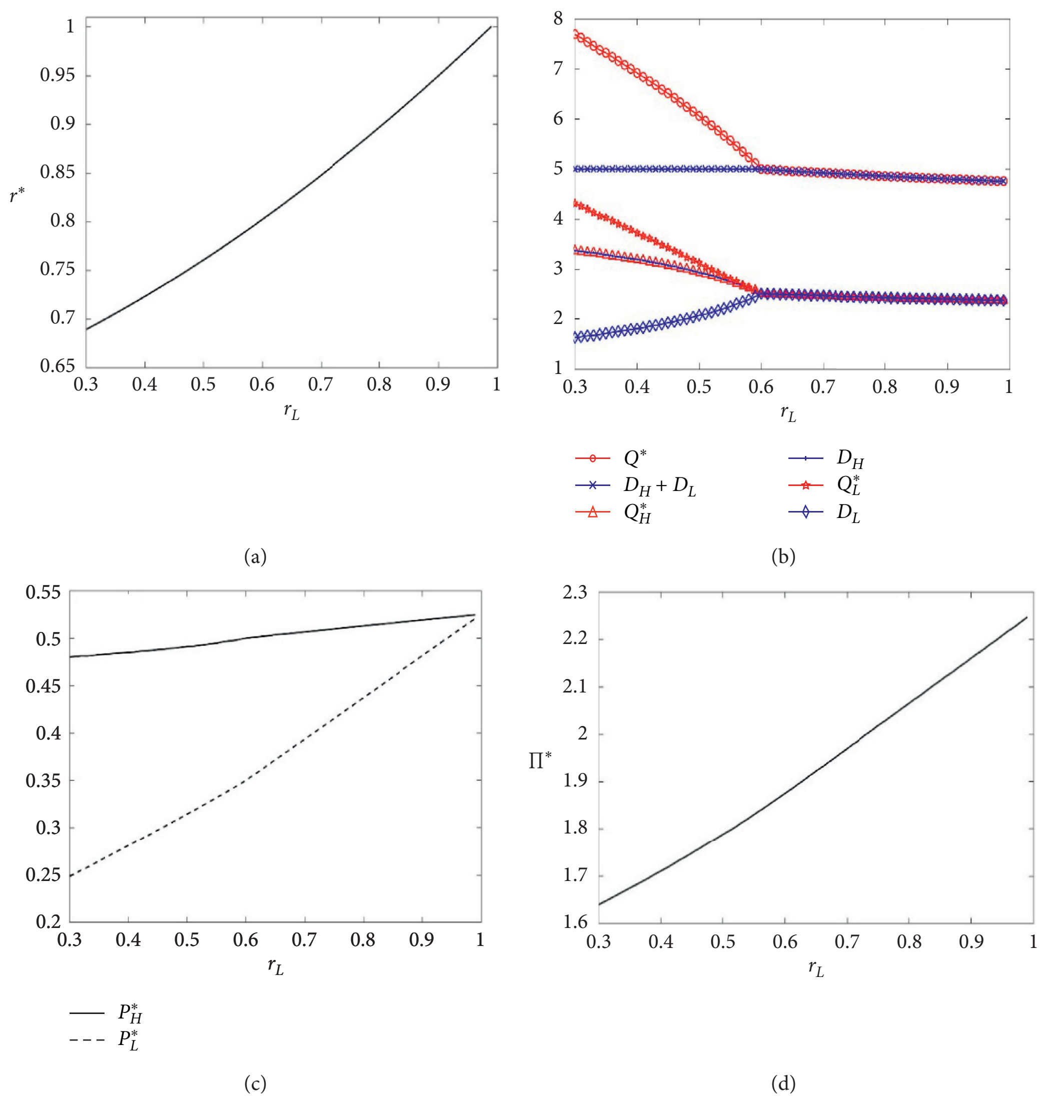

FIGURE 6: The influences of the lowest quality level r_L on the retailer's optimal decisions. (a) The influence of r_L on r, (b) the influence of r_L on D and Q, (c) the influence of r_L on P, and (d) the influence of r_L on Π.

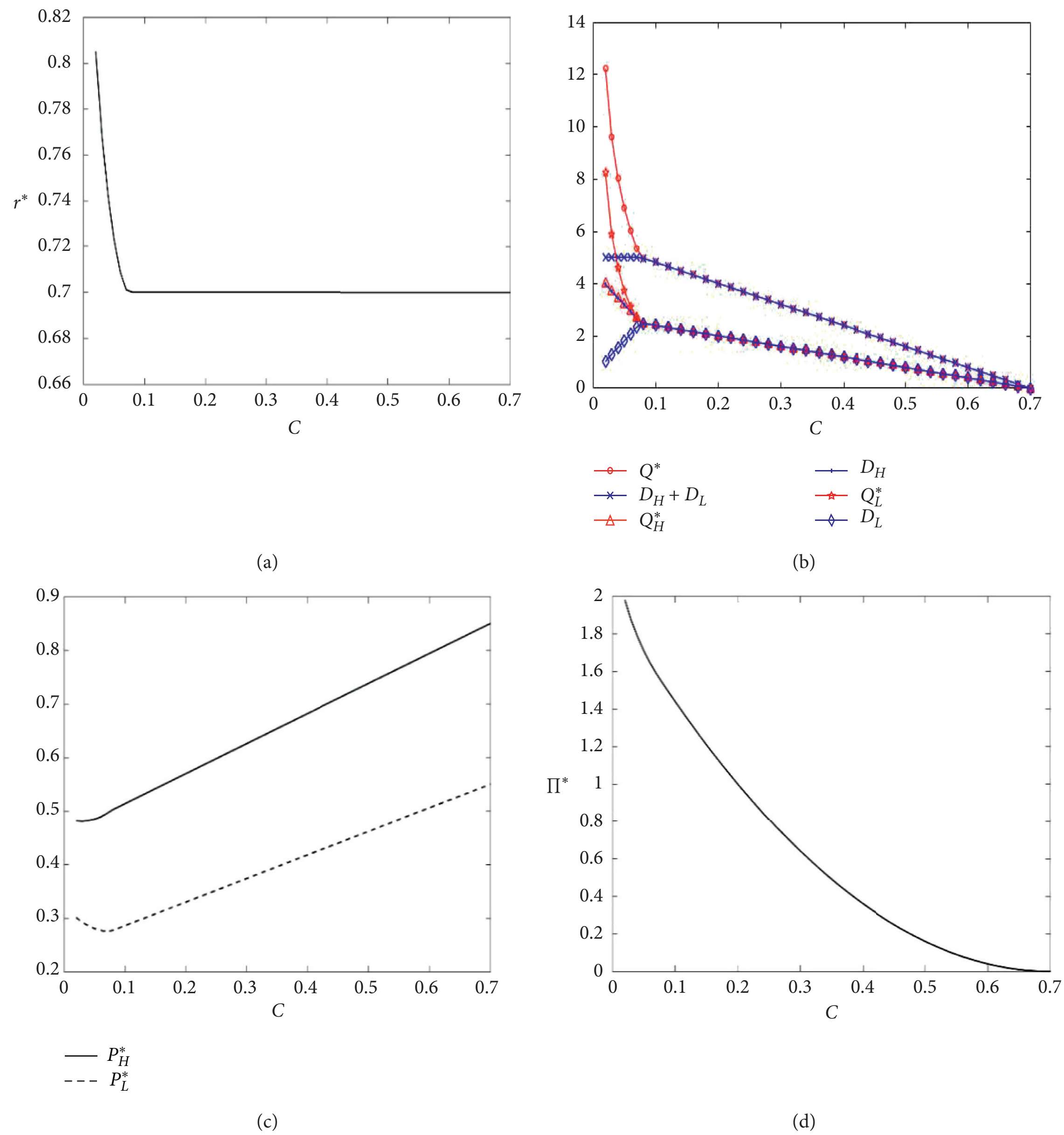

Figure 7: The influences of unit cost C on the retailer's optimal decisions. (a) The influence of C on r, (b) the influence of C on D and Q, (c) the influence of C on P, and (d) the influence of C on Π.

5.2. Sensitivity Analysis

5.2.1. The Influences of the Lowest Quality on the Retailer's Optimal Decisions. We set the value of parameters D and C as $D = 10$ and $C = 0.02$, respectively, and the lowest quality level r_L varies between $[0.3, 0.99]$. We obtain the optimal decisions of the retailer from Proposition 2. We mainly analyze the influences of the lowest quality level r_L on the retailer's optimal decisions as shown in Figure 6.

Figure 6 reveals that the optimal quality grading standard and selling price increase with the lowest quality level of fresh food. The selling price gap between high and low quality grades gradually narrows with the increase of r_L. Meanwhile, the total purchase amount, the supply, and the total market demand for the two quality grades are gradually decreasing. Interestingly, with the decline in the total purchase quantity of fresh food, the retailer's revenue is growing. The reason can be interpreted as follows. With the increase of the lowest quality level, the quality gap between the fresh food with two quality grades decreases, and the competition between products increases. Therefore, when consumer demand for the two quality grades declines, the retailer reduces the total order quantity accordingly. To maintain his sales profits, the retailer will raise the standards of quality grading. On the one hand, it can ensure that high quality fresh food can be sold at high prices, and on the other hand, low quality grades can guide the market demand and supply to match reasonably with a higher price.

The above analyzes indicate that when the unit cost of fresh food is constant, the retailer can increase profits by improving the minimum level of quality. Meanwhile, with the increase of the minimum quality level, the market competition of products with two quality grades is enhanced. The retailer can achieve profit growth by reducing the total order quantity with two quality grades and increase the standards of quality grading.

5.2.2. The Influences of Unit Cost on the Retailer's Optimal Decisions. First, we set the value of parameters D and r_L as $D = 10$, and $r_L = 0.4$, respectively, and r_L varies between $[0, 0.7]$. Then, we obtain the optimal decisions of the retailer via Proposition 2. And the influences of the unit cost C on the retailer's optimal decisions as shown in Figure 7.

As shown in Figure 7, with the increase of the unit cost, the prices of products with two quality grades also increase, while the total order quantity and sales profits of high and low quality grades decrease. When the cost is too high, the retailer will forgo purchasing fresh food. It is worth noting that the grading standard of the two quality grades first decreases and then remains unchanged with the increase in the unit cost of fresh food. This indicates that the retailer should be dedicated to providing more fresh food with high quality. As the retailer continues to reduce his total purchase quantity of fresh food, he cannot have the advantage of small profits but quick turnover. Consequently, the retailer can only increase the sales prices of the two quality levels to ensure profitability. With the increase in the cost of fresh food, the retailer will increase prices and adjust grading standards to avoid the surplus of the products. However, the loss from reduced supply clearly outweighs the gain from higher selling prices. As a result, the retailer's profit tends to decline. Therefore, the cost of fresh food is an important factor affecting the profitability of the retailer who can use the cost advantages of fresh food to be more competitive in the market and ensure profit growth.

6. Conclusion

Based on the above analysis, it is clear that the mixed sales mode for fresh food has a number of disadvantages. On the one hand, it is difficult to meet the needs of consumers with different quality preferences. On the other hand, the failure of selling low quality products will cause the retailer to lose profits. Due to the timeliness and perishability of fresh food, the differentiated sales mode based on quality grading of fresh food can effectively promote the sales of fresh food and reduce the profit loss caused by unsalable products.

Therefore, we consider a situation in which a retailer sells fresh food of two quality grades. That is, fresh food is divided into high and low quality grades based on its quality distribution. Considering consumers' preferences of quality levels, a quality selection model is used to describe consumers' purchase behavior. By building the retailer's profit function, we analyze its optimal purchase quantity, grading standard, pricing, and profit under the condition of quality grading, as well as the effects of the lowest quality and unit cost on the retailer's optimal decisions. The main conclusions are as follows:

(1) There is an optimal strategy for quality grading of fresh food, which is affected by factors such as the lowest quality, unit cost, and quality level distribution of fresh food. The retailer can explore the optimal quality grading strategy according to the actual situation and make pricing and ordering decisions based on quality grading to maximize his profit.

(2) When the lowest quality level of fresh food remains unchanged, the retailer's total profits may not be positively correlated with the total order quantity. For example, if the unit cost of fresh food is very low, the retailer's profit in the situation of "oversupply" may be higher than that when there is a good "balance of supply and demand."

(3) Raising the lowest quality level is conducive to increasing the retailer's profit from differentiated sales. The prices of products with high and low quality grades increase with the minimum quality level.

This study also has some limitations. First, we consider only two grades of quality (i.e., high and low), and product quality obeys uniform distribution. Nonetheless, the real situation may be more complex. For example, product quality is classified into multiple levels and has a more complex distribution. Second, we only study quality grading and pricing strategies of fresh food from the perspective of retailers. The decisions from the perspective of food supply chains by considering the interests of upstream producers are short of study. By analyzing these issues, we hope to provide retailers with some management insights and practical guidance in decision-making.

Appendix

A. Proof of Proposition 1

According to the retailer's revenue function, the retailer's optimal decision can be divided into four scenarios as shown in Figure 3. Since the optimal decision point of scenario 2, 3, and 4 falls on the boundary of scenario 1 region, only the optimal solution of scenario 1 needs to be discussed to obtain the overall optimal solution of the objective function.

Scenario 1: $\max \Pi (P_H, P_L) = P_H D[1 - ((2(P_H - P_L))/(1 - r_L))] + P_L D[(2(P_H - P_L)/(1 - r_L)) - (2P_L/(r + r_L))] - CQ$

$$\text{S.t.} \begin{cases} D\left[1 - \dfrac{2(P_H - P_L)}{1 - r_L}\right] \le Q \displaystyle\int_r^1 f(r)\mathrm{d}r, \\ D\left[\dfrac{2(P_H - P_L)}{1 - r_L} - \dfrac{2P_L}{r + r_L}\right] \le Q \displaystyle\int_{r_L}^r f(r)\mathrm{d}r, \\ \dfrac{P_L}{r + r_L} \le \dfrac{P_H}{1 + r} \le \dfrac{(P_H - P_L)}{1 - r_L} \le \dfrac{1}{2}, \quad P_H > P_L > 0, 0 < r_L \le r \le 1. \end{cases} \tag{A.1}$$

The first derivative is

$$\frac{\partial \Pi (P_H, P_L)}{\partial P_H} = \left[1 - \frac{4(P_H - P_L)}{1 - r_L}\right] D,$$
$$\frac{\partial \Pi (P_H, P_L)}{\partial P_L} = \left[\frac{4(P_H - P_L)}{1 - r_L} - \frac{4P_L}{r + r_L}\right] D. \tag{A.2}$$

Due to second derivative,

$$\frac{\partial \Pi^2 (P_H, P_L)}{\partial P_H^2} = -\frac{4}{1 - r_L} < 0,$$
$$\frac{\partial \Pi^2 (P_H, P_L)}{\partial P_L^2} = \frac{-4}{1 - r_L} - \frac{4}{r + r_L} < 0 \tag{A.3}$$
$$-\frac{4}{1 - r_L} * \left(\frac{-4}{1 - r_L} - \frac{4}{r + r_L}\right) - \frac{4}{1 - r_L} * \frac{4}{1 - r_L} = \frac{16}{(1 - r_L)(r + r_L)} > 0.$$

Therefore, the profit function of the retailer is the joint concave function of P_H and P_L, where the maximum value exists, and its Lagrangian function is

$$\begin{aligned} L(P_H, P_L, \lambda_1, \lambda_2, \lambda_3, \lambda_4) = {} & P_H D\left[1 - \frac{2(P_H - P_L)}{1 - r_L}\right] + P_L D\left[\frac{2(P_H - P_L)}{1 - r_L} - \frac{2P_L}{r + r_L}\right] - CQ \\ & + \lambda_1\left(Q\int_r^1 f(r)\mathrm{d}r - D\left[1 - \frac{2(P_H - P_L)}{1 - r_L}\right]\right) + \lambda_2\left(Q\int_{r_L}^r f(r)\mathrm{d}r - D\left[\frac{2(P_H - P_L)}{1 - r_L} - \frac{2P_L}{r + r_L}\right]\right) \\ & + \lambda_3\left(\frac{1 - r_L}{2} - P_H + P_L\right) + \lambda_4\left(\frac{r + r_L}{1 + r}P_H - P_L\right). \end{aligned} \tag{A.4}$$

KKT conditions are as follows:

$$\begin{aligned} \frac{\partial L}{\partial P_H} &= \left[1 - \frac{4(P_H - P_L)}{1 - r_L}\right] D + \lambda_1\left(\frac{2}{1 - r_L}\right) D + \lambda_2\left(\frac{-2}{1 - r_L}\right) D - \lambda_3 + \lambda_4\left(\frac{r + r_L}{1 + r}P_H\right) = 0, \\ \frac{\partial L}{\partial P_L} &= \left(\frac{4(P_H - P_L)}{1 - r_L} - \frac{4P_L}{r + r_L}\right) D + \lambda_1\left(\frac{-2}{1 - r_L}\right) D + \lambda_2\left(\frac{2}{1 - r_L} + \frac{2}{r + r_L}\right) D + \lambda_3 - \lambda_4 = 0, \\ & \lambda_1\left(Q\int_r^1 f(r)\mathrm{d}r - D\left[1 - \frac{2(P_H - P_L)}{1 - r_L}\right]\right) = 0, \\ & \lambda_2\left(Q\int_{r_L}^r f(r)\mathrm{d}r - D\left[\frac{2(P_H - P_L)}{1 - r_L} - \frac{2P_L}{r + r_L}\right]\right) = 0, \\ & \lambda_3\left(\frac{1 - r_L}{2} - P_H + P_L\right) = 0, \\ & \lambda_4\left(\frac{r + r_L}{1 + r}P_H - P_L\right) = 0. \end{aligned} \tag{A.5}$$

Three possible solutions are obtained:

$$
\begin{aligned}
&P_H = \frac{1+r}{4}, P_L = \frac{r+r_L}{4}, \lambda_1 = 0, \lambda_2 = 0, \lambda_3 = 0, \lambda_4 = 0, \quad \text{when } \frac{D}{2} \le Q_H \le Q \le D,\\
&P_H = \frac{r+r_L}{4} + \frac{(D-Q_H)(1-r_L)}{2D}, P_L = \frac{r+r_L}{4}, \lambda_1 = \frac{(D-2Q_H)(1-r_L)}{2D}, \lambda_2 = 0, \lambda_3 = 0, \lambda_4 = 0, \quad \text{when } Q_H \le \frac{D}{2} \le Q \le D,\\
&P_H = \frac{(D-Q)(1+r) + Q(1-r_L)\int_{r_L}^{r} f(r)\mathrm{d}r}{2D}, P_L = \frac{(D-Q)}{2D}(r+r_L),\\
&\lambda_1 = \frac{(D-2Q)(r+1)}{2D} + \frac{(1-r_L)Q\int_{r_L}^{r} f(r)\mathrm{d}r}{D}, \lambda_2 = \frac{(D-2Q)(r+r_L)}{2D}, \lambda_3 = 0, \lambda_4 = 0, \quad \text{when } 0 < Q \le \frac{D}{2}.
\end{aligned}
\tag{A.6}
$$

B. Proof of Proposition 2

According to equation (10), when $(D/2) \le Q_H \le Q$ and $r_L \le r < 1$, the retailer's profit function is $\Pi = (1 + r/8)D - CQ$; due to $(\partial\Pi/\partial r) = (D/8) > 0$, $(\partial\Pi/\partial Q) = -C < 0$, and $Q_H \ge (D/2)$, the optimal solution to the retailer's profit function must fall on $Q_H = (D/2)$, i.e. $Q = ((1 - r_L) * D/2(1 - r))$. By Proposition 1, the retailer's profit function is a continuous differentiable function about r and Q. When $Q_H < (D/2) \le Q$ and $r_L \le r \le 1$, the retailer's profit function is a strictly concave function about r and Q, and $(\partial\Pi/\partial r)(Q_H = (D/2)) = (D/8) > 0$. The retailer's profit in the scenario when $Q_H < (D/2) \le Q$ and $r_L \le r \le 1$ is always less than the profit in the scenario when $Q_H < (D/2) \le Q$ and $r_L \le r \le 1$.

And when $Q_H < (D/2) \le Q$ and $r_L \le r \le 1$, the optimal price for the two quality grades is $P_H^* = ((r + r_L)/4) + ((D - Q_H)(1 - r_L)/2D)$, $P_L^* = ((r + r_L)/4)$, and the retailer's profit function is $\Pi^* = ((DQ(1 - r_L)(1 - r) - Q^2(1 - r)^2)/(2D(1 - r_L))) + (((r + r_L)D)/8) - CQ$.

The Hessian matrix is

$$
H = \begin{pmatrix} H_1 & H_2 \\ H_3 & H_4 \end{pmatrix} = \begin{pmatrix} \dfrac{-2Q^2}{2D(1-r_L)} & \dfrac{4Q(1-r) - D(1-r_L)}{2D(1-r_L)} \\ \dfrac{4Q(1-r) - D(1-r_L)}{2D(1-r_L)} & \dfrac{-2(1-r)^2}{2D(1-r_L)} \end{pmatrix}. \tag{B.1}
$$

Due to

$$
\begin{aligned}
|H_1| &= \frac{-2Q^2}{2D(1-r_L)} < 0,\\
|H_2| &= \frac{-2Q^2}{4D^2(1-r_L)^2} \cdot \frac{-2(1-r)^2}{2D(1-r_L)} - \left(\frac{4Q(1-r) - D(1-r_L)}{2D(1-r_L)}\right)^2 > 0.
\end{aligned}
\tag{B.2}
$$

The Hessian matrix is a negative definite matrix, the objective function is strictly concave, and there is a maximum.

Owing to $(\partial\Pi/\partial r)(Q_H = (D/2)) = (D/8) > 0$, $(\partial\Pi/\partial r)(r = 1) = (D/8) - (Q/2) < 0 (Q > (D/2))$, the optimal solution of the objective function is not on the boundary of the domain $Q_H = (D/2), r = 1$. In addition, due to $(\partial\Pi/\partial Q) = -C + ((2Q(1 - r)^2 + D(1 - r)(1 - r_L))/2D)$, when $r = ((1 + r_L)/2), Q = (D/2)$, we find $(\partial\Pi/\partial Q) + C - ((1 - r_L)/8) = 0$, $(\partial\Pi/\partial r) = 0$, and if $C \ge (1 - r_L/8)$, the derivative is $\partial\Pi/\partial Q(r = (1 + r_L/2), Q = (D/2)) < 0$, $\partial\Pi/\partial r(r = (1 + r_L/2)) = 0$. At this point, the objective function achieves the optimal value at $(r, Q) = ((1 + r_L/2), (D/2))$. On the other hand, if $C < ((1 - r_L)/8)$, the optimal solution of the objective function lies within the domain. Solving for $(\partial\Pi/\partial Q) = 0$, $(\partial\Pi/\partial r) = 0$, we get the internal optimal solution is $(r^*, Q^*) = (\delta, ((1 - \delta)D/8C))$, where δ meets the following conditions.

$$
\begin{cases} (1-\delta)^3 - 4C(1-r_L)(1-\delta) + 8C^2(1-r_L) = 0, \\ r_L \le r \le 1 - 4C. \end{cases} \tag{B.3}
$$

Therefore, when $Q_H < (D/2) \le Q$ and $r_L \le r \le 1$, the retailer's optimal ordering and grading decisions are as follows:

(1) If $C \ge (1 - r_L/8)$, the optimal decisions are $r = (1 + r_L/2)$, $Q = (D/2)$, and the retailer's profit is $\Pi^* = ((5 + 3r_L - 16C)/32)D$;

(2) If $C < (1 - r_L/8)$, the optimal decisions are $r = \delta$ and $Q = ((1 - \delta)D/8C)$, and the retailer's profit is

$$\Pi^* = \frac{(1-\delta)^2 D}{16C} - \frac{(1-\delta)^4 D}{16C(1-r_L)} + \frac{(2\delta + r_L - 1)D}{8}. \quad \text{(B.4)}$$

And when $0 < Q \le (D/2)$ and $r_L < r \le 1$, the retailer's profit function is

$$\Pi^* = \frac{DQ\left(1-r_L^2\right) - \left[(1+r_L)(1-r) + \left(r^2 - r_L^2\right)\right]Q^2}{2D(1-r_L)} - CQ. \quad \text{(B.5)}$$

According to the KKT condition, the two sets of solutions are

(1) $r = ((1+r_L)/2), Q = (D/2), \lambda_1 = ((1-8C-r_L)/8), \lambda_2 = 0, \lambda_3 = 0$; the retailer's profit is $\Pi^* = ((5-16C+3r_L)/32)D$, and $C \le ((1-r_L)/8)$;

(2) $r = (1+r_L/2), Q = ((2D(1-2C+r_L))/(3+5r_L)), \lambda_1 = 0, \lambda_2 = 0, \lambda_3 = 0$; the retailer's profit is $\Pi^* = ((D(1-2C+r_L)^2)/(6+10r_L))$ and $C > ((1-r_L)/8)$.

To sum up, by comparing the optimal profit values of the three subregions of the profit function, the following conclusions can be drawn:

(1) When $C \le ((1-r_L)/8)$, the profit function is

$$\Pi^* = \max\left\{\frac{(5-16C+3r_L)}{32}D, \frac{(1-\delta)^2 D}{16C} - \frac{(1-\delta)^4 D}{16C(1-r_L)} + \frac{(2\delta+r_L-1)D}{8}\right\} = \frac{(1-\delta)^2 D}{16C} - \frac{(1-\delta)^4 D}{16C(1-r_L)} + \frac{(2\delta+r_L-1)D}{8}. \quad \text{(B.6)}$$

The retailer's optimal decision is $r^* = \delta$ and $Q^* = (((1-\delta)D)/8C)$

(2) When $C > ((1-r_L)/8)$, the profit function is $\Pi^* = \max\{((5+3r_L-16C)/32)D, ((D(1-2C+r_L)^2)/(6+10r_L))\} = (D(1-2C+r_L)^2/(6+10r_L))$. The retailer's optimal decision is $r^* = ((1+r_L)/2)$, $Q^* = ((2D(1-2C+r_L))/(3+5r_L))$;

(3) When $C \ge ((1+r_L)/2)$, we find $Q^* = 0$

C. Proof of Corollary 1

(1) When $0 < C \le ((1+r_L)/2)$, the optimal quality grading r^* of fresh food raises with the improvement of the lowest quality r_L

(i) When $0 < C < ((1-r_L)/8)$, we obtain $r^* = \delta$, that δ should satisfy the following conditions: $\{(1-\delta)^3 - 4C(1-r_L)(1-\delta) + 8C^2(1-r_L) = 0 r_L < \delta < 1-4C$. Due to $(1-\delta)^3 = 4C(1-r_L)(1-\delta) - 8C^2(1-r_L) > 0$, $3(1-\delta)^3 - 4C(1-r_L)(1-\delta) = 8C(1-r_L)(1-\delta-C)$, we find $3(1-\delta)^2 - 4C(1-r_L) > 0$. And due to $[3(1-\delta)^2 - 4C(1-r_L)](\partial\delta/\partial r_L) = 4C(1-\delta) - 8C^2 > 0$, we obtain $(\partial\delta/\partial r_L) > 0$.

(ii) When $((1-r_L)/8) < C \le ((1+r_L)/2)$, the retailer's optimal quality rating standard and purchase quantity are, respectively, $r^* = ((1+r_L)/2), Q^* = ((2D(1-2C+r_L))/(3+5r_L))$, and $(\partial r^*/\partial r_L) = (1/2) > 0$.

(2) When $0 < C < ((1-r_L)/8)$, the optimal quality grading standard of fresh food decreases with the increase of the unit cost. And when $((1-r_L)/8) < C \le ((1+r_L)/2)$, the optimal quality grading standard remains unchanged.

When $0 < C < ((1-r_L)/8)$, according to the proof of the above, we can obtain that $1-\delta > 2C$ and $3(1-\delta)^2 - 4C(1-r_L) > 0$, and since $0 < C < ((1-r_L)/8)$, $\delta > r_L$, $(1-\delta)^3 - 8C^2(1-r_L) = 4C(1-r_L)[(1-\delta)-4C]$, and $(1-\delta)^3 > (1-r_L)^3$, $0 < 8C^2(1-r_L) < ((1-r_L)^3/8)$, and we get $(1-\delta) > 4C$. And due to $[4C(1-r_L) - 3(1-\delta)^2](\partial\delta/\partial C) = 4(1-r_L)(1-\delta-4C)$, $3(1-\delta)^2 - 4C(1-r_L) > 0$, and $(1-\delta) > 4C$, we get $(\partial\delta/\partial C) < 0$.

And when $((1-r_L)/8) < C \le ((1+r_L)/2)$, the optimal quality grading standard remains unchanged. It can be easily obtained in Proposition 2.

D. Proof of Corollary 2

According to Proposition 2, when $((1-r_L)/8) < C < ((1+r_L)/2)$, the retailer's profit is $\Pi^* = ((D(1-2C+r_L)^2)/(6+10r_L))$. The first derivative of the profit function with respect to r_L and C are $(\partial\Pi^*/\partial r_L) = (((1-2C+r_L)(1+5r_L+10C)D)/(2(3+5r_L)^2)) > 0$ and $(\partial\Pi^*/\partial C) = ((-4D(1-2C+r_L))/(6+10r_L)) < 0$, so that the view is true in Corollary 2.

E. Proof of Corollary 3

(1) According to Appendix 3, we can get $3(1-\delta)^2 - 4C(1-r_L) > 0$, $(1-\delta) > 4C$. Respect to $(\partial\delta/\partial C) = ((4(1-r_L)[(1-\delta)-4C])/(4(1-r_L)C - 3(1-\delta)^2)) < 0$, and we get $(\partial Q^*/\partial C) = ((-[C(\partial\delta/\partial C) + (1-\delta)]D)/8C^2) = (((1-\delta)^3 D)/(8C^2[4(1-r_L)C - 3(1-\delta)^2])) < 0$. When $((1-r_L)/8) < C < ((1+r_L)/2)$ and $Q^* = ((2D(1-2C+r_L))/(3+5r_L))$, we obtain $(\partial Q^*/\partial C) = ((-4D)/(3+5r_L)) < 0$. And when $C \ge ((1+r_L)/2)$, the optimal purchase quantity $Q^* = 0$.

(2) (i) When $0 < C \le ((1-r_L)/8)$, we get that $3(1-\delta)^2 - 4C(1-r_L) > 0$, $(1-\delta) > 4C$, $(\partial\delta/\partial r_L) > 0$, and $(\partial Q^*/\partial r_L) = ((-(\partial\delta/\partial r_L)D)/8C)$; as a result, $(\partial Q^*/\partial r_L) < 0$. (ii) When $((1-r_L)/8) < C < ((1+r_L)/2)$, the optimal purchase quantity is

$Q^* = ((2D(1-2C+r_L))/(3+5r_L))$, and $(\partial Q^*/\partial r_L) = ((4D(5C-1))/(3+5r_L)^2)$. Hence, when $(1/5) < C < ((1+r_L)/2)$, the optimal purchase quantity is a monotonically decreasing function of the lowest quality level.

(3) When $(1/5) < C < ((1+r_L)/2)$, we get $(\partial Q^*/\partial r_L) > 0$. The optimal purchase quantity increases with the improvement of the lowest quality level.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (71771053 and 71371003), the Natural Science Foundation of Jiangsu Province (BK20201144), and the Key Research and Development Plan (Modern Agriculture) of Jiangsu Province (BE2018385).

References

[1] R. J. Polkinghorne and J. M. Thompson, "Meat standards and grading," *Meat Science*, vol. 86, no. 1, pp. 227–235, 2010.
[2] R. Kohls, J. Uhl, and C. Hurt, *Marketing of Agricultural Products*, Prentice Hall, New York, NY, USA, 10th edition, 2014.
[3] G. R. Griffith and J. M. Thompson, "The aggregate economic benefits to the Australian beef industry from the adoption of Meat Standards Australia: updated to 2010/11," *Australasian Agribusiness Review*, vol. 20, pp. 11–38, 2012.
[4] K. Kawasaki and E. Lichtenberg, "Econometric analysis of grading standards: the ordered fractional approach," *American Journal of Agricultural Economics*, vol. 96, no. 1, pp. 345–365, 2014.
[5] H. E. Erdman, "Problems in establishing grades for farm products," *Journal of Farm Economics*, vol. 32, no. 1, pp. 15–29, 1950.
[6] S. T. Shaw, "A merchandiser's view of the function of grades," *Journal of Farm Economics*, vol. 43, no. 5, pp. 1399–1404, 1961.
[7] P. Zusman, "A theoretical basis for determination of grading and sorting schemes," *Journal of Farm Economics*, vol. 49, no. 1, pp. 89–106, 1967.
[8] A. M. Zago and D. Pick, "Labeling policies in food markets: private incentives, public intervention, and welfare effects," *Journal of Agricultural and Resource Economics*, vol. 29, no. 1, pp. 150–165, 2004.
[9] D.-J. Lee, R. Schoenberger, J. Archibald, and S. McCollum, "Development of a machine vision system for automatic date grading using digital reflective near-infrared imaging," *Journal of Food Engineering*, vol. 86, no. 3, pp. 388–398, 2008.
[10] H. Hong, X. Yang, Z. You, and F. Cheng, "Visual quality detection of aquatic products using machine vision," *Aquacultural Engineering*, vol. 63, pp. 62–71, 2014.
[11] M. Baigvand, A. Banakar, S. Minaei, J. Khodaei, and N. Behroozi-Khazaei, "Machine vision system for grading of dried figs," *Computers and Electronics in Agriculture*, vol. 119, pp. 158–165, 2015.
[12] T. Jadhav, K. Singh, and A. Abhyankar, "Volumetric estimation using 3D reconstruction method for grading of fruits," *Multimedia Tools and Applications*, vol. 78, no. 2, pp. 1613–1634, 2019.
[13] B. N. I. Deplomo, J. C. D. Cruz, and J. R. Balbin, "Classifying quality grading and size of allium cepa using digital image processing algorithms," in *Proceedings of the 2020 International Conference on Communications, Information System and Computer Engineering (CISCE)*, pp. 123–126, Kuala Lumpur, Malaysia, July 2020.
[14] S. C. Matz and O. Netzer, "Using Big Data as a window into consumers' psychology," *Current Opinion in Behavioral Sciences*, vol. 18, pp. 7–12, 2017.
[15] V. Chkoniya, "Challenges in decoding consumer behavior with data science," *European Journal of Economics and Business Studies*, vol. 3, no. 3, pp. 77–87, 2020.
[16] N. Mishra, A. Singh, N. P. Rana, and Y. K. Dwivedi, "Interpretive structural modelling and fuzzy MICMAC approaches for customer centric beef supply chain: application of a Big Data technique," *Production Planning & Control*, vol. 28, no. 11-12, pp. 945–963, 2017.
[17] X. Dou, "Online purchase behavior prediction and analysis using ensemble learning," in *Proceedings of the 2020 IEEE 5th International Conference on Cloud Computing and Big Data Analytics (ICCCBDA)*, pp. 532–536, Chengdu, China, April 2020.
[18] R. Buettner, "Predicting user behavior in electronic markets based on personality-mining in large online social networks," *Electronic Markets*, vol. 27, no. 3, pp. 247–265, 2017.
[19] P. Ma, "Ordering and pricing strategies for fresh products with multiple quality levels considering consumer utility," *American Journal of Operations Research*, vol. 5, no. 3, pp. 192–198, 2015.
[20] S. Transchel, "Inventory management under price-based and stockout-based substitution," *European Journal of Operational Research*, vol. 262, no. 3, pp. 996–1008, 2017.
[21] X. Chen, Z. Gao, and B. R. McFadden, "Reveal preference reversal in consumer preference for sustainable food products," *Food Quality and Preference*, vol. 79, p. 103754, 2020.
[22] R. Wongprawmas and M. Canavari, "Consumers' willingness-to-pay for food safety labels in an emerging market: the case of fresh produce in Thailand," *Food Policy*, vol. 69, pp. 25–34, 2017.
[23] S. Yin, W. Hu, Y. Chen, F. Han, Y. Wang, and M. Chen, "Chinese consumer preferences for fresh produce: interaction between food safety labels and brands," *Agribusiness*, vol. 35, no. 1, pp. 53–68, 2019.
[24] Z. Liu, Z. Yu, S. Zhang, and J. Peng, "Three stage game research of dual-channel supply chain of fresh agricultural products under consumer preference," *International Journal of Computing Science and Mathematics*, vol. 9, no. 1, pp. 48–57, 2018.
[25] S. Wang, Q. Hu, and W. Liu, "Price and quality-based competition and channel structure with consumer loyalty," *European Journal of Operational Research*, vol. 262, no. 2, pp. 563–574, 2017.
[26] Y. Akçay, H. P. Natarajan, and S. H. Xu, "Joint dynamic pricing of multiple perishable products under consumer choice," *Management Science*, vol. 56, no. 8, pp. 1345–1361, 2010.

[27] X. Wang and D. Li, "A dynamic product quality evaluation based pricing model for perishable food supply chains," *Omega*, vol. 40, no. 6, pp. 906–917, 2012.
[28] A. Sainathan, "Pricing and replenishment of competing perishable product variants under dynamic demand substitution," *Production and Operations Management*, vol. 22, no. 5, pp. 1157–1181, 2013.
[29] B. Adenso-Díaz, S. Lozano, and A. Palacio, "Effects of dynamic pricing of perishable products on revenue and waste," *Applied Mathematical Modelling*, vol. 45, no. 6, pp. 148–164, 2017.
[30] Y. Duan and J. Liu, "Optimal dynamic pricing for perishable foods with quality and quantity deteriorating simultaneously under reference price effects," *International Journal of Systems Science: Operations & Logistics*, vol. 6, no. 4, pp. 346–355, 2019.
[31] J. Lu, J. Zhang, X. Jia, and G. Zhu, "Optimal dynamic pricing, preservation technology investment and periodic ordering policies for agricultural products," *RAIRO - Operations Research*, vol. 53, no. 3, pp. 731–747, 2019.
[32] L. Feng, "Dynamic pricing, quality investment, and replenishment model for perishable items," *International Transactions in Operational Research*, vol. 26, no. 4, pp. 1558–1575, 2019.
[33] T. Fan, C. Xu, and F. Tao, "Dynamic pricing and replenishment policy for fresh produce," *Computers & Industrial Engineering*, vol. 139, no. 8, 2020.
[34] J. Tirole, *The Theory of Industrial Organization*, MIT Press, Cambridge, MA, USA, 1988.

Hindawi
Journal of Food Quality
Volume 2021, Article ID 6616096, 18 pages
https://doi.org/10.1155/2021/6616096

Research Article

Pricing and Safety Investment Decisions in Food Supply Chains with Government Subsidy

Yanan Yu, Yong He, and Melissza Salling

School of Economics and Management, Southeast University, Nanjing 210096, China

Correspondence should be addressed to Yong He; hy@seu.edu.cn

Received 30 December 2020; Revised 31 March 2021; Accepted 9 April 2021; Published 28 April 2021

Academic Editor: Yan Zhang

As the demand for safe food has been rapidly increasing these years, more and more stakeholders are dedicated to the safety of the food in the supply chain of this sector. To expand the market share of safe food, governments of some countries also provide subsidies to encourage food processors to invest in better food safety efforts. This paper establishes a three-stage game model between the government and a two-stage food supply chain that consists of one supplier and one processor, where the government subsidizes processors to invest in food safety efforts; furthermore, this paper determines the optimal wholesale price, marginal profit, food safety investment, and government subsidies. This paper analyzes the effects of the government subsidies and risk aversion of the food processor and introduces the mode of order quantity-based payment and demand-based payment; moreover, it also analyzes the impacts of subsidies and different payment methods on demands. The results show that suppliers can increase the market share of products by adopting the demand-based payment, but this method does not always benefit the members of the supply chain. As the processor is more risk-averse, the optimal subsidy is higher, encouraging the processor to invest in more efforts. Finally, the supplier's profit increases with the processor's risk aversion indicator.

1. Introduction

Consumers across the world are increasingly adopting healthy lifestyles and thus changing their eating habits which leads to the rapid growth of the global health and wellness of the food market. The intensification and industrialization of agriculture and animal production create both opportunities and challenges of food safety in order to meet the increasing demand for food. Since the customer demand for food is an important role of formulating various agricultural and food policies, governments should make food safety a public health priority, as they play a pivotal essence in developing policies and regulatory frameworks, as well as establishing and implementing effective food safety systems. Governments in Canada subsidize food processors to reopen or upgrade facilities of processing domestic food or to modernize and automate plants that have closed or are operating at less than full capacity. India subsidizes unorganized food processing sector to provide infrastructure and services supporting the growth of new food businesses. Recently, literature on government subsidy in a supply chain is quite rich. Different forms of subsidies are also compared [1–3].

International Organization for Standardization (ISO) defines quality as the totality of features and characteristics of a product that bears its ability to satisfy stated or implied needs. It is analyzed by experts that safety is the most important factor or component of quality as lack of safety can lead to serious consequences like the serious injury or even death of a person (see https://www.fssaifoodlicense.com/different-food-safety-food-quality). Qin et al. indicated that quality is the term based on some subjective and objective measurements of the food product including measures of sensory, nutrition, safety, wholesomeness, or any other attribute of the product [4]. Although ultra-processed foods tend to taste good, they usually contain ingredients that could be harmful if consumed in excess, such as saturated fats, added sugar, and salt (see https://www.medicalnewstoday.com/articles/318630#what-is-processed-food). It was found that eating more than 4 servings of processed food daily may result in an increased risk of all-cause mortality (see https://www.bmj.com/content/365/bmj.l1949). Customers therefore hold different attitudes towards processed food, making the food supply chain members uncertain about the customers' perceived quality. Big data, combined with reliable information on food consumption, makes it possible for risk assessors to assess consumers (see https://www.efsa.europa.eu/en/topics/topic/data). In this context, we assume that the initial customers' perceived quality is observable and fluctuates within a certain range, and this paper studies the situation where the food processor is risk-averse and considers risk attitude towards pricing and safety investment decisions.

This paper focuses on studying the effects of different payment methods and government subsidies on increasing customer demands for safe food. The decisions about selling price, wholesale price, safety investment, order quantity, and government subsidies are optimized to maximize the profits of channel members and social welfare. Different from previous studies, this paper expands three aspects as follows. Firstly, this paper studies the impacts of food processing subsidies on the food safety investment, as well as pricing and market share. Secondly, the heterogeneity of the costumers' quality perception leads to demand volatility. This paper highlights the impact of food processor's risk aversion on the decision making in a food supply chain. Thirdly, we compare two payment methods, one is the order quantity-based payment in which the food processor pays the supplier regarding the order quantity and undertakes all the deterioration costs, and the other is the demand-based payment in which the supplier shares parts of the deterioration costs. The further parts of this paper are organized as follows. Section 2 summarizes relevant literature. Section 3 describes the issue, formulates the model, and solves the issue. Section 4 analyzes the influence of parameters on optimal decisions and compares different cases under different payment methods by using the numerical simulation. Finally, findings and future research directions are discussed in Section 5.

2. Relevant Literature

Our research mainly focuses on food pricing and food safety. An apparent gap exists between perceptions of the costumers and between the facts to innovative processed meat products [5]. However, food processors can affect perceived quality by adopting safety measures. Lee et al. analyzed the understanding of Chinese customers' perceptions of nonthermal processing technologies and ways to mitigate negative perceptions [6]. Asseldonk et al. found that understanding growers' preferences regarding interventions to improve the microbiological safety of their production could help to design more effective strategies for the adoption of such food safety measures by growers [7]. Regulations and specifications on processing technology in the food industry could improve product quality and customer trust [8] and could affect the expected price in the spot markets [9]. Food safety investment is confirmed to improve food quality. Hoffmann et al. reviewed the empirical research of the safety of produced and consumed food; furthermore, they suggested that midsize and larger firms should be in co-regulation and should also reward farmers and firms for investing in food safety [10]. Zheng and Fan investigated how product freshness and risk preference affect the profits of the fresh agricultural products supply chain. They found that increasing investment of science and technology on fresh agricultural products can greatly improve the quality and safety of fresh products [11]. The decisions about food pricing and quality investment are also studied. Lin studied an optimal replenishment model with dynamic pricing and quality investment for perishable products to maximize the total profit per unit time [12]. Moon et al. investigated freshness coordination decisions under the consideration of consumers' freshness preferences [13]. Wang and Zhao determined the optimal investment levels of the cold chain construction, advertisement, and optimal pricing in a fresh food supply chain. They found that collaborative cold chain investment and collaborative pricing are superior strategies for the supply chain [14].

Similar to the research above, we also investigate the operations management problems for food pricing and food safety. Differently, we focus on investigating the optimal safety improvement efforts and the corresponding pricing strategies of the risk-averse food processor which faces uncertain perceived quality. Moreover, the government subsidy on food processing is integrated into the decision framework, the feasible region and amount of government subsidy are provided, and the effects of deterioration coefficient and the food processor's risk aversion indicator on the decision of subsidy are studied, which are novel in the food quality and food safety literature.

Our research is also related to the cooperation in food supply chain. The relations between the suppliers and the degree of integration of the activities along with the supply chain are studied [15]. The benefits of cooperation are also investigated. Mesa and Gomez found that a more stable relationship between suppliers and retailers in the perishable produce market will render the supply firm more cooperative, competitive, and profitable. The retail channel and market diversification have a positive effect on the relationship between cooperation and the performance of the supplier [16]. Labrecque et al. found that in order to prosper in an uncertain marketplace, it needs to reduce its production costs, increase product awareness in the domestic market, and promote cooperation among industry members [17]. Rucabado and Cuellar suggested that small producers that are interested in short food supply chains must be aware of the special importance of social linkages and of the need to take care of them as well as of the need of establishing synergies and cooperation with other producers and stakeholders [18]. Cooperation of the perspective of operations management is also studied. Chen and Dan analyzed the cooperation based on a benefit-sharing contract used within a two-level supply chain with random production and demand [19]. Huang et al. established a Stackelberg game model for a three-level food supply chain consisting of one retailer, one vendor, and one supplier with production disruption. They found that the retailer's preservation investment can benefit all the supply chain members [20]. He et al. designed the green innovation effort level parameters and discussed the incentive strategy of cost-sharing led by manufacturers. They found that manufacturers need to stimulate their green innovation efforts by sharing the cost of suppliers, and the cost-sharing contract can optimize the overall income of the food supply chain [21]. Wang and Zhao found that collaborative cold chain investment and collaborative pricing are superior strategies for the supply chain [14].

We study the method where the processor pays the supplier based on the actual demand, and the processor and the supplier undertake the deterioration loss together, which contributes to the market expansion of the product; in addition, we also compare two payment methods, order quantity-based payment and demand-based method, respectively. Furthermore, the joint effects of government subsidies and different payment methods on the market expansion, as well as the profits of the supply chain members, are also examined.

Big data has been employed to manage food quality or food safety problems in the supply chain. Singh et al. proposed a big-data analytics-based approach that considers social media (Twitter) data to identify supply chain management issues in food industries [22]. Qian et al. presented novel technologies, including batch mixing optimization with AI, quality forecasting with big data, and credible traceability with blockchain, in the context of improving traceability performance in food processing [23]. Kappelman and Sinha considered a dynamic food supply chain with multiple process steps where the decisions at each step include supplier selection and settings for their process parameters. They proposed an integrated approach that uses big data mining techniques to study the effect of these decisions on the quality of the final product and determined the state transition matrix [24]. In terms of customers' food quality perception, Mishra et al. identified factors influencing consumer's beef purchasing decisions and established interrelationships between these factors by using big data supplemented with ISM and fuzzy MICMAC analysis [25]. Nardi et al. reviewed 128 empirical studies and found that trust, knowledge, subjective characteristics, and sociodemographic characteristics are critical driving factors of food safety risk perception (FSRP). They also analyzed the negative effects of FSRP on consumers' willingness to pay. The effects of a supply chain member's food safety risks on other members' decisions are also investigated [26]. Hou et al. surveyed Chinese fruit farmers to study the effect of farmers' risk attitude and contract arrangements on contract implementation by using a probit model [27]. Schoenherr et al. developed a framework for ensuring food safety through relationship networks. They found that consumers' stress can positively affect a firm's learning orientation and risk aversion, which in turn affected informal and formal relationship networks [28].

Big data makes the customer's perceived quality be observable. Therefore, this paper assumes that the customer's perceived quality is fixed and fluctuates within a certain range. Then, this paper studies the situation where the food processor is risk-averse and considers risk attitude towards pricing, safety investment, and subsidy decisions.

Another stream of our research is the risk-averse individual's optimal decision by using the mean-variance (mv) method. Chiu et al. considered the coordination problem with a risk-neutral manufacturer that supplies to multiple heterogeneous retailers [29]. Cui et al. studied a risk-averse retailer's optimal decision of introducing her store brand product by using the mean-variance formulation [30]. Chiu et al. considered a luxury fashion firm serving a conspicuous market consisting of two groups of customers who influence each other and investigated the optimal customer portfolios and budget allocation problem using the mean-variance framework [31]. Zhao and Zhu explored a risk-averse marketing strategy for a remanufacturer and a retailer in a remanufacturing supply chain [32]. The decision of the government is also incorporated into the model. Deng et al. studied a Stackelberg game where the government, as the leader, designs the subsidy policy to reach the electric vehicle adoption target and the risk-averse electric vehicle manufacturer, as the follower, determines the production quantity and selling price. They found that the manufacturer's profit does not necessarily decrease with the risk aversion because the production subsidy improves profit effectively [33]. Chiu and Choi [34], Choi et al. [35], and Wen and Siqin [36] provided comprehensive reviews of the applications of the mv theory in supply chains.

Different from the extant literature, this study incorporates food safety investment into the food supply chain. We consider the uncertain and endogenous customers' perceived quality which can be improved by the food processor's food safety investment and government subsidy together. We study the joint effects of two payment methods and government subsidies on market expansion and the profit of supply chain members, and we further investigate the effects of the food processor's risk aversion and deterioration coefficient on decisions.

3. The Model

Fresh food may suffer deterioration loss during the transportation and sales process due to the perishable features; similar to He et al. [37], we use f to represent the deterioration ratio of the food and $1-f$ to represent the surviving ratio of the food. Cai et al. characterized the optimal decisions of a fresh product supply chain where the freshness-keeping effort of the distributor impacts the quality and the quantity of the product delivered to the market [38]. In this article, the distributor is responsible for sales and takes on all deterioration costs. Yu and Xiao investigated the pricing and service level decisions of a fresh agri-products supply chain consisting of one supplier, one retailer, and one third-party logistics [39]. In their model, the retailer is responsible for sales, while the supplier takes on all deterioration costs. We compare two payment methods, one is the order quantity-based payment in which the food processor pays the supplier based on the order quantity and undertakes all the deterioration costs, and the other is the demand-based payment in which the supplier shares parts of the deterioration costs. We study the effects of government subsidies and different payment methods on the increasing demands for safe food.

When neglecting the government subsidy for processing the product, this paper considers a supply chain consisting of a leading food processor and a supplier. Due to the fact that the share of small-scale food producers in terms of all food producers in countries in Africa, Asia, and Latin America ranges from 40 to 85 per cent (see https://sdgs.un.org/goals/goal2), this paper assumes that the food processor dominates the supplier. We study the pricing and order decisions, and we compare the optimal decisions under order quantity-based payment and demand-based payment, respectively. Furthermore, we study the situation of a food processor who invests in the safety efforts to improve customers' belief in the quality of products and the situation of a government who dominates the whole supply chain providing the food processor subsidies to increase customer demands. We study the pricing, safety investment, order, and subsidy decisions and compare two payment methods.

3.1. Notations. The notations shown in Table 1 are used to model our problem.

3.2. Assumptions

(1) The government is the leader in the three-stage game, and it firstly determines the food processing subsidy. Secondly, the food processor determines the marginal profit and processing investment decisions, and finally, the supplier determines the wholesale price.

(2) The deterioration coefficient is a constant; this assumption can be found in [40–42]. If the order quantity is Q, the products with a portion of f will deteriorate, and the remainder of the products can be sold.

(3) The perceived quality of the product is s_q. When the food processor does not invest in additional processing efforts, $s_q = s + \varepsilon_1$; when the food processor invests in additional processing efforts, such as reopening or upgrading facilities for food processing or educating staff on how to ensure food safety practices,$s_q = q + \varepsilon_2$, where ε_1 and ε_1 are independent random variables, satisfying the distribution of mean value 0 and variance σ_i^2, $(i = 1 \text{ or } 2)$.

(4) The utility of the customers when purchasing the products is the linear function of the retail price p and the perceived quality s_q, and it is assumed to be downward sloping in retail price and upward sloping in perceived quality. Thus, the utility function can be denoted by $\mu = v + \beta s_q - p$.

(5) Since the customers' perceived quality of products is uncertain, it is assumed that the food processor is risk-averse, and the risk aversion indicator is k.

3.3. Model Construction and Analysis. According to Wen and Siqin [36], we assume that the customers' product valuations (v) are uniformly distributed in [0, 1], namely, $v \sim U(0, 1)$. The utility of the customer when buying the product with the selling price p can be expressed as $\mu = v + \beta s_q - p$. When $\mu \geq 0$, the customer will buy the product. The market size is normalized to 1, and the demand can be expressed as $D = 1 + \beta s_q - p$. Since the customer's perceived quality remains uncertain to the food processor, now we explore the impact of the food processor's risk attitudes on the equilibrium solutions. The valuation measure used herein is known in preference theory as the mean-variance approach (e.g., [43, 44]), whose form is expressed by the following equation: $U(\pi) = E(\pi) - (k\mathrm{Var}(\pi)/2)$. We compare the optimal decisions of members based on different modes of payments and subsidies, trying to examine the combined effects of the payment mode and the subsidy on increasing customer demands. Mode 1 represents the order quantity-based payment, and mode 2 represents the demand-based payment.

3.3.1. The Optimal Solutions without Subsidy. When the food processor does not incur safety investment to improve the customers' belief towards the products' quality, it is supposed that the government does not intervene in the supply chain. Thus, the supply chain consists of a supplier and a leading food processor, and the decision sequence is shown in Figure 1.

The customer's perceived quality of the product satisfies $s_q = s + \varepsilon_1$, where ε_1 is a normally distributed random factor, with mean zero and variance σ_1^2. The order quantity in this paper includes customer demands and product deterioration. Two methods based on different payments are analyzed. One method is the order quantity-based payment, where the food processor pays the supplier based on the order quantity. The other method is the demand-based payment, where the deterioration cost $c(Q - D)$ is undertaken by the processor and the supplier together. Particularly, when $r = 0$, the food processor will take on all deterioration costs, and when $r = 1$, the supplier will take on all deterioration costs. The event sequence is defined as follows: (i) the food processor determines the marginal profit m and orders products from the supplier at the beginning of sales cycle by taking the potential product decay into account; (ii) the supplier determines wholesale price w (and a fixed deterioration cost-sharing proportion r under the mode of demand-based payment); then, he transports the products to the destination market of the food processor; (iii) the decay occurs and the food processor sells the remaining products to the customers.

Case 1. Order quantity-based payment.

The food processor's expected order quantity is $(1 + \beta s - p_{11})l$, and the actual customer demand is $(1 + \beta s - p_{11})$. The quantity of deterioration is $(1 + \beta s - p_{11})(l - 1)$. Since the food processor pays the supplier based on the order quantity, the supplier's expected profit can be represented by

$$\max_{w_{11}} E(\pi_{s11}) = (w_{11} - c)(1 + \beta s - (w_{11} + m_{11}))l. \tag{1}$$

Letting $(\partial E(\pi_{s11})/\partial w_{11}) = 0$, we get

$$w_{11}^*(m_{11}) = \frac{1 + c - m_{11} + s\beta}{2}. \tag{2}$$

Table 1: Notation and explanation.

Parameters	Definition
v	The heterogeneous customer valuation, $v \sim U(0,1)$
s_q	Customers' perceived quality about food
μ	The customer utility
f	Deterioration coefficient, which is positively correlated with the deterioration rate, $(1/1-f)=l$
β	Nonnegative coefficient representing demand sensitivity to the product's perceived quality
c	The constant production cost per unit
k	The risk aversion indicator of the processor
λ	Cost coefficient of the safety investment
r	Fixed proportion of deterioration cost-sharing
Decision variables:	
m	The marginal profit per unit
w	The wholesale price per unit
p	The selling price per unit, $p = w + m$
q	The optimal safety investment
S	The government subsidy per unit
Functions:	
D	The total demand during the whole sales cycle
Q	The total order quantity during the whole sales cycle. Since the product may undergo deterioration during the process of transportation and sales, to satisfy demands, the retailer will set $Q = (E(D)/1-f)$. To simplify the model, we denote $(1/1-f)=l$.
$\mathrm{CS}(S)$	Customer's surplus, which is a function of government subsidies
$\mathrm{SW}(S)$	Social welfare, which is a function of government subsidies
$E(\pi_r)$	Expected profit of the food processor during the whole sales cycle
$E(\pi_s)$	Expected profit of the supplier during the whole sales cycle
$U(\pi_r)$	Expected utility of the risk-averse processor during the whole sales cycle

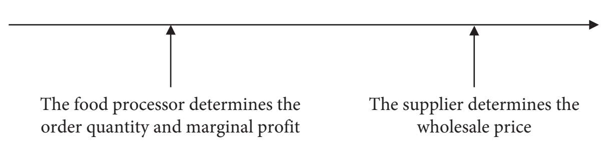

Figure 1: The decision sequence of supply chain members without safety investment.

As $(\partial^2 E(\pi_{s11})/\partial w_{11}^2) = -2l$, the expected profit function of the supplier is concave.

The food processor's expected profit is

$$E(\pi_{r11}) = (w_{11} + m_{11} - w_{11} l) D_{11}. \quad (3)$$

The conditional variance of the profit is

$$\mathrm{Var}(\pi_{r11}) = \beta^2 (w_{11} + m_{11} - w_{11} l)^2 \sigma_1^2, \quad (4)$$

and the food processor's utility can be defined as

$$\max_{m_{11}} U(\pi_{r11}) = (w_{11} + m_{11} - w_{11} l) D_{11} - \frac{k}{2}\beta^2 (w_{11} + m_{11} - w_{11} l)^2 \sigma_1^2. \quad (5)$$

Substituting $w_{11}^*(m_{11})$ into (5), by letting $(\partial U(\pi_{r11})/\partial m_{11}) = 0$, we can obtain

$$m_{11} = \frac{2(-c + l(1 + s\beta)) + k(l^2 - 1)\beta^2 (1 + c + s\beta)\sigma_1^2}{(1 + l)(2 + k(1 + l)\beta^2 \sigma_1^2)}. \quad (6)$$

As $(\partial^2 U(\pi_{r11})/\partial m_{11}^2) = -(1/4)(1 + l)(2 + k(1 + l)\beta^2 \sigma_1^2) < 0$, the expected utility function of the food processor is concave.

Substituting (6) into (2), we can obtain

$$w_{11} = \frac{(1 + c(2 + l) + s\beta) + k(1 + l)\beta^2 (1 + c + s\beta)\sigma_1^2}{(1 + l)(2 + k(1 + l)\beta^2 \sigma_1^2)}. \quad (7)$$

Combing (6) and (7), we can get the optimal decisions as shown in Table 2.

Case 2. Demand-based payment.

The deterioration cost $c(Q_{12} - D_{12})$ is undertaken by the processor and the supplier together; particularly, when $r = 0$, the food processor will take on all deterioration costs, and when $r = 1$, the supplier will take on all deterioration costs. The supplier's expected profit can be represented by

$$\max_{w_{12}} E(\pi_{s12}) = (w_{12} - c) D_{12} - rc(Q_{12} - D_{12}). \quad (8)$$

As $(\partial^2 E(\pi_{s12})/\partial w_{12}^2) = -2$, the expected profit function of the supplier is concave.

The food processor's utility can be defined as

$$\max_{m_{12}} U(\pi_{r12}) = m_{12} D_{12} - (1 - r)c(Q_{12} - D_{12}) - \frac{k}{2}\beta^2 (m_{12} - c(l - 1)(1 - r))^2 \sigma_1^2. \quad (9)$$

Table 2: The optimal decisions when the government does not provide subsidies.

	Order quantity-based payment $(j = 1)$	Demand-based payment $(j = 2)$
p_{1j}	$((1 + 2l + cl + s\beta + 2ls\beta) + kl(1 + l)\beta^2 (1 + c + s\beta)\sigma_1^2/(1 + l)(2 + k(1 + l)\beta^2\sigma_1^2))$	$(1/4)(2(1 + cl + s\beta) + (1 - cl + s\beta/1 + k\beta^2\sigma_1^2))$
w_{1j}	$((1 + c(2 + l) + s\beta) + k(1 + l)\beta^2 (1 + c + s\beta)\sigma_1^2/(1 + l)(2 + k(1 + l)\beta^2\sigma_1^2))$	$(1 + c(2 - l - 2(1 - l)r) + s\beta/2) - ((1 - cl + s\beta)/4(1 + k\beta^2\sigma_1^2))$
m_{1j}	$(2(-c + l(1 + s\beta)) + k(l^2 - 1)\beta^2 (1 + c + s\beta)\sigma_1^2/(1 + l)(2 + k(1 + l)\beta^2\sigma_1^2))$	$c(l - 1)(1 - r) + (1 - cl + s\beta/2 + 2k\beta^2\sigma_1^2)$
Q_{1j}	$((1 - cl + s\beta)l(1 + k(1 + l)\beta^2\sigma_1^2)/(1 + l)(2 + k(1 + l)\beta^2\sigma_1^2))$	$((1 - cl + s\beta)l(1 + 2k\beta^2\sigma_1^2)/4(1 + k\beta^2\sigma_1^2))$
$E(\pi_{s1j})$	$(l(1 - cl + s\beta)^2 (1 + k(1 + l)\beta^2\sigma_1^2)^2/(1 + l)^2 (2 + k(1 + l)\beta^2\sigma_1^2)^2)$	$((1 - cl + s\beta)^2 (1 + 2k\beta^2\sigma_1^2)^2/16(1 + k\beta^2\sigma_1^2)^2)$
$E(\pi_{r1j})$	$((1 - cl + s\beta)^2 (1 + k(1 + l)\beta^2\sigma_1^2)/(1 + l)(2 + k(1 + l)\beta^2\sigma_1^2)^2)$	$((1 - cl + s\beta)^2 (1 + 2k\beta^2\sigma_1^2)/((1 + k\beta^2\sigma_1^2)^2)$
$U(\pi_{r1j})$	$((1 - cl + s\beta)^2/2(1 + l)(2 + k(1 + l)\beta^2\sigma_1^2))$	$((1 - cl + s\beta)^2/8(1 + k\beta^2\sigma_1^2))$

As $(\partial^2 U(\pi_{r12})/\partial m_{12}^2) = -1 - k\beta^2\sigma_1^2 < 0$, the expected utility function of the food processor is concave.

Similarly, we can get the optimal decisions as shown in Table 2.

Proposition 1. *When the risk-averse food processor does not adopt safety investment,*

(i) *The selling price and the expected utility of the food processor decrease with k.*

(ii) *The wholesale price and the expected utility of the supplier increase with k.*

All proofs are given in the Appendix.

Proposition 1 shows that the risk-averse food processor is inclined to lower the selling price, leading to a lower utility. Meanwhile, the food processor's expected utility will be weakened. We find that the suppliers can benefit from the risk aversion of the food processor. This can be explained by the fact that a lower selling price leads to more demands, and thus the food processor tends to order more products from the supplier. The supplier will increase the wholesale price with the increase of customer demands. Therefore, the supplier will obtain more profits due to a higher wholesale price and more customer demands.

Proposition 2. *When the risk-averse food processor does not adopt safety investment, the food processor can obtain more demands and higher utility under the mode of demand-based payment.*

Proposition 2 shows that when the risk-averse food processor does not adopt safety investment, the customer demand is higher under the mode of demand-based payment. However, the supplier will benefit from the demand-based payment only when $(1+l)(1+2k\sigma_1^2\beta^2)(2+k\sigma_1^2\beta^2(1+l)) > 4\sqrt{l}(1+k\sigma_1^2\beta^2)(1+k\sigma_1^2\beta^2(1+l))$. Particularly, the food processor will be risk-neutral when $k=0$, and the supplier here will always benefit from the demand-based payment.

3.3.2. The Optimal Solutions with Subsidy. When the food processor adopts additional safety investment, the average perceived quality of the product changes from s to q, and the cost is $(\lambda/2)(q-s)^2$. The actual perceived quality of the product satisfies $s_q = q + \varepsilon_2$, and the government here subsidizes the food processor Sq in total. The decision here follows a three-stage process, in which the government acts as the leader and decides the subsidy S, the food processor then determines the marginal profit m and the safety investment q, and the supplier finally decides the wholesale price w. The decision sequence is shown in Figure 2. Using the backwards induction, we first assume that the subsidy, the marginal profit, and safety investment are known, and the supplier determines the optimal wholesale price by profit maximization. Then, the food processor determines the optimal marginal profit and safety investment by utility maximization. Finally, the government determines the optimal subsidy based on social welfare maximization.

Case 3. Order quantity-based payment.

The food processor's expected order quantity is $(1+\beta q_{21} - p_{21})l$, and the actual customer demand is $(1+\beta q_{21} - p_{21})$. The quantity of deteriorating products is $(1+\beta q_{21} - p_{21})(l-1)$. Since the food processor pays the supplier based on the order quantity, the supplier's expected profit can be represented by

$$\max_{w_{21}} E(\pi_{s21}) = (w_{21} - c)(1+\beta q_{21} - p_{21})l. \tag{10}$$

Letting $(\partial E(\pi_{s21})/\partial w_{21}) = 0$, we get

$$w_{21}^*(m_{21}) = \frac{1 + c - m_{21} + q_{21}\beta}{2}. \tag{11}$$

As $(\partial^2 E(\pi_{s21})/\partial w_{21}^2) = -2l$, the expected profit function of the supplier is concave.

The food processor's expected profit can be represented by

$$E(\pi_{r21}) = (w_{21} + m_{21} - w_{21}l)D_{21} + S_{21}q_{21} - \frac{\lambda}{2}(q_{21} - s)^2. \tag{12}$$

The conditional variance of the profit is

$$\mathrm{Var}(\pi_{r21}) = \beta^2 (w_{21} + m_{21} - w_{21}l)^2 \sigma_2^2, \tag{13}$$

and the food processor's utility can be defined as

$$U(\pi_{r21}) = (w_{21} + m_{21} - w_{21}l)D_{21} + S_{21}q_{21} - \frac{\lambda}{2}(q_{21} - s)^2 - \frac{k}{2}\beta^2 (w_{21} + m_{21} - w_{21}l)^2 \sigma_2^2. \tag{14}$$

As $(\partial^2 U(\pi_{r21}))/(\partial m_{21}^2) = -(1/4)(1+l)(2+k(1+l)\beta^2\sigma_2^2) < 0$, $(\partial^2 U(\pi_{r21}))/(\partial q_{21}^2) = (1/4)(2(1-l)\beta^2 - 4\lambda - k(-1+l)^2\beta^4\sigma_2^2) < 0$, $(\partial^2 U(\pi_{r21}))/(\partial m_{21}\partial q_{21}) = (1/4)(2l\beta + k(-1+l^2)\beta^3\sigma_2^2)$, we get $(\partial^2 U(\pi_{r21}))/(\partial m_{21}^2)(\partial^2 U(\pi_{r21}))/(\partial q_{21}^2) - (\partial^2 U(\pi_{r21}))/(\partial m_{21}\partial q_{21})^2 = (1/4)(-\beta^2 + 2(1+l)\lambda + k(1+l)^2\beta^2\lambda\sigma_2^2) > 0$. Therefore, when $1/4(-\beta^2 + 2(1+l)\lambda + k(1+l)^2\beta^2\lambda\sigma_2^2) > 0$, the expected utility function of the food processor is concave.

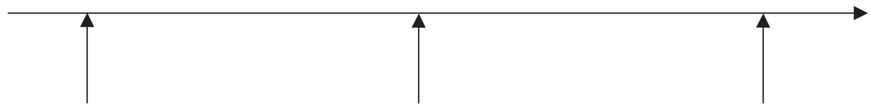

FIGURE 2: The decision sequence of supply chain members with safety investment.

Substituting $w_{21}^{*}(m_{21})$ into (14), by letting $(\partial U(\pi_{r21})/\partial m_{21}) = (\partial U(\pi_{r21})/\partial q_{21}) = 0$, we can obtain

$$m_{21} = \frac{\left(\left(l\beta(2S_{21} - c\beta) + 2l(1 + s\beta)\lambda + c\left(\beta^2 - 2\lambda\right)\right) + k\left(l^2 - 1\right)\beta^2\left(S_{21}\beta + (1 + c + s\beta)\lambda\right)\sigma_2^2\right)}{\left(2(1 + l)\lambda + \beta^2\left(k(1 + l)^2\lambda\sigma_2^2 - 1\right)\right)}, \tag{15}$$

$$q_{21} = \frac{\left(2(1 + l)S_{21} - cl\beta + 2(1 + l)s\lambda\right) + \beta\left(1 + k(1 + l)^2\beta\left(S_{21} + s\lambda\right)\sigma_2^2\right)}{2(1 + l)\lambda + \beta^2\left(k(1 + l)^2\lambda\sigma_2^2 - 1\right)}. \tag{16}$$

Substituting (15) and (16) into (11), we can obtain

$$w_{21} = \frac{(1 + c(2 + l) + s\beta) + k(1 + l)\beta^2(1 + c + s\beta)\sigma_2^2}{(1 + l)\left(2 + k(1 + l)\beta^2\sigma_2^2\right)}. \tag{17}$$

Combing (15), (16), and (17), we can get the optimal decisions as shown in Table 3.

Case 4. Demand-based payment.

The quantity of deteriorating products is $(1 + \beta q_{22} - p_{22})(l - 1)$. The deterioration cost $c(Q_{22} - D_{22})$ is undertaken by the processor and the supplier together; particularly, when $r = 0$, the food processor will take on all deterioration costs, and when $r = 1$, the supplier will take on all deterioration costs. The supplier's expected profit can be represented by

$$\begin{aligned}\max_{w_{22}} E(\pi_{s22}) &= (w_{22} - c)D_{22} - rc(Q_{22} - D_{22}) \\ &= (w_{22} - c - rc(l - 1)) \\ &\quad \cdot (1 + \beta q_{22} - (w_{22} + m_{22})).\end{aligned} \tag{18}$$

As $(\partial^2 E(\pi_{s22})/\partial w_{22}^2) = -2l$, the expected profit function of the supplier is concave.

The food processor's utility can be defined as

$$\begin{aligned}\max_{q_{22},m_{22}} U(\pi_{r22}) = {} & m_{22}D_{22} - (1 - r)c(Q_{22} - D_{22}) + S_{22}q_{22} \\ & - \frac{\lambda}{2}(q_{22} - s)^2 - \frac{k}{2}\beta^2 \\ & \cdot (m_{22} - c(l - 1)(1 - r))^2\sigma_2^2.\end{aligned} \tag{19}$$

As $(\partial^2 U(\pi_{r22}))/(\partial m_{22}^2) = -1 - k\beta^2\sigma_2^2 < 0$, $(\partial^2 U(\pi_{r22})/\partial q_{22}^2) = -\lambda < 0$, $(\partial^2 U(\pi_{r22}))/(\partial m_{22}\partial q_{22}) = \beta/2$, we get $(\partial^2 U(\pi_{r22}))/(\partial m_{22}^2)(\partial^2 U(\pi_{r22})/\partial q_{22}^2) - (\partial^2 U(\pi_{r22}))/(\partial m_{22}\partial q_{22})^2 = -(\beta^2/4) + \lambda + k\beta^2\lambda\sigma_2^2 > 0$, the expected utility function of the food processor is concave. Therefore, to ensure the joint concavity of expected utility function of the food processor on (m_{21}, q_{21}), (m_{22}, q_{22}), $\lambda > (\beta^2/4(1 + k\beta^2\sigma_2^2))$ is needed.

Proposition 3. *When the risk-averse food processor adopts safety investment strategy, if the subsidy is fixed* $(S_{21} = S_{22})$,

(i) The safety investment, the selling price, and the utility of the food processor decrease with k.

(ii) If the food processor pays the supplier based on the order quantity, and if the customer's quality sensitivity $\beta < (>)\sqrt{(1 + l)\lambda}$, *the wholesale price and the expected profit of the supplier increase (decrease) with k.*

(iii) If the food processor pays the supplier based on the customer demand, and if the customer's quality sensitivity $\beta < (>)\sqrt{2\lambda}$, *the wholesale price and the expected profit of the supplier increase (decrease) with k.*

Proposition 3 shows that risk aversion discourages retailers from adopting safety investment strategy. Meanwhile, the food processor will reduce the selling price, resulting in a lower expected utility. When the customers are less sensitive to the perceived quality, e.g., $\beta < \sqrt{(1 + l)\lambda}$ under the method of order quantity-based payment or $\beta < \sqrt{2\lambda}$ under the method of demand-based payment, the suppliers still benefits from the food processor's risk aversion behavior. When the customers are more sensitive to the perceived quality, the safety investment will decrease with the risk aversion indicator, weakening customer demands seriously. The supplier tends to reduce the wholesale price to mitigate the decrease of customer demands, but it still leads to profit loss.

Table 3: The optimal decisions when the government provides subsidies.

	Order quantity-based payment $(j = 1)$	Demand-based payment $(j = 2)$
p_{2j}	$\left(\left(\begin{array}{c}(\beta(S_{21} + 2lS_{21} - cl\beta) + cl\lambda + (1 + 2l)(1 + s\beta)\lambda) \\ +kl(1 + l)\beta^2(S_{21}\beta + (1 + c + s\beta)\lambda)\sigma_2^2\end{array}\right)/(2(1 + l)\lambda + \beta^2(k(1 + l)^2\lambda\sigma_2^2 - 1))\right)$	$\left(\left(\begin{array}{c}(3S_{22}\beta + 3(1 + s\beta)\lambda + cl(-\beta^2 + \lambda)) \\ +2k\beta^2(S_{22}\beta + (1 + cl + s\beta)\lambda)\sigma_2^2\end{array}\right)/4\lambda + \beta^2(4k\lambda\sigma_2^2 - 1)\right)$
w_{2j}	$\left(\left(\begin{array}{c}\beta(S_{21} - c\beta) + (1 + c(2 + l) + s\beta)\lambda \\ +k(1 + l)\beta^2(S_{21}\beta + (1 + c + s\beta)\lambda)\sigma_2^2\end{array}\right)/(2(1 + l)\lambda + \beta^2(k(1 + l)^2\lambda\sigma_2^2 - 1))\right)$	$\left(\left(\begin{array}{c}2k\beta^2(S_{22}\beta + (1 + c(2 - l + 2(l - 1)r) + s\beta)\lambda)\sigma_2^2 \\ +(1 + c(4 - l + 4(l - 1)r) + s\beta)\lambda + \beta(S_{22} + c(r - 1 - lr)\beta)\end{array}\right)/(4\lambda + \beta^2(4k\lambda\sigma_2^2 - 1))\right)$
m_{2j}	$\left(\left(\begin{array}{c}(l\beta(2S_{21} - c\beta) + 2l(1 + s\beta)\lambda + c(\beta^2 - 2\lambda)) \\ +k(l^2 - 1)\beta^2(S_{21}\beta + (1 + c + s\beta)\lambda)\sigma_2^2\end{array}\right)/(2(1 + l)\lambda + \beta^2(k(1 + l)^2\lambda\sigma_2^2 - 1))\right)$	$-c(1 - l)(1 - r) + (2S_{22}\beta + 2(1 - cl + s\beta)\lambda/4\lambda + \beta^2(4k\lambda\sigma_2^2 - 1))$
q_{2j}	$((2(1 + l)S_{21} - cl\beta + 2(1 + l)s\lambda) + \beta(1 + k(1 + l)^2\beta(S_{21} + s\lambda)\sigma_2^2)/2(1 + l)\lambda + \beta^2(k(1 + l)^2\lambda\sigma_2^2 - 1))$	$((4S_{22} - cl\beta + 4s\lambda) + \beta(1 + 4k\beta(S_{22} + s\lambda)\sigma_2^2)/4\lambda + \beta^2(4k\lambda\sigma_2^2 - 1))$
Q_{2j}	$((S_{21}\beta + (1 - cl + s\beta)\lambda)l(1 + k(1 + l)\beta^2\sigma_2^2)/2(1 + l)\lambda + \beta^2(k(1 + l)^2\lambda\sigma_2^2 - 1))$	$((S_{22}\beta + (1 - cl + s\beta)\lambda)l(1 + 2k\beta^2\sigma_2^2)/4\lambda + \beta^2(4k\lambda\sigma_2^2 - 1))$
$E(\pi_{s2j})$	$(l(S_{21}\beta + (1 - cl + s\beta)\lambda)^2(1 + k(1 + l)\beta^2\sigma_2^2)^2/(2(1 + l)\lambda + \beta^2(k(1 + l)^2\lambda\sigma_2^2 - 1))^2)$	$((S_{22}\beta + (1 - cl + s\beta)\lambda)^2(1 + 2k\beta^2\sigma_2^2)^2/(4\lambda + \beta^2(4k\lambda\sigma_2^2 - 1))^2)$
$U(\pi_{r2j})$	$\left(\left(\begin{array}{c}2S_{21}(S_{21} + lS_{21} - cl\beta) + \lambda + c^2l^2\lambda \\ -2(cl - 2(1 + l)sS_{21} + cls\beta)\lambda + 2\beta(S_{21} + s\lambda) \\ +\beta^2(s^2\lambda + k(1 + l)^2S_{21}(S_{21} + 2s\lambda)\sigma_2^2)\end{array}\right)/2(2(1 + l)\lambda + \beta^2(k(1 + l)^2\lambda\sigma_2^2 - 1))\right)$	$\left(\left(\begin{array}{c}\lambda + c^2l^2\lambda + 2\beta(S_{22} + s\lambda) \\ -2(-2S_{22}^2 + cl(1 + s\beta)\lambda + S_{22}(cl\beta - 4s\lambda)) \\ +\beta^2(s^2\lambda + 4kS_{22}(S_{22} + 2s\lambda)\sigma_2^2)\end{array}\right)/8\lambda + \beta^2(8k\lambda\sigma_2^2 - 2)\right)$

Proposition 4. *When the government subsidy is fixed ($S_{21} = S_{22} = S$), if the food processor pays the supplier based on the customer demand, the food processor will invest in more safety efforts and obtain more demands and higher utility.*

Proposition 4 shows that when the subsidy is fixed, if the food processor pays the supplier based on the demand and the supplier shares a portion of the deterioration costs, the food processor will benefit from investing in more safety efforts. However, the supplier will benefit from the demand-based payment only when $(1+l)(1+2k\sigma_2^2\beta^2)(2+(1+l)k\sigma_2^2\beta^2) > 4\sqrt{l}(1+k\sigma_2^2\beta^2)(1+(1+l)k\sigma_2^2\beta^2)$. Particularly, the food processor will be risk-neutral when $k = 0$, and the supplier will always benefit from the demand-based payment.

The above analysis is based on the fixed government subsidy. Using the backwards induction, the government finally decides the optimal subsidy by maximizing social welfare. The social welfare function $CS(S)$ constructed in this paper consists of the following parts:

(1) Customer surplus, $CS(S)$: as commonly defined in the literature (e.g., [45, 46]), we obtain the function of customer surplus as follows:

$$E(CS) = E\left(\int_{p-\beta s_q}^{1}\left(v+\beta s_q - p\right)f(v)\mathrm{d}v\right) = \frac{\left(1-p+\beta s_q\right)^2}{2}. \tag{20}$$

(2) Supplier chain's profit: it is calculated as follows:

$$E(\pi_{sc2i}) = (p_{2i} - cl)D_{2i} + S_{2i}q_{2i} - \frac{\lambda}{2}(q_{2i} - s)^2. \tag{21}$$

(3) Subsidy expense.

Combining components (1), (2), and (3), the total social welfare in case 3 and case 4 for a given S_{2j} is

$$\max_{S_{2j}} SW_{2j} = \left(p_{2j} - cl\right)\left(1 - p_{2j} + \beta q_{2j}\right) + \frac{\left(1 - p_{2j} + \beta q_{2j}\right)^2}{2} - \frac{\lambda}{2}\left(q_{2j} - s\right)^2. \tag{22}$$

The problem to be solved by the government (Stackelberg leader) is to determine the subsidy S_{2j} that would maximize the total social welfare; finally, we can obtain the optimal subsidy as shown in Proposition 5.

Proposition 5. *When the food processor is risk-averse, the government's optimal subsidy under different payment modes can be expressed as*

(i) If the food processor pays the food supplier based on the order quantity and if $\lambda > \max\{(\beta^2(3+4l+k(1+l)\beta^2\sigma_2^2(4+6l+k(1+l)(1+2l)\beta^2\sigma_2^2))/(1+l)^2(2+k(1+l)\beta^2\sigma_2^2)^2), \lambda > (\beta^2/4(1+k\beta^2\sigma_2^2))\}$, $S_{21} = (\beta(1-cl+s\beta)\lambda(-(1+2l)-k(1+l)(3+5l)\beta^2\sigma_2^2 - k^2(1+l)^2(1+2l)\beta^4\sigma_2^4)/(k^2(1+l)^2(1+2l)\beta^6\sigma_2^4 - 4(1+l)^2\lambda + \beta^2(3+4l-4k(1+l)^3\lambda\sigma_2^2) + k\beta^4\sigma_2^2(2(1+l)(2+3l) - k(1+l)^4\lambda\sigma_2^2)))$.

(ii) If the food processor pays the food supplier based on the demand and if $\lambda > \max\{(\beta^2(1+2k\beta^2\sigma_2^2)(7+6k\beta^2\sigma_2^2)/16(1+k\beta^2\sigma_2^2)^2), \lambda > (\beta^2/4(1+k\beta^2\sigma_2^2))\}$, $S_{22} = (\beta(1-cl+s\beta)\lambda(3+16k\beta^2\sigma_2^2+12k^2\beta^4\sigma_2^4)/(16\lambda - 12k^2\beta^6\sigma_2^4 + 4k\beta^4\sigma_2^2(4k\lambda\sigma_2^2 - 5) + \beta^2(32k\lambda\sigma_2^2 - 7)))$.

Proposition 5 shows that only when the safety investment cost is large, the government will provide subsidies. In order to further analyze the influence of other parameters on the decision of government subsidy, this paper further assumes $k = 0.3$, $\beta = 0.6$, $\sigma_2^2 = 1$, $\lambda = 0.5$, $s = 0.5$, and $c = 0.1$ in Figure 3(a) to study the effect of deterioration coefficient on the decision of government subsidy. It assumes $l = 1.1$, $\beta = 0.6$, $\sigma_2^2 = 1$, $\lambda = 0.5$, $s = 0.5$, and $c = 0.1$ in Figure 3(b) to study the effect of the risk aversion indicator on the decision of government subsidy.

To ensure $\lambda > (\beta^2/4(1+k\beta^2\sigma_2^2))$, $\lambda > 0.0812$ and $\lambda > (0.09/1+0.36k)$ are needed in Figures 3(a) and 3(b), respectively. Figure 3(a) is divided into regions (A), (B), and (C), and Figure 3(b) is divided into regions (A), (B), (C), and (D). The regions where the government can maximize social welfare by providing subsidies under order quantity-based payment are (B) and (C), and that under demand-based payment is (C). Figures 3(a) and 3(b) show that the government is more inclined to provide subsidies under order quantity-based payment. The government does not provide subsidies in regions (A) and (D). Figure 3(a) shows that when λ is very small, the government does not provide subsidies under two methods; when l and λ are both relatively small, the government does not provide subsidies under the mode of order quantity-based payment; the decision of subsidies is not affected by l under the method of demand-based payment. Figure 3(b) shows that when λ is very small or when k is greater than a threshold and λ is relatively small, the government does not provide subsidies. This implies that although the subsidy increases with k (see Proposition 6 (i)), a too high-risk aversion indicator will discourage the government from providing subsidies.

Proposition 6. *When the government decides the subsidy,*

(i) The subsidy increases with k.

(ii) The safety investment increases with k.

(iii) The supplier's profit increases with k.

(iv) The customer demand will be higher if the food processor pays the supplier based on the demand.

Proposition 6 shows that when the government decides the subsidy, in order to encourage the risk-averse food processors to invest in more efforts, the optimal subsidy

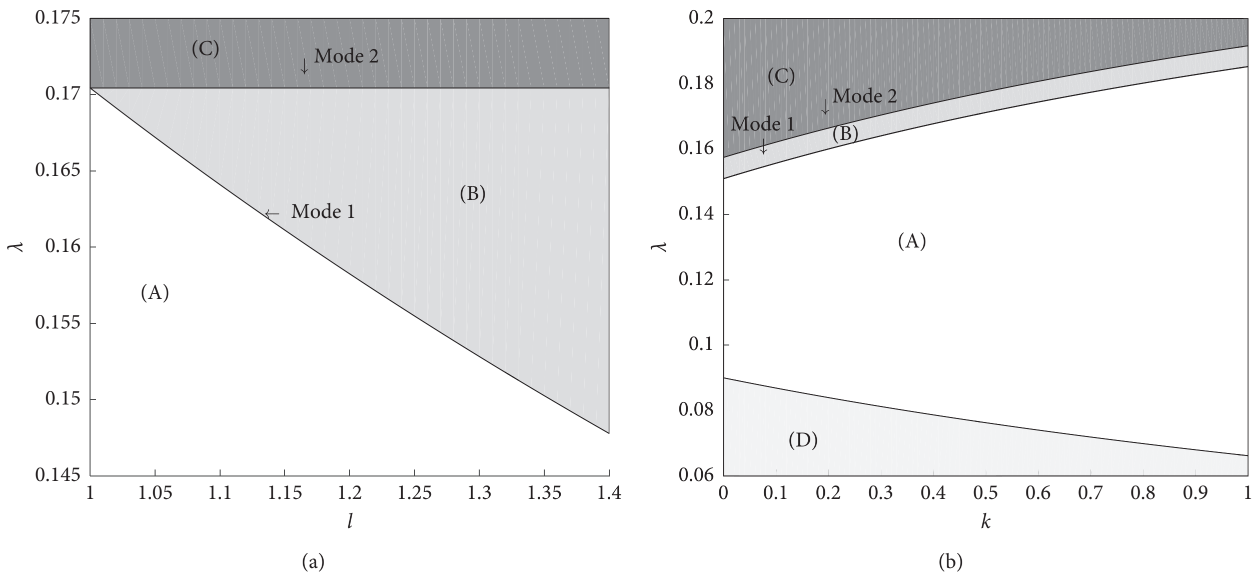

Figure 3: (a) The government decision on the subsidy as l changes. (b) The government decision on the subsidy as k changes.

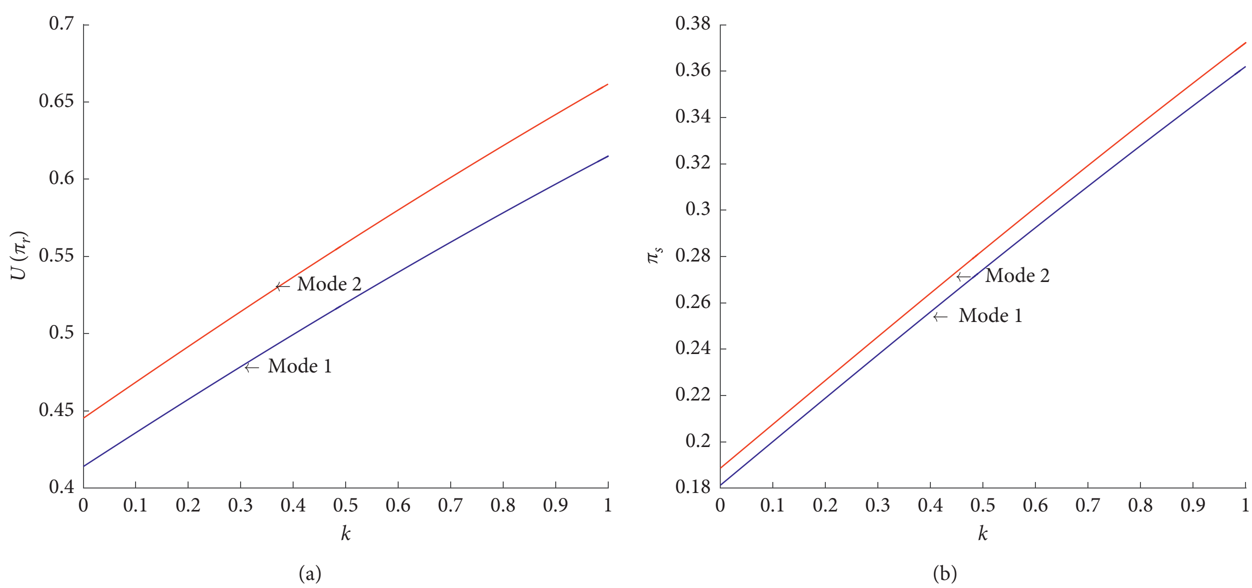

Figure 4: (a) The food processor's utility as k changes. (b) The supplier's profit as k changes.

increases with the food processor's risk aversion indicator. Different from Proposition 3, the supplier here always benefits from the food processor's risk-averse behavior. This can be explained by the fact that the subsidy here can increase the wholesale price and the demand; therefore, Proposition 6 shows that the supplier's profit always increases with k. Combining Proposition 2, Proposition 4, and Proposition 6 (iv), it can be concluded that the customer demand will increase under the method of demand-based payment. Therefore, from the perspective of increasing market share, it is necessary for suppliers to share a part of the food processor's deterioration costs.

4. Numerical Simulation

This part makes numerical experiments to analyze the effects of the food processor's risk aversion coefficient, deterioration coefficient on the food processor's expected utility, the supplier's profit, and the social welfare.

4.1. The Effects of Risk Aversion Coefficient on the Food Processor's Expected Utility and the Supplier's Profit When the Government Provides Subsidies. When we study the impact of the food processor's risk aversion coefficient on the

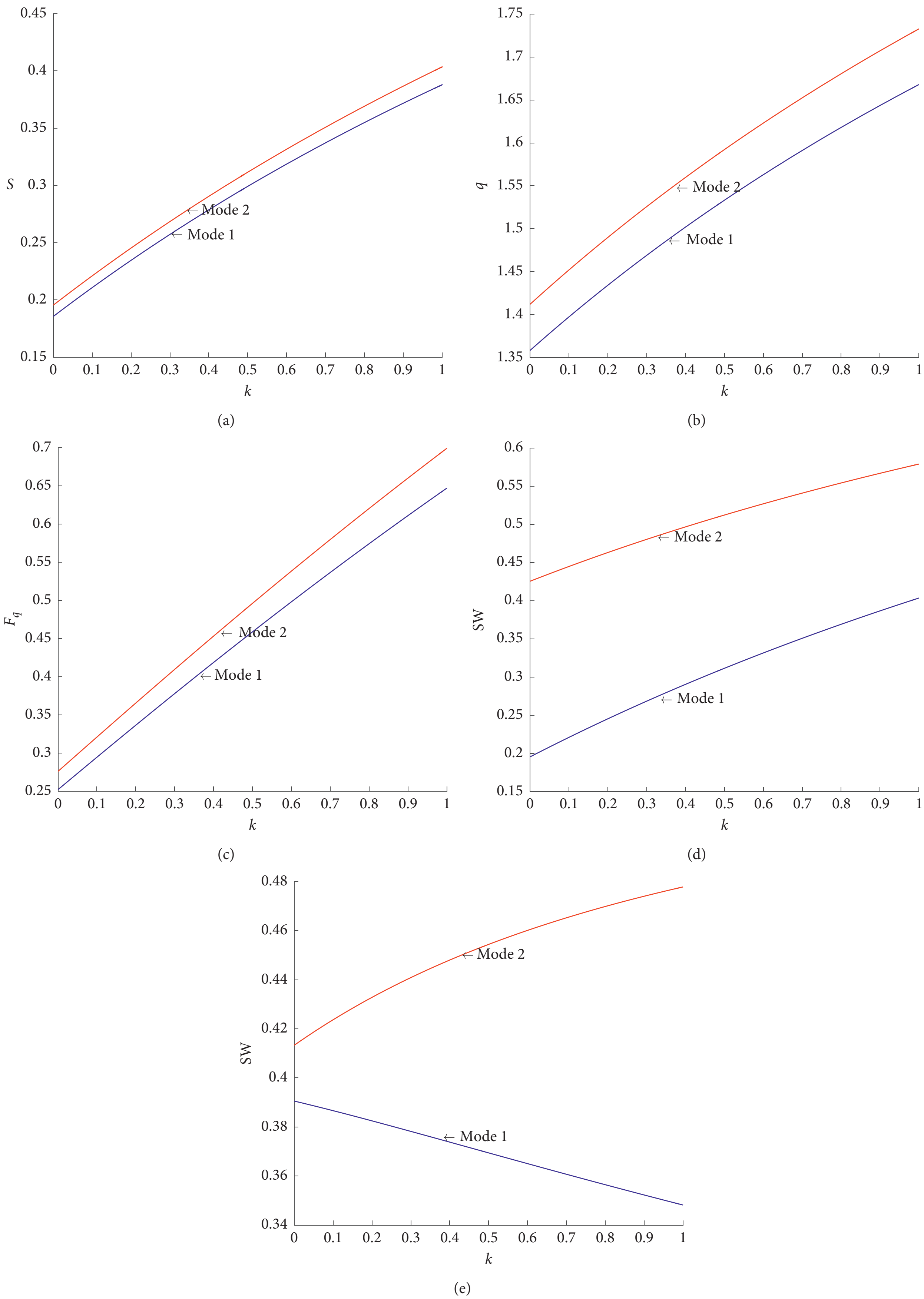

Figure 5: (a) The government subsidy as k changes. (b) The safety investment as k changes. (c) The government expenditure as k changes. (d) The social welfare as k changes when the government decides the subsidy. (e) The social welfare as k changes when $S = 0$.

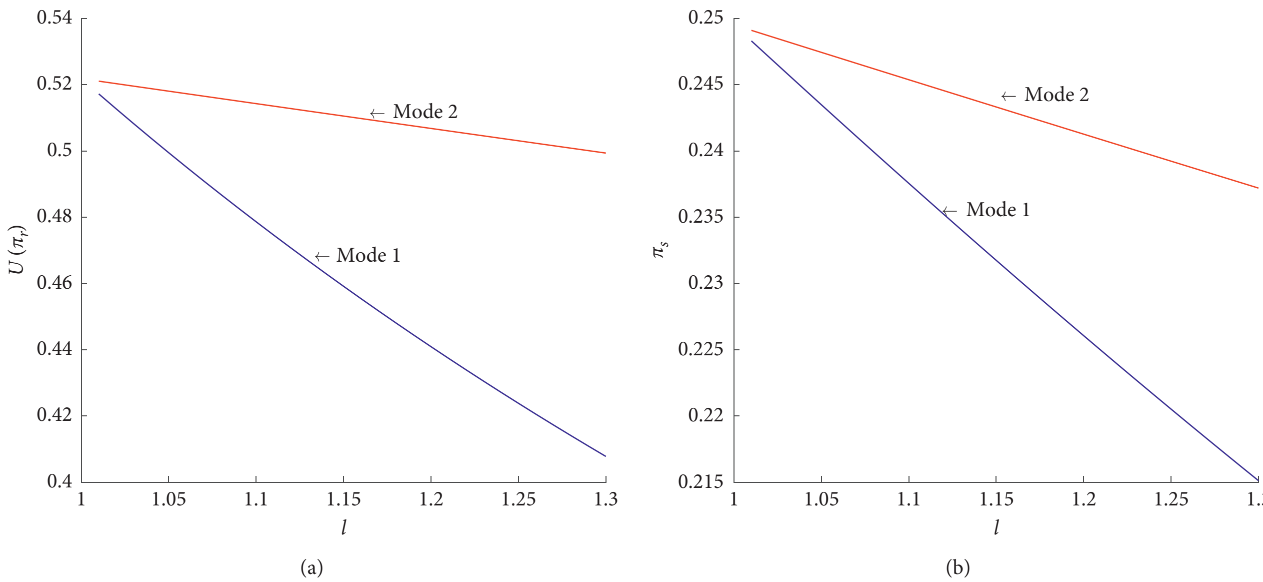

Figure 6: (a) The food processor's utility as l changes. (b) The supplier's profit as l changes.

decisions, we assume that $l = 1.1$, $\beta = 0.6$, $\sigma_2^2 = 1$, $\lambda = 0.5$, $s = 0.5$, and $c = 0.1$.

As can be seen from Figure 4(a), the food processor's utility increases with the risk-averse indicator. This is because the government tends to subsidize the food processor more to encourage the risk-averse food processor to carry out safety investment. Figure 4(a) also shows that the food processor's expected utility under the method of demand-based payment is greater than that under the method of order quantity-based payment. Figure 4(b) shows that the supplier's profit increases with the food processor's risk aversion indicator, which verifies Proposition 6 (iii). Figure 4(b) shows that suppliers can obtain more profits under the method of demand-based payment. Combining Figures 4(a) and 4(b), we find when the government endogenously decides the subsidy, the demand-based payment can improve the supplier's profit and the food processor's utility. When the government provides endogenous subsidy, it is necessary for the food supplier to share a portion of deterioration costs. As the government provides higher subsidy facing a more risk-averse food processor, risk aversion will benefit supply chain members.

4.2. The Effects of Risk Aversion Coefficient on Government Subsidies, Safety Investment, and Social Welfare. Figures 5(a) and 5(b) show that when the government decides the subsidy, as the food processor is more risk-averse, the government will provide higher subsidies. This also encourages food processors to invest in more efforts and obtain more subsidies. As the per-unit subsidy and subsidy quantity (the amount of safety investment) under the method of demand-based payment are higher than those under the method of order quantity-based payment, the total government expenditure under the method of demand-based payment is larger, and Figure 5(c) validates it. Figure 5(d) shows that the demand-based payment can lead to a higher social welfare, and the social welfare increases with k when the government decides the subsidy. When the government does not provide the subsidy, Figure 5(e) shows that the social welfare decreases with k under the method of order quantity-based payment, whereas the social welfare increases with k under the method of demand-based payment. Comparing Figures 5(d) and 5(e), we find the demand-based payment is beneficial to the social welfare no matter whether the government provides subsidies or not. When the government does not provide subsidies, it is necessary for the food processor to reduce risk aversion under the mode of order quantity-based payment from the perspective of social welfare. However, if two members adopt demand-based payment, risk aversion will benefit social welfare.

4.3. The Effects of Deterioration Coefficient on the Food Processor's Expected Utility and the Supplier's Profit When the Government Provides Subsidies. When we study the effects of deterioration coefficient on the decisions, we assume that $k = 0.3$, $\beta = 0.6$, $\sigma_2^2 = 1$, $\lambda = 0.5$, $s = 0.5$, and $c = 0.1$.

Figures 6(a) and 6(b) show that the demand-based payment is a better method for supply chain members, and the gap between the demand-based payment and the order quantity-based payment increases with l. However, the supplier's profit and the food processor's utility will decrease with l.

4.4. The Effects of Deterioration Coefficient on Government Subsidies, Safety Investment, and Social Welfare When the Government Provides Subsidies. As shown in Figure 7(a), the unit government subsidy decreases as l increases, discouraging food processors from investing in safety investment

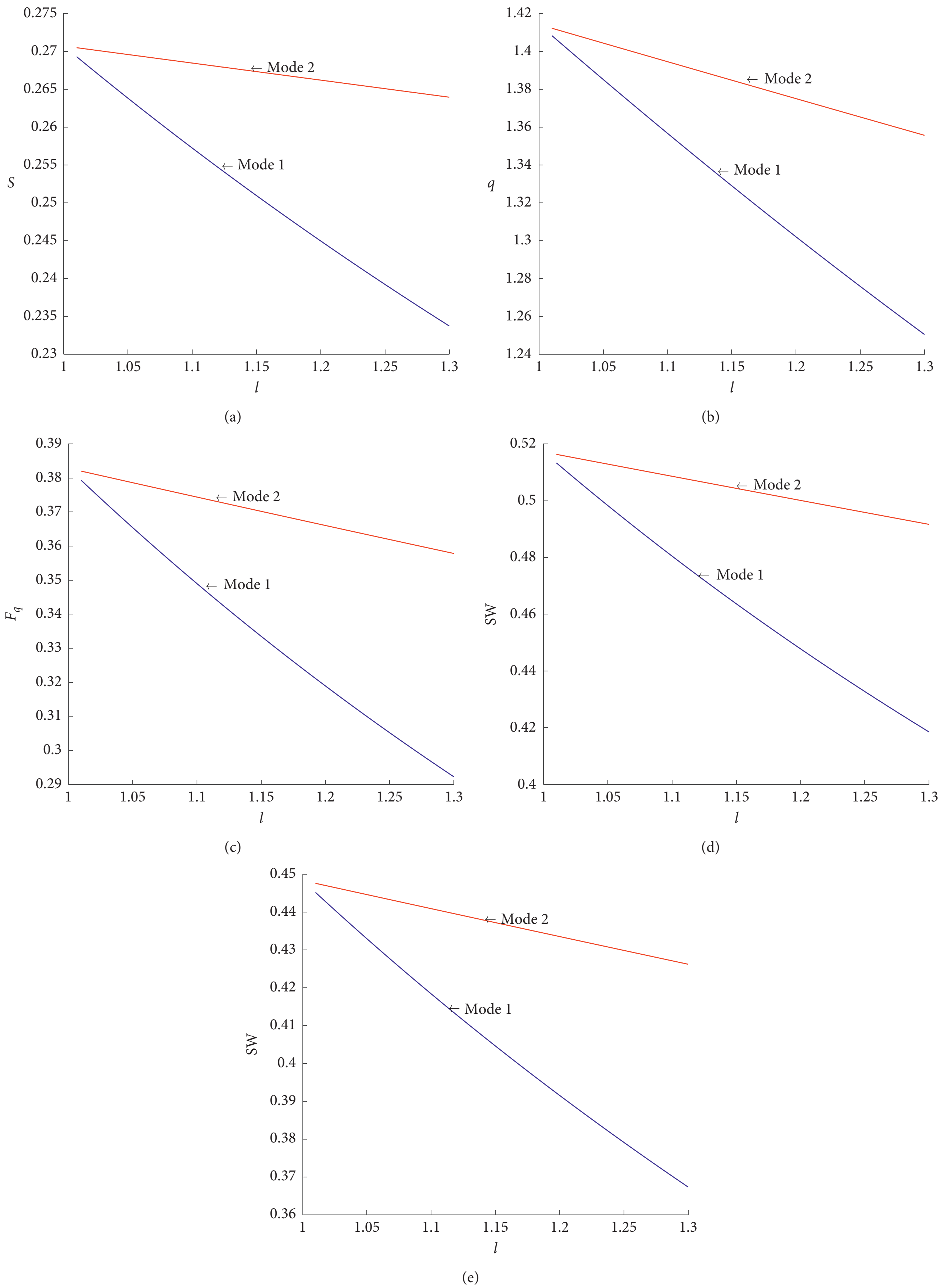

Figure 7: (a) The unit government subsidy as l changes. (b) The safety investment as l changes. (c) The government expenditure as l changes. (d) The social welfare as l changes when the government decides the subsidy. (e) The social welfare as l changes when $S = 0$.

efforts. Figures 7(a) and 7(b) show that the per-unit subsidy and subsidy quantity both decrease with l, and thus Figure 7(c) finally shows that the overall government expenditure will decrease with l. Figure 7(d) shows that the demand-based payment can lead to a higher social welfare, and the social welfare decreases with l when the government decides the subsidy. Figures 7(d) and 7(e) also show that the demand-based payment is beneficial to the social welfare. Combing Sections 4.3 and 4.4, it is essential for food supply chain members to reduce the deterioration coefficient. As the deterioration coefficient is larger, it is necessary for the members to adopt demand-based payment to obtain higher profit or utility.

5. Conclusion

5.1. Summary of Findings. This paper studies the food supply chain where the food processor is the leader of the channel and processes the food which intrinsically attributes as nutritive, organoleptic, or other biochemical and biophysical characteristic values are unknown to the customers. Thus, the demand will depend on the customer's perception quality, which is uncertain for the food processor; however, the food processor can adopt safety investment to improve the customers' belief towards quality. The government as the leader in the three-stage game provides the food processor subsidies to raise the demand for safe food. Meanwhile, this paper compares the order quantity-based payment and the demand-based payment to discover the effects of payment methods on customer demands, the supplier's profit, and the food processor's utility. This paper also studies four cases based on different government subsidies and payment methods and determines the optimal wholesale price, marginal profit, safety investment, and government subsidies.

The main findings of this paper are as follows. (1) Suppliers can increase customer demands by sharing parts of the deterioration costs, but the demand-based payment is not always beneficial to supply chain members. (2) To encourage the risk-averse food processor to adopt safety investment, the subsidy increases with the food processor's risk-averse coefficient. The supplier's profit increases with the retailer's risk aversion indicator. (3) If the food processor does not adopt safety investment or the government endogenously decides the subsidy, the supplier's profit will increase with the retailer's risk aversion indicator. If the food processor adopts safety investment and the government does not decide subsidies, i.e., the subsidy is fixed at value, when the customer is relatively quality-sensitive, the supplier's profits will decrease with the food processor's risk aversion indicator.

5.2. Management Implications. In accordance with the conclusions of this research, the following suggestions are offered to the government and supply chain members. (1) Government subsidies can encourage the risk-averse processors to invest more in safety and improve the social welfare. When the cost coefficient of safety efforts is greater than a threshold, the government can maximize the social welfare by providing processing subsidies. (2) If the government does not provide subsidies, the processor should reduce risk aversion to improve utility. However, if the government decides the subsidy level aimed at social welfare maximization, the processor's utility will increase with the risk aversion indicator, but the government will increase expenditure. (3) It is necessary for the supplier to share parts of deterioration costs to increase the product demand; however, supply chain members may suffer profit loss.

5.3. Future Studies. Finally, the research detailed within this paper is summarized, along with its limitations, and possible directions for future research are also presented. In future research, one can incorporate the cooperation on safety investment into the model and examine the joint effects of supply chain members' cooperation and government subsidies on the demand for safe food. Since the supplier can improve the quality or safety of the food, we will consider the endogenous initial quality of food by taking the food supplier's safety efforts into account.

Appendix

Proof of Proposition 1

(i) $(\partial p_{11}/\partial k) = -(\beta^2 (1 - cl + s\beta)\sigma_1^2/(2 + k(1 + l)\beta^2\sigma_1^2)^2) < 0$, $(\partial U(\pi_{r11})/\partial k) = -(\beta^2 (1 - cl + s\beta)^2\sigma_1^2/2(2 + k(1 + l)\beta^2\sigma_1^2)^2) < 0$, $(\partial p_{12}/\partial k) = -(\beta^2 (1 - cl + s\beta)\sigma_1^2/4(1 + k\beta^2\sigma_1^2)^2) < 0$, $(\partial U(\pi_{r12})/\partial k) = -(\beta^2 (1 - cl + s\beta)^2 \sigma_1^2/8(1 + k\beta^2\sigma_1^2)^2) < 0$.

(ii) $(\partial w_{11}/\partial k) = (\beta^2 (1 - cl + s\beta)\sigma_1^2/(2 + k(1 + l)\beta^2\sigma_1^2)^2) > 0$, $(\partial E(\pi_{s11})/\partial k) = (2l\beta^2 (1 - cl + s\beta)^2 \sigma_1^2 (1 + k(1 + l)\beta^2\sigma_1^2)/(1 + l)(2 + k(1 + l)\beta^2\sigma_1^2)^3) > 0$, $(\partial w_{12}/\partial k) = (\beta^2 (1 - cl + s\beta)\sigma_1^2/4(1 + k\beta^2\sigma_1^2)^2) > 0$, $(\partial E(\pi_{s12})/\partial k) = (\beta^2 (1 - cl + s\beta)^2\sigma_1^2 (1 + 2k\beta^2\sigma_1^2)/8(1 + k\beta^2\sigma_1^2)^3) > 0$. □

Proof of Proposition 2

$(U(\pi_{r12})/U(\pi_{r11})) = ((1 + l)(2 + k(1 + l)\beta^2\sigma_1^2)/2(2 + 2k\beta^2\sigma_1^2)) > 1$, $Q_{12} - Q_{11} = l(1 - cl + s\beta)((l - 1)(2 + k(3 + l)\beta^2\sigma_1^2 + 2k^2 (1 + l)\beta^4\sigma_1^4)/4(1 + k\beta^2\sigma_1^2)(1 + l)(2 + k(1 + l)\beta^2\sigma_1^2)) > 0$. □

Proof of Proposition 3

(i) $(\partial p_{21}/\partial k) = -((1 + l)\beta^2 (l\beta^2 + (1 + l)\lambda)(S_{21}\beta + (1 - cl + s\beta)\lambda)\sigma_2^2/(2(1 + l)\lambda + \beta^2 (k(1 + l)^2\lambda\sigma_2^2 - 1))^2) < 0$, $(\partial q_{21}/\partial k) = -((1 + l)^2\beta^3 (S_{21}\beta + (1 - cl + s\beta)\lambda)\sigma_2^2/(2(1 + l)\lambda + \beta^2 (k(1 + l)^2\lambda\sigma_2^2 - 1))^2) < 0$, $(\partial U(\pi_{r21})/\partial k) = -((1 + l)^2\beta^2 (S_{21}\beta + (1 - cl + s\beta)\lambda)^2 \sigma_2^2/2(2(1 + l)\lambda + \beta^2 (k(1 + l)^2\lambda\sigma_2^2 - 1))^2) < 0$, $(\partial p_{22}/\partial k) = -(2\beta^2 (\beta^2 + 2\lambda)(S_{22}\beta + (1 - cl + s\beta)\lambda)\sigma_2^2/(4\lambda + \beta^2 (4k\lambda\sigma_2^2 - 1))^2) < 0$, $(\partial q_{22}/\partial k) = -(4\beta^3 (S_{22}\beta + (1 - cl + s\beta)\lambda)\sigma_2^2/(4\lambda + \beta^2 (4k\lambda\sigma_2^2 - 1))^2) < 0$, $(\partial U(\pi_{r22})/\partial k) = -(2\beta^2 (S_{22}\beta + (1 - cl + s\beta)\lambda)^2 \sigma_2^2/(4\lambda + \beta^2 (4k\lambda\sigma_2^2 - 1))^2) < 0$.

(ii) $(\partial w_{21}/\partial k) = ((1+l)\beta^2(-\beta^2+(1+l)\lambda)\ (S_{21}\beta+(1-cl+s\beta)\lambda)\sigma_2^2/(2(1+l)\lambda+\beta^2(k(1+l)^2\lambda\ \sigma_2^2-1))^2)$, if $\beta^2<(1+l)\lambda$, $(\partial w_{21}/\partial k)>0$, else, $(\partial w_{21}/\partial k)<0$. $(\partial E(\pi_{s21})/\partial k) = (2l(1+l)\beta^2\ (-\beta^2+(1+l)\lambda)\ (S_{21}\beta+(1-cl+s\beta)\lambda)^2\sigma_2^2(1+k(1+l)\beta^2\sigma_2^2)/(2\ (1+l)\lambda+\beta^2(k(1+l)^2\lambda\sigma_2^2-1))^3)$, if $\beta^2<(1+l)\lambda$, $(\partial E(\pi_{s21})/\partial k)>0$, else, $(\partial E(\pi_{s21})/\partial k)<0$. $(\partial D_{21}/\partial k) = -((1+l)\beta^2(\beta^2-(1+l)\lambda)(S_{21}\beta+(1-cl+\ s\beta)\lambda)\sigma_2^2/(2(1+l)\lambda+\beta^2(-1+k\ (1+l)^2\lambda\sigma_2^2))^2)$, if $\beta^2<(1+l)\lambda$, $(\partial D_{21}/\partial k)>0$, else, $(\partial D_{21}/\partial k)<0$.

(iii) $(\partial w_{22}/\partial k) = -(2\beta^2(\beta^2-2\lambda)\ (S_{22}\beta+(1-cl+s\beta)\lambda)\sigma_2^2/(4\lambda+\beta^2(-1+4k\lambda\sigma_2^2))^2)$, if $\beta^2<2\lambda$, $(\partial w_{22}/\partial k)>0$, else, $(\partial w_{22}/\partial k)<0$. $(\partial E(\pi_{s22})/\partial k) = -(4\beta^2(\beta^2-2\lambda)(S_{42}\beta+(1-cl+s\beta)\lambda)^2\sigma_2^2\ (1+2k\beta^2\sigma_2^2)/(4\lambda+\beta^2(-1+4k\lambda\sigma_2^2))^3)$, if $\beta^2<2\lambda$, $(\partial E(\pi_{s22})/\partial k)>0$, else, $(\partial E(\pi_{s22})/\partial k)<0$. $(\partial D_{22}/\partial k) = -(2l\beta^2(\beta^2-2\lambda)\ (S_{22}\beta+(1-cl+s\beta)\lambda)\sigma_2^2/(4\lambda+\beta^2(-1+4k\lambda\sigma_2^2))^2)$, if $\beta^2<2\lambda$, $\partial D_{22}/\partial k>0$, else, $\partial D_{22}/\partial k<0$. □

Proof of Proposition 4

$q_{22}-q_{21} = ((1-l)\beta(-\lambda+cl\lambda-\beta(S+s\lambda))\ (2+k(3+l)\beta^2\sigma_2^2)/(4\lambda+\beta^2(-1+4k\lambda\sigma_2^2))(2(1+l)\lambda+\beta^2(-1+k\ (1+l)^2\lambda\sigma_2^2)))>0$, $Q_{22}-Q_{21} = l(S\beta+\lambda-cl\lambda+s\beta\lambda)((l-1)(2\lambda+k\beta^2\sigma_2^2(\beta^2+(3+l)\lambda+2k(1+l)\beta^2\lambda\sigma_2^2))/(4\lambda+\beta^2\ (-1+4k\lambda\sigma_2^2))(2(1+l)\lambda+\beta^2(-1+k(1+l)^2\lambda\sigma_2^2)))>0$, $U(\pi_{r22})-U(\pi_{r21}) = (l-1)(S\beta+(1-cl+s\beta)\lambda)^2\ (2+k(3+l)\beta^2\sigma_2^2)/2(4\lambda+\beta^2(-1+4k\lambda\sigma_2^2))(2(1+l)\lambda+\beta^2(-1+k\ (1+l)^2\lambda\sigma_2^2))>0$. □

Proof of Proposition 5

(i) $SW_{21} = (1/2(2(1+l)\lambda+\beta^2(-1+k(1+l)^2\ \lambda\sigma_2^2))^2)(((-1+cl-s\beta)\lambda-\beta S_{21})^2\ (1+k(1+l)\beta^2\sigma_2^2)^2+2(((-1+cl-s\beta))\lambda-\beta S_{21})^2(1+k(1+l)\beta^2\sigma_2^2)\ (1+2l+kl(1+l)\beta^2\sigma_2^2)-\lambda\ (\beta(-1+cl-s\beta)-(1+l)S_{21}(2+k\ (1+l)\beta^2\sigma_2^2))^2)$, $(\partial SW_{21}/\partial S_{21}) = (1/2(2(1+l)\lambda+\ \beta^2(-1+k(1+l)^2\lambda\sigma_2^2))^2)(2\beta(1-cl+s\beta)\lambda(1+2l+k\ (1+l)\beta^2\sigma_2^2(3+5l+k(1+l)(1+2l)\beta^2\sigma_2^2))+2S_{21}((3+4l)\beta^2-4(1+l)^2\lambda+k(1+l)\ \beta^2\sigma_2^2((4+6l)\beta^2-4(1+l)^2\lambda-k(1+l)\beta^2(-(1+2l)\beta^2+\ (1+l)^2\lambda)\sigma_2^2)))$,

$(\partial^2 SW_{21}/\partial S_{21}^2) = ((3+4l)\beta^2-4(1+l)^2\lambda+k\ (1+l)\beta^2\sigma_2^2((4+6l)\beta^2-4(1+l)^2\lambda-k(1+l)\beta^2\ (-(1+2l)\beta^2+\ (1+l)^2\lambda)\sigma_2^2)/(2(1+l)\lambda+\beta^2(-1+k(1+l)^2\lambda\sigma_2^2))^2)$, if $\lambda>(\beta^2(3+4l+k(1+l)\beta^2\sigma_2^2(4+6l+k(1+l)(1+2l)\ \beta^2\sigma_2^2))/(1+l)^2(2+k(1+l)\beta^2\sigma_2^2)^2)$, $(\partial^2 SW_{21}/\partial S_{21}^2)<0$. Therefore, when $\lambda>\beta^2(3+4l+k(1+l)\beta^2\sigma_2^2(4+6l+k\ (1+l)(1+2l)\beta^2\sigma_2^2))/(1+l)^2(2+k(1+l)\beta^2\sigma_2^2)^2$, the social welfare function is concave.

(ii) Since the proof here is similar to that in (i), we omit them. □

Proof of Proposition 6

(i) $\partial S_{21}/\partial k = (1+l)^2\beta^3(1-cl+s\beta)\lambda\sigma_2^2 f_1(k)/((3+4l)\beta^2-4(1+l)^2\lambda+k(1+l)\beta^2\sigma_2^2((4+6l)\beta^2-4\ (1+l)^2\lambda-k(1+l)\beta^2\ (-(1+2l)\beta^2+(1+l)^2\lambda)\sigma_2^2)^2)$, $f_1(k) = -((5+8l)\beta^2+4(1+l)\ (2+3l)\lambda+k(1+l)\beta^2\ \sigma_2^2((2(1+2l)(-2\beta^2+3(1+l)\lambda))+k(1+l)\beta^2((-(1+2l)\ \beta^2+\lambda+l(4+3l)\lambda)\sigma_2^2))$; since $\lambda>(\beta^2(3+4l+k(1+l)\ \beta^2\sigma_2^2(4+6l+k(1+l)(1+2l)\beta^2\sigma_2^2))/(1+l)^2(2+k(1+l)\beta^2\sigma_2^2)^2)$, we get $f_1(k)>2\beta^2\ (2l+k\beta^2\sigma_2^2(1+5l(1+l)+kl(1+l)(1+2l)\ \beta^2\sigma_2^2)+1-(1/2+k(1+l)\beta^2\sigma_2^2)/1+l)>0$, and thus we get $\partial S_{21}/\partial k>0$.

$\partial S_{22}/\partial k = (4\beta^3(1-cl+s\beta)\ \lambda\sigma_2^2 f_2(k)/(7\beta^2-16\lambda+4k\beta^2\sigma_2^2(5\beta^2-8\lambda+k\beta^2(3\beta^2-4\lambda)\sigma_2^2))^2)$, $f_2(k) = -13\beta^2+40\lambda-4k\beta^2\sigma_2^2(6(\beta^2-3\lambda)+\ k\beta^2(3\beta^2-8\lambda)\sigma_2^2)$; since $\lambda>(\beta^2(1+2k\beta^2\sigma_2^2)(7+\ 6k\beta^2\sigma_2^2)/16(1+k\beta^2\sigma_2^2)^2)$, we get $f_2(k)>(1/2)\beta^2\ (10-(1/1+k\beta^2\sigma_2^2)+4k\beta^2\sigma_2^2(11+6k\beta^2\ \sigma_2^2))>0$, and thus we get $(\partial S_{22}/\partial k)>0$.

(ii) $q_{21} = -1/-\ (3+4l)\beta^2+4(1+l)^2\lambda+k(1+l)\ \beta^2\sigma_2^2(-2(2+3l)\beta^2+4(1+l)^2\lambda+k(1+l)\ \beta^2(-(1+2l)\beta^2+(1+l)^2\lambda)\sigma_2^2)1/((3+4l)\ (-1+cl)\beta-4(1+l)^2s\lambda+k(1+l)\beta^2\ \sigma_2^2(2(2+3l)(-1+cl)\beta-4(1+l)^2\ s\lambda+k(1+l)\beta^2((1+2l)(-1+cl)\beta-(1+l)^2s\lambda)\sigma_2^2)$,

$q_{22} = (7(-1+cl)\beta-16s\lambda+4k\beta^2\sigma_2^2\ (5(-1+cl)\beta-8s\lambda+k\beta^2\ (3(-1+cl)\beta-4s\lambda)\sigma_2^2)/7\beta^2-16\lambda+4k\beta^2\sigma_2^2(5\beta^2-8\lambda+k\beta^2\ (3\beta^2-4\lambda)\sigma_2^2))$.

$\partial q_{21}/\partial k = 2(1+l)^3\beta^3\ (1-cl+s\beta)\lambda\sigma_2^2(2+4l+k(1+l)\beta^2\sigma_2^2(1+4l+kl(1+l)\beta^2\sigma_2^2))/\ (-(3+4l)\beta^2+4(1+l)^2\lambda+k(1+l)\beta^2\sigma_2^2(-2(2+3l)\beta^2+\ 4(1+l)^2\lambda+k(1+l)\beta^2(-(1+2l)\beta^2+(1+l)^2\lambda)\sigma_2^2))^2>0$,

$\partial q_{22}/\partial k = 32\beta^3\ (1-cl+s\beta)\lambda\sigma_2^2(1+k\beta^2\sigma_2^2)(3+2k\beta^2\sigma_2^2)/(7\beta^2-16\lambda+4k\beta^2\sigma_2^2(5\beta^2-8\lambda+k\beta^2\ (3\beta^2-4\lambda)\sigma_2^2))^2>0$.

(iii) $\pi_{s21} = -l(1+l)(-1+cl-s\beta)\lambda\ (1+k(1+l)\beta^2\sigma_2^2)(2+k(1+l)\beta^2\sigma_2^2)/-\ (3+4l)\ \beta^2+4(1+l)^2\lambda+k(1+l)\beta^2\sigma_2^2(-2(2+3l)\beta^2+4(1+l)^2\lambda+k\ (1+l)\beta^2(-(1+2l)\beta^2+(1+l)^2\lambda)\sigma_2^2)$, $\partial\pi_{s21}/\partial k = l(1+l)^2\beta^2(1-cl+s\beta)\lambda\sigma_2^2 f_1(\lambda)/((3+4l)\beta^2-4\ (1+l)^2\lambda+k(1+l)\beta^2\sigma_2^2((4+6l)\beta^2-4(1+l)^2\lambda-k(1+l)\ \beta^2(-(1+2l)\beta^2+(1+l)^2\lambda)\sigma_2^2))^2$, $f_1(\lambda) = -\beta^2+4(1+l)^2\lambda+k(1+l)\beta^2\sigma_2^2\ (-2\beta^2+4(1+l)^2\lambda+k(1+l)\beta^2(-\beta^2+(1+l)^2\lambda)\sigma_2^2)$, $\lambda>\beta^2(3+4l+k(1+l)\beta^2\ \sigma_2^2(4+6l+k(1+l)\ (1+2l)\beta^2\sigma_2^2))/(1+l)^2(2+k(1+l)\beta^2\sigma_2^2)^2$, $f_1(\lambda)>2\ \beta^2(1+2l+k(1+l)\beta^2\sigma_2^2(1+3l+kl(1+l)\beta^2\sigma_2^2\ ))>0$, $\partial\ \pi_{s21}/\partial k>0$.

$\pi_{s22} = 16(1-cl+s\beta)^2\lambda^2(1+k\beta^2\sigma_2^2)^2(1+2k\beta^2\sigma_2^2)^2/(7\beta^2\ -16\lambda+4k\beta^2\sigma_2^2(5\beta^2-\ 8\lambda+k\beta^2(3\beta^2-4\lambda)\sigma_2^2))^2$, $\partial\pi_{s22}/\partial k = 32\beta^2(1-\ cl+s\beta)^2\lambda^2\sigma_2^2\ (1+k\beta^2\sigma_2^2)\ (1+2k\beta^2\sigma_2^2)f_2(\lambda)/(7\beta^2-16\lambda+4k\beta^2\sigma_2^2(5\beta^2-8\lambda+k\beta^2(3\beta^2\ -4\lambda)\sigma_2^2))^3$, $f_2(\lambda) = \beta^2-16\lambda+4k\beta^2\sigma_2^2(\beta^2-8\lambda+k\beta^2(\beta^2-4\lambda)\sigma_2^2)$, $\lambda>\beta^2(1+2k\beta^2\sigma_2^2)(7+6k\beta^2\sigma_2^2)/16(1+k\beta^2\sigma_2^2)^2$, $f_2(\lambda)<-2\beta^2(3+4k\beta^2\sigma_2^2(2+k\beta^2\sigma_2^2))<0$, $\partial\pi_{s22}/\partial k>0$.

(iv) $Q_{21} = (1+l)(1-cl+s\beta)\lambda(2+k(1+l)\beta^2\sigma_2^2(3+k(1+l)\beta^2\sigma_2^2))/f_3(\lambda)$, $f_3(\lambda) = -(3+4l)\beta^2 + 4(1+l)^2\lambda + k(1+l)\beta^2\sigma_2^2(-2(2+3l)\beta^2 + 4(1+l)^2\lambda + k(1+l)\beta^2(-(1+2l)\beta^2 + (1+l)^2\lambda)\sigma_2^2)$, $Q_{22} = 4(-1+cl-s\beta)\lambda(1+k\beta^2\sigma_2^2)(1+2k\beta^2\sigma_2^2)/7\beta^2 - 16\lambda + 4k\beta^2\sigma_2^2(5\beta^2 - 8\lambda + k\beta^2(3\beta^2 - 4\lambda)\sigma_2^2)$,

$Q_{22} - Q_{21} = (1-cl+s\beta)\lambda(l-1)/(7\beta^2 - 16\lambda + 4k\beta^2\sigma_2^2(5\beta^2 - 8\lambda + k\beta^2(3\beta^2 - 4\lambda)\sigma_2^2))(-f_3(\lambda))(16(1+l)\lambda - 2\beta^2 + k\beta^2\sigma_2^2((3+l)(-3\beta^2 + 16(1+l)\lambda) + k\beta^2\sigma_2^2((15+l(12+l))(-\beta^2 + 4(1+l)\lambda) + 4k(1+l)\beta^2\sigma_2^2((3+l)(-\beta^2 + 3(1+l)\lambda) + k(1+l)\beta^2(-\beta^2 + 2(1+l)\lambda)\sigma_2^2)))) > 0.$ □

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This study was supported by the National Natural Science Foundation of China (nos. 71771053 and 71371003), the Key Research and Development Plan (Modern Agriculture) of Jiangsu Province (no. BE2018385), and the Natural Science Foundation of Jiangsu Province (no. BK20201144).

References

[1] I. E. Nielsen, S. Majumder, S. S. Sana, and S. Saha, "Comparative analysis of government incentives and game structures on single and two-period green supply chain," *Journal of Cleaner Production*, vol. 235, pp. 1371–1398, 2019.

[2] S. Saha, S. Majumder, and I. E. Nielsen, "Is it a strategic move to subsidized consumers instead of the manufacturer?" *IEEE Access*, vol. 7, pp. 169807–169824, 2019.

[3] I. E. Nielsen, S. Majumder, and S. Saha, "Game-theoretic analysis to examine how government subsidy policies affect a closed-loop supply chain decision," *Applied Sciences*, vol. 10, 2020.

[4] Y. Qin, J. Wang, and C. Wei, "Joint pricing and inventory control for fresh produce and foods with quality and physical quantity deteriorating simultaneously," *International Journal of Production Economics*, vol. 152, pp. 42–48, 2014.

[5] Y. Hung, W. Verbeke, and T. M. de Kok, "Stakeholder and consumer reactions towards innovative processed meat products: insights from a qualitative study about nitrite reduction and phytochemical addition," *Food Control*, vol. 60, pp. 690–698, 2016.

[6] P. Y. Lee, K. Lusk, M. Mirosa, and I. Oey, "Effect of information on Chinese consumers' perceptions and purchase intention for beverages processed by high pressure processing, pulsed-electric field and heat treatment," *Food Quality and Preference*, vol. 40, pp. 16–23, 2015.

[7] M. A. P. M. V. Asseldonk, L. Malaguti, M. L. H. Breukers, and H. J. van der FELS-KLERX, "Understanding preferences for interventions to reduce microbiological contamination in Dutch vegetable production," *Journal of Food Protection*, vol. 81, no. 6, pp. 892–897, 2018.

[8] H.-W. Huang, S.-J. Wu, J.-K. Lu, Y.-T. Shyu, and C.-Y. Wang, "Current status and future trends of high-pressure processing in food industry," *Food Control*, vol. 72, pp. 1–8, 2017.

[9] N. N. Mohand, A. Hammoudi, M. S. Radjef et al., "How do food safety regulations influence market price? A theoretical analysis," *British Food Journal*, vol. 119, no. 8, pp. 1687–1704, 2017.

[10] V. Hoffmann, C. Moser, and A. Saak, "Food safety in low and middle-income countries: The evidence through an economic lens," *World Development*, vol. 12, 2019.

[11] Q. Zheng and T. Fan, "Design of incentive contract for fresh agricultural products supply chain considering risk preference," *Journal of Industrial Engineering and Engineering Management*, vol. 32, no. 2, pp. 171–178, 2018.

[12] F. Lin, "Dynamic pricing, quality investment, and replenishment model for perishable items," *International Transactions in Operational Research*, vol. 26, no. 4, pp. 1558–1575, 2019.

[13] I. Moon, Y. J. Jeong, and S. Saha, "Investment and coordination decisions in a supply chain of fresh agricultural products," *Operational Research*, vol. 20, no. 4, pp. 2307–2331, 2020.

[14] M. Wang and L. Zhao, "Cold chain investment and pricing decisions in a fresh food supply chain," *International Transactions in Operational Research*, vol. 28, no. 2, pp. 1074–1097, 2021.

[15] M. S. Vodenicharova, "Supply chain study in food industry in Bulgaria," *International Journal of Retail & Distribution Management*, vol. 48, no. 9, pp. 921–938, 2020.

[16] J. C. P. Mesa and E. G. Gomez, "Collaborative firms managing perishable products in a complex supply network: an empirical analysis of performance," *Supply Chain Management: An International Journal*, vol. 20, no. 2, pp. 128–138, 2015.

[17] J. Labrecque, B. Dulude, and S. Charlebois, "Sustainability and strategic advantages using supply chain-based determinants in pork production," *British Food Journal*, vol. 117, no. 11, pp. 2630–2648, 2015.

[18] P. T. Rucabado and P. M. Cuellar, "Short food supply chains for local food: a difficult path," *Renewable Agriculture and Food Systems*, vol. 35, no. 2, pp. 182–191, 2020.

[19] J. Chen and B. Dan, "Fresh agricultural product supply chain coordination under the physical loss-controlling," *Systems Engineering-Theory & Practice*, vol. 29, no. 3, pp. 54–62, 2009.

[20] H. Huang, Y. He, and D. Li, "Pricing and inventory decisions in the food supply chain with production disruption and controllable deterioration," *Journal of Cleaner Production*, vol. 180, pp. 280–296, 2018.

[21] J. He, Y. Lei, X. Fu et al., "How Can manufacturers promote green innovation in food supply chain? cost sharing strategy for supplier motivation," *Frontiers in Psychology*, vol. 11, 2020.

[22] A. Singh, N. Shukla, and N. Mishra, "Social media data analytics to improve supply chain management in food industries," *Transportation Research Part E: Logistics and Transportation Review*, vol. 114, pp. 398–415, 2018.

[23] J. Qian, B. Dai, B. Wang et al., "Traceability in food processing: problems, methods, and performance evaluations-a review," *Critical Reviews in Food Science and Nutrition*, 2020.

[24] A. C. Kappelman and A. K. Sinha, "Optimal control in dynamic food supply chains using big data," *Computers & Operations Research*, vol. 126, 2021.

[25] N. Mishra, A. Singh, N. P. Rana et al., "Interpretive structural modelling and fuzzy MICMAC approaches for customer centric beef supply chain: application of a big data technique,"

Production Planning & Control, vol. 28, no. 11-12, pp. 945–963, 2017.

[26] V. A. Nardi, R. Teixeira, W. J. Ladeira, and F. D. Santini, "A meta-analytic review of food safety risk perception," *Food Control*, vol. 112, 2020.

[27] J. Hou, L. Wu, and B. Hou, "Risk attitude, contract arrangements and enforcement in food safety governance: a China's agri-food supply chain scenario," *International Journal of Environmental Research and Public Health*, vol. 17, no. 8, p. 2733, 2020.

[28] T. Schoenherr, R. Narasimhan, and P. Bandyopadhyay, "The assurance of food safety in supply chains via relational networking," *International Journal of Operations & Production Management*, vol. 35, no. 12, pp. 1662–1687, 2015.

[29] C.-H. Chiu, T.-M. Choi, G. Hao, and X. Li, "Innovative menu of contracts for coordinating a supply chain with multiple mean-variance retailers," *European Journal of Operational Research*, vol. 246, no. 3, pp. 815–826, 2015.

[30] Q. Cui, C.-H. Chiu, X. Dai, and Z. Li, "Store brand introduction in a two-echelon logistics system with a risk-averse retailer," *Transportation Research Part E: Logistics and Transportation Review*, vol. 90, pp. 69–89, 2016.

[31] C.-H. Chiu, T.-M. Choi, X. Dai, B. Shen, and J.-H. Zheng, "Optimal advertising budget allocation in luxury fashion markets with social influences: a mean-variance analysis-fluences: a mean-variance analysis," *Production and Operations Management*, vol. 27, no. 8, pp. 1611–1629, 2018.

[32] S. Zhao and Q. Zhu, "A risk-averse marketing strategy and its effect on coordination activities in a remanufacturing supply chain under market fluctuation," *Journal of Cleaner Production*, vol. 171, pp. 1290–1299, 2018.

[33] S. Deng, W. Li, and T. Wang, "Subsidizing mass adoption of electric vehicles with a risk-averse manufacturer," *Physica A: Statistical Mechanics and Its Applications*, vol. 547, 2020.

[34] C.-H. Chiu and T.-M. Choi, "Supply chain risk analysis with mean-variance models: a technical review," *Annals of Operations Research*, vol. 240, no. 2, pp. 489–507, 2016.

[35] T.-M. Choi, X. Wen, X. Sun, and S.-H. Chung, "The mean-variance approach for global supply chain risk analysis with air logistics in the blockchain technology era," *Transportation Research Part E: Logistics and Transportation Review*, vol. 127, pp. 178–191, 2019.

[36] X. Wen and T. Siqin, "How do product quality uncertainties affect the sharing economy platforms with risk considerations? A mean-variance analysis," *International Journal of Production Economics*, vol. 224, 2020.

[37] B. He, X. Gan, and K. Yuan, "Entry of online presale of fresh produce: a competitive analysis," *European Journal of Operational Research*, vol. 272, no. 1, pp. 339–351, 2019.

[38] X. Cai, J. Chen, Y. Xiao et al., "Optimization and coordination of fresh product supply chains with freshness-keeping effort," *Production and Operations Management*, vol. 19, no. 3, pp. 261–278, 2010.

[39] Y. Yu and T. Xiao, "Pricing and cold-chain service level decisions in a fresh agri-products supply chain with logistics outsourcing," *Computers & Industrial Engineering*, vol. 111, pp. 56–66, 2017.

[40] L. Yang, R. Tang, and K. Chen, "Call, put and bidirectional option contracts in agricultural supply chains with sales effort," *Applied Mathematical Modelling*, vol. 47, pp. 1–16, 2017.

[41] C. Wang and X. Chen, "Option pricing and coordination in the fresh produce supply chain with portfolio contracts," *Annals of Operations Research*, vol. 248, no. 1-2, pp. 471–491, 2017.

[42] M. Wang, L. Zhao, and M. Herty, "Modelling carbon trading and refrigerated logistics services within a fresh food supply chain under carbon cap-and-trade regulation," *International Journal of Production Research*, vol. 56, no. 12, pp. 4207–4225, 2018.

[43] J. Wu, J. Li, S. Wang, and T. Cheng, "Mean-variance analysis of the newsvendor model with stockout cost☆," *Omega*, vol. 37, no. 3, pp. 724–730, 2009.

[44] W. Xing, S. Wang, and L. Liu, "Optimal ordering and pricing strategies in the presence of a B2B spot market," *European Journal of Operational Research*, vol. 221, no. 1, pp. 87–98, 2012.

[45] D. Krass, T. Nedorezov, and A. Ovchinnikov, "Environmental taxes and the choice of green technology," *Production and Operations Management*, vol. 22, no. 5, pp. 1035–1055, 2013.

[46] S. Mohammadreza and R.-B. Morteza, "A game theoretic approach for pricing, greening, and social welfare policies in a supply chain with government intervention," *Journal of Cleaner Production*, vol. 196, pp. 1443–1458, 2018.

Hindawi
Journal of Food Quality
Volume 2021, Article ID 8817003, 10 pages
https://doi.org/10.1155/2021/8817003

Research Article

Fairness Perception, Trust Perception, and Relationship Quality in Agricultural Supply Chains

Yuling Sun,[1] **Zeyu Zhu**,[1] **and Hui Yang**[2]

[1]*School of Economics and Management, Nanjing Tech University, Nanjing 211816, China*
[2]*School of Economics and Management, Nanjing University of Science and Technology, Nanjing 210094, China*

Correspondence should be addressed to Yuling Sun; syl_nj@njtech.edu.cn

Received 2 October 2020; Revised 20 February 2021; Accepted 1 March 2021; Published 10 March 2021

Academic Editor: Yong He

Suppliers are important members of the agricultural supply chain. Moreover, their behavior decisions may affect the sustainable development of the agricultural supply chain. Considering agricultural supplier trust, this study examines the direct impact of trust perception on relationship quality and the indirect impact of supplier fairness perception on relationship quality. Based on the survey data of agricultural product suppliers, this study uses the structural equation model method for empirical analysis. The analysis results show that both fairness perception and trust perception have a significant positive impact on the relationship quality of the agricultural supply chain. Trust perception particularly has a positive direct impact on the relationship quality of the agricultural supply chain, while fairness perception has an indirect influence on the relationship quality of the agricultural supply chain through trust perception. In addition, information sharing, price satisfaction, income level, and environmental certainty have a significant positive impact on suppliers' fairness perception. Therefore, retailers comprehensively consider both fairness perception and trust perception of suppliers, which will help improve the relationship quality of the supply chain.

1. Introduction

Many experiments in behavioral economics have shown that the fairness perception of decision-makers refers to the comparison between the efforts and benefits of oneself and that of others, wherein the idea of fairness is derived [1]. In China, the agricultural supply chain is usually dominated by retailers or wholesalers. The suppliers only obtain less revenue and bear too many market risks [2]. The inequality of distributed wealth could prompt suppliers to take certain illegal actions to reduce production costs and increase their own profits. These behaviors may cause agricultural product quality safety incidents. For example, the Shanghai Shenglu Food Company dyes white flour into cornmeal buns and Heinz Meiweiyuan (Guangzhou) Food Company adds "Sudan Red No. 1" to chili sauce. These incidents damage the relationship quality between agricultural supply chains. Therefore, supplier fairness perception is one of the key factors affecting the stability of supply chain cooperation [3]. However, trust has a positive role in promoting relationship quality [4]. If suppliers trust retailers, they will make effort to maintain the stability of the quality of agricultural products for long-term cooperation. It is helpful to improve the efficiency of cooperation and the stability of relationship quality [5]. Once the agricultural product supplier loses trust in the retailer, conducting behaviors that damage the relationship quality of the agricultural supply chain is possible [6]. Suppliers' trust to retailers is an important part of supply chain management [7].

In supply chain management research, the relationship quality of the supply chain is important for describing the basic characteristics of the supply chain. Food safety and quality issues have largely affected the relationship quality of the supply chain [8]. Fairness perception and trust perception of suppliers may affect the relationship quality of the agricultural supply chain. As we have shown, some scholars have conducted empirical studies on the influence of fairness perception on relationship quality, and they found that fairness perception has a positive effect on relationship quality [9, 10]. In addition, other scholars have studied the influence of trust perception on relationship quality [11]. However, their main concern was the impact of the retailer's fairness perception or trust perception on relationship quality. To the best of our knowledge, there has been little research on the impact of both suppliers' fairness perception and trust perception on the relationship quality of the agricultural supply chain. Based on survey data sets of agricultural product suppliers, this study analyzes the impact of agricultural product suppliers' fairness perception and trust perception on the relationship quality of the supply chain. The research results will provide scientific guidance and suggestions for the sustainable development of agricultural supply chains.

2. Theoretical Background and Assumptions

2.1. Factors Influencing Suppliers' Fairness Perception. Both distributive and procedural fairness are important dimensions for measuring fairness perception and have been widely used in previous literature. Many scholars have studied the influence of distributive and procedural fairness in the supply chain and their own influence [12, 13]. This study uses both distributive and procedural fairness to describe the fairness perception of agricultural product suppliers. Informational fairness and interactional fairness are also reflected in the article. Openness and transparency of information and the equality of information exchange are considered through information sharing, and equality of both agricultural product suppliers' transaction process and interaction is considered through procedural fairness.

Price satisfaction is essential and affects fairness perception [14]. Price satisfaction has a positive and significant impact on fairness perception [15]. Simultaneously, price satisfaction can affect not only the degree of fairness perception but also the cooperation between suppliers and retailers in the supply chain of agricultural products [16]. Higher price satisfaction will make cooperation between agricultural product suppliers and retailers more stable and lasting. This study makes the following assumptions:

H1a: price satisfaction has a positive impact on distributive fairness

H1b: price satisfaction has a positive impact on procedural fairness

Studies have shown that information sharing could improve supply chain performance [17]. Therefore, information sharing is an essential role in the cooperation process of supply chain members. For example, information sharing can promote operational performance improvement, reduce supply chain costs, and increase supply chain profits [18, 19]. Simultaneously, information sharing has a positive impact on fairness [20]. Information sharing and fairness perception are considered closely related, and information sharing can have a certain impact on fairness perception. As the degree of information sharing increases, agricultural product suppliers can obtain more information. This study makes the following assumptions:

H2a: information sharing has a positive impact on distributive fairness

H2b: information sharing has a positive impact on procedural fairness

Income is the main indicator reflecting utility and satisfaction [21]. Income inequality triggers the unfairness perception of agricultural product suppliers, which can significantly reduce the enthusiasm of agricultural product suppliers. Changes in income levels significantly affect fairness perception [22]. When the income level fluctuates abnormally, it will even affect the fairness of the whole society and cause people to change the concept of social fairness [23]. An increase in income level will enhance the fairness perception of suppliers of agricultural products and promote cooperation between suppliers and retailers. This study makes the following assumptions:

H3a: income level has a positive impact on distributive fairness

H3b: income level has a positive impact on procedural fairness

Environmental certainty has a significant impact on fairness perception, namely, distributive fairness and procedural fairness, and has an impact on the stability of supply chain partnerships [24]. Therefore, the uncertainty of the agricultural product market environment brings risk and unfairness perception to agricultural product suppliers. Increasing environmental certainty promotes the fairness perception of agricultural product suppliers and stabilizes the cooperative relationship of agricultural supply chains. This study makes the following assumptions:

H4a: environmental certainty has a positive impact on distributive fairness

H4b: environmental certainty has a positive impact on procedural fairness

2.2. Fairness Perception and Trust Perception. This study divides trust perception into two dimensions: integrity trust and good faith trust. Integrity trust means that the supplier of agricultural products trusts the promise from the retailer and regards the retailer as the most loyal partner. Good faith trust shows that the supplier of agricultural products fully trusts that the retailer can provide assistance, support, and understanding.

In the agricultural supply chain, both fairness perception and trust perception play very important roles. However, no clear conclusion about the relationship between trust perception and fairness perception exists. We assume that fairness perception affects trust perception among members of the agricultural supply chain.

On the one hand, distributive fairness has a significant impact on trust perception. Distributive fairness is mainly manifested in the fairness of income distribution. When the income or benefits' distribution was unfair, people's participation also became affected, thereby affecting trust

[25, 26]. Christopher and Matthew [27] proved that trust was affected by a social distribution or unfair income distribution, and unfair income distribution reduced public trust. Sonja and Juan [28] highlighted that unfair income distribution had a negative impact on trust. Distributive fairness can be the decisive factor of trust perception. In the agricultural supply chain, unfair income distribution will stimulate conflicts between suppliers and retailers, affect the trust of both parties, and damage the willingness of both parties to continue cooperating. Therefore, distributive fairness has a certain impact on trust perception.

On the other hand, procedural fairness could affect trust perception. Procedural fairness is defined as the fairness of participants during the planning process [29]. Trust is usually formed during the planning process [30, 31]. Christoph [32] showed that procedural fairness directly affected participants' trust. Gross [33] proved that procedural fairness has a positive impact on trust. Procedural fairness is an important determinant of trust perception in the agricultural supply chain because procedural fairness reduces conflicts of interest, enhances the stability of the supply chain, and increases trust between both parties. Good mutual trust helps reduce the adverse effects of communication, stabilize the supply chain environment, and increase market vitality. Thus, procedural fairness affects trust perception to a certain extent.

Aryee et al. [34] proved that both distributive fairness and procedural fairness affected trust. In addition, distributive and procedural fairness has a comprehensive impact on trust fairness. Ghasem et al. [35] further highlighted that distributive fairness has a more significant impact on trust. Therefore, trust fairness in agricultural product suppliers will be affected by fairness perception. This study makes the following assumptions:

H5a: distributive fairness has a positive impact on integrity trust

H5b: distributive fairness has a positive impact on good faith trust

H6a: procedural fairness has a positive impact on integrity trust

H6b: procedural fairness has a positive impact on good faith trust

2.3. Trust Perception and Relationship Quality. Commitment is essential in relationship quality, and supplier trust will have a significant impact on commitment [36]. From a psychological point of view, commitment is largely affected by trust, and this effect is enduring [37]. Some scholars have found that fairness has an indirect impact on commitment, and trust has a direct impact on commitment [38, 39]. Suppliers will maintain stable commitment and long-term cooperation with the retailer if they trust the retailer. This study makes the following assumptions:

H7a: integrity trust has a positive impact on commitment

H7b: good faith trust has a positive impact on commitment

Trust perception is critical to investment willingness. Trust will affect investment willingness and income [40, 41]. The willingness of suppliers to continue investing is also affected by trust [42]. Therefore, the trust perception of agricultural product suppliers has an impact on investment willingness. This study makes the following assumptions:

H8a: integrity trust has a positive impact on investment willingness

H8b: good faith trust has a positive impact on investment willingness

Continuity expectation means that the agricultural product suppliers do not want to change the relationship in a short time but to keep cooperating with the retailer. Trust will affect the continuity of the cooperative relationship and has an intangible effect on future cooperation between two parties [43]. Trust is related to fairness, which affects the results of cooperation and the possibility of long-term cooperation, that is, continuous expectations [44, 45]. Thus, the continuity expectation is possibly affected by trust perception. This study makes the following assumptions:

H9a: integrity trust has a positive impact on continuity expectations

H9b: good faith trust has a positive impact on continuity expectations

Based on the above analysis, this study establishes a theoretical model and research hypothesis framework of the relationship between fairness perception, trust perception, and agricultural supply chain quality, as shown in Figure 1.

3. Methods of Empirical Research

3.1. Variable Definitions and Measurements. This study examines the impact of both fairness perception and trust perception on relationship quality. The factors influencing fairness perception include price satisfaction, information sharing, income level, and environmental certainty. Fairness perception is separated into distributive and procedural fairness. Trust perception includes integrity trust and good faith trust. Relationship quality comprises commitment, investment willingness, and continuity expectations. To ensure the reliability and validity of the scale, this study adopts a seven-point Likert scale widely used in empirical research.

This article defines price satisfaction as the degree of satisfaction of suppliers with agricultural product prices, with five items, the scale of which comes from Hellberg and Spiller [46]. This article defines information sharing as the ability of agricultural product suppliers to share their own information with retailers with six items, and its scale is adapted from Frazier et al. [47]. Income level is defined as the profit that the retailer can bring to the agricultural product supplier. The scale is rooted in the study by Anderson and Narus [48], with four items. Environmental uncertainty means that the demand and sales forecasting of

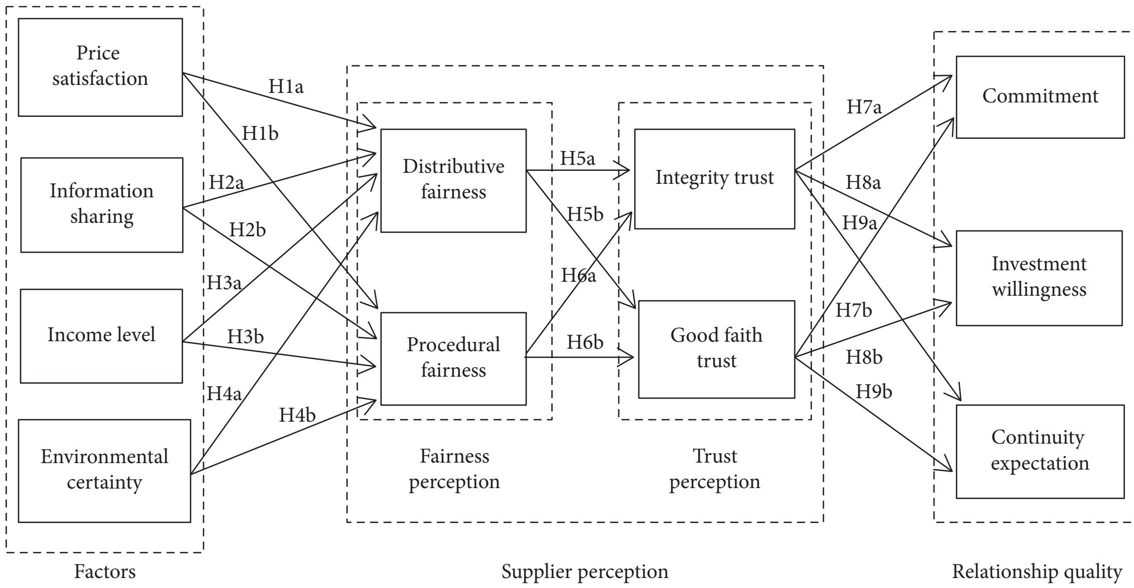

Figure 1: Theoretical model.

suppliers on the agricultural product market is not ascertainable, and its scale is adapted from Heide and John [49].

This study defines distributive fairness as the distribution of profit being fair in the cooperation between agricultural product suppliers and retailers and that procedural fairness as the process of cooperation between suppliers and retailers remaining fair. The scale of distributive fairness is measured by five items, and the scale is derived from Price and Mueller [50]. The scale of procedural fairness is adapted from Kim and Mauborgne [51], with eight items. Integrity trust means that agricultural product suppliers trust the retailer's promises and suggestions, and good faith trust means that agricultural product suppliers trust the retailer's support and assistance. Integrity trust and good faith trust are measured by five items, and the scale comes from Kumar et al. [52].

Commitment means that the supplier of agricultural products is willing to make corresponding promises to the retailers with three items, and the scale comes from Meyer et al. [53]. Investment willingness is defined as the willingness of agricultural product suppliers to invest and cooperate with retailers. The scale is selected from Kumar et al. [52], which is described by three items. This article defines continuity expectation as the idea of long-term cooperation between agricultural product suppliers and retailers with three items, and the source of the scale is the study by Frazier et al. [47].

3.2. Sample Selection and Data Collection. This article conducts surveys via questionnaire. The objects of the questionnaire are representative suppliers from wholesale markets of agricultural products in various cities, and most of them have rich experience in the agricultural industry. The objects of the questionnaire cover major cities in Jiangsu Province. The questionnaire is distributed to agricultural product suppliers through e-mail and visits. A total of 1,000 questionnaires were distributed, and 562 were returned. The questionnaires were screened after the questionnaires were returned, and 112 questionnaires were eliminated, because the subjects of 53 questionnaires did not meet the requirements of middle- and high-level supplier managers, and the result of 13 questionnaires had the same blockbuster options. In addition, 25 questionnaires contained missing information, and 21 questionnaires showed wrong answers to reverse questions and polygraph questions. Finally, 450 valid questionnaires were obtained with an effective recovery rate of 45%.

4. Empirical Research Results

4.1. Reliability and Validity Analysis. This study used SPSS 25.0 to test the reliability and validity of the questionnaire based on the collected data. Both reliability and validity were analyzed. The specific analysis results are shown in Table 1.

The study analyzes the Cronbach's α coefficient from 11 aspects such as price satisfaction, information sharing, income level, environmental certainty, distributive fairness, procedural fairness, integrity trust, good faith trust, commitment, investment willingness, and continuity expectation. According to the reliability analysis, the Cronbach's α value of the total variable was 0.952, indicating that the reliability of the total sample data was good. From Table 1, that Cronbach's α values in various aspects are 0.732–0.849, which is all greater than 0.7 acceptable values. This shows that each indicator has high internal consistency, and each variable has good reliability.

The study also calculates KMO (Kaiser-Meyer-Olkin) values of the total sample and the chi-square value of Bartlett's sphericity test and analyzes the factor load of each variable. According to the validity analysis, the KMO value is 0.912, and Bartlett's sphericity chi-square value is 15706.585. This means that the sample data are very suitable for analysis. Simultaneously, the factor load of each variable is greater than 0.5, which indicates that the sample data have good validity.

Table 1: Reliability and validity analysis of variables.

Variable	Question	α	Factor load
Price satisfaction	Q1-1	0.732	0.792
	Q1-2		0.764
	Q1-3		0.683
	Q1-4		0.776
	Q1-5		0.815
Information sharing	Q2-1	0.787	0.591
	Q2-2		0.745
	Q2-3		0.798
	Q2-4		0.634
	Q2-5		0.739
	Q2-6		0.719
Income level	Q3-1	0.849	0.846
	Q3-2		0.684
	Q3-3		0.735
	Q3-4		0.572
Environmental certainty	Q4-1	0.815	0.742
	Q4-2		0.847
	Q4-3		0.692
	Q4-4		0.788
Distributive fairness	Q5-1	0.774	0.792
	Q5-2		0.745
	Q5-3		0.761
	Q5-4		0.831
	Q5-5		0.579
Procedural fairness	Q5-6	0.831	0.543
	Q5-7		0.861
	Q5-8		0.789
	Q5-9		0.767
	Q5-10		0.668
	Q5-11		0.812
	Q5-12		0.792
	Q5-13		0.755
Integrity trust	Q6-1	0.792	0.696
	Q6-2		0.867
	Q6-3		0.571
	Q6-4		0.724
	Q6-5		0.761
Good faith trust	Q6-6	0.763	0.740
	Q6-7		0.716
	Q6-8		0.763
	Q6-9		0.738
	Q6-10		0.762
Commitment	Q7-1	0.826	0.849
	Q7-2		0.654
	Q7-3		0.737
Investment willingness	Q8-1	0.779	0.799
	Q8-2		0.782
	Q8-3		0.813
Continuity expectation	Q9-1	0.786	0.726
	Q9-2		0.751
	Q9-3		0.798

4.2. Model Fitness Analysis. This study uses AMOS25.0 software to perform confirmatory factor analysis (CFA) for each variable. These variables include price satisfaction, information sharing, income levels, environmental certainty, distributive fairness, procedural fairness, integrity trust, good faith, trust, commitment, investment willingness, and continuity expectation. The model's goodness-of-fit is shown in Table 2. According to the standard of goodness-of-fit [54], $\chi^2/df < 2$, RMSEA < 0.05, GFI, AGFI, NFI, CFI, TLI, RFI, and IFI are all equal to or greater than 0.90, thereby confirming a favorable goodness-of-fit. These data indicate that the model has a great goodness-of-fit. The research results of the sample data in this study show that the absolute fit index $\chi^2/df = 1.431$, RMSEA = 0.039, the relative fit index GFI = 0.912, AGFI = 0.964, NFI = 0.937, CFI = 0.957, TLI = 0.953, RFI = 0.926, and IFI = 0.971. The goodness-of-fit of the model can be considered well (see Table 2).

The average variance extraction (AVE) of each variable is 0.551–0.741, and the combined reliability (CR) of each variable is 0.739–0.956. Thus, all average variance extractions (AVEs) are greater than 0.5, and all combined reliabilities (CRs) are greater than 0.7. In short, all relative fitting indexes satisfy the fitting standard. Model adaptability is considered good in this study (see Table 3).

4.3. Path Analysis. The study conducts a path analysis using AMOS 25.0 to analyze the influencing factors of fairness perception of agricultural product suppliers, fairness perception, trust perception, and relationship quality. The analysis results are shown in Figure 2.

From Figure 2, all $p < 0.001$ are established; that is, all paths have reached a highly significant level. This study further analyzes the correlation of variables, path coefficients, and the significant levels they reach, as shown in Table 4. The correlation p reflects the degree of correlation. When $p < 0.05$, the correlation is significant; when $p < 0.01$, the correlation is more significant; when $p < 0.001$, the correlation is highly significant. From Table 4, hypotheses H1a, H1b, H2a, H2b, H3a, H4a, H4b, H5a, H6a, H6b, H7b, H8b, and H9b have proven to be highly significant correlations.

4.4. Results Analysis. This article analyzes the reliability and validity of the sample data. The analysis results show that the data are all valid and reliable. The structural equation modeling (SEM) method is used to test the hypothesis, and the influence between all paths is tested.

The results showed that all assumptions about fairness perception and trust perception have been verified. Concerning influencing factors of fairness perception, both price satisfaction and information sharing and environmental certainty have a highly significant positive impact on the fairness perception of suppliers. So, the supplies will feel higher fairness if a more reasonable wholesale price is given by the retailers. The increased information-sharing degree of retailers will promote an increase of suppliers' fairness perception and then the increased fairness perception of suppliers is conducive to mutual trust between suppliers and retailers. Furthermore, when the demand market is more predictable and the scale of market demand is more stable, suppliers' fairness perception will increase. In addition, information sharing has strong positive impacts on suppliers' procedural fairness. Both price satisfaction and income level have a more significant impact on distributive

Table 2: Goodness-of-fit of the model.

Statistical test	χ^2/df	RMSEA	GFI	AGFI	NFI	CFI	TLI	RFI	IFI
Adaptation standard	<2	<0.05	>0.90	>0.90	>0.90	>0.90	>0.90	>0.90	>0.90
Fitted value	1.431	0.039	0.912	0.964	0.937	0.957	0.953	0.926	0.971

Table 3: Model adaptability.

Variable	M	SD	AVE	CR
(1) Price satisfaction	4.757	1.135	0.589	0.877
(2) Information sharing	4.657	1.147	0.501	0.856
(3) Income level	4.692	1.171	0.513	0.805
(4) Environmental certainty	4.674	1.126	0.592	0.852
(5) Distributive fairness	4.781	1.119	0.557	0.861
(6) Procedural fairness	4.734	1.152	0.569	0.912
(7) Integrity trust	4.520	1.114	0.533	0.849
(8) Good faith trust	4.725	1.065	0.554	0.861
(9) Commitment	4.919	1.132	0.564	0.793
(10) Investment willingness	4.608	1.098	0.637	0.840
(11) Continuity expectation	4.510	1.157	0.576	0.803

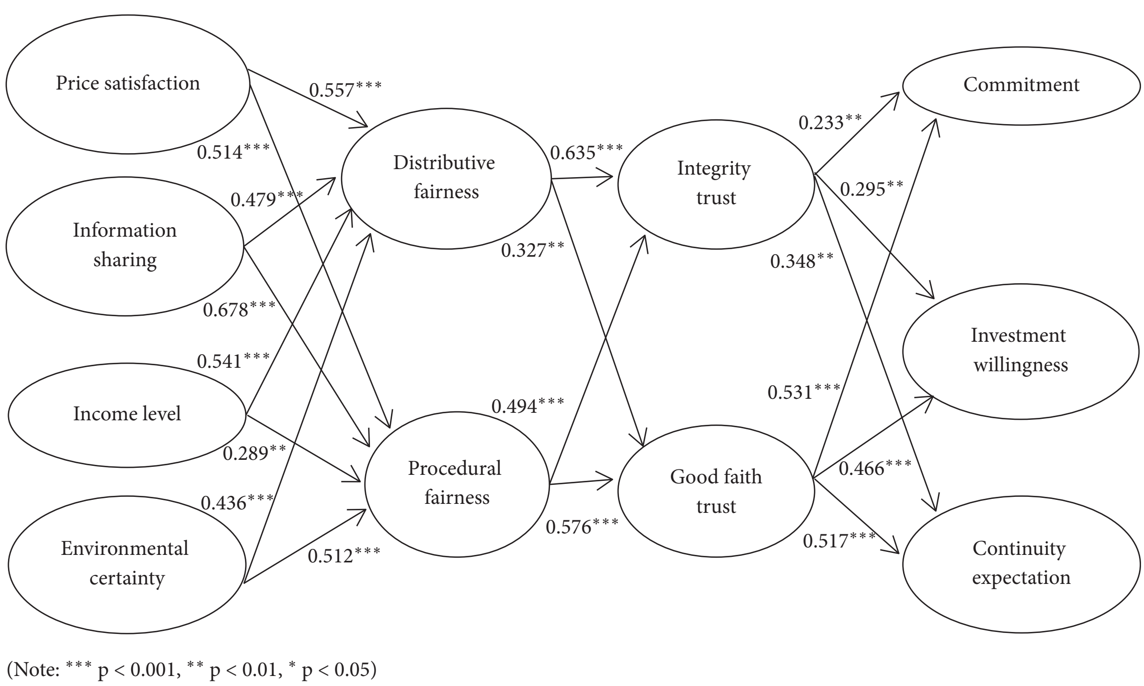

Figure 2: Model path analysis diagram.

fairness than on procedural fairness. But environmental certainty has a greater impact on procedural fairness than distributive fairness.

Through the impact of fairness perception on trust perception, it is found that procedural fairness and distributive fairness have a highly significant positive impact on both integrity trust and good faith trust. Improving suppliers' fairness perception will increase the suppliers' trust in retailers and enhance the long-term cooperation between the two sides. The impact of distributive fairness on integrity trust is more significant than on good faith trust. Procedural fairness has a highly significant positive impact on integrity trust and a more significant positive impact on good faith trust.

Considering the influence of trust perception on relationship quality, integrity trust and good faith trust both have a significant positive impact on relationship quality. On the one hand, a higher supplier's trust perception will induce a greater possibility of cooperation with the retailer. This will be conducive to continuous and long-term cooperation between suppliers and retailers. On the other hand, the increased trust of suppliers in retailers will prompt suppliers to make more reliable commitments to retailers, such as long-term cooperation and quality assurance, which is

Table 4: Hypothesis verification results.

Suppose	Path	Path coefficient	p	Conclusion
H1a	Price satisfaction⟶distributive fairness	0.557	***	Stand by
H1b	Price satisfaction⟶procedural fairness	0.514	***	Stand by
H2a	Information sharing⟶distributive fairness	0.479	***	Stand by
H2b	Information sharing⟶procedural fairness	0.678	***	Stand by
H3a	Income level⟶distributive fairness	0.541	***	Stand by
H3b	Income level⟶procedural fairness	0.289	**	Stand by
H4a	Environmental certainty⟶distributive fairness	0.436	***	Stand by
H4b	Environmental certainty⟶procedural fairness	0.512	***	Stand by
H5a	Distributive fairness⟶integrity trust	0.635	***	Stand by
H5b	Distributive fairness⟶good faith trust	0.327	**	Stand by
H6a	Procedural fairness⟶integrity trust	0.494	***	Stand by
H6b	Procedural fairness⟶good faith trust	0.576	***	Stand by
H7a	Integrity trust⟶commitment	0.233	**	Stand by
H7b	Good faith trust⟶commitment	0.531	***	Stand by
H8a	Integrity trust⟶investment willingness	0.295	* *	Stand by
H8b	Good faith trust⟶investment willingness	0.466	***	Stand by
H9a	Integrity trust⟶continuity expectation	0.348	**	Stand by
H9b	Good faith trust⟶continuity expectation	0.517	***	Stand by

$^{***}p < 0.001$, $^{**}p < 0.01$, and $^{*}p < 0.05$.

conducive to the stable development of the supply chain. Compared with integrity trust, good faith trust has a more significant impact on relationship quality. The results of the study show that integrity trust has the most significant impact on continuity expectations. Good faith trust has strong positive impacts on commitment.

Our study shows that the influencing factors of fairness perception have a significant positive impact on supplier perception. Simultaneously, supplier perception has a significant positive impact on relationship quality.

Using Bollen's analysis method [55], this study further analyzes the indirect impact of fairness perception on the relationship quality of the supply chain. The analysis results show that the indirect effects of distributive fairness and procedural fairness on commitments are 0.43 and 0.39, the indirect effects on investment willingness are 0.45 and 0.40, and the indirect effects on continuity expectations are 0.47 and 0.44, respectively. Therefore, fairness perception has a positive indirect impact on the relationship quality of the agricultural supply chain. Among them, distributive fairness has the most significant indirect influence on commitment, investment willingness, and continuity expectations. Distributive fairness is the key to improve the relationship quality of the supply chain.

5. Main Conclusions and Research Prospects

5.1. Main Conclusion. Based on the perspective of agricultural product suppliers, this study uses the structural equation model to analyze the impact of agricultural product suppliers' fairness perception and trust perception on the relationship quality of the agricultural supply chain. The conclusions of this study mainly include the following four aspects. (1) Price satisfaction, information sharing, and income level have a significant positive impact on fairness perception, wherein information sharing has the most significant impact on fairness perception. (2) Fairness perception has a significant positive impact on suppliers' trust perception. (3) Suppliers' trust perception has a significant positive impact on the relationship quality of the supply chain. (4) Fairness perception has a positive indirect impact on the relationship quality of the supply chain through trust perception.

Based on the above conclusions, this article presents four management suggestions. First, retailers should strengthen information sharing with suppliers, such as sharing product information, business development, and company development status. In the supply chain, information sharing has become a key factor in supply chain cooperation. Enhancing information sharing between retailers and suppliers will improve suppliers' fairness perception and promote cooperation between two parties.

Second, retailers need to reasonably set purchase prices and conduct profit distribution so that the income of agricultural product suppliers can be guaranteed and suppliers' distributive fairness perception can be improved. In addition, retailers also need to prohibit fraud in the transaction process and enhance mutual frankness to improve suppliers' procedural fairness perception. In the agricultural supply chain, whether the profits and returns obtained by suppliers are fair and whether they are treated fairly during transactions with retailers are important factors affecting suppliers' trust perception.

Third, the retailer should ensure the fairness of the supplier and enhance the sincerity of cooperation by proactively requesting the expansion of the cooperation period between the two parties and boosting willingness to cooperate, which can increase suppliers' trust perception. Because agricultural product quality risk and supply risk mainly come from suppliers, increasing suppliers' trust in retailers will improve the relationship quality of the agricultural supply chain.

Fourth, retailers should strengthen cooperation with suppliers by increasing the quantity and frequency of purchases of agricultural products and reduce conflicts in the transaction process by satisfying supplier demand and adopting supplier opinions. It will enhance suppliers' fairness perception and trust perception and improve the positive impact on the relationship quality of the agricultural supply chain. Retailers should not only pay attention to the significant impact of trust perception on relationship quality but also the impact of suppliers' fairness perception on relationship quality. When suppliers perceive that they are being treated fairly, it will significantly promote trust between suppliers and retailers, thereby increasing the indirect impact of the relationship quality of the agricultural supply chain. Trust perception could improve the relationship quality of the agricultural supply chain. The comprehensive effect of the supplier's fairness perception and trust perception has a more significant impact on the relationship quality of the agricultural supply chain.

5.2. Research Outlook. This study examines the impact of fairness perception and trust perception on the relationship quality of the agricultural supply chain from the suppliers' perspective. The research conclusions provide a theoretical basis for improving the stability of cooperation among members of the agricultural supply chain and improving the efficiency of the agricultural supply chain. In the future, further consideration should be given to the influence of retailers on improving the relationship quality of the agricultural supply chain. In addition, this study analyzes the influence of trust perception on the relationship quality of the supply chain. In the future, we will consider the influence of variables such as solidarity and vendor dependence on the relationship quality of the supply chain.

Data Availability

The data used to support the findings of this study are collected from agricultural products suppliers in China. The objects of the questionnaire cover 13 major cities in Jiangsu Province, including Changzhou, Zhenjiang, and Wuxi. The data used to support the findings of this study are included within the article. These data are open for the reader after the paper is published in the future. The author can be contacted at syl_nj@njtech.edu.cn.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors acknowledge the financial support received from the National Natural Science Foundation of China (71301073, 71571099, and 71701092), the Ministry of Education Humanities and Social Sciences Youth Fund (20YJC630142), the Social Science Innovation Team Foundation of Nanjing Tech University (SKTD2017001), and Jiangsu Social Science (Youth) Fund (17GLC009).

References

[1] W. Keren and J. W. Kristy, "Organisational justice, trust and perceptions of fairness in the implementation of agenda for change," *Radiography*, vol. 17, no. 1, pp. 61–66, 2011.

[2] U. Broll, P. Welzel, K. Pong Wong et al., "Price risk and risk management in agriculture," *Contemporary Economics*, vol. 7, no. 2, pp. 17–20, 2013.

[3] Y. S. Du, F. Y. Ma, and J. Y. Zhang, "The impact of perceptions of fairness and efficiency on the stability of supply chain partnerships: environmental uncertainty as a moderating variable," *Enterprise Economy*, vol. 31, no. 10, pp. 43–47, 2012.

[4] B. X. Li and J. Huang, "On trust and relationship quality," *Business Times*, vol. 16, no. 12, pp. 25–32, 2005.

[5] H. J. Ma and K. R. Shi, "The trust relationship and contract flexibility of supply chain members: a model of multiple intermediary effects," *Journal of Management Engineering*, vol. 30, no. 3, pp. 161–169, 2016.

[6] C. Yilmaz, "Relative effects of trust and service quality assessments on perceptions of relationship quality in Interfere relations in the context of conventional distribution channels," *Economic and Social Development (ESD)*, vol. 21, no. 3, pp. 546–553, 2017.

[7] Q. Cheng and L. H. Tian, "Research on supplier trust in supply chain," *Logistics Technology*, vol. 31, no. 23, pp. 389–392, 2012.

[8] R. Y. Chen, L. Shi, and J. Liu, "Research on safety quality management and incentive mechanism of food supply chain—based on structure, information and relationship quality," *Journal of Southeast University (Philosophy and Social Sciences Edition)*, vol. 15, no. 4, pp. 34–40, 2013.

[9] S. A. Samaha, R. W. Palmatier, and R. P. Dant, "Poisoning relationships: perceived unfairness in channels of distribution," *Journal of Marketing*, vol. 75, no. 3, pp. 99–117, 2011.

[10] Y. Sun, Z. Liu, and H. Yang, "How does suppliers' fairness affect the relationship quality of agricultural product supply chains?" *Journal of Food Quality*, vol. 2018, Article ID 9313068, 15 pages, 2018.

[11] G. Elisa, V. Fabio, D. G. Teresa et al., "A theory of planned behaviour perspective for investigating the role of trust in consumer purchasing decision related to short food supply chains," *European Journal of Operational Research*, vol. 252, no. 1, pp. 170–182, 2016.

[12] J. W. Thibaut and L. Walker, *Procedural Justice: A Psychological Analysis*, Erlabum Publisher, Hillsdale, MI, USA, 1975.

[13] G. L. Frazier, "Interorganizational exchange behavior in marketing channels: a broadened perspective," *Journal of Marketing*, vol. 47, no. 4, pp. 68–78, 1983.

[14] H. B. Anneke and S. Achim, "How to treat farmers fairly?–results of a farmer survey," *The International Food and Agribusiness Management Review*, vol. 15, no. 3, pp. 87–97, 2012.

[15] A. Ali, J. K. Pool, and M. R. Jalilvand, "The effect of perceived price fairness through satisfaction and loyalty on international tourists' price acceptance of Islamic-Iranian art products," *Education, Business and Society:Contemporary Middle Eastern Issues*, vol. 7, no. 4, pp. 201–215, 2014.

[16] S. M. Anna and S. Choi, "The impact of hotel pricing policies on perceived fairness and satisfaction with the reservation process," *Journal of Hospitality and Leisure Marketing*, vol. 13, no. 1, pp. 25–39, 2006.

[17] L. Myongran, H. G. Lee, S. Jo, and J. Park, "Utility value and fairness consideration for information sharing in a supply chain," *Advances in Production Management Systems*, vol. 246, pp. 213–220, 2007.

[18] F. Ye and X. J. Xu, "The impact of trust and relationship commitment between supply chain partnerships on information sharing and operational performance," *System Engineering Theory and Practice*, vol. 29, no. 8, pp. 36–49, 2009.
[19] M. Khan, M. Hussain, and H. M. Saber, "Information sharing in a sustainable supply chain," *International Journal of Production Economics*, vol. 181, no. 21, pp. 208–214, 2016.
[20] F. Fossati, S. Hoteit, S. Moretti, and S. Secci, "Fair resource allocation in systems with complete information sharing," *IEEE/ACM Transactions on Networking*, vol. 26, no. 6, pp. 2801–2814, 2018.
[21] T. Tavor, L. D. Gonen, M. Weber, and U. Spiegel, "The effects of income levels and income inequalities on happiness," *Journal of Happiness Studies*, vol. 19, no. 7, pp. 2115–2137, 2018.
[22] Z. Yuan, H. Zheng, and Y. Han, "Income level, distribution justice and happiness," *Contemporary Finance & Economics*, vol. 35, no. 11, pp. 5–15, 2013.
[23] B. Q. Ouyang and G. S. Zhang, "Intergenerational differences in income level and relative deprivation of migrant workers—an examination and explanation based on the perspective of social justice," *Commercial Research*, vol. 18, no. 3, pp. 162–170, 2018.
[24] Y. S. Du, F. Y. Ma, and J. Y. Zhang, "The impact of fairness perception and efficiency perception on the stability of supply chain partnerships: the impact of environmental certainty," *Business Economy*, vol. 34, no. 10, pp. 43–47, 2012.
[25] T. R. Tyler, K. A. Rasinski, and K. M. McGraw, "The influence of perceived injustice on the endorsement of political leaders1," *Journal of Applied Social Psychology*, vol. 15, no. 8, pp. 700–725, 1985.
[26] K. Kaltenthaler, S. Ceccoli, and R. Gelleny, "Attitudes toward eliminating income inequality in europe," *European Union Politics*, vol. 9, no. 2, pp. 217–241, 2008.
[27] C. J. Christopher and M. M. Matthew, "The sensitive left and the impervious right: multilevel models and the politics of inequality, ideology, and legitimacy in Europe," *Comparative Political Studies*, vol. 41, no. 4, pp. 564–599, 2008.
[28] Z. Sonja and C. C. Juan, "Income inequality, distributive fairness and political trust in Latin America," *Social Science Research*, vol. 52, pp. 179–192, 2015.
[29] N. M. A. Huijts, E. J. E. Molin, and L. Steg, "Psychological factors influencing sustainable energy technology acceptance: a review-based comprehensive framework," *Renewable and Sustainable Energy Reviews*, vol. 16, no. 1, pp. 525–531, 2012.
[30] N. M. A. Huijts, C. J. H. Midden, and A. L. Meijnders, "Social acceptance of carbon dioxide storage," *Energy Policy*, vol. 35, no. 5, pp. 2780–2789, 2007.
[31] J. Firestone, W. Kempton, M. B. Lilley, and K. Samoteskul, "Public acceptance of offshore wind power: does perceived fairness of process matter?" *Journal of Environmental Planning and Management*, vol. 55, no. 10, pp. 1387–1402, 2012.
[32] E. M. Christoph, "Examining the inter-relationships between procedural fairness, trust in actors, risk expectations, perceived benefits, and attitudes towards power grid expansion projects," *Energy Policy*, vol. 141, pp. 1–9, 2020.
[33] C. Gross, "Community perspectives of wind energy in Australia: the application of a justice and community fairness framework to increase social acceptance," *Energy Policy*, vol. 35, no. 5, pp. 2727–2736, 2007.
[34] S. Aryee, P. S. Budhwar, and Z. X. Chen, "Trust as a mediator of the relationship between organizational justice and work outcomes: test of a social exchange model," *Journal of Organizational Behavior*, vol. 23, no. 3, pp. 267–285, 2002.
[35] Z. Ghasem, N. T. Zhaleh, C. H. Stephan et al., "Do supplier perceptions of buyer fairness lead to supplier sales growth?" *Industrial Marketing Management*, vol. 53, pp. 160–171, 2016.
[36] M. G. Abdul, "Instrumental and interpersonal determinants of relationship satisfaction and commitment in industrial markets," *Journal of Business Research*, vol. 68, no. 5, pp. 619–628, 2005.
[37] L. Q. Peng and Q. Li, "An empirical study on the impact of distributors' perception of fairness on relationship commitment: a case study of China's home appliance industry," *Journal of Guangdong University of Business Studies*, vol. 25, no. 4, pp. 31–37+67, 2010.
[38] S. Tan and L. James, "The impact of performance measures on employee fairness perceptions, job satisfaction and organisational commitment," *Journal of Applied Management Accounting Research*, vol. 10, no. 2, pp. 57–72, 2012.
[39] M. Ziaullah, F. Yi, Y. Feng, S. N. Akhter, and S. Ahmad, "An investigation of justice in supply chain trust and relationship commitment-an empirical study of Pakistan," *Journal of Competitiveness*, vol. 7, no. 1, pp. 71–87, 2015.
[40] G. F. Huang and X. M. Jia, "Alumni relations, trust and venture capital transactions," *Economic Management*, vol. 40, no. 7, pp. 161–177, 2018.
[41] W. Cui, "Research on the relationship between trust, market participation and investment income," *The Journal of World Economic*, vol. 36, no. 9, pp. 127–138, 2013.
[42] Y. Jiang, Y. Liu, and R. Q. Jiang, "An empirical study of P2P online loan platform users' continuous investment willingness based on risk and trust," *Business Economy*, vol. 36, no. 2, pp. 156–160, 2017.
[43] S. M. Wagner, L. S. Coley, and E. Lindemann, "Effects of suppliers' reputation on the future of buyer-supplier relationships: the mediating roles of outcome fairness and trust," *Journal of Supply Chain Management*, vol. 47, no. 2, pp. 29–48, 2011.
[44] A. Adel, B. Martine, and D. Michel, "Multi-cloud cooperative intrusion detection system:trust and fairness assurance," *Annals of Telecommunications*, vol. 74, no. 9, pp. 637–653, 2019.
[45] M. Ozawa, "Trust and European-Russian energy cooperation: the case of oil and gas partnerships and long-term contracts," *Cambridge Working Papers in Economics*, vol. 21, no. 6, pp. 29–37, 2014.
[46] A. H. Hellberg and A. Spiller, "How to treat farmers fairly? results of a farmer survey?" *International Food and Agribusiness Management Review*, vol. 15, no. 3, pp. 87–98, 2012.
[47] G. L. Frazier, E. Maltz, K. D. Antia, and A. Rindfleisch, "Distributor sharing of strategic information with suppliers," *Journal of Marketing*, vol. 73, no. 4, pp. 31–43, 2009.
[48] J. C. Anderson and J. A. Narus, "A model of the distributor's perspective of distributor-manufacturer working relationships," *Journal of Marketing*, vol. 48, no. 4, pp. 62–74, 1984.
[49] J. B. Heide and G. John, "The role of dependence balancing in safeguarding transaction-specific assets in conventional channels," *Journal of Marketing*, vol. 52, no. 1, pp. 20–35, 1988.
[50] J. L. Price and W. Charles, *Handbook of Organizational measurements*, Pittman, Marshfield, MA, USA, 1986.
[51] W. C. Kim and R. A. Mauborgne, "Implementing global strategies: the role of procedural justice," *Strategic Management Journal*, vol. 12, no. S1, pp. 125–143, 1991.
[52] N. Kumar, L. K. Scheer, and J.-B. E. M. Steenkamp, "The effects of supplier fairness on vulnerable resellers," *Journal of Marketing Research*, vol. 32, no. 1, pp. 54–65, 1995.

[53] J. P. Meyer, N. J. Allen, and C. A. Smith, "Commitment to organizations and occupations: extension and test of a three-component conceptualization," *Journal of Applied Psychology*, vol. 78, no. 4, pp. 538–551, 1993.
[54] F. Chan, G. K. Lee, E. J. Lee et al., "Structural equation modeling in rehabilitation counseling research," *Rehabilitation Counseling Bulletin*, vol. 51, no. 1, pp. 44–57, 2007.
[55] K. A. Bollen, *Structural Equations with Latent Variables*, Wiley-Interscience Publication, New York, NY, USA, 1989.

Hindawi
Journal of Food Quality
Volume 2020, Article ID 8854238, 13 pages
https://doi.org/10.1155/2020/8854238

Research Article

Value of Mass Media in Food Safety Information Disclosure from the Perspective of Big Data

Qiaoling Zou,[1] **Jingai Ma**,[2] **Tao Chu**,[2] **Lei Zou**,[3] **Jeannette V. L. Pope**,[4] **and Zishun Su**[5,6]

[1]*Beijing Film Academy Modern Creative Media College, 689 Jin Sha Tan Road, Huangdao District, Qingdao 266520, China*
[2]*School of Business, Qingdao University, Shinan District, Qingdao 266071, China*
[3]*Qingdao News Network Communication Co. Ltd., Shinan District, Qingdao 266071, China*
[4]*Beijing Film Academy Modern Creative Media College, Huangdao District, Qingdao 266520, China*
[5]*Shanghai Business School, Xuhui District, 2271 West Zhong Shan Road, Shanghai 200235, China*
[6]*East China University of Science and Technology, Meilong Road 130, Xuhui District, Shanghai 200237, China*

Correspondence should be addressed to Zishun Su; zssu@foxmail.com

Received 1 October 2020; Revised 17 November 2020; Accepted 17 November 2020; Published 8 December 2020

Academic Editor: Victor Shi

The advent of *big data infrastructure* has promoted the development of media forms and content. Food safety information disclosure (FSID) is an effective solution to regulate food safety issues. The mass media, government regulatory agencies, and food companies jointly participate in the disclosure of food safety information. Due to social responsibilities and common interests, a tripartite game relationship is formed. After an evolutionary game model was established with China as an example, the mass media's participation in food safety information disclosure can affect the public's decision-making, and true disclosure can promote the process and effectiveness; however, false disclosure will have adverse effects on all three parties. The application of big data technology doubles the positive and negative effects. Therefore, the government needs to strengthen the supervision of the mass media's participation, and food companies need to actively provide correct disclosure information. The media should strengthen their management and use big data rationally, formulate corresponding disclosure strategies, and coordinate the three parties to promote food safety information disclosure.

1. Introduction

Food is an important basis for human survival. With the development of social economy and the improvement of people's living standards, people's demand for food has changed from quantity to quality, and food safety has been paid more attention. However, at present, the outbreak of incidents in food safety and the quality of food and food safety are current concerns. Because of the asymmetry in information, consumers often cannot always identify some of the inherent attributes of food: whether they contain harmful additives or if the source of food is contaminated. In the long run, this will not only erode consumer trust in the food industry but also raise questions about the credibility of the government as a regulator [1, 2]. For example, the "Sanlu melamine milk powder incident" in 2008, which killed six children and sickened about 300,000 in January 2009, not only led to the bankruptcy of the Sanlu group, but also eventually made China's dairy industry suffer a major blow. Numerous dairy farmers went bankrupt. Therefore, improving the food safety supervision system, strengthening food safety management, and reestablishing consumer confidence in food safety are the focus of the current food safety work.

The system of disclosing food safety information is an effective way to solve the problem of asymmetric food safety information and an outlet for solving food safety problems. Some developed countries, such as the United States, the European Union, and Japan, have achieved solid results in this regard [3]. For consumers, disclosing food safety information helps to trace the source of food production, so as to ensure the safety of the food purchased. It is conducive to building a good market for producers and avoiding the “lemon market” caused by frequent food safety incidents [4]. For the government departments as the supervisor, the food safety information disclosure is conducive to improving the level of food safety management, forming strong supervision, reducing the occurrence of food safety incidents, and avoiding the adverse impact on the credibility of the government. In the process, mass media, government supervision departments, and food enterprises constitute the main body of information disclosure. Among them, the government has a dominant position in the information disclosure process because of its administrative powers. It provides the most powerful administration for information disclosure by formulating laws and regulations on food safety information disclosure [5]. Food companies occupied a relatively active position in this process. They fully grasp the content of the information disclosed and can determine the content and degree of disclosure of food safety information. However, there are some problems in both of the above; although under the constraints of relevant laws and regulations food companies have to disclose food information [6], they will selectively disclose information that is beneficial to them and hide unfavorable information, and the government may change and conceal the content of disclosure due to an unclear division of responsibilities or because of excessive protection of their own interests. The reliability is difficult to guarantee [7]. Therefore, the involvement of the mass media as a third-party entity can not only supervise the disclosure behavior of government departments and food companies, but also serve as an important tool for information disclosure in the process of food safety [8].

Mass media spreads information to the masses via newspapers, magazines, radio, television, movies, books, and the Internet [9]. The advent of the big data era has brought new opportunities and challenges to the mass media. First of all, cloud computing and the Internet of Things have made large-scale data production, storage, and processing a reality. The media content is constantly enriched, and the transmission speed is getting faster and faster, which increases the audience’s demand for communication [10]. In addition, the types of media continue to develop and merge, and the emergence of interactive media platforms enhances the wiliness of the audience to engage. Today, there are more than 10 million photo updates and 3 billion clicks on Facebook every day; Google processes more than 24PT data every day, and more than 400 million micro blog posts appear on Twitter every day. In the era of big data, the communication power of the media cannot be ignored, and it will play a better role in the disclosure of food safety information.

Big data needs to be effectively used with the help of new technological means to reflect its own stronger decision-making power, observational powers, and integration of large-scale, fast-growing, and diversified assets [11, 12]. It is not a single technology presentation but a technology group composed of a variety of different forms, different functions, and different architectures, including data collection and storage, data screening and processing, data analysis and prediction, data mining and integration, and data results display [13]. It analyzes massive amounts of data to obtain products and services with great value and deep insights [14]. Big data has four characteristics: super large data scale, fast data flow, diverse data types, and low value density [15]. Based on these characteristics, big data will have new advantages when participating in the operation of the media in food safety information disclosure. First of all, big data promotes the innovation of media types, promotes media integration, and jointly completes the dissemination of the disclosure content through all media in the food safety information disclosure. In the era of big data, the boundaries of media types are increasingly blurred, and they are integrated with each other to form an all-media communication method. Media content can be freely converted between multiple media, which provides a more flexible medium for food safety information disclosure. Second, big data has promoted the innovation of media content and changed the way that mass media content is constructed. In the era of big data, the media can use a variety of technical means to capture user information such as identification number (ID), password, web pages browsed, and stay time and then through a large number of users across platforms, devices, and applications. The integration of data behavior is through dynamic tracking and correlation analysis, the analysis and comparison of these information, the audience’s natural attributes (demographic characteristics, region, and time) and social attributes (hobbies, consumption habits, and interpersonal relationships), and the behavior preferences of the audience when receiving media information [16]. In this way, big data can help the mass media to realize the intelligent matching of the audience’s needs, complete the precise positioning of the audience, and, by choosing appropriate communication methods, construct a reasonable and appropriate communication content, realize the accurate communication of food safety information disclosure, and enhance the mass media’s communication effectiveness. Moreover, in the process of FSID (food safety information disclosure), the use of data to analyze and demonstrate food safety information and food safety incidents, instead of just relying on superficial occurrences, can increase the credibility of the media and enable the audience to trust more in food safety [17]. Third, big data technology facilitates the collection and analysis of audience feedback, which is conducive to better play the role of mass media supervision.

Based on the technical background of big data, this article focuses on the communication effectiveness and authenticity of the mass media and, based on this, builds an evolutionary game theory model, analyzes the interaction mechanism of the tripartite game between the media, government supervision departments, and food companies in the process of food safety information disclosure, demonstrates the value of media participation in FSID, and explores how to use big data to make media accurately reach more audiences.

2. Multiagent Evolutionary Game Construction of Food Safety Information Disclosure in the Era of Big Data

2.1. Model Description. In the era of big data, the communication power of the media has been continuously strengthened and is more precise, and the role of the mass media in the disclosure of food safety information has become increasingly apparent. Based on the role of the mass media as a "watchkeeper" and considering the authenticity and accuracy of information disseminated by the mass media in the context of big data, this paper takes China as an example to construct an evolutionary game model for stakeholders in food safety information disclosure. The three-party game relationship is shown in Figure 1.

As shown in Figure 1, food safety information disclosure involves four main stakeholders: the government, the food companies, the public, and the mass media. The media, government departments, and food companies constitute the main body of information disclosure, and the public is the audience of food safety information disclosure. Therefore, this model mainly considers the interaction mechanism of the government, food companies, and mass media. The public is limited by their own ability to entrust the right to supervise food safety to relevant government departments. Through the use of administrative power, the government regularly discloses food safety information to the society to maintain market order. However, due to the complexity of "unified" supervision, it is difficult for relevant government departments to disclose food safety information in a timely and effective manner. With the development of big data technology, the disclosure of food safety information by the mass media has become an effective supplement to government disclosure. The mass media uses big data to collect information about food safety in a professional way and discloses it to consumers objectively. To a certain extent, it can alleviate the information asymmetry in the food trading market, supervise the supervision of government departments, and affect public purchases. Decisions, in turn, affect the market share and profits of food companies. However, in the face of the massive information brought by the era of big data, the mass media is affected by factors such as their own interests, and exaggerated and inaccurate reports are not uncommon. Exaggerated and inaccurate reports can lead to misleading the public and food companies. Thus, the food industry will have a bad influence, and the mass media will also face the risk of losing credibility. Therefore, the government needs to regulate and guide the mass media, improve the authenticity and accuracy of information disclosed, and reduce social costs.

2.2. Model Symbol Description. Based on the above-mentioned tripartite evolutionary game relationship diagram, this paper sets the strategic space of relevant government regulatory agencies as {supervision, no supervision}, in which the proportion of selected supervision is $x\,(0 \le x \le 1)$; the strategic space of the food business group is set as {true disclosure, false disclosure}, where the proportion of food companies that choose true disclosure is $y\,(0 \le y \le 1)$; the strategic space of the mass media group is set to {accurate and realistic reports, exaggerated and inaccurate reports}, of which the proportion of the mass media groups who choose to report in reality is $z\,(0 \le z \le 1)$. Through the analysis of the game focus, the main parameters involved in the evolutionary game of the three subjects in the food safety information disclosure are shown in Table 1.

2.3. Model Assumptions

Hypothesis 1. The government supervision department groups, food company groups, and mass media groups participating in the game are all rationally bounded. They learn and imitate continuously in the dynamic game process and finally reach a stable state. It should be noted that the behavioral norms of the participating subjects are affected by many factors such as social systems and culture. This article takes the subjects involved in food safety information disclosure under the national conditions in China as the research object. It studies the interactive mechanism of the participating subjects in information disclosure.

Hypothesis 2. This article assumes that all food companies will actively disclose food safety information to the society. Companies that produce high-quality food will truly disclose food safety information, while companies that produce low-quality food will hide unfavorable information and disclose false food safety information to the public. Because of the particularity of food, it is difficult for the public to identify some internal attributes that are invisible to the naked eye, such as whether it contains harmful additives and whether the source of the food is contaminated. Therefore, food companies that falsely disclose due to poor quality production are not exposed. The former and the real disclosure of high-quality production of food companies have the same income. Because the true disclosure of food safety information requires companies to pay more effort and cost, it is shown as $C_{f_1} > C_{f_2}$.

Hypothesis 3. Food safety issues are the focus of social attention. It is assumed that the mass media will spontaneously increase their attention to food safety issues and disclose food safety information of inferior manufacturers to the public [18]. Because the mass media with exaggerated and inaccurate reports failed to conduct thorough investigations, their reporting costs are lower than the reporting costs of the mass media when they report accurately, which is $C_{m_1} > C_{m_2}$. In addition, because exaggerated and inaccurate public reports can attract the public's attention and generate more clicks, the income of the mass media's accurate and true disclosure of food information is lower than the income of exaggerated and inaccurate disclosure of food safety information, which is $R_{m_1} > R_{m_2}$. However, the be-

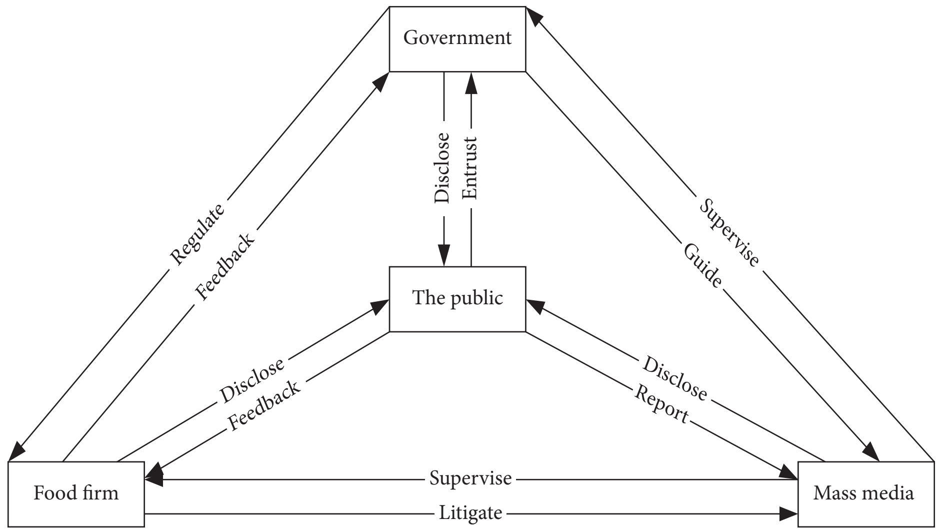

Figure 1: Tripartite evolutionary game diagram.

Table 1: Symbols and meanings.

Symbols	Symbol meaning and description
x	Based on the probability of serious supervision by government regulators; $1-x$ is the probability of nonfalse disclosure regulation.
y	Based on the probability of true disclosure among food enterprise groups; $1-y$ is the probability of false disclosure.
z	The probability of accurate and realistic coverage by mass media groups; $1-z$ is the probability of exaggerated and inaccurate reporting.
R_g	The reputation gain is dependent on the government carefully supervising the timely and correct disclosure of food safety information.
C_g	The government does not supervise the timely and correct disclosure of food safety information; reputational damage arises from food safety issues.
C_g'	Because of mass media reports, the exaggerated and inaccurate safety information disclosure of high-quality produced food caused reputational damage to the government.
	Because of the exaggerated and inaccurate reports by the mass media, the rumors cause damage to the government.
C_{g_1}	The total cost of government is the oversight of food safety markets.
	The profit depends on the food enterprises when the quality production is truly disclosed.
R_{f_0}	The profit depends on the food enterprises before safety information is exposed due to false disclosure of inferior production.
C_f	Food enterprises make false disclosure because of inferior production; reputation loss when food safety information is exposed by the media (decline in brand influence).
C_f'	When the quality production of food enterprises is truly disclosed, the reputation of the enterprises will be damaged due to the rumors generated by the exaggerated and inaccurate reports of mass media.
C_{f_1}	The cost is dependent on the true disclosure of high-quality products produced by food enterprises.
C_{f_2}	The cost is dependent on the false disclosure when a food company produces inferior products.
C_{f_3}	The economic loss of food enterprises is dependent on when food insecurity information is exposed (sales to reduce, consumer claim, losses from product recalls).
P_f	A fine paid by a food enterprise to the regulatory authorities is dependent on after its false disclosure of food safety information was exposed by the media.
R_{m_1}	The profit of accurate food safety information reporting is dependent on the mass media.
R_{m_2}	The benefit of exaggerated and inaccurate reporting of food safety information is dependent on the mass media.
C_{m_1}	The cost of accurately reporting food safety information is dependent on the mass media.
C_{m_2}	The cost of exaggerated and inaccurate reporting of food safety information is dependent on mass media.
R_m	Reputation gain is dependent on when the mass media accurately and faithfully reports the food safety information of inferior production.
C_m	Reputation loss is dependent on when mass media exaggerates and misreports food safety information of poor quality production.
P_m	A fine paid by the government is dependent on when an exaggerated or inaccurate report is reported by the mass media.
α	Reputational impact factor is dependent on the attention of event due to the application of big data (the reputation of all parties changes in the impact).

havior of the mass media to exaggerate and misrepresent food safety information may expose them to the risk of being eliminated by the market. Therefore, the reputation loss of exaggerated and misrepresented food safety information is not less than the reputation benefit of true and accurate disclosure, which is $R_m - C_m \leq 0$. At the same time, the Chinese government, as a service-oriented government, aims to maximize social welfare and will resolutely perform its duties. Assuming that the government's food regulatory agency fulfills the regulatory responsibilities, it can always disclose food safety information in a timely and correct manner and punish problem companies, which will increase government credibility; if the government does not carefully supervise the information and the problematic food safety information is reported by the mass media, it will have a negative impact on the government's credibility. The government will then penalize the problematic enterprises in order to make up for the fault.

Hypothesis 4. Due to consumer misreporting or unfair competition in the same industry, the mass media may disclose relevant issues out of a sense of social responsibility and may make exaggerated and false reports on the safety information of high-quality produced food that is truly disclosed. At this time, the exaggeration is false. The impact of reports on the reputation of the mass media is negligible. The mass media needs a strong sense of social responsibility and scientific literacy in order to report accurately and truthfully on food safety issues [19]. Therefore, this article assumes that the mass media's accurate disclosure of poor-quality food safety information will affect the public's judgment on the media's reputation. Exaggerated and false reports of truly disclosed high-quality production food safety information will have negative reputational effects on the government and enterprises, C_g' and C_f', respectively, and at this time, the reputation impact on the two parties is less than the reputation loss caused by the government's nonregulation and the company's poor quality production, which are $C_g' < C_g$ and $C_f' < C_f$.

Hypothesis 5. The application of big data is becoming more and more extensive. With the help of big data to realize the personalized customization of user news content and news feed form, this will undoubtedly increase the public's attention to news events. The higher the attention of news events, the greater the impact on the reputation changes of all parties. Therefore, this article mainly uses the influence factor α for the reputation of all parties to reflect the impact of the authenticity and accuracy of mass media food safety information disclosure in the context of big data. It assumes the reputation impact factor in the context of big data as $\alpha > 1$.

2.4. Establishment of Multiagent Game Model. Based on the game relationship diagram of government regulatory agencies, food companies, and mass media and the above basic assumptions, it is concluded that the mass media in the food safety information disclosure in the era of big data chooses accurate and practical strategies and exaggerated and inaccurate strategies. The income matrix is shown in Tables 2 and 3.

From the above income matrix, we can see the expected income of the government by choosing the regulatory strategy U_{g_1}. The expected income of choosing the non-regulatory strategy U_{g_2} and the expected income U_g of the government group are

$$\begin{aligned} U_{g_1} &= U_{g_1}\left(\alpha R_g - C_{g_1}\right) + y(1-z)\left(\alpha R_g - C_{g_1} - \alpha C_g' + P_m\right) + y(1-y)\left(\alpha R_g - C_{g_1} + P_f\right) + (1-y)(1-z)\left(\alpha R_g - C_{g_1} + P_f + P_m\right) \\ &= \alpha R_g - C_{g_1} + P_f + P_m - y\alpha C_g' - yP_f + yz\alpha C_g' - zP_m, \end{aligned} \tag{1}$$

$$\begin{aligned} U_{g_2} &= y(1-z)\left(-\alpha C_g'\right) + (1-y)z\left(-\alpha C_g + P_f\right) + y(1-y)(1-z)\left(-\alpha C_g\right) \\ &= -\alpha C_g + y\alpha C_g - y\alpha C_g' + yz\alpha C_g' - yzP_f + zP_f, \end{aligned} \tag{2}$$

$$U_g = xU_{g_1} + (1-x)U_{g_2}. \tag{3}$$

Table 2: The income matrix under the mass media's selection of accurate and practical reporting strategies (z).

Government	Food company	
	True disclosure (y)	False disclosure $(1-y)$
Supervision (x)	$(\alpha R_g - C_{g_1}; R_{f_0} - C_{f_1}; R_{m_1} - C_{m_1})$	$(\alpha R_g - C_{g_1} + P_f;\ R_{f_0} - C_{f_2} - \alpha C_f - C_{f_3} - P_f;\ R_{m_1} - C_{m_1} + \alpha R_m)$
Not regulated $(1-x)$	$(0; R_{f_0} - C_{f_1}; R_{m_1} - C_{m_1})$	$(-\alpha C_g + P_f; R_{f_0} - C_{f_2} - \alpha C_f - C_{f_3} - P_f; R_{m_1} - C_{m_1} + \alpha R_m)$

The expected benefits of food companies choosing the true disclosure strategies are U_{f_1}. The expected benefits of choosing false disclosure strategies U_{f_2} and the expected benefits U_f of food business groups are

$$\begin{aligned}
U_{f_1} &= xz\left(R_{f_0} - C_{f_1}\right) + x(1-z)\left(R_{f_0} - C_{f_1} - \alpha C_f'\right) + (1-x)z\left(R_{f_0} - C_{f_1}\right) + (1-x)(1-z)\left(R_{f_0} - C_{f_1} - \alpha C_f'\right) \\
&= R_{f_0} - C_{f_1} - \alpha C_f' + z\alpha C_f', \\
U_{f_2} &= xz\left(R_{f_0} - C_{f_2} - \alpha C_f - C_{f_3} - P_f\right) + x(1-z)\left(R_{f_0} - C_{f_2} - \alpha C_f - C_{f_3} - P_f\right) \\
&\quad + (1-x)z\left(R_{f_0} - C_{f_2} - \alpha C_f - C_{f_3} - P_f\right) + (1-x)(1-z)\left(R_{f_0} - C_{f_2}\right) \\
&= R_{f_0} - C_{f_2} - x\left(\alpha C_f - C_{f_3} - P_f\right) - (1-x)z\left(\alpha C_f + C_{f_3} + P_f\right), \\
U_f &= yU_{f_1} + (1-y)U_{f_2}.
\end{aligned} \tag{4}$$

The expected benefits of food companies choosing true disclosure strategies are U_{m_1}, the expected benefits of choosing false disclosure strategies are U_{m_2}, and the expected benefits U_m of food business groups are

$$\begin{aligned}
U_{m_1} &= xy\left(R_{m_1} - C_{m_1}\right) + x(1-y)\left(R_{m_1} - C_{m_1} + \alpha R_m\right) + (1-x)y\left(R_{m_0} - C_{m_1}\right) + (1-x)(1-y)\left(R_{m_0} - C_{m_1} + \alpha R_m\right) \\
&= R_{m_1} - C_{m_1} + \alpha R_m - y\alpha R_m, \\
U_{m_2} &= xy\left(R_{m_2} - C_{m_2} - P_m\right) + x(1-y)\left(R_{m_2} - C_{m_2} - \alpha C_m - P_m\right) + (1-x)y\left(R_{m_2} - C_{m_2}\right) + (1-x)(1-y)\left(R_{m_2} - C_{m_2} + \alpha R_m\right) \\
&= R_{m_2} - C_{m_2} - \alpha C_m - xP_m + y\alpha C_m, \\
U_m &= zU_{m_1} + (1-z)U_{m_2}.
\end{aligned} \tag{5}$$

According to the evolutionary game replication dynamic equation method, formulae (1) and (2) can be combined to obtain the replication dynamic equation selected by the government supervision strategy:

$$F_g(x) = \frac{dx}{dt} = x(1-x)\left[\alpha R_g + \alpha C_g - C_{g_1} + P_f + P_m - y\left(P_f + \alpha C_g\right) - z\left(P_f - yP_f + P_m\right)\right]. \tag{6}$$

Similarly, the dynamic equations for the selection of food safety information disclosure strategies of food companies and the selection of mass media reporting strategies are as follows:

$$F_f(y) = \frac{dy}{dt} = y(1-y)\left[C_{f_2} - C_{f_1} + \alpha C_f' + x\left(\alpha C_f + C_{f_3} + P_f\right) + (1-x)z\left(\alpha C_f + C_{f_3} + P_f\right) + z\alpha C_f'\right], \tag{7}$$

$$F_m(z) = \frac{dz}{dt} = z(1-z)\left[R_{m_1} - R_{m_2} + C_{m_2} - C_{m_1} + \alpha\left(R_m + C_m\right) + xP_m - y\alpha\left(R_m + C_m\right)\right]. \tag{8}$$

Table 3: The income matrix under the mass media's choice of exaggerated and inaccurate reporting strategies $(1-z)$.

Government	Food company	
	True disclosure (y)	False disclosure $(1-y)$
Supervision (x)	$(\alpha R_g - C_{g_1} - \alpha C_g' + P_m; R_{f_0} - C_{f_1} - \alpha C_f'; R_{m_2} - C_{m_2} - P_m)$	$(\alpha R_g - C_{g_1} + P_f + P_m; R_{f_0} - C_{f_2} - \alpha C_f - C_{f_3} - P_f; R_{m_2} - C_{m_2} + \alpha C_m - P_m)$
Not regulated $(1-x)$	$(-\alpha C_g'; R_{f_0} - C_{f_1} - \alpha C_f'; R_{m_2} - C_{m_2})$	$(-\alpha C_g; R_{f_0} - C_{f_2}; R_{m_2} - C_{m_2} - \alpha C_m)$

3. Evolutionary Game Analysis

3.1. Analysis of the Evolution Stability of Government Strategy. According to the stability theorem of the differential equation, when the government selects a strategy that satisfies $F_g(x) = 0$, and its first derivative is less than 0 ($F_g'(x) < 0$), the strategy is an evolutionary stable strategy of the government.

To the government's replicated dynamic equation (6), the first derivative with respect to x is

$$F_m'(x) = (1-2x)\left[\alpha R_g + \alpha C_g - C_{g_1} + P_f + P_m - y\left(P_f + \alpha C_g\right) - z\left(P_f - yP_f + P_m\right)\right]. \quad (9)$$

Based on different value ranges, we will analyze the stability of government supervision strategies.

To facilitate analysis, assume $z_0 = (\alpha R_g + \alpha C_g - C_{g_1} + P_f + P_m - y(P_f + \alpha C_g))/P_f + P_m - yP_f$.

(1) When $z = z_0$, $\forall x \in [0,1]$, there is $F_g(x) = 0$, that is, any proportions of behavioral strategies in the government group are stable strategies. At this time, the government's choice of the supervision strategy will not change over time.

(2) When $z \neq z_0$, then $x = 0$ and $x = 1$ are two possible evolutionary stable equilibrium points.

If $z_0 < 0$, then $\alpha R_g - C_{g1} + (1-y)P_f + P_m < -\alpha C_g + y\alpha C_g$, there are always $z > z_0$, $F_g'(0) < 0$, and $F_g'(1) > 0$, and $x = 0$ is an evolutionary stable strategy by copying the stability theorem of the dynamic equation, that is, when the net income of the government choosing supervision is lower than the net income of nonregulation, the bounded rational government supervision department will choose not to supervise the strategy.

If $z_0 > 1$, then $\alpha R_g + \alpha C_g - C_{g_1} + P_f + P_m - y(P_f + \alpha C_g) > P_f + P_m - yP_f$, that is, $\alpha R_g + \alpha C_g - C_{g_1} - y\alpha C_g > 0$, and there will always be $z < z_0$. Since $F_g'(0) > 0$, $F_g'(1) < 0$, and $x = 1$ are an evolutionary stable strategy, at this time, the net income of serious supervision by the government is greater than the net income of nonregulation, and the government's penalties for problematic food companies and the mass media for exaggerated and false reports are not considered. When the net income is still greater than the unregulated net income, bounded rational government regulatory agencies will choose a regulatory strategy.

When $0 < z_0 < 1$, there are two situations. First, when it is $0 < z_0 < z < 1$, after long-term evolution, the government tends to adopt a nonregulatory strategy. Second, as the reputation of government supervision increases, the cost of supervision decreases, the penalties for the mass media for falsely disclosing food companies and exaggerated and inaccurate reports increase, and the negative impact of nonregulation of food safety issues on government credibility increases. Then, it will be $0 < z < z_0 < 1$ situations when the government group strategy changes from nonregulation to regulation.

It can be seen that the choice of government supervision strategy is not only affected by the strategy of food companies and mass media, but also by the reputation gained by government supervision, reputation loss after nonregulation of food safety issues, and supervision costs, and the risk of false disclosure of food companies and exaggerated and false reports are influenced by factors such as the punishment of the mass media. It is worth noting that the application of big data has increased the degree of attention to food safety incidents, which in turn affected the government's strategic choices for food safety information disclosure and promoted the transformation of the government to a service-oriented government.

3.2. Analysis of the Evolution Stability of Food Companies. In the same way, to the food companies' replicated dynamic equation (7), the first derivative with respect to y is

$$F_f'(y) = (1-2y)\left[C_{f_2} - C_{f_1} + \alpha C_f' + x\left(\alpha C_f + C_{f_3} + P_f\right) + (1-x)z\left(\alpha C_f + C_{f_3} + P_f\right) + z\alpha C_f'\right]. \quad (10)$$

Based on different range values, the evolutionary stability analysis of the recycling processor strategy is now performed.

Assuming $x_0 = (C_{f_2} - C_{f_1} + \alpha C_f' - z(\alpha C_f + C_{f_3} + P_f) + z\alpha C_f')/(\alpha C_f + C_{f_3} + P_f - z(\alpha C_f + C_{f_3} + P_f))$ and guarantee the existence of x_0.

(1) At $x = x_0$, $\forall y \in [0,1]$, there are $F_f(y) = 0$, that is, the behavioral strategies of any proportion of the food company group are stable strategies. In this case, the food safety information disclosure strategy selection of the food company will not change over time.

(2) When $x \neq x_0$, then $y = 0$ and $y = 1$ are two possible evolutionary stable equilibrium points.

If $x_0 < 0$, $C_{f_1} - C_{f_2} + \alpha C_f' - z\alpha C_f' < z(\alpha C_f + C_{f_3} + P_f)$, always have $x > x_0$. Because of $F_f'(0) > 0$ and $F_f'(1) < 0$, at this time, $y = 1$ is an evolutionary stable strategy. When the sum of the cost saved by the false disclosure of food companies and the reputation risk cost of high-quality food companies due to media exaggerated and inaccurate reports is lower than the risk of exposure due to false disclosure of food information and due to the production of low-quality food, food companies will choose to increase production quality and then choose the true disclosure of food safety information. Through the above formula, it is not difficult to find that whether the mass media choosing accurate and realistic reports has an important influence on the strategic choices of food companies and the application of big data technology in news reports deepens this influence.

If $x_0 > 1$, then $C_{f_1} - C_{f_2} + \alpha C_f' - z\alpha C_f' > z(\alpha C_f + C_{f_3} + P_f)$ and $C_{f_1} - C_{f_2} + \alpha C_f' - z\alpha C_f' > \alpha C_f + C_{f_3} + P_f$, there is always $x < x_0$. Because $F_f'(0) < 0$ and $F_f'(1) > 0$, so $y = 0$ are evolutionary stable strategies. That is to say, the cost saved by the false disclosure of information by food companies is greater than the loss caused by the exposure of false disclosure of food information due to the production low quality, so food companies will choose false disclosure strategies.

If $0 < x_0 < 1$, it can be divided into two situations. First, when $0 < x < x_0 < 1$, after a long period of evolution, food companies tend to adopt false disclosure strategies; second, with the reduction in cost savings of food companies' false disclosure of food safety information, the reduction in the loss of reputation caused by the mass media's exaggerated and inaccurate reports on food companies that truly disclose food companies, and the increase in the loss of companies' false disclosures, the probability of food companies choosing true disclosure strategies increases. When $0 < x < x_0 < 1$, the behavioral strategy of food companies will shift from false disclosure to true disclosure, thereby promoting the healthy development of the food safety market.

Therefore, the strategic choices of food companies are not only affected by government and mass media strategies, but also by the cost savings of falsely disclosing food safety information, the reputation loss caused by exaggerated and inaccurate reports to true disclosure companies, and the impact of false disclosure of food safety information on production due to poor quality production. Through the above analysis, it can be found that the choice of mass media reporting strategies has an important impact on the choice of food companies' strategies, and the duality of the application of big data to the supervision of corporate food safety information disclosure can also be verified in the above discussion; that is, it has increased accurate and effective reporting which affects the reputation of those falsely disclosing companies and expands the negative impact of exaggerated and false reports on those companies that truly disclose.

3.3. Analysis of the Evolution Stability of Mass Media.

In the same way, to the mass media' replicated dynamic equation (8), the first derivative with respect to z is

$$F_m'(z) = (1 - 2z)\left[R_{m_1} - R_{m_2} + C_{m_2} - C_{m_1} + \alpha(R_m + C_m) + xP_m - y\alpha(R_m + C_m)\right]. \tag{11}$$

Now, according to different value ranges, the stability analysis of the mass media evolution strategy is carried out.

Assume $y_0 = (R_{m_1} - R_{m_2} + C_{m_2} - C_{m_1} + \alpha(R_m + C_m) + xP_m)/(\alpha(R_m + C_m))$.

(1) When $y = y_0$, $\forall z \in [0,1]$, there are $F_m(z) = 0$, that is, any proportions of behavioral strategies in the mass media group are stable strategies. At this time, the strategic choice of the mass media will not change over time.

(2) When $y \neq y_0$, then $z = 0$ and $z = 1$ are two possible evolutionary stable equilibrium points.

If $y_0 < 0$, then $R_{m_1} - C_{m_1} + \alpha R_m < R_{m_2} - C_{m_2} - \alpha C_m - xP_m$, there is always $y > y_0$. Because of $F_m'(0) < 0$ and $F_m'(1) > 0$, at this time, $z = 0$ is an evolutionary stable strategy. When the mass media accurately and effectively reports that the net income of companies that falsely disclose food safety information is lower than the net income of exaggerated and misrepresented food safety information companies, the mass media groups will choose the strategy of exaggerated and misreported reports.

If $y_0 > 1$, then $R_{m_1} - C_{m_1} + \alpha R_m > R_{m_2} - C_{m_2} - \alpha C_m - xP_m$ and $R_{m_1} - C_{m_1} > R_{m_2} - C_{m_2} - xP_m$, there is always $y < y_0$. At this time, $F_m'(0) > 0$ and $F_m'(1) < 0$, so $z = 1$ are evolutionary stable strategies. That is to say, when the net income of the mass media from accurately and realistically reporting food safety information is higher than the net income from exaggerating and inaccurate reporting of food safety information, the mass media groups will choose accurate and practical reporting strategies.

If $0 < y_0 < 1$, it can be divided into two situations. First, when $0 < y_0 < y < 1$, after long-term evolution, the mass media tends to exaggerate and misrepresent reporting strategies; second, with the increase in the net income of the mass media's accurate and effective reporting, the decrease in the net income of exaggerated and inaccurate reporting, the increase in reputation gains/losses due to accurate/exaggerated and false reporting, the increase in government supervision, and the mass media's choice of exaggeration, the probability of misreporting strategies is reduced; when $0 < y < y_0 < 1$, the behavioral strategies of the mass media will change from exaggerated and inaccurate reports to realistic and accurate reports.

The choice of the mass media strategy is not only affected by government strategies and food business strategies, but also by factors such as the cost/benefit of accurate and realistic/exaggerated false reports, the profit/cost of accurate and realistic/exaggerated false reports, and government penalties. The positive effect of big data application in regulating the behavior of mass media is reflected in the above analysis, that is, it not only increases the reputation benefits of accurate and realistic reporting of enterprises, but also increases the reputation cost of exaggerated and false reports by mass media. The application of big data can improve the social responsibility of the mass media and regulate the development of the industry.

3.4. Stability Analysis of System Evolution Strategy. Combining equations (6)–(8) together, the three-dimensional copying power system of the government, food companies, and mass media can be obtained as

$$\begin{cases} F_g(x) = x(1-x)\left[\alpha R_g + \alpha C_g - C_{g1} + P_f + P_m - y\left(P_f + \alpha C_g\right) - z\left(P_f - yP_f + P_m\right)\right], \\ F_f(y) = y(1-y)\left[C_{f_2} - C_{f_1} - \alpha C_f' + x\left(\alpha C_f + C_{f_3} + P_f\right) + (1-x)z\left(\alpha C_f + C_{f_3} + P_f\right) + z\alpha C_f'\right], \\ F_m(z) = z(1-z)\left[R_{m_1} - R_{m_2} + C_{m_2} - C_{m_1} + \alpha\left(R_m + C_m\right) + xP_m - y\alpha\left(R_m + C_m\right)\right]. \end{cases} \quad (12)$$

Let in formula (12), $F_g(x) = F_f(y) = Fz(z) = 0$, and it is easy to get 8 pure strategy partial equilibrium points $E_1(0,0,0), E_2\ (1,0,0), E_3(0,1,0), E_4\ (0,0,1), E_5(1,1,0), E_6(1,0,1), E_7(0,1,1)$, and $E_8(1,1,1)$ and 1 mixed strategy stable equilibrium point $E_9 = (x^*, y^*, z^*)$. For $E_9 = (x^*, y^*, z^*)$, it is established true if and only if $0 \le x^*, y^*, z^* \le 1$, among them:

$$\begin{cases} x^* = \dfrac{C_{f_1} - C_{f_2} + \alpha C_f' - z^*\left(\alpha C_f + C_{f_3} + P_f\right) - z^*\alpha C_f'}{\alpha C_f + C_{f_3} + P_f - z^*\left(\alpha C_f + C_{f_3} + P_f\right)}, \\ y^* = \dfrac{R_{m_1} - C_{m_2} + C_{m_2} - C_{m_1} + \alpha\left(R_m + C_m\right) + x^* P_m}{\alpha\left(R_m + C_m\right)}, \\ z^* = \dfrac{\alpha R_g + \alpha C_g - C_{g_1} + P_f + P_m - y^*\left(P_f + \alpha C_g\right)}{P_f + P_m - y^* P_f}. \end{cases} \quad (13)$$

According to research by Ritzberger and Weibull [20], three-party evolutionary game analysis only needs to analyze the stability of the above eight equilibrium points. Following Friedman's method, the Jacobian matrix is used to perform local stability analysis on 8 stable points to obtain the evolutionary stability strategy, and the Jacobian matrix of the system is

$$J = \begin{bmatrix} \dfrac{\partial F_g(x)}{\partial x} & \dfrac{\partial F_g(x)}{\partial y} & \dfrac{\partial F_g(x)}{\partial z} \\ \dfrac{\partial F_f(y)}{\partial x} & \dfrac{\partial F_f(y)}{\partial y} & \dfrac{\partial F_f(y)}{\partial z} \\ \dfrac{\partial F_f(z)}{\partial x} & \dfrac{\partial F_f(z)}{\partial y} & \dfrac{\partial F_f(z)}{\partial z} \end{bmatrix} = \begin{bmatrix} J_{11} & J_{12} & J_{13} \\ J_{21} & J_{22} & J_{23} \\ J_{31} & J_{32} & J_{33} \end{bmatrix}. \quad (14)$$

Substituting the eight equilibrium points into the Jacobian matrix (14), the eigenvalues of the Jacobian matrix corresponding to the equilibrium points can be obtained as shown in Table 4.

According to the judgment method of the evolutionary stable strategy, when the Jacobian matrix eigenvalues of a certain equilibrium point are all nonpositive, the strategy is an evolutionary stable strategy.

According to Hypothesis 2, there is a difference between the cost of truly disclosing food safety information and false disclosure of food safety information by food companies, that is, $C_{f_1} > C_{f_2}$, so $-(C_{f_2} - C_{f_1} - \alpha C_f') > 0$; therefore, $E_3(0,1,0)$ cannot be an evolutionary strategy. According to the different levels of perfection of the food safety information disclosure mechanism in the market, this paper divides it into two different development stages: development stage $E_2(1,0,0)$ and mature stage $E_8(1,1,1)$. The following two stages will analyze the levels separately.

In the development stage, it must be satisfied that $\lambda_1^{E_2}$, $\lambda_2^{E_2}$, and $\lambda_3^{E_2}$ are all nonpositive, which is satisfied $\alpha R_g - C_{g_1} + P_f + P_m > \alpha C_g$, $C_{f_2} + \alpha C_f + C_{f_3} + P_f < C_{f_1} + \alpha C_f'$, and $R_{m_1} - C_{m_1} + \alpha R_m < R_{m_2} - C_{m_2} - \alpha C_m - P_m$. At this time, the total benefits of government supervision of falsely disclosing companies and cracking down on the mass media of exaggerated and inaccurate reports are greater than the total benefits of nonregulation of food safety issues; the sum of the cost of food companies' false food safety disclosure and the food companies' losses after exposure is lower than the sum of the company's true disclosure of food safety information costs, and the sum of the reputation losses caused by media is exaggerated and misrepresented reports; in addition, in the face of problem companies, the total revenue of accurate and realistic reports by the mass media is less than the total revenue of exaggerated and false reports. Therefore, as the leader of the food safety information disclosure mechanism, the government will actively supervise the food safety market. However, based on the principle of maximizing their own interests, food companies and mass media groups, respectively, choose to falsely

Table 4: Jacobian matrix eigenvalues.

Equilibrium point	Eigenvalues λ_1	Eigenvalues λ_2	Eigenvalues λ_3
$E_1\,(0,0,0)$	$\alpha R_g + \alpha C_g - C_{g_1} + P_f + P_m$	$C_{f_2} - C_{f_1} - \alpha C_f'$	$R_{m_1} - R_{m_2} + C_{m_2} - C_{m_1} + \alpha(R_m + C_m)$
$E_2\,(1,0,0)$	$-(\alpha R_g + \alpha C_g - C_{g_1} + P_f + P_m)$	$C_{f_2} - C_{f_1} - \alpha(C_f - C_f') + C_{f_3} + P_f$	$R_{m_1} - R_{m_2} + C_{m_2} - C_{m_1} + \alpha(R_m + C_m) + P_m$
$E_3\,(0,1,0)$	$\alpha R_g - C_{g_1} + P_m$	$-(C_{f_2} - C_{f_1} - \alpha C_f')$	$R_{m_1} - R_{m_2} + C_{m_2} - C_{m_1}$
$E_4\,(0,0,1)$	$\alpha R_g + \alpha C_g - C_{g_1}$	$C_{f_2} - C_{f_1} + \alpha C_f + C_{f_3} + P_f$	$-[R_{m_1} - R_{m_2} + C_{m_2} - C_{m_1} + \alpha(R_m + C_m)]$
$E_5\,(1,1,0)$	$-(\alpha R_g - C_{g_1} + P_m)$	$-(C_{f_2} - C_{f_1} - \alpha C_f' + \alpha C_f + C_{f_3} + P_f)$	$R_{m_1} - R_{m_2} + C_{m_2} - C_{m_1} + P_m$
$E_6\,(1,0,1)$	$-(\alpha R_g - \alpha C_g - C_{g_1})$	$C_{f_2} - C_{f_1} + \alpha C_f + C_{f_3} + P_f$	$-[R_{m_1} - R_{m_2} + C_{m_2} - C_{m_1} + \alpha(R_m + C_m) + P_m]$
$E_7\,(0,1,1)$	$\alpha R_g - C_{g_1}$	$-(C_{f_2} - C_{f_1} + \alpha C_f + C_{f_3} + P_f)$	$-(R_{m_1} - R_{m_2} + C_{m_2} - C_{m_1})$
$E_8\,(1,1,1)$	$-(\alpha R_g - C_{g_1})$	$-(C_{f_2} - C_{f_1} + \alpha C_f + C_{f_3} + P_f)$	$-(R_{m_1} - R_{m_2} + C_{m_2} - C_{m_1} + P_m)$

disclose food safety information and exaggerate and misrepresent food safety issues.

In addition, it can be seen from the above analysis that the application of big data has different effects on different subjects. For the government, big data plays a positive role in promoting the government's fulfillment of its regulatory responsibilities; for food companies, the application of big data has two sides. It will not only increase the supervision of problem companies, but also increase the degree of harm to "injure" companies. For the mass media, big data has a positive effect on improving the accuracy and authenticity of reports.

With the enhancement of government supervision, the proportion of food companies choosing to truly disclose food information continues to increase, and mass media groups are gradually increasing the proportion of accurate and practical reports under government regulations. The food safety information disclosure mechanism continues to improve to a mature stage $E_8\,(1,1,1)$, satisfying $\alpha R_g > C_{g_1}$, $C_{f_2} + \alpha C_f + C_{f_3} + P_f > C_{f_1}$, and $R_{m_1} - C_{m_1} > R_{m_2} - C_{m_2} - P_m$. That is, when the reputation benefits obtained by government supervision are higher than the cost of government supervision, the sum of the cost of food companies' false disclosure of food safety information and the loss after being exposed by the media is higher than the cost of companies' true disclosure of safety information; and in the face of truly disclosed food companies, when the net income of the mass media's true reports is higher than the net income of false reports, the government will play its leading role in food safety information disclosure and choose to supervise the food market. Food companies will choose to improve food quality based on their own interests and then truly disclose food safety information. The mass media will play their complementary role in food safety disclosure and choose accurate and practical reporting strategies. It is worth noting that in the mature stage of the food safety information disclosure mechanism, the negative impact of the application of big data on food companies disappears. Through the analysis of the two stages, it can be seen that the choice of the mass media reporting strategy mainly depends on the level of net income of different strategies. This conclusion can be fully proved by the comparative analysis of $E_5\,(1,1,0)$ and $E_8\,(1,1,1)$. Therefore, in order to give full play to the role of the mass media as a "watchkeeper," it is necessary to increase the net income of accurate and realistic reports by the mass media and at the same time reduce the net income of exaggerated and inaccurate reports through government regulations and guidance measures.

4. Conclusions and Recommendations

The above research shows that mass media plays an important role in the disclosure of food safety information and influences the strategic choice of government regulators and food enterprises. Both in line with their own interests, maximization principle, and mass media social responsibility, positive real information disclosure will be beneficial to food safety supervision and management. To participate in the game of government regulators, food companies and media have a positive development; on the other hand, false information disclosure can make the three parties lose the trust of the audience and have loss of economic benefits and their reputation. Therefore, starting from the Chinese nation, the government should strengthen the supervision of the mass media to avoid false information; food enterprises should actively cooperate with the mass media to improve the strength and scope of information disclosure; the mass media itself should strengthen media literacy where true information shall be disclosed to put an end to false information. Although disparate countries will affect the government's regulatory actions and efforts due to their different political systems, the participation of big data in media communication will enhance the effectiveness of the mass media's participation in food safety information disclosure. In this case, both positive and negative effects will be amplified. Therefore, rationally and maximally playing the positive role of big data in mass media can double the value of mass media in food safety information disclosure, bringing maximum benefits to the three parties in the game and also ensuring food safety to the maximum extent.

First: using big data to segment the audience to achieve accurate communication. Accurate communication requires mass media to carefully divide audiences into different groups according to their psychological characteristics, interest preferences, and psychological preferences and output different communication contents for different groups. The segmentation of audience needs to rely on big data for user research, such as searching and browsing traces of Internet users or viewing data on video platforms. In the process of food safety information disclosure, the accurate push of different disclosure content according to different user needs can increase the public's interest in reading and improve the reading rate of the disclosed contents, and at the same time, different push times can be set for different audiences. All these measures can improve the efficiency of food safety information disclosure.

Second: choosing the media reasonably. In the era of big data, the media preference of the audiences can be accurately calculated, and mass media that are closer to their reading preferences can be adopted. In addition, the concept of Omnimedia is widely used in the selection of media. Omnimedia can be regarded as a new mode of media operation. It integrates content production and form and is a comprehensive application of traditional media and new media. Any two or more media can freely convert to each other. In the food safety information disclosure, the disclosure can use their data analysis system for food safety information as well as collecting and monitoring public preferences, choosing the reasonable mass media in the production process to push, and later in the use of the Internet platform to accept their reading feedback and use the feedback to adjust disclosure content.

Third: optimizing the communication content. On the premise of audience segmentation, the subject of food safety information disclosure needs to customize differentiated communication content and produce accurate communication content for different audiences. In the process of content production, attention should also be paid to content processing to make the disclosed content more effective and more in line with the audience's aesthetic taste under the guidance of big data. In terms of content expression, it should be designed according to the ideological consciousness, cultural leveling, and cognitive ability of different audiences, so that the disclosure of food safety information can improve the communication efficiency and encourage more people to accept it.

Despite theoretical and managerial contributions of this study, there are still limitations.

In different countries, due to political, historical, cultural, and other factors, the unity of opposition between government supervision, mass media communication, and factory disclosure is complicated and cannot be generalized. In this article, we only adopt a method suitable for China's national conditions to establish an analysis of the model. However, this does not mean that our topic does not have universal value. These elements can still be harmonized with each other to achieve a beneficial state for the proposition of food safety. Therefore, this article can be expanded from the following directions in the future: (1) based on the differences in social environment, studying the role of media in food safety information disclosure in the era of big data under different social environment backgrounds, conducting comparative analysis, proposing strategies more suitable for the development of China, and improving the food safety supervision system and strengthening food safety management. (2) Studying this issue based on the perspective of the global supply chain, enhancing the international influence of Chinese media, and at the same time enhancing the international competitiveness of food companies, and providing the world with effective Chinese solutions.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by the Shanghai Philosophy and Social Fund Project (grant no. 2019EWY010); "Chenguang Program" supported by Shanghai Education Development Foundation and Shanghai Municipal Education Commission (grant no. 15CG73); and "Qimingxing" Research Project by Shanghai Business School (grant no. 18KY-PQMX-15).

References

[1] J. Spink, D. C. Moyer, H. Park et al., "Introducing food fraud including translation and interpretation to Russian, Korean, and Chinese languages," *Food Chemistry*, vol. 189, pp. 102–107, 2015.

[2] S. Charlebois, A. Schwab, R. Henn, and C. W. Huck, "Food fraud: an exploratory study for measuring consumer perception towards mislabeled food products and influence on self-authentication intentions," *Trends in Food Science & Technology*, vol. 50, pp. 211–218, 2016.

[3] H. Hu, *Research on Food Safety Information Disclosure System of China*, Jiangnan University, Wuxi, China, 2016.

[4] G. A. Akerlof, "The market for "lemons": quality uncertainty and the market mechanism," *The Quarterly Journal of Economics*, vol. 84, no. 3, pp. 488–500, 1970.

[5] X. Liu, "On the improvement of the efficiency of China's food safety information disclosure system," *Journal of Jiangsu University*, vol. 14, pp. 89–92, 2012.

[6] H. Spencer and J. Caswell, "Food safety regulation: an overview of contemporary issues," *Food Policy*, vol. 24, pp. 589–603, 1999.

[7] X. Ni, j. Shen, and S. Shen, "Improvement and analysis on China's current food safety information disclosure system," *Journal of Food Safety and Quality*, vol. 5, pp. 2940–2947, 2014.

[8] M. Zhang, H. Qiao, M.-z. Pu, Z.-j. Yu, and F.-t. Zheng, "The third-party regulation on food safety in China: a review," *Journal of Integrative Agriculture*, vol. 14, no. 11, pp. 2176–2188, 2015.

[9] D. P. Yu and L. Zhang, *General Theory of Communication*, Tsinghua University Press, Beijing, China, 2008.

[10] G. Jie, *Study on the Guidance of Public Opinion in Emergency Events in the Age of Big Data—From the Perspective of Changing Discourse Right in Agenda-Setting*, Chongqing University, Chongqing, China, 2013.

[11] M. Wessler, *Big Data Analytics for Dummies*, John Wiley & Sons Inc, Hoboken, NJ, USA, 2013.

[12] ZhangXueyi and C. Peng, "Philosophical reflection on big data technologies," *Science & Technology Progress and Policy*, vol. 33, pp. 130–134, 2016.

[13] Pierre·Bourdieu, *An Invitation to Reflexive Sociology*, University of Chicago Press, Chicago, IL, USA, 1992.

[14] J. Manyika, M. Chui, B. Brown et al., *Big Data: The Next Frontier for Innovation, Competition, and Productivity*, The Mc Kinsey Global Institute, Las Vegas, NV, USA, 2013.

[15] V. Mayer-Schonberger and K. Cukier, *Big Data: A Revolution that Will Transform How We Live, Work, and Think*, Eaman Dolan/Houghton Mifflin Harcourt, Boston, MA, USA, 2013.

[16] F. Liu, "On precision advertising in big data era and its communication strategy," *Journal of Puer University*, vol. 34, pp. 83-84, 2018.

[17] V. Mayer-Schonberger and K. Cukier, *Big Data: A Revolution that Will Transform How We Live, Work, and Think*, Hodder & Stoughton, London, UK, 2013.

[18] Y. Cao, Y. Zheng, and G. Wan, "Evolution game study," *Chinese Journal of Management Science*, vol. 25, pp. 179–187, 2017.

[19] P. Yuan, "Food safety media reporting strategies," *China Publishing Journal*, vol. 14, pp. 14–17, 2014.

[20] K. Ritzberger and J. W. Weibull, "Evolutionary selection in normal-form games," *Econometrica*, vol. 63, no. 6, p. 1371, 1995.