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Research Article

The Impact of Food Quality Information Services on Food Supply Chain Pricing Decisions and Coordination Mechanisms Based on the O2O E-Commerce Mode

Xiaoqiu Yu [1] and Xiaoxue Ren [2]

[1] *School of Science, Heilongjiang Bayi Agricultural University, Daqing 163319, China*
[2] *School of Economics and Management, Heilongjiang Bayi Agricultural University, Daqing 163319, China*

Correspondence should be addressed to Xiaoqiu Yu; 64992117@qq.com

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This paper considers the price conflict problem between the online channel of a food processing factory and the offline channel of the food retailers in food supply chains by analyzing the pricing decisions and coordination mechanisms between the food processing factory and food retailers under the influence of a food quality information service. First, the Stackelberg game method and the Bertrand game method are used to optimize the pricing decisions with the goal of maximizing the profits of the food processing factory and retailer. The analysis shows that the food quality information service level is positively correlated with the price of the factory's own channel, and the influence of the food quality information service level on the price of the food processing factory's or the food retailer's own channel is stronger than its influence on the price of a competitor's channel. Second, the food supply chain members' pricing decisions are analyzed using the case analysis method by considering practical problems in the food supply chain. The results indicate that the food processing factory should use the Stackelberg game to make pricing decisions. However, it is optimal for the food retailer to make pricing decisions under the Bertrand game, and the total profit of the food supply chain is optimized under centralized decision making. Finally, we use both the quantitative discount mechanism and the Stackelberg game method to analyze the profits obtained by the food processing factory and retailer. The results indicate that the food processing factory should implement a quantitative discount mechanism when the quantity discount coefficient is greater than 0.4, and the retailer should implement a quantity discount mechanism when the quantity discount coefficient is in the range of 0.25 to 0.4.

1. Introduction

The O2O mode refers to the combination of an online channel and an offline channel. A food quality information service is an important criterion in consumers' channel selection and purchase decisions. In this article, a food quality information service is provided by members of a food supply chain to provide consumers information about food quality. Zeithaml [1] reported that such information is delivered to consumers in different ways, and food quality information services can be distinguished in terms of having practical significance or symbolic significance. There is abundant food quality information that interests consumers, including price, brand, date of manufacture, appearance, signals of quality and safety, manufacturer, production environment, storage, and media promotion. In this article, the online channel that provides consumers with food quality information is a network platform that provides consumers basic food information, such as price, brand, production date, and whether the item is being sold at a discount, while the offline channel provides consumers food quality information by allowing them to experience shopping firsthand and personally examine the freshness of the food, among other visual inputs.

A food supply chain is a network structure formed by upstream and downstream enterprises, and it includes the food production and circulation processes involved in the products or services provided to consumers. Nianyugou Wangu Processing Co., Ltd., is located in Zhaoyuan farms, Daqing city, province of Heilongjiang, China. It is a food processing factory that uses a JD e-commerce platform in its Nianyugou flagship store (online channel) to sell products; at the same time, it also uses offline physical stores

(offline channel) to sell products. Its success stems from its business philosophy, which involves the provision of services to retailers and consumers through its online and offline channels. The company aggregates consumer information obtained from food retailers and strives to respond to changes in consumer demand.

The research for this article is based on the food processing factory and a food retailer that provide food to consumers through online and offline channels, respectively. However, there are many problems in the food supply chain. On the one hand, the food quality information service level affects consumers' channel selection decision, and food retailers have a significant information advantage over the food processing factory in terms of food quality information. On the other hand, the food processing factory has a price advantage over the food retailers, resulting in price competition in the food supply chain. Therefore, this problem needs to be resolved to set reasonable sales prices and optimize and coordinate the profits in the food supply chain.

In recent years, food supply chains have experienced substantial changes [2]. Information is transmitted in a food supply chain to check the quality of the food, for example, by tracing the food upward or tracking it downward in the supply chain [3]. Moreover, the concepts of food quality information services and food safety are often viewed as two sides of the same coin [4]. Food safety has become very important for food quality information services [5, 6]. However, some authors have stated that traceability has not been implemented in systems to improve the food quality information [7]. Because of a decrease in liability claims, responsibilities along the supply chain can be precisely identified [3, 8].

Recent studies have focused on the quality, safety, and sustainability of food [9]. From a new perspective, sustainability in the food supply chain has been discussed [10–13]. Third-party certifications have facilitated patrons' evaluations of food and service quality [14]. However, the current practice of evaluating food contact surface cleanliness by sight and touch to meet regulatory requirements might be inadequate (Cunningham et al. 2017). In the food industry, food quality information is affected by food processing and logistics activities, such as transportation and packaging (Riccardo et al. 2017). Food quality depends on intrinsic and extrinsic factors, such as the storage temperature, concentration of oxygen, and relative humidity [15, 16].

The factors affecting food quality information services—customer service level and satisfaction, safety, sustainability, and cost-efficiency—are the primary targets of an effective food supply chain [17]. Food quality is significantly affected by the use of a standard (or nonstandard) container. The quality and taste of food products depend on both the food processing procedure and logistics, including transportation and packaging processes [18, 19]. The impacts of certain attributes of food service quality on consumers have been evaluated. Overall, consumers perceive that service quality attributes are more important than food quality attributes. [20]. In the food service industry, food processing factories receive food from manufacturing plants [21, 22].

Food service quality attributes, such as the wait time and the server's attentiveness and helpfulness, account for 31.8% of customers' satisfaction. Richard et al. investigated the importance of service quality in customers' selection of food products [23]. Many researchers have studied customers' satisfaction with restaurants' food services (Folinas et al. 2016). Awareness of and attitudes toward traceability in the food supply chain were examined within British small and medium-sized enterprises (SMEs) [24]. Because of the unique aspects of a hospital environment, consumers require higher food quality information when in a hospital [25]. In addition, reliable suppliers are chosen based on raw material specifications and supplier audits, thereby reducing the likelihood of contaminated products entering the market [21, 26]. However, testing must occur to verify that risk mitigation measures are working as expected. Therefore, a sampling plan must be designed [27, 28].

In summary, the literature related to this research has primarily focused on the impact of factors such as food quality, food safety, and food quality information on consumers' evaluations. However, with the development of e-commerce, food processing factories are providing consumers services through online channels, and food retailers are providing consumers services through offline channels, resulting in the online-to-offline (O2O) mode. The emergence of the O2O mode has brought the online and offline channels into competition. Therefore, the rational formulation of pricing decisions and coordination among the members of a food supply chain have become urgent problems. Based on the characteristics of a food supply chain, this paper considers a situation in which the online channel of a food processing factory cooperates with the offline channel of a food retailer to provide food quality information services.

Secondary food supply chains are based on the O2O mode. First, according to the demand function, this paper introduces the food quality information service level into the demand function, and based on transaction cost theory, the total profit function of the food processing factory, food retailer, and food supply chain is established. Second, we discuss the food supply chain's pricing decision under centralized decision making and decentralized decision making, and we obtain the optimal prices for the online and offline channels and the optimal profits for the food processing factory and food retailer. Then, we discuss the relationship between the food quality information service level and prices and profits. With the goal of optimizing the profitability of the food supply chain, we can establish a mechanism to coordinate a food supply chain quantitative discount and ensure a profitable relationship for the food processing factory and the retailer. Finally, the validity of the theoretical assumptions is verified using numerical simulations, and the coordination efficiency of the food supply chain is evaluated.

2. Materials and Methods

2.1. Model Description. Based on the supply chain management business philosophy of Nianyugou Wangu Processing Co., Ltd., this paper considers a situation in which the food processing factory is part of the food quality information services that a food retailer must review, and the food retailer

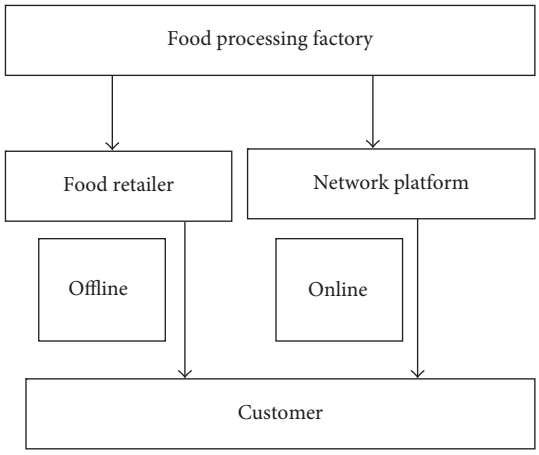

Figure 1: The structure of the food supply chain under the O2O mode.

receives the appropriate compensation, which is that the food processing factory cooperates with the food retailer in providing food quality information.

The food supply chain under the O2O mode consists of the online channel of the food processing factory and the offline channel of the food retailer. In a food supply chain dominated by a food processing factory, the food processing factory provides the food retailer with food at wholesale prices. Although the food processing factory sells its products through the food retailer's offline channel, it also sells food directly through an online channel, resulting in price conflicts between the two channels, as shown in Figure 1.

2.2. Framework of the Research Methodology. To solve the problem of the price conflict and to increase the coordination between the food processing factory and food retailers in the food supply chain, this article relies on game theory and establishes a Stackelberg game model and a Bertrand game model to determine the optimal price and profit of the two channels given the constraints. Matlab software is used to visualize the relationship between the variables.

As shown in Figure 2, first, this paper incorporates the food quality information service level into the demand function, and based on transaction cost theory, the total profit function of the food processing factory, the food retailer, and the food supply chain is established. Second, using the methods of the Stackelberg game and the Bertrand game, this paper analyzes the influence of food quality information services on price under centralized and decentralized decision making, respectively. Further, we obtain the optimal pricing decision for the food processing factory, food retailer, and food supply chain. Then, with the goal of optimizing the profitability of the food supply chain, we establish a food supply chain quantitative discount coordination mechanism. Finally, using Matlab software for a numerical simulation, we validate and optimize the relationship between the variables involved in the food supply chain.

Why did we choose these two models? When we conducted a survey among employees of Nianyugou Wangu Processing Co., Ltd., we found that the game relationship between the subjects involved in the food supply chain when making pricing decisions could be accurately reflected by the Bertrand and Stackelberg game models.

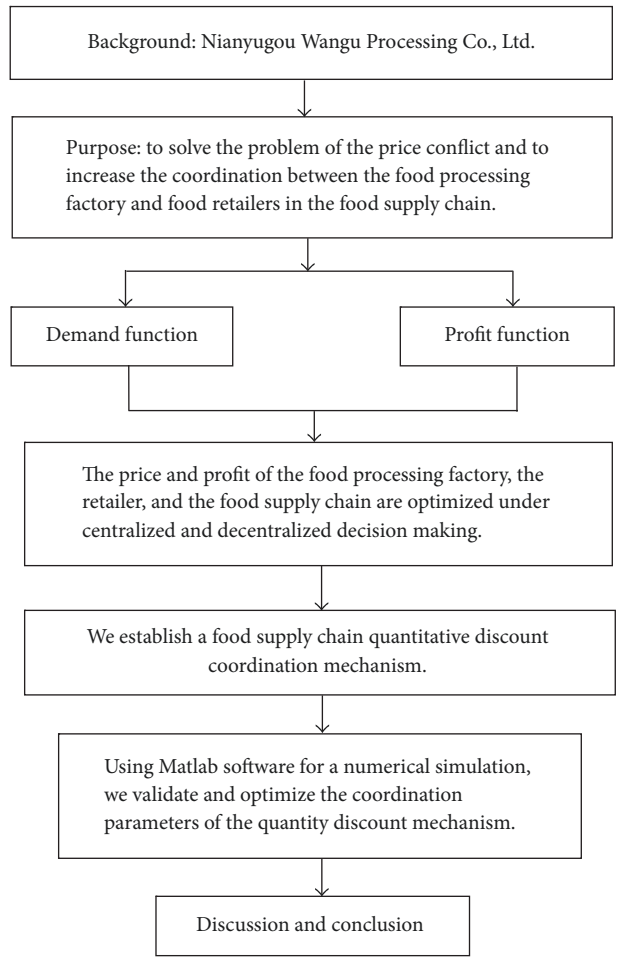

Figure 2: The roadmap of this paper.

2.2.1. Exogenous Parameters

a_i: The market size

c: The unit cost of the product

w: The wholesale price provided by the food processing factory to the food retailer

α_1: The market demand for the price level of the elasticity coefficient

α_2: The market demand for the food quality information service level of the elasticity coefficient

β_1: The market demand for the price level difference in the transfer coefficient

β_2: The market demand for the food quality information service level difference of the transfer coefficient.

2.2.2. Decision Variables

p_i: The sales price

s_i: The food quality information service level, where ($s_i \geq 0$) indicates the food quality information service level ($i = 1$, the online channel; $i = 2$, the offline channel) and $s_i = 0$, which means that food quality information services are not considered. The larger the value of s_i is, the higher the level of the food quality information service is, where ($0 < s_i \leq 5$) indicates a lower food quality information service level, ($6 < s_i < 15$) indicates a moderate food quality information service level, and ($s_i \geq 15$) indicates a high food quality information service level

η_i: The service cost coefficient of the food quality information

D_i: The demand

($i = 1$, the online channel; $i = 2$, the offline channel)

Π_i^j: The profit

where ($j = 1$, under the Bertrand game; $j = 2$ under the Stackelberg game; $j = 3$, under the centralized decision) ($i = 1$, for the food processing factory; $i = 2$, for the food retailer, and $i = 3$, for the food supply chain).

2.2.3. Contract Terms under Negotiation

k: The quantity discount coefficient.

2.3. Model Construction

Assumption 1. The wholesale price is determined by the market price.

Assumption 2. The impact of channel prices on demand is greater than the effect of price differences between the two channels. The impact of the level of a channel's food quality information service on demand is greater than the impact of the difference in the level of the food quality information service between the two channels.

Assumption 3. Assuming that the food quality information service level is certain, the food retailers' food quality information service costs are lower than the food processing factory's costs; that is, $\eta_2 < \eta_1$.

Assumption 4. The food processing factory provides consumers with food quality information services through the online channel of its own network platform, while the food retailer provides consumers with food quality information services through the offline channel.

Referring to the demand function constructed by Yao et al. [29, 30], introducing the factors of the food quality information service on demand, the linear demand function for both the online channel of the food processing factory and the offline channel of the food retailer can be expressed as follows:

$$\begin{aligned} D_1 &= a_1 - \alpha_1 p_1 + \alpha_2 s_1 + \beta_1 (p_2 - p_1) + \beta_2 (s_1 - s_2) \\ D_2 &= a_2 - \alpha_1 p_2 + \alpha_2 s_2 + \beta_1 (p_1 - p_2) + \beta_2 (s_2 - s_1). \end{aligned} \tag{1}$$

Referring to the model by Chen [31], we establish a function of the food quality information service cost as follows:

$$c(s) = \frac{\eta s^2}{2}. \tag{2}$$

The profit function of the food processing factory, the food retailer, and the total food supply chain can be expressed as follows:

$$\Pi_1 = (p_1 - c - c(s_1)) D_1 + (w - c) D_2 \tag{3}$$

$$\Pi_2 = (p_2 - w - c(s_2)) D_2 + (c(s_1) - c^*(s_1)) D_1 \tag{4}$$

$$\Pi_3 = \Pi_1 + \Pi_2, \tag{5}$$

where the cost of the food quality information service of the food processing factory, that of the food retailer, and that of the food quality information service paid for by the food processing factory are $c(s_1) = \eta_1 s_1^2/2$, $c(s_2) = \eta_2 s_2^2/2$, and $c^*(s_1) = \eta_2 s_1^2/2$, respectively.

2.4. Bertrand Game Pricing Decisions in the Food Supply Chain. The Bertrand game model conditions apply. First, there is competition between enterprises, and at the same time, the enterprises make pricing decisions. In the market, no other enterprises have entered the competition. The Bertrand game occurs without the enterprises knowing the decision behaviors of the other players, and all of the parties set their own prices to maximize profits.

The food processing factory and the retailer are of similar strength, and the parties use the decentralized decision making of the Bertrand game to maximize their own profits as the goal. The approach to solving the model is consistent with the literature [32]. The order of the Bertrand game is as follows: in the first stage, the food processing factory, to maximize its own profit, sets the online channel price; in the second stage, the food retailer, given the unknown online channel price, sets the offline channel sales price to maximize its own profit.

Referring to (3)–(5), we can construct the objective function as follows:

$$\begin{aligned} \max \Pi_1 (p_1, p_2) &= (p_1 - c - c(s_1)) D_1 + (w - c) D_2 \\ \max \Pi_2 (p_1, p_2) &= (p_2 - w - c(s_2)) D_2 \\ &\quad + (c(s_1) - c^*(s_1)) D_2. \end{aligned} \tag{6}$$

Proposition 5. *Under decentralized decision making in the food supply chain, one can solve the optimal food sales prices in the online channel and the offline channel according to the Bertrand game method. Thus, the optimal food sales prices in the online channel and the offline channel are as follows in (9):*

Let

$$\frac{\partial \Pi_1}{\partial p_1} = a_1 + \alpha_2 s_1 - (c - w - p_2)\beta_1 + (s_1 - s_2)\beta_2 + (\alpha_1 + \beta_1)\left(\frac{\eta_1 s_1^2}{2} + c - 2p_1\right) = 0. \tag{7}$$

Let

$$\frac{\partial \Pi_2}{\partial p_2} = a_2 + \alpha_2 s_2 + \beta_1\left(p_1 + \frac{\eta_1 s_1^2}{2} - \frac{\eta_2 s_1^2}{2}\right) - \beta_2(s_1 - s_2) + (\alpha_1 + \beta_1)\left(\frac{\eta_2 s_2^2}{2} - 2p_2 + w\right) = 0. \tag{8}$$

We can obtain

$$p_1^1 = \frac{C_1 s_1^2 + C_2 s_1 + C_3 s_2^2 + C_4 s_2 + C_5}{2(4\alpha_1^2 + 3\beta_1^2 + 8\alpha_1\beta_1)}$$
$$p_2^1 = \frac{D_1 s_1^2 + D_2 s_1 + D_3 s_2^2 + D_4 s_2 + D_5}{2(4\alpha_1^2 + 3\beta_1^2 + 8\alpha_1\beta_1)}, \tag{9}$$

where

$$C_1 = 2\alpha_1^2\eta_1 + 3\beta_1^2\eta_1 + 4\alpha_1\beta_1\eta_1 - \beta_1^2\eta_2$$
$$C_2 = 4\alpha_1\alpha_2 + 4\beta_2\alpha_1 + 4\beta_1\alpha_2 + 2\beta_1\beta_2$$
$$C_3 = \alpha_1\beta_1\eta_2 + \beta_1^2\eta_2$$
$$C_4 = 2\alpha_2\beta_1 - 4\alpha_1\beta_2 - 2\beta_1\beta_2$$
$$C_5 = 2\beta_1 a_2 + 4\beta_1 a_1 + 4a_1\alpha_1 + 4\alpha_1^2 c + 4\alpha_1\beta_1 c + 6\alpha_1\beta_1 w + 6\beta_1^2 w$$
$$D_1 = 3\alpha_1\beta_1\eta_1 - 2\alpha_1\beta_1\eta_2 + 3\beta_1^2\eta_1 - 2\beta_1^2\eta_2$$
$$D_2 = -4\alpha_1\beta_2^2 + 2\alpha_2\beta_1 - 2\beta_1\beta_2$$
$$D_3 = 2\alpha_1^2\eta_2 + 4\alpha_1\beta_1\eta_2 + 2\beta_1^2\eta_2$$
$$D_4 = 4\alpha_1\beta_2 + 4\alpha_1\alpha_2 + 4\beta_1\alpha_2 + 2\beta_1\beta_2$$
$$D_5 = 2\beta_1 a_1 + 4\alpha_1 a_2 + 4\beta_1 a_2 + 4w\alpha_1^2 + 2c\alpha_1\beta_1 + 6w\beta_1^2 + 8w\alpha_1\beta_1. \tag{10}$$

Furthermore, substituting (9) into (3)–(5), we derive the food processing factory's optimal profit, and the retailer's and total food supply chain's profits under the Bertrand game are as follows:

$$\Pi_1^1 = \left(p_1^1 - c - \frac{\eta_1 s_1^2}{2}\right)D_1^1 + (w - c)D_2^1 \tag{11}$$

$$\Pi_2^1 = \left(p_1^2 - w - \frac{\eta_2 s_2^2}{2}\right)D_2^1 + \left(\frac{\eta_1 s_1^2}{2} - \frac{\eta_2 s_1^2}{2}\right)D_1^1 \tag{12}$$

$$\Pi_3^1 = \left(p_1^1 - c - c^*(s_1)\right)D_1^1 + \left(p_2^1 - c - c(s_2)\right)D_2^1. \tag{13}$$

Inference 6. In the food supply chain under the O2O mode, the price is positively correlated with the food quality information service level of the channel.

$$\frac{\partial p_1^1}{\partial s_1} = \frac{\left(8\alpha_1\beta_1 + 4\alpha_1^2 + 6\beta_1^2\right)s_1\eta_1 + 2\beta_1\beta_2 - 2\beta_1^2 s_1\eta_2 + 4\alpha_1\alpha_2 + 4\alpha_1\beta_2 + 4\alpha_2\beta_1}{6\beta_1^2 + 8\alpha_1^2 + 16\alpha_1\beta_1} > 0$$
$$\frac{\partial p_2^1}{\partial s_2} = \frac{\left(4\alpha_1^2 + 4\beta_1^2\right)s_1\eta_1 + 2\beta_1\beta_2 + 8\alpha_1\beta_1\eta_1 s_2 + 4\alpha_1\alpha_2 + 4\alpha_1\beta_2 + 4\alpha_2\beta_1}{6\beta_1^2 + 8\alpha_1^2 + 16\alpha_1\beta_1} > 0. \tag{14}$$

Inference 7. In the food supply chain under the O2O mode, the food quality information service level at one channel's price is greater than that of another channel.

$$\frac{\partial P_1^1}{\partial s_1} - \frac{\partial P_2^1}{\partial s_1} = \frac{(\beta_1\eta_2 + \alpha_1\eta_1)s_1 + \alpha_2 + 2\beta_2}{2\alpha_1 + 3\beta_1} > 0$$
$$\frac{\partial P_1^1}{\partial s_2} - \frac{\partial P_2^1}{\partial s_2} = \frac{-(\beta_1\eta_2 + \alpha_1\eta_1)s_1 - \alpha_2 - 2\beta_2}{2\alpha_1 + 3\beta_1} < 0. \tag{15}$$

From the above theoretical derivation, we conclude by theoretical analysis that, in the food supply chain under the Bertrand game, the price is positively correlated with the food quality information service level of the food processing factory's or the food retailer's own channel. When the food quality information service level provided by the food retailer is certain, the price in the online channel is higher than that in the offline channel when the food quality information service level is provided by the food processing factory. In contrast, when the food quality information service level provided by the food processing factory is certain, the price in the offline channel is higher than that in the online channel when the food quality information service level is provided by the food retailer. The specific conclusions are verified by the following numerical simulation.

2.5. Stackelberg Game Pricing Decisions in the Food Supply Chain. In the Stackelberg game model for a leader and a

follower, the food supply chain in the O2O mode is shown in Figure 1; dominated by the food processing factory, the parties adopt the Stackelberg game under decentralized decision making, and both parties' goal is to maximize their own profits. The Stackelberg game has a reverse order solution. We analyzed the Stackelberg game dominated by the food processing factory. In the first stage, the food processing factory determines the wholesale price to maximize its profits. In the second stage, the food retailer, based the wholesale price determined by the food processing factory's pricing decision, formulates the offline channel price to maximize its own profits.

Referring to (3)–(5), we can construct the objective function as follows:

$$\begin{aligned}\max \Pi_2(p_1, p_2) &= (p_2 - w - c(s_2)) D_2 \\ &\quad + (c(s_1) - c^*(s_1)) D_1 \\ \max \Pi_1(p_1, p_2) &= (p_1 - c - c(s_1)) D_1 + (w - c) D_2.\end{aligned} \tag{16}$$

Proposition 8. *The food supply chain is shown in Figure 1. According to the Stackelberg method, the optimal food sales prices in the online and the offline channels are*

$$p_1^2 = \frac{E_1 s_1^2 + E_2 s_1 + E_3 s_2^2 + E_4 s_2 + E_5}{4(2\alpha_1^2 + 4\alpha_1\beta_1 + \beta_1^2)} \tag{17}$$

$$p_2^2 = \frac{F_1 s_1^2 + F_2 s_1 + F_3 s_2^2 + F_4 s_2 + F_5 + F_6}{8(2\alpha_1^2 + 4\alpha_1\beta_1 + \beta_1^2)(\alpha_1 + \beta_1)} \tag{18}$$

$$\begin{aligned}E_1 &= 2\alpha_1^2\eta_1 + 2\beta_1^2\eta_1 + 4\alpha_1\beta_1\eta_1 - \beta_1^2\eta_2 \\ E_2 &= 4\alpha_1\alpha_2 + 4\beta_2\alpha_1 + 4\beta_1\alpha_2 + 2\beta_1\beta_2 \\ E_3 &= \alpha_1\beta_1\eta_2 + \beta_1^2\eta_2 \\ E_4 &= 2\alpha_2\beta_1 - 4\alpha_1\beta_2 - 2\beta_1\beta_2 \\ E_5 &= 4\alpha_1 a_1 + 4\beta_1 a_1 + 4\alpha_1^2 c + 6c\alpha_1\beta_1 + 2\beta_1 a_2 \\ &\quad + 4w\alpha_1\beta_1 + 4\beta_1^2 w \\ F_1 &= 2\beta_1^2\alpha_1\eta_1 - 8\beta_1^2\alpha_1\eta_2 + 6\alpha_1^2\beta_1\eta_1 - 4\alpha_1^2\beta_1\eta_2 \\ &\quad + 4\beta_1^3\eta_1 - 3\beta_1^3\eta_2 \\ F_2 &= 4\alpha_2\beta_1^2 - 12\alpha_1\beta_1\beta_2 - 2\beta_1^2\beta_2 - 8\alpha_1^2\beta_2 + 4\beta_1\alpha_1\alpha_2 \\ F_3 &= 12\alpha_1^2\beta_1\eta_2 + 3\beta_1^3\eta_2 + 4\alpha_1^3\eta_2 + 11\alpha_1\beta_1^2\eta_2 \\ F_4 &= 2\beta_1^2\beta_2 + 8\alpha_1^2\alpha_2 + 16\alpha_1\alpha_2\beta_1 + 6\beta_1^2\alpha_2 + 12\alpha_1\beta_1\beta_2 \\ &\quad + 8\alpha_1^2\beta_2 \\ F_5 &= 24\alpha_1^2\beta_1 w + 6c\alpha_1\beta_1^2 + 16\alpha_1\beta_1 a_2 + 24w\alpha_1\beta_1^2 \\ &\quad + 8w\beta_1^3 \\ F_6 &= 4c\alpha_1^2\beta_1 + 8w\alpha_1^3 + 8a_2\alpha_1^2 + 4\alpha_1\beta_1 a_1 + 8\beta_1^2 a_1 \\ &\quad + 6\beta_1^2 a_2.\end{aligned} \tag{19}$$

The reverse induction method is used to solve the model. Based on the sales price in the online channel, the food retailer determines the price in the offline channel to maximize its own profit. Based on the price in the offline channel, the food processing factory sets the price in the online channel to maximize its own profit.

Let

$$\frac{\partial \Pi_2}{\partial p_2} = a_2 + \alpha_2 s_2 + \beta_1\left(p_1 + \frac{\eta_1 s_1^2}{2} - \frac{\eta_2 s_1^2}{2}\right) - \beta_2(s_1 - s_2) + (\alpha_1 + \beta_1)\left(\frac{\eta_2 s_2^2}{2} - 2p_2 + w\right) = 0 \tag{20}$$

$$p_2^S = \frac{a_2 + \beta_1 P_1 + \alpha_2 s_2 - \beta_2(s_1 - s_2) + \beta_1\left(\left(\eta_1 s_2^2/2\right) - \left(\eta_2 s_2^2/2\right)\right) + (\alpha_1 + \beta_1)\left(\left(\eta_2 s_2^2/2\right) + w\right)}{2\alpha_1 + 2\beta_1}. \tag{21}$$

Substituting (21) into (3) and substituting the response into the derivative of its profit on the price,

$$\begin{aligned}\frac{\partial \Pi_1}{\partial p_1} &= a_1 + \frac{3\alpha_1 - \beta_1}{2} p_1 + \alpha_2 s_1 \\ &\quad + \frac{\beta_2(2\alpha_1 + \beta_1)}{2(\alpha_1 + \beta_1)}(s_1 - s_2) \\ &\quad + \frac{\alpha_1(\alpha_1 + 2\beta_1)}{2(\alpha_1 + \beta_1)}\left(\frac{\eta_1 s_1^2}{2} + c\right) + \frac{\beta_1 s_2^2 \eta_2}{4} \\ &\quad + \frac{\beta_1 a_2 + \beta_1\alpha_2 s_2 + \beta_1^2\left(\left(\eta_1 s_1^2/2\right) - \left(\eta_2 s_1^2/2\right)\right)}{2(\alpha_1 + \beta_1)} \\ &\quad + \beta_1 w - \frac{\beta_1 c}{2} = 0.\end{aligned} \tag{22}$$

Furthermore, we derive the food processing factory's optimal price.

The Stackelberg game method is used to solve the optimal food sales price in the online and offline channels. According to the demand function, we obtain the demand and the optimal wholesale price.

$$w^2 = \frac{J_1 s_1^2 + J_2 s_1 + J_3 s_2^2 + J_4 s_2 + J_5}{4(\alpha_1^3 + 12\alpha_1^2\beta_1 + 8\alpha_1\beta_1^2)} \tag{23}$$

$$\begin{aligned}J_1 &= 2\alpha_1\beta_1^2\eta_2 - 2\alpha_1\beta_1^2\eta_1 - 2\alpha_1^2\beta_1\eta_1 + \alpha_1^2\beta_1\eta_2 \\ J_2 &= 2\alpha_1\alpha_2\beta_1 + 2\alpha_2\beta_1^2 - 2\alpha_1\beta_1\beta_2 - 2\alpha_1^2\beta_2\end{aligned}$$

$$\begin{aligned} J_3 &= -\alpha_1^3\eta_2 - 2\alpha_1\beta_1^2\eta_2 - 3\alpha_1^2\beta_1^2\eta_2 \\ J_4 &= 2\beta_1^2\beta_2 + 2\alpha_2\beta_1^2 + 2\beta_1^2\beta_2 + 4\alpha_1\alpha_2\beta_1 + 2\alpha_1\beta_1\beta_2 \\ J_5 &= 2\alpha_1^2 a_1 + 2\alpha_1^3 c + 2\beta_1^2 a_1 + 2\beta_1^2 a_2 + 4\alpha_1\beta_1^2 c \\ &\quad + 6\alpha_1^2\beta_1 c + 2\alpha_1\beta_1 a + 4\alpha_1\beta_1 a_2. \end{aligned} \tag{24}$$

Furthermore, we derive the optimal profit of the food processing factory, food retailer, and food supply chain under the Stackelberg game as follows:

$$\Pi_1^2 = \left(p_1^2 - c - \frac{\eta_1 s_1^2}{2}\right) D_1^2 + \left(w_1^2 - c\right) D_2^2 \tag{25}$$

$$\Pi_2^2 = \left(p_2^2 - w_2^2 - \frac{\eta_2 s_2^2}{2}\right) D_2^2 + \left(\frac{\eta_1 s_1^2}{2} - \frac{\eta_2 s_1^2}{2}\right) D_1^2 \tag{26}$$

$$\Pi_3^2 = \left(p_1^2 - c - c^*\left(s_1\right)\right) D_1^2 + \left(p_2^2 - c - c\left(s_2\right)\right) D_2^2. \tag{27}$$

Inference 9. According to the food supply chain under the O2O mode, the price is positively correlated with the food quality information service level of the food processing factory's or the food retailer's channel.

$$\begin{aligned} \frac{\partial P_1^2}{\partial s_1} &= \frac{\left(8\alpha_1\beta_1\eta_1 + 4\beta_1^2\eta_1 + 4\alpha_1^2\eta_1 - 2\beta_1^2\eta_2\right) s_1 + 4\alpha_1\alpha_2 + 4\alpha_2\beta_1 + 4\alpha_1\beta_2 + 2\beta_1\beta_2}{2\left(\alpha_1^2 + 4\alpha_1\beta_1 + \beta_1^2\right)} > 0 \\ \frac{\partial P_2^2}{\partial s_2} &= \frac{\left(24\alpha_1^2\beta_1 + 22\alpha_1\beta_1^2 + 6\beta_1^3 + 8\alpha_1^3\right)\eta_2 s_2 + 8\alpha_1^2\alpha_2 + 8\alpha_1^2\beta_2 + 16\beta_1\alpha_1\alpha_2 + 12\alpha_1\beta_1\beta_2 + 6\alpha_2\beta_1^2 + 2\beta_1^2\beta_2}{2\left(\alpha_1^2 + 4\alpha_1\beta_1 + \beta_1^2\right)} > 0. \end{aligned} \tag{28}$$

Inference 10. According to the food supply chain under the O2O mode, the food quality information service level at one channel's price is greater than that of another channel.

$$\begin{aligned} &\frac{\partial P_1^2}{\partial s_1} - \frac{\partial P_2^2}{\partial s_1} \\ &\quad = \frac{\left(6\alpha_1\beta_1^2\eta_2 + 6\alpha_1^2\beta_1\eta_1 + 4\alpha_1^2\beta_1\eta_2 + \eta_2\beta_1^3 + 4\alpha_1^3\eta_1\right) s_1 + \left(8\beta_2 + 4\alpha_2\right)\alpha_1^2 + \left(12\beta_2 + 6\alpha_2\right)\beta_1\alpha_1 + 3\beta_2\beta_1^2 + 2\beta_1^2\alpha_2}{2\alpha_1 + 3\beta_1} > 0 \\ &\frac{\partial P_1^2}{\partial s_2} - \frac{\partial P_2^2}{\partial s_2} = \frac{\left(-10\alpha_1^2\beta_1 + 7\alpha_1\beta_1^2 + \beta_1^3 + 4\alpha_1^3\right)\eta_2 s_1 - \left(4\alpha_2 + 8\beta_2\right)\alpha_1^2 - \left(6\alpha_1 + 12\beta_2\right)\beta_1\alpha_1 - 3\beta_2\beta_1^2 - \beta_1^2\alpha_2}{2\alpha_1 + 3\beta_1} < 0. \end{aligned} \tag{29}$$

We conclude through theoretical analysis that in the food supply chain under the Stackelberg game, the price is positively correlated with the food quality information service level of the food processing factory's or the food retailer's own channel. Therefore, the food processing factory and food retailer should reasonably optimize the network layout of the offline channel and continuously improve the food quality information service level, which involves optimizing the functions of different types of offline channels and improving the control level of the food quality information.

2.6. Centralized Pricing Decisions in the Food Supply Chain. The food supply chain under centralized pricing decisions (that is, the food processing factory and the retailer) aims to maximize the total supply of the food supply chain.

Referring to (3)–(5), we can construct the objective function as follows:

$$\begin{aligned} \max \Pi_{P_1} &= \left(p_1 - c - c^*\left(s_1\right)\right) D_1 \\ &\quad + \left(p_2 - c - c\left(s_2\right)\right) D_2 \end{aligned}$$

$$\begin{aligned} \max \Pi_{P_2} &= \left(p_1 - c - c^*\left(s_1\right)\right) D_1 \\ &\quad + \left(p_2 - c - c\left(s_2\right)\right) D_2. \end{aligned} \tag{30}$$

Let

$$\begin{aligned} \frac{\partial \Pi}{\partial p_1} &= a_1 - \beta_1\left(\frac{\eta_2 s_2^2}{2} - 2p_2\right) + \alpha_2 s_1 + \beta_2\left(s_1 - s_2\right) \\ &\quad + \alpha_1 c + \left(\alpha_1 + \beta_1\right)\left(\frac{\eta_2 s_2^2}{2} - 2p_2\right) = 0 \\ \frac{\partial \Pi}{\partial p_2} &= a_2 - \beta_1\left(\frac{\eta_2 s_2^2}{2} - 2p_1\right) + \alpha_2 s_1 + \beta_2\left(s_1 - s_2\right) \\ &\quad + \alpha_1 c + \left(\alpha_1 + \beta_1\right)\left(\frac{\eta_2 s_2^2}{2} - 2p_2\right) = 0. \end{aligned} \tag{31}$$

$H = \begin{bmatrix} -2b_1-2\beta_1 & 2\beta_1 \\ 2\beta_1 & -2b_1-2\beta_1 \end{bmatrix}$, as of $|H| = 4\alpha_1^2 + 8\alpha_1\beta_1 > 0$, and the first-order master $-2b_1 - 2\beta_1 < 0$, so the total profit function of the food supply chain is the concave function for p_1 and p_2. Joining the above first-order partial derivatives and solving the equation, we obtain the optimal price in the online and offline channels under centralized decision making.

Proposition 11. *Under centralized decision making in the food supply chain, the food supply chain's profit can be maximized. In this case, the pricing decision is the global optimum. Thus, the optimal food sales price in the online channel and offline channel are*

$$p_1^3 = \frac{(\alpha_1 + 2\beta_1)\alpha_1\beta_2 s_1^2 + 2(\alpha_1\alpha_2 + \alpha_1\beta_2 + \alpha_2\beta_1)s_1 + 2(\alpha_2\beta_1 - \alpha_1\beta_2)s_2 + G_1}{4\alpha_1^2 + 8\alpha_1\beta_1} \tag{32}$$

$$p_2^3 = \frac{(\alpha_1 + 2\beta_1)\alpha_1\beta_2 s_2^2 + 2(\alpha_1\alpha_2 + \alpha_1\beta_2 + \alpha_2\beta_1)s_2 + 2(\alpha_2\beta_1 - \alpha_1\beta_2)s_1 + G_2}{4\alpha_1^2 + 8\alpha_1\beta_1}, \tag{33}$$

where

$$\begin{aligned} G_1 &= 2(\alpha_1 + \beta_1)a_1 + 2\beta_1 a_2 + 2(\alpha_1 + 2\beta_1)\alpha_1 c \\ G_2 &= 2(\alpha_1 + \beta_1)a_2 + 2\beta_1 a_1 + 2(\alpha_1 + 2\beta_1)\alpha_1 c. \end{aligned} \tag{34}$$

Furthermore, we derive the optimal profits of the food processing factory, retailer, and the total food supply chain under centralized decision making:

$$\Pi_1^3 = \left(p_1^3 - c - \frac{\eta_1 s_1^2}{2}\right)D_1^3 + (w - c)D_2^3 \tag{35}$$

$$\Pi_2^3 = \left(p_2^3 - w - \frac{\eta_2 s_2^2}{2}\right)D_2^3 + \left(\frac{\eta_1 s_1^2}{2} - \frac{\eta_2 s_1^2}{2}\right)D_1^3 \tag{36}$$

$$\Pi_3^3 = \left(p_1^3 - c - c^*(s_1)\right)D_1^3 + \left(p_2^3 - c - c(s_2)\right)D_2^3. \tag{37}$$

Inference 12. Based on the food supply chain under the O2O mode, the price is positively correlated with the food quality information service level of the food processing factory's or the food retailer's channel.

$$\begin{aligned} \frac{\partial P_1^3}{\partial s_1} &= \frac{(\alpha_1 + 2\beta_1)\alpha_1\eta_2 + \alpha_1\alpha_2 + \alpha_1\beta_2 + \alpha_2\beta_1}{2\alpha_1(\alpha_1 + 2\beta_1)} > 0 \\ \frac{\partial P_2^3}{\partial s_2} &= \frac{(\alpha_1 + 2\beta_1)\alpha_1\eta_2 + \alpha_1\alpha_2 + \alpha_1\beta_2 + \alpha_2\beta_1}{2\alpha_1(\alpha_1 + 2\beta_1)} > 0. \end{aligned} \tag{38}$$

Inference 13. With the food supply chain under the O2O mode, the food quality information service level at the food processing factory's or the food retailer's own channel price is greater than that of another channel.

$$\begin{aligned} \frac{\partial P_1^3}{\partial s_1} - \frac{\partial P_2^3}{\partial s_1} &= \frac{(\beta_1\eta_2 + \alpha_1\eta_1)s_1 + \alpha_2 + 2\beta_2}{2\alpha_1 + 3\beta_1} > 0 \\ \frac{\partial P_1^3}{\partial s_2} - \frac{\partial P_2^3}{\partial s_2} &= \frac{-(\beta_1\eta_2 + \alpha_1\eta_1)s_1 - \alpha_2 - 2\beta_2}{2\alpha_1 + 3\beta_1} < 0. \end{aligned} \tag{39}$$

We conclude through theoretical analysis that in the food supply chain under centralized decision making, the price is positively correlated with the food quality information service level of the food processing factory's or the food retailer's own channel.

The conclusions can be summarized as follows. Under centralized and decentralized decision making, the online channel price of the food processing factory is positively correlated with the food quality information service level of its own channel, and the same is true for the food retailer. The results show that as the food processing factory improves the level of its food quality information service, the costs of that service will increase. Thus, the food processing factory will need to increase the sales price to compensate for the service cost, whereas the food retailer can take the opportunity to increase its price.

The food quality information service level of the food processing factory has a greater impact on the price in its own channel than on the price in the food retailer's offline channel. The same is true for the food retailer. The results show that when the level of the offline channel's food quality information service is reduced, the price in the online channel decreases. The food retailer adopts the decision to reduce the price. However, when the retailer improves the food quality information service level, the price in the offline channel increases. The food processing factory adopts the decision to increase the price.

2.7. Quantity Discount Coordination Mechanism in the Food Supply Chain. To study a food supply chain that is in effective and continuous operation with high efficiency (reasonable cost), high credit, and high quality, we choose a supply chain with the following attributes. First, based on the previously discussed conclusions, we study a food processing factory that sets its wholesale prices based on the number of wholesale products for food retailers [33]. Second, we optimize the execution of a long-term discount contract that benefits the main body of the food supply chain and maximizes its profits. Additionally, we coordinate the range of parameters to benefit the distribution between the food processing factory and food retailers. Thus, we build a food supply chain with a quantitative discount coordination mechanism.

We can establish the quantity discount mechanism of the food supply chain as follows:

$$w(k) = w - kD, \tag{40}$$

where w is the optimal value of the wholesale price of the food, D is the demand, and k is the quantity discount coefficient. The decision order is the same as with the Stackelberg game. We establish the profit objective function of the food retailer as

$$\Pi_2 = \left(p_2 - w(D_2) - \frac{\eta_2 s_2^2}{2}\right) D_2 + \left(\frac{\eta_1 s_1^2}{2} - \frac{\eta_2 s_1^2}{2}\right) D_1$$

$$\begin{aligned}\Pi_2 = {} & \left(p_2 - w - \frac{\eta_2 s_2^2}{2}\right)[a_2 - \alpha_1 p_2 + \alpha_2 s_2 \\ & + \beta_1(p_1 - p_2) + \beta_2(s_2 - s_1)] + k[a_2 - \alpha_1 p_2 \\ & + \alpha_2 s_2 + \beta_1(p_1 - p_2) + \beta_2(s_2 - s_1)]^2 + \left(\frac{\eta_1 s_1^2}{2} \right. \\ & \left. - \frac{\eta_2 s_1^2}{2}\right)[a_1 - \alpha_1 p_1 + \alpha_2 s_1 + \beta_1(p_2 - p_1) \\ & + \beta_2(s_1 - s_2)].\end{aligned} \tag{41}$$

Let

$$\begin{aligned}\frac{\partial \Pi_2}{\partial p_2} = {} & \left(p_2 - w - \frac{\eta_2 s_2^2}{2}\right)(-\alpha_1 - \beta_1) \\ & + (2k(-\alpha_1 - \beta_1) + 1) \\ & \cdot [a_2 - \alpha_1 p_2 + \alpha_2 s_2 + \beta_1(p_1 - p_2) + \beta_2(s_2 - s_1)] \\ & + \beta_1\left(\frac{\eta_1 s_1^2}{2} - \frac{\eta_2 s_1^2}{2}\right) = 0.\end{aligned} \tag{42}$$

We obtain the reaction function of the food retailer as

$$\begin{aligned} & p_2(p_1) \\ & = \frac{[a_2 + (\alpha_1 + \beta_1)(\eta_2 s_2^2/2) + w] + \beta_1 P_1 + \alpha_2 s_2 + \alpha_1((\eta_1 s_1^2/2) - (\eta_2 s_1^2/2)) - \beta_2(s_1 - s_2) - 2k(\alpha_1 + \beta_1)[a_2 + \beta_1 P_1 + \alpha_2 s_2 + \beta_2(s_2 - s_1)]}{2\alpha_1 + 2\beta_1 - 2k(\alpha_1 + \beta_1)^2}.\end{aligned} \tag{43}$$

Then, by substituting $p_2(p_1)$ into (1), we obtain the demand D_1^{QD}, D_2^{QD}.

The food processing factory optimizes the profits of the food supply chain based on the response of the food retailer.

$$\Pi_3^{QD} = \left(p_1^{QD} - c - \frac{\eta_2 s_1^2}{2}\right) D_1^{QD} + \left(p_2^{QD} - c - \frac{\eta_2 s_2^2}{2}\right) D_2^{QD}. \tag{44}$$

Substituting p_2^{QD}, D_1^{QD}, D_2^{QD} into Π_3^{QD}, let $\Pi_3^{QD}/w = 0$, $\Pi_3^{QD}/k = 0$, $\Pi_3^{QD}/P_1 = 0$:

$$p_1^{QD} = \frac{(\alpha_1 + 2\beta_1)\alpha_1\eta_2 s_1^2 + w + 2(\alpha_1\alpha_2 + \alpha_1\beta_2 + \alpha_2\beta_1)s_1 + 2(\alpha_2\beta_1 - \alpha_1\beta_2)s_2 + 2(\alpha_1 + \beta_1)a_1 + 2\beta_1 a_2 + 2(\alpha_1 + 2\beta_1)\alpha_1 c}{4\alpha_1(\alpha_1 + 2\beta_1)} \tag{45}$$

$$\begin{aligned} & p_2(p_1) \\ & = \frac{[a_2 + (\alpha_1 + \beta_1)(\eta_2 s_2^2/2) + w] + \beta_1 P_1 + \alpha_2 s_2 + \alpha_1((\eta_1 s_1^2/2) - (\eta_2 s_1^2/2)) - \beta_2(s_1 - s_2) - 2k(\alpha_1 + \beta_1)[a_2 + \beta_1 P_1 + \alpha_2 s_2 + \beta_2(s_2 - s_1)]}{2\alpha_1 + 2\beta_1 - 2k(\alpha_1 + \beta_1)^2}.\end{aligned} \tag{46}$$

We obtain the optimal wholesale price:

$$\begin{aligned} w^{QD} = {} & \frac{I_1 s_1^2 + I_2 s_1 + I_3 s_2 + I_4}{4(\alpha_1^3 + 3\alpha_1^2\beta_1^2 + 2\alpha_1\beta_1^2)} \\ & + k\frac{I_5 s_1^2 + I_6 s_1 + I_7 s_2^2 + I_8 s_2 + I_9}{4\alpha_1(\alpha_1^2 + 3\alpha_1\beta_1 + 2\beta_1^2)}\end{aligned}$$

$$I_1 = 2\alpha_1\beta_1^2\eta_2 - 2\alpha_1\beta_1^2\eta_1 - 4\alpha_1\beta_1^2\eta_1 + \alpha_1^2\beta_1^2\eta_2$$

$$I_2 = 2\alpha_1\alpha_2\beta_1 + 2\alpha_2\beta_1^2 + 2\alpha_1\beta_1\beta_2$$

$$I_3 = -2\alpha_1\beta_1\beta_2 + 2\alpha_2\beta_1^2$$

$$\begin{aligned} I_4 = {} & 4\alpha_1\beta_1^2 c + 2\alpha_1\beta_1 a_1 + 2\beta_1^2 a_1 + 2\beta_1^2 a_2 \\ & + 10\alpha_1^2\beta_1 c + 4c\alpha_1^3\end{aligned}$$

$$I_5 = -4\alpha_1\beta_1^3\eta_2 - 6\alpha_1^2\beta_1^2\eta_2 - 2\alpha_1^3\beta_1\eta_2$$

$$I_6 = 8\alpha_1\beta_1^2\beta_2 + 12\alpha_1^2\beta_1\beta_2 + 4\alpha_1^3\beta_2$$

$$I_7 = 4\alpha_1\beta_1^3\eta_2 + 10\alpha_1^2\beta_1^2\eta_2 + 8\alpha_1^3\beta_1\eta_2 + 2\alpha_1^4\eta_2$$

$$\begin{aligned} I_8 = {} & -8\alpha_1\beta_1^2\beta_2 + 12\alpha_1^2\beta_1\beta_2 - 8\alpha_1\alpha_2\beta_1^2 - 12\alpha_1^2\alpha_2\beta_1 \\ & - 4\alpha_1^3\alpha_2 - 4\alpha_1^3\beta_2\end{aligned}$$

$$I_9 = -8\alpha_1\beta_1^2 a_2 + 8\alpha_1^2\beta_1^2 c + 12\alpha_1^3\beta_1 c + 12\alpha_1^2\beta_1 a_2 + 4\alpha_1^4 c - 4\alpha_1^3 a_2. \tag{47}$$

Substituting p_1^{QD}, w into p_2, we obtain

$$p_2^{QD} = \frac{(\alpha_1 + 2\beta_1)\alpha_1\eta_2 s_2^2 + 2(\alpha_1\alpha_2 + \alpha_1\beta_2 + \alpha_2\beta_1)s_2 + 2(\alpha_2\beta_1 - \alpha_1\beta_2)s_1 + 2(\alpha_1 + \beta_1)a_2 + 2\beta_1 a_1 + 2(\alpha_1 + 2\beta_1)\alpha_1 c}{4\alpha_1(\alpha_1 + 2\beta_1)}. \tag{48}$$

At this time, $p_2^{QD} = p_2^C$. The optimal pricing of the food processing factory under the Stackelberg game is equal to the optimal price under centralized decision making. In other words, the quantitative discount mechanism enables the coordination of the food supply chain.

Proposition 14. *The food supply chain is shown in Figure 1. According to the Stackelberg game method, we analyzed the Stackelberg game dominated by the food processing factory. Thus, the profits of the food processing factory and food retailer under the Stackelberg game are*

$$\Pi_1^2 = \left(p_1^2 - c - \frac{\eta_1 s_1^2}{2}\right)D_1^2 + \left(w_1^2 - c\right)D_2^2 \tag{49}$$

$$\Pi_2^2 = \left(p_2^2 - w_2^2 - \frac{\eta_2 s_2^2}{2}\right)D_2^2 + \left(\frac{\eta_1 s_1^2}{2} - \frac{\eta_2 s_1^2}{2}\right)D_1^2. \tag{50}$$

After coordinating the food processing factory and food retailer, the profits are as follows:

$$\begin{aligned}\Pi_1^{QD} &= \left(p_1^{QD} - c - \frac{\eta_1 s_1^2}{2}\right)D_1^{QD} + \left[\left(w_1^{QD} - kD_2^{QD}\right) - c\right]D_2^{QD}\\ \Pi_2^{QD} &= \left[p_2^{QD} - \left(w_2^{QD} - kD_2^{QD}\right) - \frac{\eta_2 s_2^2}{2}\right]D_2^{QD} + \left(\frac{\eta_1 s_1^2}{2} - \frac{\eta_2 s_1^2}{2}\right)D_1^{QD}.\end{aligned} \tag{51}$$

3. Results and Discussion

Nianyugou Wangu Processing Co., Ltd., uses its own retail channel and brand, and its downstream retailer provides a variety of support services. With this system, the relationships between the supply chain partners are more stable, and a win-win effect is achieved. Therefore, we combined the success stories involving Nianyugou Wangu Processing Co., Ltd., and we make recommendations for food processing factory management.

For the parameter selection, we draw on the literature, such as Garnett et al. and Bin et al., and we analyze the actual food supply chain situation, the basic parameter values of which are given as follows:

$$\begin{aligned} a_1 &= 210,\\ a_2 &= 240,\\ c &= 4,\\ w &= 10,\\ \beta_1 &= 2,\\ \beta_2 &= 1,\\ \alpha_1 &= 4,\\ \alpha_2 &= 2,\\ \eta_1 &= 7,\\ \eta_2 &= 2.\end{aligned} \tag{52}$$

With the above theoretical deduction formula, we analyze the impact of the food quality information service level on the food processing factory's and retailer's pricing decisions under a different decision regime.

3.1. The Impact of the Level of the Online Channel's Food Quality Information Service on Price. According to (9), (17)-(18), and (32)-(33), we use $s_2 = 6$, $s_1 \in [0, 10]$, and the results are shown in Table 1. Then, Matlab software is used to graph the results (see Figure 3). We analyze the impact of the level of the online channel's food quality information service on price as follows.

As shown in Figure 3, with improvements in the food quality information service level in the online channel, the sales prices in the online channel and the offline channel will increase. Research by Bin et al. and Chen et al. concluded that the service level is positively correlated with price in the supply chain. However, we consider a very different industry application. This paper establishes the profit function of the food quality information service level under the O2O mode. We analyze the food quality information service in a food supply chain consisting of a food processing factory and a food retailer. We have verified the conclusion that the food quality information service level is positively correlated with the price. Under the Stackelberg and Bertrand games, the level of the online channel's food quality information service has a greater impact on the price in its own channel than on the price in the offline channel. Under the Stackelberg game,

Table 1: The impact of the level of the online channel's food quality information service on price.

s_1	0	1	2	3	4	5	6	7	8	9	10
p_1^B	28.2	30.26	36.06	45.6	58.89	75.91	96.69	121.2	149.5	181.5	217.2
P_2^B	49.2	50.01	52.54	56.79	62.74	70.41	79.8	90.9	103.7	118.2	134.5
p_1^S	28.38	31.34	39.59	53.13	71.97	96.1	125.5	160.3	200.3	245.6	296.2
P_2^S	50.26	50.6	51.69	53.53	56.13	59.49	63.6	68.46	74.08	80.46	87.59
p_1^C	29.19	29.94	31.69	34.44	38.19	42.94	48.69	55.44	63.19	71.94	81.69
P_2^C	31.06	31.81	33.56	36.31	40.06	44.81	50.56	57.31	65.06	73.81	87.59

Table 2: The impact of the level of the offline channel's food quality information service on price.

s_2	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
p_1^B	93.86	93.9	94.1	94.5	95.06	95.79	96.69	97.76	99	100.4	102	103.8	106.1	107.8	110.1	112.5
P_2^B	55.2	55.96	57.74	60.56	64.4	69.27	75.17	82.1	90.06	99.04	109.1	120.1	132.2	145.3	159.4	174.6
p_1^S	122.6	122.7	122.9	123.3	123.9	124.6	125.5	126.6	127.9	129.4	131	132.8	134.8	137	139.3	141.8
P_2^S	50.26	50.6	51.69	53.53	56.13	59.49	63.6	68.46	74.08	80.46	87.59	95.47	104.1	113.5	123.7	134.6
p_1^C	48.69	48.69	48.69	48.69	48.69	48.69	48.69	48.69	48.69	48.69	48.69	48.69	48.69	48.69	48.69	48.69
P_2^C	31.06	31.81	33.56	36.31	40.06	44.81	50.56	57.31	65.06	73.81	83.56	94.31	106.1	118.8	132.6	147.3

there is an optimal price for the online channel when the food quality information service level it provides is greater than the critical value of 2, and there is an optimal price for the offline channel when the food quality information service level it provides is less than the critical value of 2. The price difference between the two channels is the largest under the Stackelberg game.

3.2. The Impact of the Level of the Offline Channel's Food Quality Information Service on Price. According to (9), (17)-(18), and (32)-(33), we use $s_1 = 6$, $s_2 \in [0, 15]$, and the results are shown in Table 2. Then, Matlab software is used to graph the results (see Figure 4). We analyze the impact of the level of the offline channel's food quality information service on price as follows.

As shown in Figure 4, with improvements in the food quality information service level of the offline channel, the sales prices of both the online and offline channels increase. Therefore, the food quality information service level is positively correlated with the price of the food processing factory's and the food retailer's own channel. Moreover, the change amplitude of the price for the online channel is greater than that for the offline channel. There is an optimal price for the online channel under the Bertrand game with an improvement in the level of the offline channel's food quality information service. The price in the online channel is higher than that in the offline channel in the case of centralized decision making in which the food quality information service level provided by the offline channel is less than the critical value of 5.4, and there is a small price difference between the two channels. The price in the online channel is lower than that in the offline channel in the case of centralized decision making in which the food quality information service level provided by the offline channel is higher than the critical value of 5.4, while the price difference between the two channels is the largest.

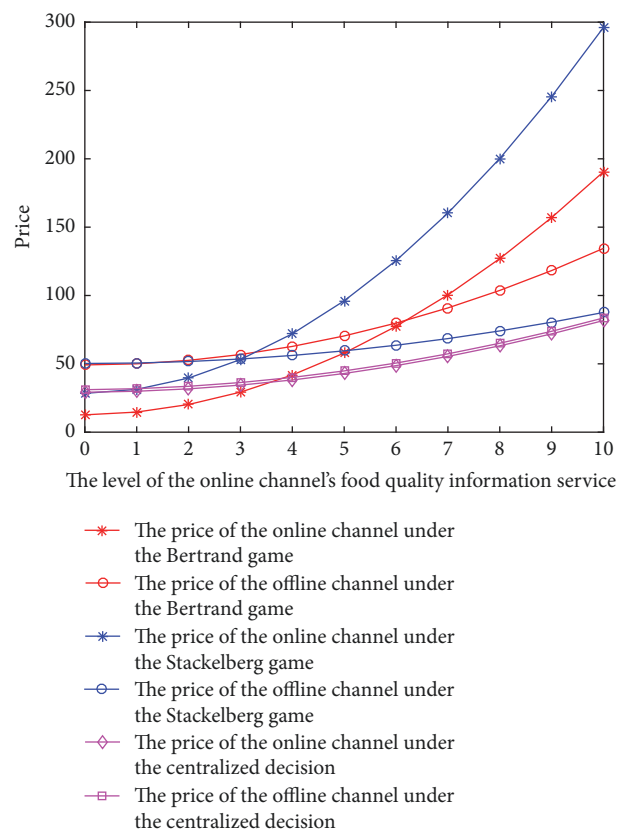

Figure 3: The impact of the level of the online channel's food quality information service on price.

Therefore, if the food processing factory and retailer want to increase their profits, they should continuously improve their level of food quality information service. At the same time, service regulations for food quality information should be adopted. On the one hand, the food retailer should

Table 3: The impact of the level of the online channel's food quality information service on the food processing factory's profit.

s_1	0	0.8	1.6	2.4	3.2	4	4.8	5.6	6.4	7.2	8	8.8	9.6
Π_1^B	1802	1562	958	218.7	−274	13.28	1766	5823	14000	25000	42000	67000	100000
Π_1^S	4279	3986	3161	1978	735.6	−141	−98.24	1541	5583	13000	25000	42000	60000
Π_1^C	3851	3543	2545	971.9	−970	−2987	−4697	−5630	−5527	−2841	2265	11000	24000

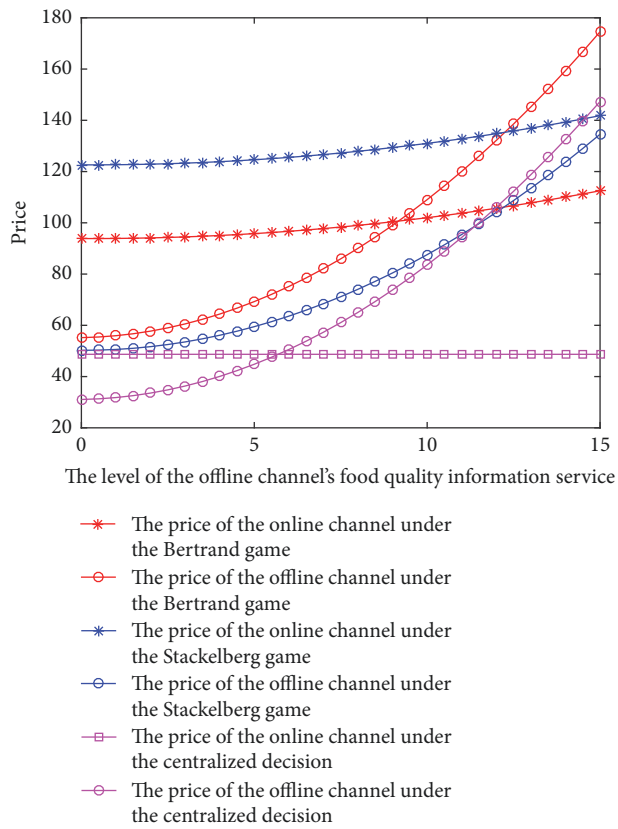

Figure 4: The impact of the level of the offline channel's food quality information service on price.

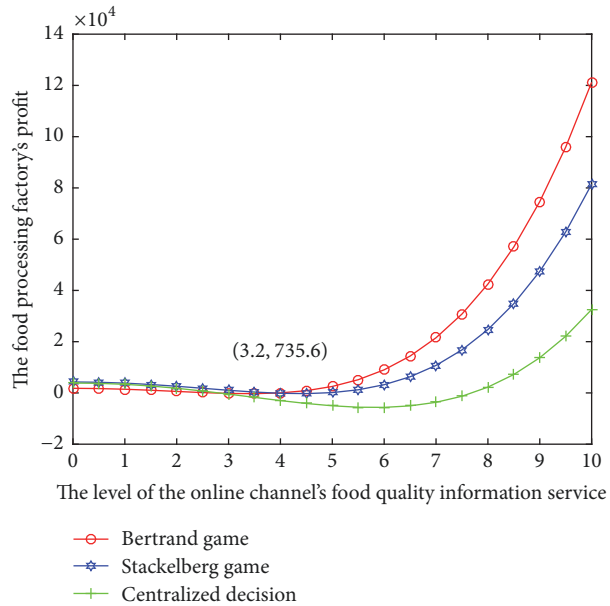

Figure 5: The relationship between the level of the online channel's food quality information service and the food processing factory's profit.

improve the filter level for the food processing factory, including both food quality information and food production information. Through the constraints of the service contract, the level of the food quality information services can be improved. On the other hand, the food processing factory should strengthen its food quality information timeliness, and through its contractual relations, the fairness and validity of the contract under the Bertrand game pricing decision in the food supply chain will improve.

3.3. The Impact of the Level of the Online Channel's Food Quality Information Service on the Food Processing Factory's Profit. According to (11), (25), and (35), we use $s_2 = 6$, $s_1 \in [0, 9.6]$. The results are shown in Table 3. Then, Matlab software is used to graph the results (see Figure 5). We analyze the impact of the level of the online channel's food quality information service on the food processing factory's profit as follows.

As seen from the inflection point in Figure 5, the food processing factory's profit is gradually reduced under the Stackelberg game and the Bertrand game when the level of the online channel's food quality information service is less than the critical value of 3.2. The food processing factory's profit gradually increases under the Stackelberg game and the Bertrand game when the level of the online channel's food quality information service is greater than the critical value of 3.2. However, the food processing factory's profit is gradually reduced under centralized decision making when the level of the online channel's food quality information service is less than the critical value of 5.6. The food processing factory's profit gradually increases under centralized decision making when the level of the online channel's food quality information service is greater than the critical value of 5.6. Compared with the three decision methods, it can be concluded that the profit is optimal when the food processing factory chooses the Stackelberg game. Therefore, it is wise for the food processing factory to compete with the food retailer under the Stackelberg game.

3.4. The Impact of the Level of the Online Channel's Food Quality Information Service on the Food Retailer's Profit. According to (12), (26), and (36), we use $s_2 = 6$, $s_1 \in [0, 3.5]$, and then we use Matlab software to graph the results (see Figure 6). We analyze the impact of the level of the online channel's food quality information service on the food retailer's profit as follows.

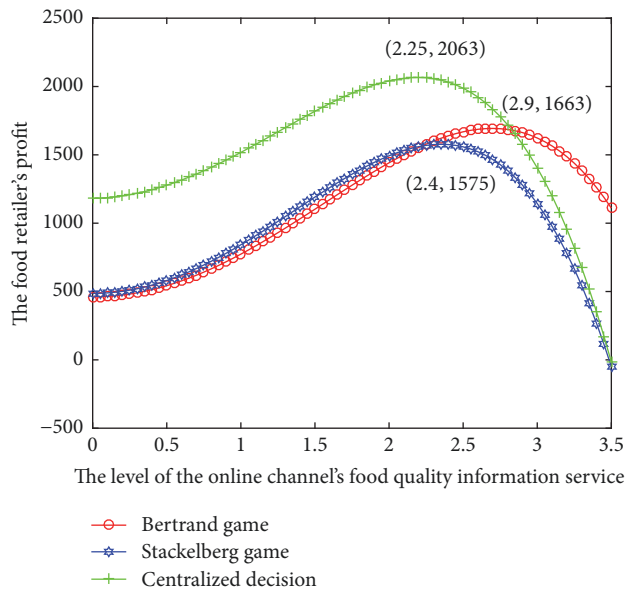

Figure 6: The relationship between the level of the online channel's food quality information service and the food retailer's profit.

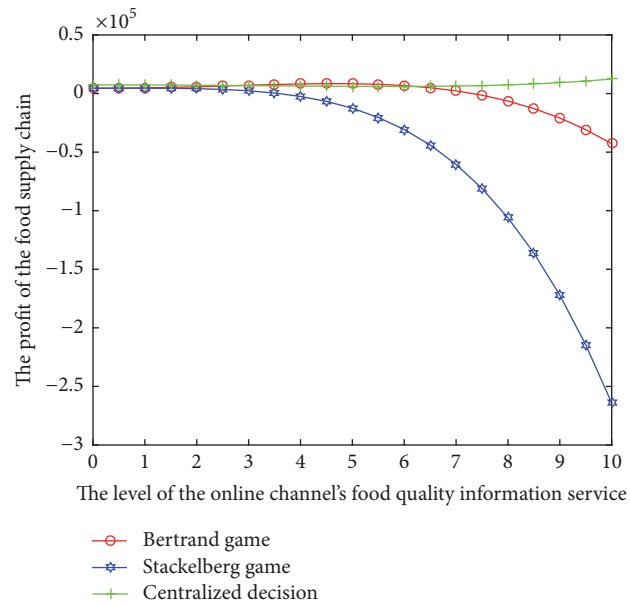

Figure 7: The relationship between the level of the online channel's food quality information service and the profit of the food supply chain.

As shown in Figure 6, the food retailer's profit is gradually reduced under centralized decision making when the level of the online channel's food quality information service reaches the critical value of 2.25. The food retailer's profit is gradually reduced under the Stackelberg game when the level of the online channel's food quality information service achieves the critical value of 2.4. However, the food retailer's profit is gradually reduced under the Bertrand game when the level of the online channel's food quality information service achieves the critical value of 2.9. Improving the level of the online channel's food quality information service exerts pressure on the food retailer. Based on the above analysis, the food retailer should choose the centralized decision making profit to achieve an optimal pricing decision.

3.5. The Impact of the Level of the Online Channel's Food Quality Information Service on the Total Profit of the Food Supply Chain. According to (13), (17), (18), (21), (23), (25), (26), (27), and (37), we use $s_2 = 6$, $s_1 \in [0, 10]$, and then we use Matlab software to graph the results (see Figure 7). We analyze the impact of the level of the online channel's food quality information service on the profit of the food supply chain as follows.

As shown in Figure 7, with improved food quality information service level of the food processing factory under decentralized decision making, the total profit of the food supply chain decreases. However, the total profit of the food supply chain gradually decreases under centralized decision making. Therefore, there is an optimal profit value in the food supply chain under centralized decision making.

In summary, when the food quality information service is provided by the online channel, the online channel's food quality information service level is positively related to the profits of the food processing factory and negatively related to those of the food retailer. At this point, the total profit of the food supply chain also decreases. As a result, the food processing factory chooses the Stackelberg game to make pricing decisions, so the food retailer should choose to make a centralized pricing decision. In other words, the online channel's food quality information service level only brings its profits, and for the retailer and the food supply chain, it is not the best decision.

Therefore, if the food processing factory wants to increase its profits, it should continuously improve the level of the food quality information service provided by the online channel. There are many shortcomings in the food quality information services provided by online channels, such as business fraud related to product information (quality), fictional product sizes, the uploading of fake photos, and other types of poor quality food information provided to consumers.

Therefore, to improve the online channel's food quality information service level in terms of technical aspects, the information in the online channel should be quantified through graded information, and data sharing with food regulatory authorities should occur to provide consumers with adequate information. Regarding delivery, the online channel improves the logistical speed and enhances consumer confidence. In terms of business strategies, we recommend providing additional information in the online food categories, such as increasing the product information for imported food products, differentiating online products from those in the offline channel, and fully discussing the online channel advantages. To improve the online food traceability system, food production and "one-vote pass" distribution should be used to make the source of food quality information traceable, to ensure that quality and safety are controllable and to improve the transparency of food quality information services and thereby increase consumer confidence.

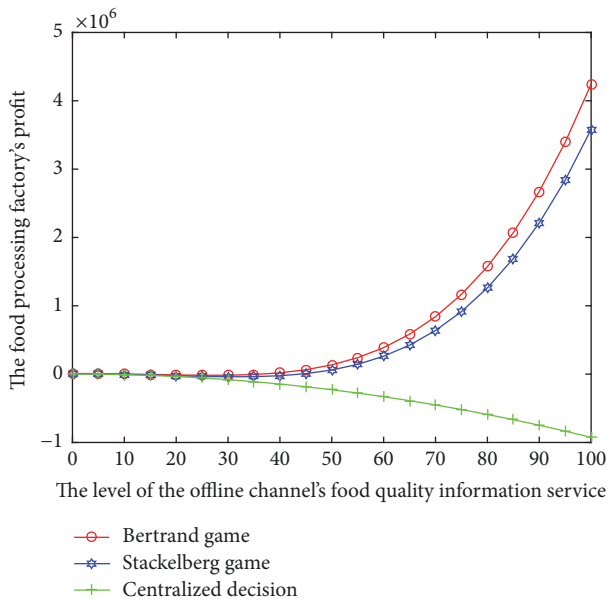

Figure 8: The relationship between the level of the offline channel's food quality information service and the food processing factory's profit.

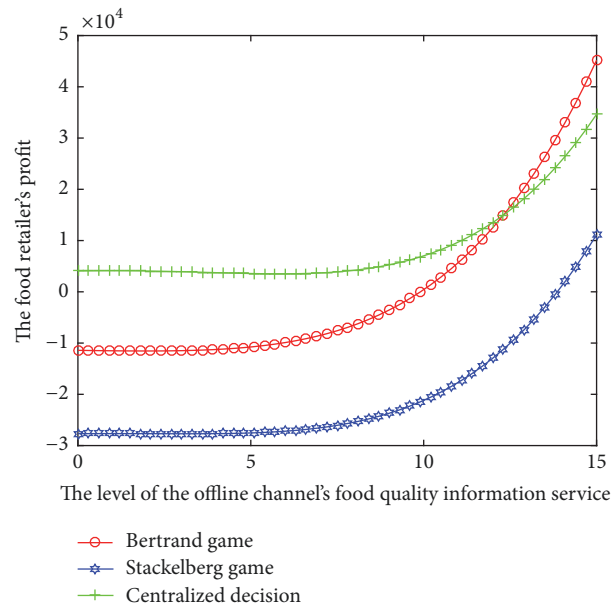

Figure 9: The relationship between the level of the offline channel's food quality information service and the food retailer's profit.

3.6. The Impact of the Level of the Offline Channel's Food Quality Information Service on the Food Processing Factory's Profit. According to (11), (25), and (35), we use $s_1 = 6$, $s_2 \in [0, 100]$, and then we use Matlab software to graph the results (see Figure 8). We analyze the impact of the level of the offline channel's food quality information service on the food processing factory's profit as follows.

In Figure 8, we see that when the food quality information service level provided by the online channel is certain, the food processing factory's profit gradually increases under decentralized decision making when the food quality information service is provided by the offline channel. In contrast, the food processing factory's profit gradually decreases under centralized decision making. Therefore, in crafting pricing strategies, the food processing factory should consider developmental changes in the level of the offline channel's food quality information service.

3.7. The Impact of the Level of the Offline Channel's Food Quality Information Service on the Food Retailer's Profit. According to (12), (26), and (36), we use $s_1 = 6$, $s_2 \in [0, 15]$, and then we use Matlab software to graph the results (see Figure 9). We analyze the impact of the level of the offline channel's food quality information service on the food retailer's profit as follows.

From Figure 9, we see that when the level of the online channel's food quality information service is certain, the food processing factory's profit gradually increases with the level of the offline channel's food quality information service. The food retailer should set the price under the Bertrand game when the level of the offline channel's food quality information service is greater than 12.3. The food retailer tends to set the price under centralized decision making when the level of the offline channel's food quality information service is less than 12.3.

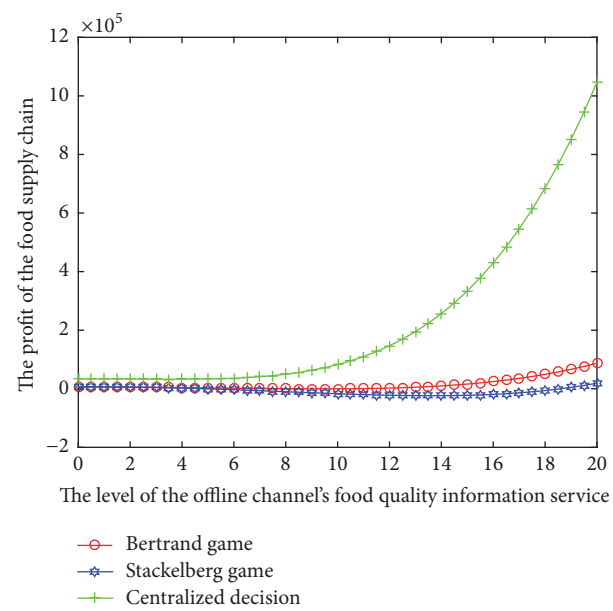

Figure 10: The relationship between the level of the offline channel's food quality information service and the total profit of the food supply chain.

3.8. The Impact of the Level of the Offline Channel's Food Quality Information Service on the Total Profit of the Food Supply Chain. Based on (13), (27), and (37), we use $s_2 = 6$, $s_1 \in [0, 10]$, and then we use Matlab software to graph the results (see Figure 10). We analyze the impact of the level of the offline channel's food quality information service on the profit of the food supply chain as follows.

As shown in Figure 10, there is an optimal profit value in the food supply chain under centralized decision making. To obtain the maximum benefit, the supply chain members should formulate their pricing strategies under centralized decision making.

Overall, when the food quality information service is provided by the offline channel, the profitability of the entire supply chain is optimal. It is optimal when the food processing factory chooses decentralized decision making and when the food retailer chooses centralized decision making. As a result, the food retailer using the offline channel to improve the food quality information services is the best decision for the entire food supply chain.

Therefore, to achieve an optimal food supply chain overall, the level of the food quality information service of the offline channel should be improved. Considering marketing strategies, the offline channel should take advantage of the nature of offline retail to meet customers' needs. For example, after the first purchase, it could improve customer experience and ensure food quality. Through the news media, it could use APP and other channels to deliver food quality information. A combination of online and offline information sources could also be used to increase the technical input and design a food quality information traceability system based on Android and QR codes to improve information sharing. At the staff level, employees should be trained in providing food quality information to enhance their understanding and to ensure accuracy and professionalism when providing such information, thus enhancing service awareness and the staff's professional ethics.

3.9. The Impact of the Quantity Discount Mechanism on the Food Retailer and the Food Processing Factory before and after Coordination. We consider the operational decisions of Nianyugou Wangu Processing Co., Ltd., which provides food retailers with a variety of discounts. The food processing factory offers returns to food retailers in the form of lower prices, which are conducive to stabilizing the partnership with downstream members of the supply chain. However, a portion of the profits of Nianyugou Wangu Processing Co., Ltd., comes from the services that it offers to retailers, which in turn enhance the profits of the food supply chain. Therefore, by examining the successful experience of Nianyugou Wangu Processing Co., Ltd., we analyze the impact of quantitative discount mechanisms on food retailers and the food processing factory using numerical examples. Then, we optimize the effective range of the quantity discount factor.

In the food supply chain under the O2O mode, the basic parameter values are as follows: $a_1 = 210$, $a_2 = 240$, $c = 100$, $\beta_1 = 2$, $\beta_2 = 1$, $\alpha_1 = 4$, $\alpha_2 = 2$, $\eta_1 = 7$, $\eta_2 = 2$.

We can compare the changes in profit for the food processing factory and food retailers before and after coordination.

Using (33), the food processing factory's profit before coordinating under the Stackelberg game is

$$\Pi_1^S = \left(p_1^S - c - \frac{\eta_1 s_1^2}{2}\right) D_1^S + \left(w_1^S - c\right) D_2^S. \tag{53}$$

The prices in the online and offline channels under the Stackelberg game are p_1^S, p_2^S, respectively; see (17) and (18), and taking p_1^S, p_2^S into (1), we can obtain the demand of the online and offline channels under the Stackelberg game, D_1^S, D_2^S, respectively. Finally, we insert the parameter values into (25) and find that the food processing factory's profit before coordination is 18354.

Using (49), the food processing factory's profit after coordination under the quantity discount mechanism is

$$\begin{aligned}\Pi_1^{QD} = &\left(p_1^{QD} - c - \frac{\eta_1 s_1^2}{2}\right) D_1^{QD} \\ &+ \left[\left(w_1^{QD} - kD_2^{QD}\right) - c\right] D_2^{QD}.\end{aligned} \tag{54}$$

The prices in the online and the offline channels under the quantity discount mechanism are p_1^{QD}, p_2^{QD}, respectively. Seeing (45) and (48) and inserting p_1^{QD}, p_2^{QD} into (1), we obtain the demand of the online and offline channels under the quantity discount mechanism D_1^{QD}, D_2^{QD}, respectively. Finally, we insert the parameter values into (49) and find that the food processing factory's profit before coordination is $5180k + 16303$.

Using (26), the food retailer's profit before coordination under the Stackelberg game is as follows:

$$\Pi_2^S = \left(p_2^S - w_2^S - \frac{\eta_2 s_2^2}{2}\right) D_2^S + \left(\frac{\eta_1 s_1^2}{2} - \frac{\eta_2 s_1^2}{2}\right) D_1^S. \tag{55}$$

The prices in the online and offline channels under the Stackelberg game are p_1^S, p_2^S, respectively; based on (17) and (18), inserting p_1^S, p_2^S into (1), we obtain the demand of the online and the offline channels under the Stackelberg game, D_1^S, D_2^S, respectively. Finally, we insert the parameter values into (33) and find that the food retailer's profit before coordination is 6688.

Using (50), the food retailer's profit after coordination under the quantity discount mechanism is

$$\begin{aligned}\Pi_2^{QD} = &\left[p_2^{QD} - \left(w_2^{QD} - kD_2^{QD}\right) - \frac{\eta_2 s_2^2}{2}\right] D_2^{QD} \\ &+ \left(\frac{\eta_1 s_1^2}{2} - \frac{\eta_2 s_1^2}{2}\right) D_1^{QD}.\end{aligned} \tag{56}$$

The prices in the online and offline channels under the quantity discount mechanism are p_1^{QD}, p_2^{QD}, respectively; using (45) and (48) and inserting p_1^{QD}, p_2^{QD} into (1), we obtain the demand of the online and offline channels under the quantity discount mechanism, D_1^{QD}, D_2^{QD}, respectively. Finally, inserting the parameter values into (50), we find that the profit of the food retailer before coordination is $-5180k + 7884$.

Based on the above results, the relationship between the profit and quantity discount coefficients before and after coordination between the food processing factory and the retailers under the Stackelberg game and the quantitative

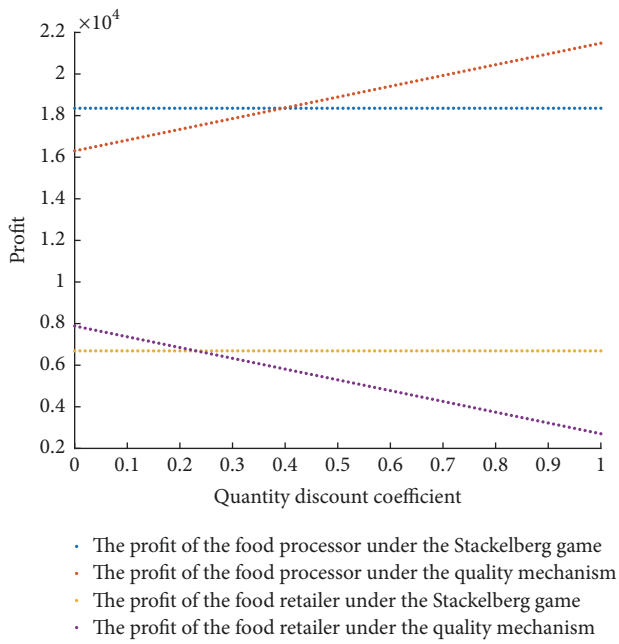

Figure 11: The relationship between profit and the quantity discount coefficients of the food retailer and the processor before and after coordination.

discount mechanism is shown in Figure 11, which is depicted graphically by Matlab software.

In Figure 11, we can observe the profit changes of the food processing factory and retailer when the quality discount coefficient has different values. The food retailer's profits decrease when the quantity of discount factors increases, and its profits are greater than the profits under the Stackelberg game. At this point in time, the profits of the food processing factory are optimized. Therefore, at this time, the coordination mechanism is effective. In fact, the food processing factory is willing to implement the volume discount mechanism as long as the profit brought by its market share resulting from the implementation of the quantity discount mechanism exceeds the price loss. The food processing factory's profits increase when the quantity of discount factors increases under the quantity discount mechanism, and when K is higher than 0.4, these profits are higher than those under the Stackelberg game. In contrast, the food retailer's profit decreases when the quantity of discount factors increases, and its profit is less than its profit under the Stackelberg game. Both 0.4 and 0.25 are critical values, and the quantity discount mechanism has advantages for both the food processing factory and the retailer. The quantity discount mechanism is effective, and the food retailer's profit is optimized. The food processing factory can share in the extra profit margins of the food retailer, which is equivalent to reducing the cost of retailers buying excess goods.

4. Conclusion

This paper analyzes the pricing coordination decisions of a food processing factory and a food retailer in a food supply chain based on the O2O mode. We also discuss the impacts of the food quality information service level on prices and profits in the food supply chain. The following conclusions are drawn based on a numerical simulation analysis.

First, we have comprehensively analyzed the impact of food quality information services on price. We observe that there is an optimal price for the food processing factory under the Stackelberg game. When the level of the offline channel's food quality information service is certain, the food quality information service level provided by the online channel is higher than the critical value. At the same time, there is an optimal price in the offline channel under the Bertrand game when the food quality information service level provided by the online channel is less than the critical value. Therefore, the food processing factory should make its price decision by adopting the Stackelberg game method, and the food retailer should make its price decision by adopting the Bertrand game method. Therefore, if the food processing factory and the retailer want to increase their profits, they should continuously improve the level of their food quality information services.

Second, we comprehensively analyze the impact of food quality information services on profits. We conclude that the food processing factory and the retailer should use centralized pricing decision making when the level of the online channel's food quality information service is certain and the level of the food quality information service provided by the offline channel is lower than the critical value. At the same time, the food processing factory and retailer should adopt the Bertrand game method and the Stackelberg game method, respectively, when the food quality information service level provided by the offline channel is higher than the critical value. Therefore, the online and the offline channels should improve the food quality information service level in terms of technology, distribution, and business strategies. Further, the reliability of information services, warehousing, and logistics is one advantage of the offline channel, but these features are often inadequate for online channels. However, efficiency, informatization, and systematization are the strengths of online channels. Hence, the two channels can strengthen their cooperation to improve the food industry.

Third, the food processing factory's profit increases when the quantity of discount factors increases under the quantity discount mechanism when K is less than 0.25, but this profit is less than that under the Stackelberg game; meanwhile, the profit of the food retailer decreases when the quantity of the discount factors increases and is higher than its profit under the Stackelberg game. The food processing factory's profit increases when the quantity of discount factors increases under the quantity discount mechanism when K is higher than 0.4, and it is higher than its profit under the Stackelberg game. In contrast, the profit of the food retailer decreases when the quantity of discount factors increases and is less than its profit under the Stackelberg game. The quantity discount coordination mechanism generally improves, and from our numerical results, we observe that a quantitative discount coordination mechanism in general can improve the profitability of the food processing factory and retailer, thereby improving the overall efficiency of the food supply chain. The value of coordinating contracts is even more pronounced

when the level of the food quality information service increases. Therefore, as the main member of the food supply chain, the food processing factory should set reasonable coordination parameters for quantitative discount mechanisms to improve the efficiency of the food supply chain.

In summary, food processing factories should reduce their food quality information service costs and cooperate with food retailers with low service costs. At the same time, food processing factories should also improve the level of their food quality information services and competitiveness and thereby provide reasonable prices and food quality information services for consumers. The members of a food supply chain must consider competitors after coordinating with the other members and then make optimal competitive decisions. The competition between several food retailers and a food processing factory will be considered in future research.

Additional Points

Practical Applications. This study could be used to aid both food processing factories and food retailers in making pricing coordination decisions under the influence of a food quality information service. The study could further help food processing factories and retailers coordinate and optimize their profits. We provide recommendations based on a reasonable range of the coordination coefficient, and we recommend that food processing factories cooperate with food retailers that provide lower-cost food quality information services.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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