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Research Article

Quality Effort Strategy of O2O Takeout Service Supply Chain under Three Operation Modes

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This paper investigates channel selection and quality effort in O2O takeout service supply chain consisting of a takeout platform, a catering business, and a distribution rider. By analyzing the three operation modes of platform distribution, business self-distribution, and business self-built platform + distribution, the profit functions of O2O takeout service supply chain members are constructed, respectively. On the basis of game theory, the optimal quality effort and profits are obtained. Combined with numerical simulation, the effects of revenue sharing rate and market size on the optimal quality effort and profits under different scenarios are discussed. The results reveal that O2O takeout platform should cooperate with more catering businesses, and adopt appropriate strategies considering different market sizes of catering businesses. Additionally, the catering business should properly consider the market size and adopt different online and offline prices. Meanwhile, the rider should choose a reasonable quality effort according to the revenue sharing rate.

1. Introduction

O2O (online to offline) takeout service, as a new mode of catering industry in the era of "Internet +," has gradually become an efficient and convenient way to choose meals in China. Especially in the special period of COVID-19, young people are more likely to choose takeout to solve their dietary problems. Referring statistical report on the development of Internet in China issued by China Internet Information Center (CNNIC) in February 2021, as of December 2020, the number of online takeout users in China had reached 419 million, an increase of 21.03 million over March 2020. With the emergence of various PC and mobile platforms, online payment functions are becoming perfect. There are many modes of operation for takeout service industry.

Takeout business is considered to be an O2O business model applied to the catering industry [1]. With its convenient and fast characteristics, it has become the first choice for many people [2]. O2O takeout refers to the food that customers place orders through the online platform; then, the restaurant prepares and packages the food, and the deliverer (rider) delivers the food provided by the restaurant offline [3]. Online takeout platforms such as "Meituan" and "Ele.me" provide takeout ordering services for people in China. Meanwhile, with Alibaba's wholly owned acquisition company of "Ele.me," the competition of O2O takeout service industry is more and more vigorous [4]. Companies with greater market demand such as McDonald's and KFC can choose offline catering. Moreover, they can cooperate with online platforms such as "Meituan" for online sales or build their own platforms for online catering services [5]. Therefore, choosing a reasonable operation mode to maximize revenue and increase market demand has become an important direction in the O2O takeout service supply chain [6].

The takeout industry brings convenience and choice to people's life, but it brings practical problems that cannot be ignored [7]. The online ordering platform "Ele.me" has been exposed to many unlicensed catering merchants using its online platform to sell catering, and some of its franchised restaurants have encountered serious food safety problems during the production process. O2O takeout service supply chain members need to be responsible for normal operation and choose reasonable service quality effort [8]. Therefore, we should pay more attention to the efforts of O2O takeout supply chain members in terms of service quality. We designed the appropriate situation considering the above description.

The objectives of this study inquire about the following questions:

(i) Which is the optimal operation mode for O2O takeout supply chain members to choose?

(ii) How will the prices of online and offline channels evolve in different operation modes?

(iii) What is the impact of revenue sharing rate on optimal decision strategy and profits of O2O takeout service supply chain members?

In general, our research has three main contributions. Firstly, combined with the characteristics and actual operation of O2O takeout service supply chain, this paper further refines the online and offline channel, increases the number of supply chain members, and tentatively analyzes the operation strategy of O2O takeout service supply chain with three supply chain members (takeout platform, catering business, and riders). Secondly, this paper takes revenue sharing rate into consideration and attempts to build three special operation modes. Furthermore, the optimal quality effort strategy and optimal profit under different operation modes are optimized and compared. Research findings would help O2O takeout supply chain members to choose the appropriate operation mode and concentrate on increasing their quality effort and profits.

We explore channel selection and quality decision in O2O takeout service supply chain considering profit sharing. The remainder of the paper is organized as follows. Section 2 reviews relevant literature. Section 3 describes the problem and the benchmark model. Section 4 solves three different decision-making models and analyzes the impacts of profit sharing on quality effort and impact factor of utility. Section 5 provides numerical simulation to demonstrate some related issues. Section 6 illustrates managerial insights of the model. Finally, conclusions and suggestions of the research are provided in Section 7. All proofs in this paper are provided in the Appendix.

2. Literature Review

2.1. Service Supply Chain. There is a lot of research that has been done on service supply chain (SSC), and it has reaped excellent fruits. The rapid development of information technology has promoted the digital transformation of the service supply chain [9]. For the logistics service supply chain, Jia et al. [10] dealt with the multistage problem of pricing and time-to-market for multigeneration products sold through an online direct channel in a service supply chain with a manufacturer and a logistics service provider. Aiming at the carbon emission reduction service supply chain, He et al. [11] investigated a service supply chain consisting of a service provider who is in charge of carbon emission reduction and service, and a service integrator who is responsible for low-carbon advertising, considering corporate social responsibility. For platform supply chain, He et al. [12]considered an e-commerce platform service supply chain consisting of a manufacturer, an e-commerce platform, and a possible third-party logistics service company. They explored the impacts of the manufacturer's channel encroachment and the e-commerce platform's logistics integration. Taking the hospitality and tourism industries as typical examples, He et al. [13] investigated three decision modes (i.e., decentralized, cost-sharing, and integrated) for the platform service supply chain. Results indicated that perceived service quality and brand image vary over time, and they gradually converge to a steady state. For the financial service supply chain, Chen et al. [14] derived the optimal ranking and production strategy with or without put options under service-level constraints. For service supply chains that focus on consumers, Ma and Hong [15] believed that retailers tend to provide presales services to attract more customers, and the services provided by retailers have a positive impact on manufacturers' sales. Meanwhile, Ma et al. [16] believed that the consumer's reference effect causes consumers to produce an "anchor mentality," which causes manufacturers and retailers to reduce quality levels. However, the existing research results are mainly explored from the perspectives of the logistics service supply chain, financial service supply chain, and so on, and there is a lack of specific research on takeout service supply chain, especially on the service quality effort of takeout service supply chain members.

2.2. Online to Offline. In the era of digital economy, online to offline (O2O) has become a rapidly developing e-commerce model all over the world. Related issues have attracted extensive attention of scholars [17]. Taking the delivery service and the inconvenience of shopping in physical stores into account, consumers can choose online or offline channels to purchase products [18]. For O2O channel selection issues, Wang et al. [19] pointed out that when consumers choose channels, they should comprehensively consider online product price, perceived product quality, and business reputation, and balance perceived product quality, business reputation, and promotion intensity. Aiming at online channels, Forghani et al. [20] discussed the impact of digital marketing strategy on customers' purchase behavior in online shopping stores. He et al. [21] believed that the online presale of fresh agricultural products can reduce the circulation loss rate, while the traditional sales channels have a huge waste in circulation. Chen and Su [22] discussed the cooperation in the consignment supply chain with complementary products under O2O mode. On the coordination of dual-channel supply chain, Hosseini-Motlagh et al. [23] firstly researched reverse supply chain systems optimization and coordination with dual-channel and demand disruptions. And then, he discussed triparty reverse supply chain coordination with competitive product acquisition process [24]. Considering the low-carbon awareness of online shoppers, Wu et al. [25] proposed a demand function of online shopping supply chain based on O2O integration. In order to improve customer experience and service satisfaction of catering O2O, Shi, et al. [26] took "Meituan" takeout as an example, integrated big data analytics, and grounded theory to explore influencing factors of catering O2O customer experience. Meanwhile, for catering O2O, Xue et al. [3] introduced a two-stage model to optimize scheduling of riders for instant food deliveries. Considering deterioration property of products in dual-channel business models, He et al. [27] studied a single-retailer-single-vendor dual-channel supply chain model in which the vendor sells deteriorating products through its direct online channel and the indirect retail channel. Scholars have conducted extensive and in-depth research on some types of O2O supply chains and reached rich research conclusions. The previous literature mainly focused on the channel selection of O2O supply chain and partially analyzed two supply chain members (manufacturers and retailers). There are few studies on different operation modes and three members of O2O supply chain. Based on the realistic background, this paper proposes three different operation modes, increases the number of supply chain members, and analyzes the O2O takeout service supply chain problems of three supply chain members (takeout platform, catering business, and rider).

2.3. Service Quality Effort. Service quality effort is the foundation and guarantee of sustainable development for SSC, and it determines the profit and performance of the whole SSC [28]. Gu et al. [29] considered a fresh product supply chain to research the optimal effort decision and pricing decision of quality effort and preservation. Yang et al. [30] considered the food supply chain and believed that the level of quality effort is very important for food safety and has positive externalities. For service quality efforts in the field of carbon emission reduction, Hosseini-Motlagh et al. [31] researched competitive channels coordination in a closed-loop supply chain based on energy-saving effort and cost-tariff contract. Hosseini-Motlagh et al. [32] indicated that coordinating the manufacturer's green quality and competing retailers' warranty periods increase the economic profitability of all supply chain members. Similarly, Sana [33] considered the income of sales projects, the cost of green quality, and the contribution of social responsibility activities, and its main goal is to find out the best price and green quality. Gupta et al. [34] studied the optimal pricing decisions and performance of multi-echelon supply chains under uncertainty by market power structure, advertising, and quality efforts. Likewise, Das Roy and Sana [35] investigated a multi-echelon green supply chain system and tried to reduce the expected integrated total cost by optimizing the investment. Moreover, Sana [36] investigated a production-inventory model and derived optimal buffer inventory to minimize the expected costs per unit item. It is assumed that the whole items are sold with free minimal repair warranty if any fault arises after sale. Ma et al. [37] investigated how quality efforts and patient concerns affect supply chain performance and the level of quality efforts of medical device manufacturers. Therefore, the previous literature on quality efforts mainly focused on food quality, carbon emission reduction, medical treatment, and other fields. There is a lack of research on the service quality efforts of O2O takeout service supply chain members, especially the specific research on the service quality efforts of rider and takeout platform.

In summary, firstly, the research content of the existing related literature mainly focuses on the logistics service supply chain, financial service supply chain, etc. There is a lack of specific research on O2O takeout service supply chain, especially on the service quality effort of the members of the takeout service supply chain. Secondly, the previous literature mainly focused on the channel selection of O2O supply chain and partially analyzed two supply chain members (manufacturers and retailers). There are few studies on different operation modes and three members of O2O supply chain. Therefore, based on the previous literature and combined with the characteristics of takeout service, this paper puts forward three different operation modes, increases the number of supply chain members, and analyzes the O2O takeout service supply chain problems of three supply chain members (takeout platform, catering business, and rider). This paper quantifies quality effort as a linear function related to market size and uses quantitative analysis methods to analyze the impact of quality effort on SSC.

3. Description of the Problem and Benchmark Model

3.1. Problem Description and Assumptions

(1) Our models consider a dual-channel takeout service supply chain for a single product. The catering business supplies the food to the consumer through a takeout platform online and sells the product directly offline. Consumers may choose the online channel or offline channel to obtain the food.

(2) The catering business has three models to choose, platform distribution model (PDM), business self-distribution model (BSM), and business self-built platform + distribution model (SDM). In PDM, riders are hired by the platform. The platform extracts the catering business's revenue sharing rate and the rider's revenue sharing rate (Figure 1). In BSM, the catering business distributes through its own capacity. The platform extracts the catering business's revenue sharing rate; the business pays the rider a fixed wage and extracts the rider's revenue sharing rate (Figure 2). In SDM, the catering business establishes its own online platform and hires riders (Figure 3).

(3) The platform determines the level of online service quality efforts, mainly involving matching algorithm, real-time accuracy of distribution information, improving the convenience of platform operation and user security, and other related services. The rider determines the delivery service quality effort level, including delivery efficiency, food integrity, and service attitude. The catering business decides on

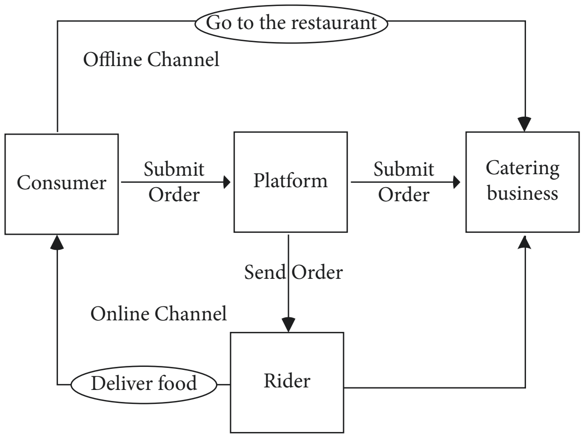

Figure 1: PDM structure.

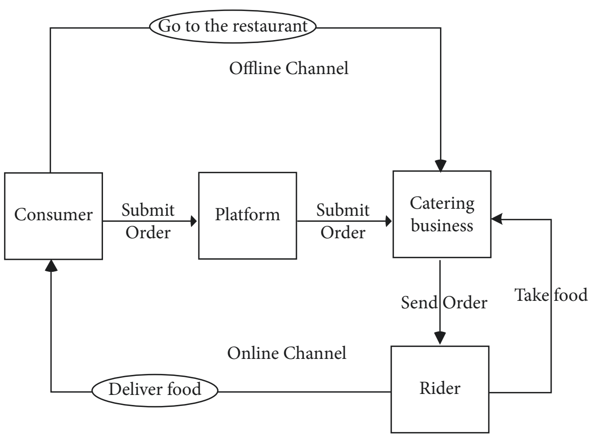

Figure 2: BSM structure.

sales price and service quality level in dual channels, including shop cleanliness, service attitude, and dining environment.

(4) Online demand is dependent on online price, offline price, service quality effort of the platform, and rider. Offline demand is dependent on offline price, online price, and service quality effort of the catering business. Supply chain contains a takeout platform, a catering business, and a distribution rider. They have equal status, simultaneous action, and independent decision-making to maximize their own benefits.

(5) When the platform hires the rider, the platform does not pay fixed wages. The rider can deliver takeout from multiple catering businesses, and the order volume is relatively large. The rider can get part of the distribution fee for each distribution. However, the catering business hires the rider to establish a long-term and stable cooperative relationship. They are only responsible for the catering distribution of fixed businesses. The order volume is relatively small, so they need to pay a stable wage M_1. This is similar to the cost expression used by Liu, et al. [38].

(6) As is common in the literature, we further normalize the food cost of the catering business to zero [39, 40]. These assumptions aim to simplify the mathematical derivations of the models while preserving the fundamental qualitative results in the problem.

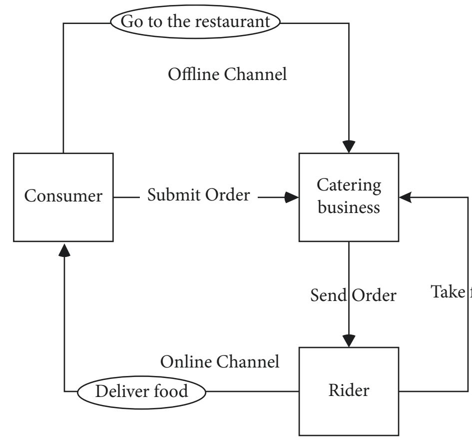

Figure 3: SDM structure.

3.2. Notations and Benchmark Model. Supply chain contains a takeout platform, a catering business, and a distribution rider. They have equal status, simultaneous action, and independent decision making to maximize their own benefits. We use the subscript p to represent the platform; use the subscript b to represent the business; and use the subscript r to represent the rider. The notations and corresponding definitions involved in this research are shown in Table 1.

To obtain the demand functions of the online channel (D_{on}) and the offline channel (D_{off}), this work extends the framework established by [41–44]. Accordingly, the demand function for online channel and offline channel in this paper, respectively, can be expressed as follows:

$$D_{\text{on}} = \theta\alpha - b_1(p_{\text{on}} + m) + b_2 p_{\text{off}} + \beta(e_p + e_r), \tag{1}$$

$$D_{\text{off}} = (1-\theta)\alpha - b_1 p_{\text{off}} + b_2(p_{\text{on}} + m) + \beta e_b. \tag{2}$$

In (1) and (2), the demand function of each channel is reversely affected by its own selling price and has a direct relationship with the other channel's price. The platform's service quality and the rider's service quality are the factors decided by the platform; the rider's service quality has a direct relationship with demand of online channel. Offline service quality has a direct influence on demand of offline channel. We can use function $qe^2/2$ to describe the service quality effort cost. Based on the assumed demand functions in (1) and (2), the problem will be modeled in three operation structures including PDM, BSM, and SDM.

4. Analysis and Solution of the Models

4.1. PDM. In PDM, riders are hired and managed by the platform. Consumers buy food through the platform at the price of p_{on} and pay the distribution fee m for the rider. The platform charges the business a revenue sharing rate λ_1 and charges the rider a revenue sharing rate λ_2. Furthermore, the platform decides the platform's service quality, and the

Table 1: Notation and definitions.

Notation	Definitions
c	Unit cost of offline rent
α	The market size
θ	Customer preference coefficient for online channel
λ_1	The catering business's revenue sharing rate extracted by the platform
λ_2	The rider's revenue sharing rate extracted by the platform or the catering business
m	Average distribution cost for the rider
b_1	Self-price elasticity coefficient
b_2	Cross-price elasticity coefficient
β	Quality of service sensitivity parameter of the demand
q_p	Cost factor for enhancing quality of online service for the platform
q_b	Cost factor for enhancing quality of offline service for the catering business
q_r	Cost factor for enhancing quality of distribution service for the distribution rider
π_i^j	Profit functions, $i \in \{p, b, r\}$, $j \in \{p, b, s\}$
M_1	Fixed wage for the distribution rider
M_2	Cost of establishing platform in SDM
Decision variables	
p_{on}	Selling prices of the product in the online channel
p_{off}	Selling prices of the product in the offline channel
e_p	The level of service quality efforts of the platform
e_b	The level of service quality efforts of the offline service
e_r	The level of service quality efforts of the rider

catering business decides on the food selling price in each channel and the quality of offline service. The rider decides on the quality of distribution service in the online channel.

Under the PDM, the profit functions of the platform, the catering business, and the rider in the dual-channel supply chain, respectively, can be formulated as follows:

$$\pi_p^p = (\lambda_1 p_{\text{on}} + \lambda_2 m) D_{\text{on}} - \frac{q_p e_p^2}{2}, \tag{3}$$

$$\pi_b^p = p_{\text{on}} (1 - \lambda_1) D_{\text{on}} + (p_{\text{off}} - c) D_{\text{off}} - \frac{q_b e_b^2}{2}, \tag{4}$$

$$\pi_r^p = m (1 - \lambda_2) D_{\text{on}} - \frac{q_r e_r^2}{2}. \tag{5}$$

Equation (3) illustrates the profit of the platform in which the first part indicates marginal profit drawn from the catering business and the rider, and the second part denotes demand of online channel, and then, we subtract the cost of quality of service on the platform. In (4), the catering business's profits consist of online and offline parts. And the first part indicates profit that the catering business earns from online channel and the second part is the profit through offline channel. Then, we subtract the cost of quality of offline service on the catering business (5). The first part represents the marginal profit of the rider, and the second part denotes demand of online channel, and then, we subtract the cost of service quality.

Proposition 1. *Under a Nash equilibrium, the optimal decisions are as follows:*

$$e_p^{p*} = \frac{\beta}{A_1} \left\{ \begin{array}{c} \Delta\Delta 2 m q_r \lambda_2 \left[\beta^2 b_1 + 2 q_b \left(b_2^2 - b_1^2\right)\right] + \lambda_1^2 (A_7 + A_4 - q_r A_6) + \lambda_1 \left\{2 m b_1^2 q_b q_r (1 + 2\lambda_2) - A_4 + \right. \\ \left. \Delta\Delta b_1 \left[2 q_b (A_5 - \alpha\theta q_r) - m\beta^2 q_r (1 + 2\lambda_2)\right] + q_r \{A_6 + b_2 q_b [\alpha(\theta - 1) + b_2 (c - m - 3m\lambda_2)]\}\right\} \end{array} \right\}, \tag{6}$$

$$e_b^{p*} = \frac{\beta q_r (\lambda_1 - 1)\{A_3 + [\alpha(\theta - 1) + c b_1]\}\left[\left(\beta^2 \lambda_1 - 2 b_1 q_p\right) + b_2 A_2\right]}{A_1}, \tag{7}$$

$$e_r^{p*} = \frac{m\beta (1 - \lambda_2)}{q_r}, \tag{8}$$

$$p_{\text{on}}^{p*} = \frac{1}{A_1} \left\{ \begin{array}{c} q_p q_r \left\{b_2 \left[c\beta^2 (1 - \lambda_1) - \alpha q_b (\theta - 1)(\lambda_1 - 2)\right] - b_2^2 q_b (c - m)(\lambda_1 - 2) - \alpha\beta^2 \theta (\lambda_1 - 1)\right\} \\ -b_1 \left\{\left\{q_b q_r \left[2 m b_1 (\lambda_1 - 2) - 2\alpha\theta(\lambda_1 - 2) - c b_2 (\lambda_1 - 1)\right] - m\beta^2 (\lambda_1 - 2)\right\} + 2 A_5 q_b q_r (\lambda_1 - 2)\right\} \\ + A_7 + A_4 (\lambda_1 - 1) - m\beta^2 q_p q_r \lambda_2 \left(\beta^2 - 2 b_1 q_b\right)(\lambda_1 - 1) \end{array} \right\}, \tag{9}$$

$$p_{\text{off}}^{p*} = \frac{A_3 + q_r\{c\beta^2 + q_b[\alpha(\theta-1) - cb_1]\}(\lambda_1 - 1)(\beta^2\lambda_1 - 2b_1q_p) + b_2q_bA_2(\lambda_1 - 1)}{A_1}, \tag{10}$$

The proof process can be seen in Appendix B.

We use nation $A_1, A_2, A_3, A_4, A_5, A_6, A_7$ to simply equilibrium solutions. Nations are presented in Appendix A.

Corollary 1. *Under the platform distribution mode, the optimal profits of O2O takeout platform, catering business, and distribution rider are π_p^{p*}, π_b^{p*}, and π_r^{p*}, respectively (see Table 2 for details).*

4.2. BSM. In BSM, the catering business distributes through their capacity. Customers buy food through the platform at the price of p_{on} and pay the distribution fee m for the rider. The platform extracts the catering business's revenue sharing rate λ_1 and decides the quality of service on the platform. The catering business pays the rider fixed wages M_1 and extracts the rider's revenue sharing rate λ_2. The catering business makes decisions on the food selling price in each channel and the quality of offline service. The rider decides on the quality of distribution service in the online channel.

Under the BSM, the profit functions of the platform, the catering business, and the rider in the dual-channel supply chain, respectively, can be formulated as follows:

$$\pi_p^b = \lambda_1 p_{\text{on}} D_{\text{on}} - \frac{q_p e_p^2}{2}, \tag{11}$$

$$\pi_b^b = [(1-\lambda_1)p_{\text{on}} + \lambda_2 m]D_{\text{on}} + (p_{\text{off}} - c)D_{\text{off}} - \frac{q_b e_b^2}{2} - M_1, \tag{12}$$

$$\pi_r^b = m(1-\lambda_2)D_{\text{on}} + M_1 - \frac{q_r e_r^2}{2}. \tag{13}$$

Equation (11) illustrates the profit of the platform drawn from the catering business in the online channel. Then, we subtract the cost of quality service on the platform. In (12), the first term denotes the profit earned by selling products through the online channel, and the second term indicates the earned profit from selling products via offline channel. Finally, we subtract the cost of service quality on the offline and fixed cost of the rider. Equation (13) represents the profit of the rider including the fixed wage and the cost of service quality effort.

Proposition 2. *Under a Nash equilibrium, the optimal decisions are as follows:*

$$e_p^{b*} = \frac{\beta\lambda_1(B_1 + B_3)}{A_1}, \tag{14}$$

$$e_b^{b*} = \frac{\beta B_4(\lambda_1 - 1) - q_r[\alpha(\theta-1) + cb_1](\lambda_1 - 1)(2b_1q_p - \beta^2\lambda_1) + b_2B_2}{A_1}, \tag{15}$$

$$e_r^{b*} = \frac{m\beta(1-\lambda_2)}{q_r}, \tag{16}$$

$$p_{\text{on}}^{b*} = \frac{q_p(B_1 + B_3)}{A_1}, \tag{17}$$

$$p_{\text{off}}^{b*} = \frac{B_4 + q_r\{c\beta^2 + q_b[\alpha(\theta-1) - cb_1]\}(\lambda_1 - 1)(\beta^2\lambda_1 - 2b_1q_p) + b_2q_bB_2}{A_1}. \tag{18}$$

We use nation B_1, B_2, B_3, B_4 to simplify equilibrium solutions. Nations are presented in Appendix A.

Corollary 2. *Under the catering business distribution mode, the optimal profits of O2O takeout platform, catering business, and distribution rider are π_p^{b*}, π_b^{b*}, and π_r^{b*}, respectively (see Table 2 for details).*

4.3. SDM. In SDM, the catering business establishes its own platform and hires riders for distribution. Customers buy food through the platform at the price of p_{on} and pay the distribution fee m for the rider. The business pays the rider fixed wages M_1 and charges the rider a revenue sharing rate λ_2. The cost for the catering business to build its online platform is M_2. The catering business makes decisions on the food selling price in each channel and the quality of online and offline service. The rider decides on the quality of distribution service in the online channel.

Under the SDM, the profit functions of the catering business and the rider in the dual-channel supply chain, respectively, can be formulated as follows:

Table 2: Optimal profits under different decision models.

Mode	Profit function	
PDM	$\pi_p^{p*} = (\lambda_1 p_{\text{on}}^{p*} + \lambda_2 m)[\theta\alpha - b_1(p_{\text{on}}^{p*} + m) + b_2 p_{\text{off}}^{p*} + \beta(e_p^{p*} + e_r^{p*})] - q_p e_p^{p*2}/2$	(26)
	$\pi_b^{p*} = p_{\text{on}}^{p*}(1-\lambda_1)[\theta\alpha - b_1(p_{\text{on}}^{p*} + m) + b_2 p_{\text{off}}^{p*} + \beta(e_p^{p*} + e_r^{p*})],$ $+(p_{\text{off}}^{p*} - c)[(1-\theta)\alpha - b_1 p_{\text{off}}^{p*} + b_2(p_{\text{on}}^{p*} + m) + \beta e_b^{p*}] - q_b e_b^{p*2}/2$	(27)
	$\pi_r^{p*} = m(1-\lambda_2)[\theta\alpha - b_1(p_{\text{on}}^{p*} + m) + b_2 p_{\text{off}}^{p*} + \beta(e_p^{p*} + e_r^{p*})] - q_r e_r^{p*2}/2$	(28)
BSM	$\pi_p^{b*} = \lambda_1 p_{\text{on}}^{b*}[\theta\alpha - b_1(p_{\text{on}}^{b*} + m) + b_2 p_{\text{off}}^{b*} + \beta(e_p^{b*} + e_r^{b*})] - q_p e_p^{b*2}/2$	(29)
	$\pi_b^{b*} = [(1-\lambda_1)p_{\text{on}}^{b*} + \lambda_2 m][\theta\alpha - b_1(p_{\text{on}}^{b*} + m) + b_2 p_{\text{off}}^{b*} + \beta(e_p^{b*} + e_r^{b*})],$ $+(p_{\text{off}}^{b*} - c)[(1-\theta)\alpha - b_1 p_{\text{off}}^{b*} + b_2(p_{\text{on}}^{b*} + m) + \beta e_b^{b*}] - (q_b e_b^{b*2}/2) - M_1$	(30)
	$\pi_r^{b*} = m(1-\lambda_2)[\theta\alpha - b_1(p_{\text{on}}^{b*} + m) + b_2 p_{\text{off}}^{b*} + \beta(e_p^{b*} + e_r^{b*})] + M_1 - q_r e_r^{b*2}/2$	(31)
SDM	$\pi_b^{s*} = (p_{\text{on}}^{s*} + \lambda_2 m)[\theta\alpha - b_1(p_{\text{on}}^{s*} + m) + b_2 p_{\text{off}}^{s*} + \beta(e_p^{s*} + e_r^{s*})],$ $+(p_{\text{off}}^{s*} - c)[(1-\theta)\alpha - b_1 p_{\text{off}}^{s*} + b_2(p_{\text{on}}^{s*} + m) + \beta e_b^{s*}] - q_p e_p^{s*2}/2 - q_b e_b^{s*2}/2 - M_1 - M_2$	(32)
	$\pi_r^{s*} = m(1-\lambda_2)[\theta\alpha - b_1(p_{\text{on}}^{s*} + m) + b_2 p_{\text{off}}^{s*} + \beta(e_p^{s*} + e_r^{s*})] - q_r e_r^{s*}/2 + M_1$	(33)

$$\pi_b^s = (p_{\text{on}} + \lambda_2 m)D_{\text{on}} + (p_{\text{off}} - c)D_{\text{off}} - \frac{q_p e_p^2}{2} - \frac{q_b e_b^2}{2} - M_1 - M_2, \tag{19}$$

$$\pi_r^s = m(1-\lambda_2)D_{\text{on}} - \frac{q_r e_r^2}{2} + M_1, \tag{20}$$

In (19), the first term denotes the profit earned by selling products through the online channel, and the second term indicates the earned profit from selling products via offline channel. Then, we subtract the cost of quality service on the platform. Finally, we subtract the cost of service quality on the offline and fixed cost of the rider. Equation (3) represents the profit of the rider including the fixed wage and the cost of service quality.

Proposition 3. *Under a Nash equilibrium, the optimal decisions are as follows:*

$$e_p^{s*} = \frac{1}{C_1}\left\{\beta\left[b_1\left[2q_b C_2 - m\beta^2 q_r(\lambda_2 - 1)\right] - q_r C_3 + m\beta^4(\lambda_2 - 1) + 2mb_1^2 q_b q_r(\lambda_2 - 1)\right]\right\}, \tag{21}$$

$$e_b^{s*} = \frac{\beta\left\{2cb_2^2 q_p q_r + [\alpha(\theta-1) + cb_1](\beta^2 - 2b_1 q_p)q_r + b_2\left[2q_p C_2 + m\beta^2 q_r(\lambda_2 - 1)\right]\right\}}{C_1}, \tag{22}$$

$$e_r^{s*} = \frac{m\beta(1-\lambda_2)}{q_r}, \tag{23}$$

$$p_{\text{on}}^{s*} = \frac{C_7 + q_p\left(C_6 + b_1\left(2q_b C_2 + m\beta^2 q_r(1+\lambda_2)\right) - q_r\left(\alpha\beta^2\theta + b_2 C_5\right)\right)}{C_1}, \tag{24}$$

$$p_{\text{off}}^{s*} = \frac{(\beta^2 - 2b_1 q_p)C_4 q_r - 2cb_2^2 q_p q_b q_r + b_2 q_b\left(2q_p C_2 + m\beta^2 q_r(-1+\lambda_2)\right)}{C_1}. \tag{25}$$

We use nation $C_1, C_2, C_3, C_4, C_5, C_6, C_7$ to simplify equilibrium solutions. Nations are presented in Appendix A.

Corollary 3. *Under the business self-built platform + distribution mode, the optimal profits of O2O takeout platform, catering business, and distribution rider are π_p^{s*}, π_b^{s*}, and π_r^{s*}, respectively (see Table 2 for details).*

4.4. Comparison of Three Operation Modes

4.4.1. Comparison of Business Profits under Three Operation Modes. According to Equations (27), (30), and (32), meanwhile, $\Delta\pi_b^1 = \pi_b^{b*} - \pi_b^{p*}$, and $\Delta\pi_b^2 = \pi_b^{s*} - \pi_b^{b*}$, further analysis shows that

$$\Delta\pi_b^1 = m\lambda_2(\alpha\theta + \beta(e_1 + e_3) + b_2 p_{\text{off}} - b_1(m + p_{\text{on}})) - M_1. \tag{26}$$

(1) If $\Delta\pi_b^1 > M_1$, $\pi_b^{b*} > \pi_b^{p*}$, or vice versa;

Obviously, if the fixed wage paid to riders is relatively large, the catering business should choose PDM mode; on the contrary, when the fixed wage is relatively small, the catering business can consider choosing BSM mode. Actually, the fixed wage of riders is a very important reference factor for catering businesses. Several large catering businesses, such as “Pizza hut” and “KFC,” will choose to hire their own riders; on the contrary, generally small catering businesses prefer to cooperate with takeout platforms because of the high cost of hiring riders.

$$\Delta\pi_b^2 = p_{\text{on}}\left(\alpha\theta + \beta\left(e_1 + e_3\right) + b_2 p_{\text{off}} - b_1\left(m + p_{\text{on}}\right)\right)\lambda_1 - \frac{1}{2}e_1^2 q_1 - M_2. \quad (27)$$

(2) If $\Delta\pi_b^2 > M_2$, $\pi_b^{s*} > \pi_b^{b*}$, or vice versa;

Through the above formula, it can be concluded that when the cost of built platform is relatively large, catering businesses should choose SDM mode; conversely, when the cost is in a relatively small range, BSM mode can be considered. The similarity of the two models is that both catering businesses employ the rider, and thus, catering businesses should pay more attention to the cost of building their own platform. If the catering business has strong strength, such as "McDonald's" and other chain enterprises, they can build their own platform to realize the sustainable growth of profits; if the catering business is a small enterprise, they try to cooperate with the takeout platform to obtain greater profits.

4.4.2. Comparison of Service Effort Level. According to (6), (14), and (21), meanwhile, $\Delta e_p^{1*} = e_p^{b*} - e_p^{p*}$, further analysis shows that

$$\Delta e_p^{1*} = \frac{m\beta\lambda_2\left(\lambda_1 - 2\right)\left(\beta^2 b_1 + 2q_2\left(b_2^2 - b_1^2\right)\right)}{b_2^2 q_1 q_2\left(\lambda_1 - 2\right)^2 + 4b_1^2 q_1 q_2\left(\lambda_1 - 1\right) + \beta^4\left(\lambda_1 - 1\right)\lambda_1 - 2\beta^2 b_1\left(\lambda_1 - 1\right)\left(q_1 + q_2\lambda_1\right)}. \quad (28)$$

(1) If $\Delta e_p^{1*} > 0$, $e_p^{b*} > e_p^{p*}$, or vice versa;

According to (7), (15), (22), meanwhile, $\Delta e_b^{2*} = e_b^{b*} - e_b^{p*}$, further analysis shows that

$$\Delta e_b^{2*} = \frac{m\beta b_2\lambda_2\left(2\beta^2 + \left(b_1 q_1 - 2\beta^2\right)\lambda_1\right)}{b_2^2 q_1 q_2\left(\lambda_1 - 2\right)^2 + 4b_1^2 q_1 q_2\left(\lambda_1 - 1\right) + \beta^4\left(\lambda_1 - 1\right)\lambda_1 - 2\beta^2 b_1\left(\lambda_1 - 1\right)\left(q_1 + q_2\lambda_1\right)}. \quad (29)$$

(2) If $\Delta e_b^{2*} > 0$, $e_b^{b*} > e_b^{p*}$, or vice versa;

Noticeably, for takeout platforms and catering businesses, the extraction proportion has a great impact on them. O2O takeout platform should cooperate with more catering businesses and adopt different strategies considering different market sizes of catering businesses. On the one hand, it can improve the market share of the platform and urge the platform to ensure higher service quality. For catering businesses, they can adopt different online and offline price strategies to dynamically ensure dual-channel sales.

5. Numerical Analysis

Since there are many parameters in the model and the expressions are more complicated, in order to analyze the optimal strategy and optimal profit comparison under the three different operating modes more intuitively, numerical examples are used for analysis. In the numerical simulation studied, we consider $\alpha = 100$; $\beta = 1$; $\theta = 0.5$; $b_1 = 0.8$; $b_2 = 0.2$; $m = 2$; $c = 2$; $\lambda_1 = 0.4$; $\lambda_2 = 0.2$; $q_p = 20$; $q_b = 20$; and $q_r = 20$.

5.1. Sensitivity Analysis on λ_1 and λ_2. To create more insights toward creating SSC, a set of sensitivity analyses on the extract proportion is λ_1 and λ_2. In this regard, the impacts of change in the extract proportion λ_1 and λ_2 on decision variables and profit functions are investigated.

5.1.1. Service Quality Effort. Table 3 observes that in PDM and BSM, the platform's optimal service quality effort increases with the catering business's revenue sharing rate. However, in BSM the platform's optimal service quality effort decreases with the rider's revenue sharing rate. Moreover, in BSM, the catering business's service quality effort decreases with the revenue sharing rate. The platform can appropriately improve the revenue sharing rate to obtain higher service quality, gain a better reputation, and attract more catering businesses and consumers. Under the condition of maintaining service quality to satisfy consumers, the catering business should control costs for sustainable operation. In addition, if the catering business builds its own platform, it can keep its online and offline service quality similar. Furthermore, the rider prefers to cooperate with the catering business or platform with low revenue sharing rate.

5.1.2. Price of Online and Offline. Based on Table 4, in PDM and BSM, online price is positively correlated with λ_1, while offline price is negatively correlated with λ_1. In SDM, online and offline prices have nothing to do with λ_1, while offline price is positively correlated with platform extracted proportion λ_2. The platform should take a cautious attitude toward the increase of the revenue sharing rate, which may lead catering businesses to increase their online prices to maintain operations; obviously, if the catering business moderately increases the rider's revenue sharing rate, it can appropriately reduce online and offline prices to expand

Table 3: Impact of change in λ_1 and λ_2 on the quality of service.

λ_1	λ_2	e_p^{p*}	e_b^{p*}	e_r^{p*}	e_p^{b*}	e_b^{b*}	e_r^{b*}	e_p^{s*}	e_b^{s*}	e_r^{s*}
0.1	0.1	0.218	2.085	0.09	0.208	2.085	0.09	2.130	2.123	0.09
0.1	0.2	0.228	2.085	0.08	0.207	2.084	0.08	2.135	2.123	0.08
0.1	0.3	0.238	2.085	0.07	0.206	2.083	0.07	2.140	2.123	0.07
0.2	0.1	0.434	2.067	0.09	0.423	2.067	0.09	2.130	2.122	0.09
0.2	0.2	0.445	2.067	0.08	0.422	2.066	0.08	2.135	2.122	0.08
0.2	0.3	0.455	2.067	0.07	0.421	2.065	0.07	2.140	2.122	0.07
0.3	0.1	0.661	2.050	0.09	0.649	2.050	0.09	2.130	2.121	0.09
0.3	0.2	0.671	2.050	0.08	0.647	2.049	0.08	2.135	2.121	0.08
0.3	0.3	0.681	2.050	0.07	0.644	2.048	0.07	2.140	2.121	0.07

Table 4: Impact of change in λ_1 and λ_2 on dual-channel price.

λ_1	λ_2	p_{on}^{p*}	p_{off}^{p*}	p_{on}^{b*}	p_{off}^{b*}	p_{on}^{s*}	p_{off}^{s*}
0.1	0.1	41.699	43.706	41.580	43.704	42.400	44.452
0.1	0.2	41.699	43.706	41.461	43.700	42.297	44.451
0.1	0.3	41.699	43.706	41.343	43.697	42.194	44.450
0.2	0.1	42.456	43.345	42.322	43.449	42.400	44.452
0.2	0.2	42.456	43.345	42.189	43.334	42.297	44.451
0.2	0.3	42.456	43.345	42.055	43.329	42.194	44.450
0.3	0.1	43.418	43.008	43.266	43.000	42.400	44.452
0.3	0.2	43.418	43.008	43.113	42.992	42.297	44.451
0.3	0.3	43.418	43.008	42.960	42.985	42.194	44.450

market demand. Moreover, the online optimal price is less than the offline optimal price. It can be concluded that the self-distribution catering business should formulate differentiated online and offline prices to achieve optimal profit.

5.1.3. The Platform's Optimal Profit. Figure 4 illustrates that under the PDM and BSM, the optimal platform's profit increases with λ_1. Meanwhile, in PDM, the platform's optimal profit increases with the λ_2. By comparison, regardless of how the revenue sharing rate changes, the platform is more inclined to choose PDM mode to obtain higher profits. In reality, referring to the operation modes of "Ele.me" company and "Meituan" company, they are striving to build and improve their own takeout platforms to achieve sustainable profit growth.

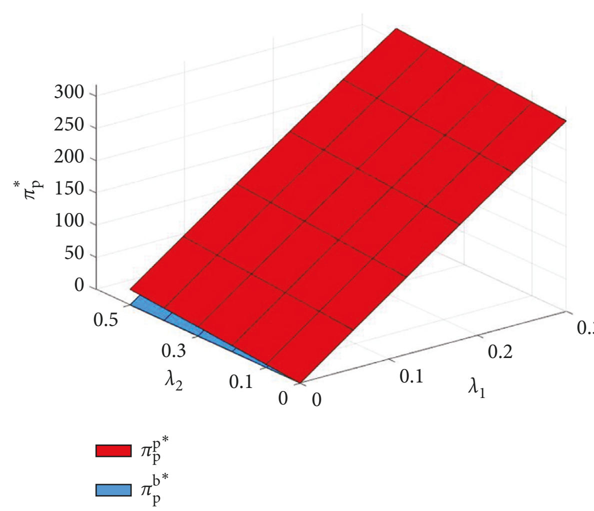

Figure 4: Impact of change in λ_1 and λ_2 on the platform's optimal profit.

5.1.4. The Catering Business's Optimal Profit. Figure 5 demonstrates that the optimal profits of the catering business decrease with λ_1. However, in PDM and BSM, the optimal profit of the catering business increases with λ_2. Consequently, when the catering business's revenue sharing rate is relatively small, catering businesses can choose PDM mode; on the contrary, when the revenue sharing rate exceeds a certain range, catering businesses should choose SDM mode to obtain higher profits. Obviously, for some large catering businesses, such as McDonald's and KFC, they can cooperate with takeout platforms and build their own platforms to expand multichannel sales; for small catering businesses, it is recommended to cooperate with the takeout platform to achieve a win-win situation.

5.1.5. The Rider's Optimal Profit. As shown in Figure 6, the rider's optimal profits increase with λ_1. However, the rider's optimal profit decreases with λ_2. In BSM and SDM, the rider has a certain fixed wage, and the decline is relatively slow. This symbolizes that the riders prefer the mode with fixed wage, which is conducive to higher profits. Therefore, the rider can choose BSM and SDM modes to obtain higher profits. Furthermore, with the change of revenue sharing rate, SDM mode is a better choice. In reality, the rider prefers to cooperate with a fixed catering business. Referring to the employment model of "Burger King" company, we take the

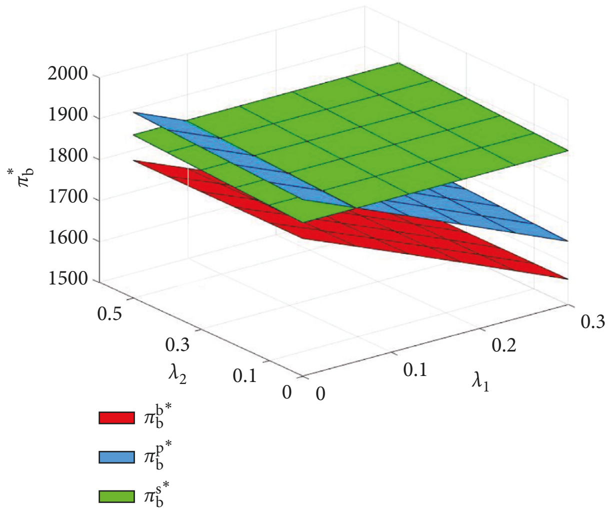

Figure 5: Impact of change in λ_1 and λ_2 on the catering business's optimal profit.

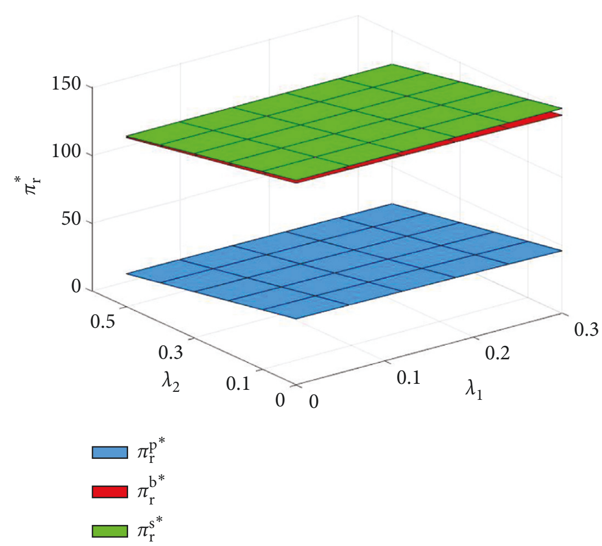

Figure 6: Impact of change in λ_1 and λ_2 on the rider's optimal profit.

fixed wage as the basic income of riders and motivate riders by controlling the change of revenue sharing rate.

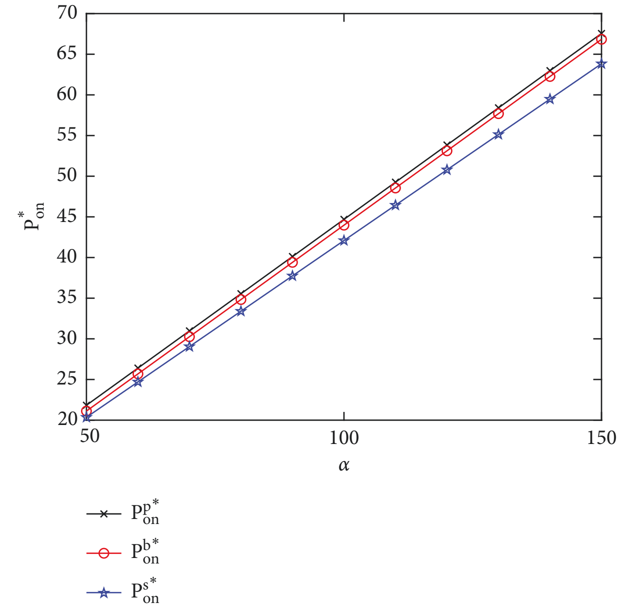

Figure 7: Impact of change in α on online price.

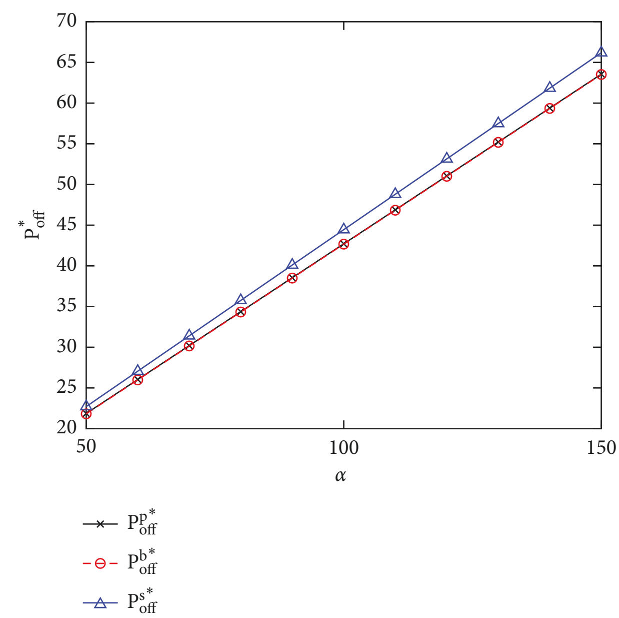

Figure 8: Impact of change in α on offline price.

5.2. Sensitivity Analysis on Market Size α. To create more insights on the investigated problem, Figures 7 and 8 illustrate the impact of market potential α for optimal online price and offline price, respectively.

5.2.1. Price of Online and Offline. As can be seen in Figures 7 and 8, in all modes, the optimal prices of both online and offline are always positively correlated with α. When market size is the same, the online optimal price P_{on}^{p*} is always higher than P_{on}^{b*} and P_{on}^{s*}. However, the offline optimal price P_{off}^{p*} and P_{off}^{b*} are always lower than P_{off}^{s*}. Meanwhile, the P_{off}^* of PDM and BSM is similar. In PDM mode, the platform charges a higher percentage of the catering business's revenue sharing rate; thus, the catering business will increase the online price to ensure profits, which makes the online price highest. Meanwhile, in SDM, the catering business needs to pay a fixed wage to the rider and bears the cost of building the platform, which leads to the optimal offline price greater than that in PDM and BSM mode. Therefore, the catering business should set higher online prices and lower offline prices to obtain optimal profit. For consumers, SDM mode should be selected when ordering takeout online, PDM and BSM modes are better choices when choosing offline restaurants.

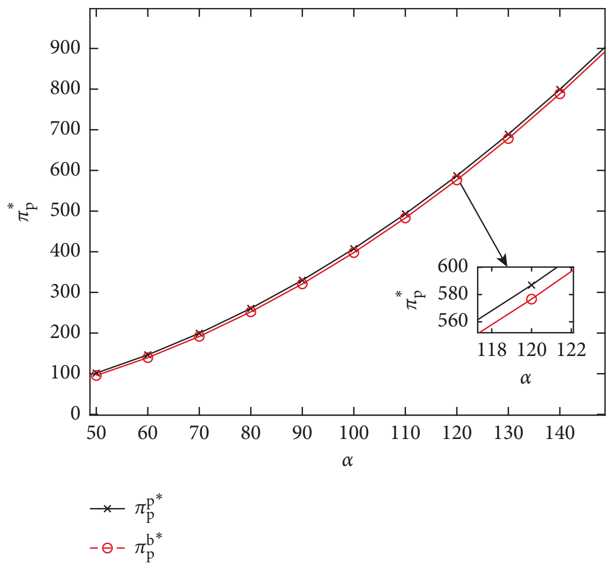

Figure 9: Impact of change in α on the platform's optimal profit.

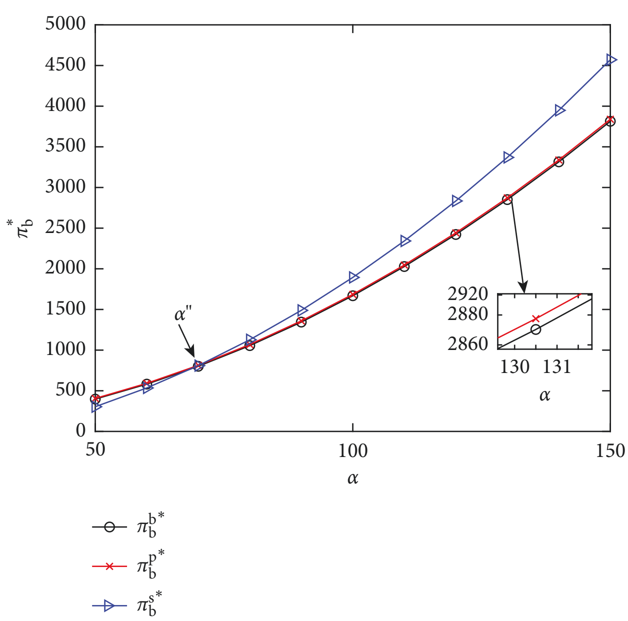

Figure 10: Impact of change in α on the business's optimal profit.

5.2.2. Optimal Profit. From Figure 9, it can be observed that under the given proportion, the optimal profit of the platform increases with the market size under both modes. The optimal profit of the platform under the PDM mode is larger than that under the BSM mode, which is $\pi_p^{p*} > \pi_p^{b*}$. This reveals that PDM mode is the best choice for takeout platform. In fact, with the increase of market size, companies such as "Meituan" are upgrading their takeout platforms to make greater profits.

Figure 10 illustrates that the optimal profit of the catering business increases with the market size under all modes. When the market size is small, the optimal profit under PDM and BSM is larger than that under the SDM. When the market size $a > a''$, the optimal profit of the

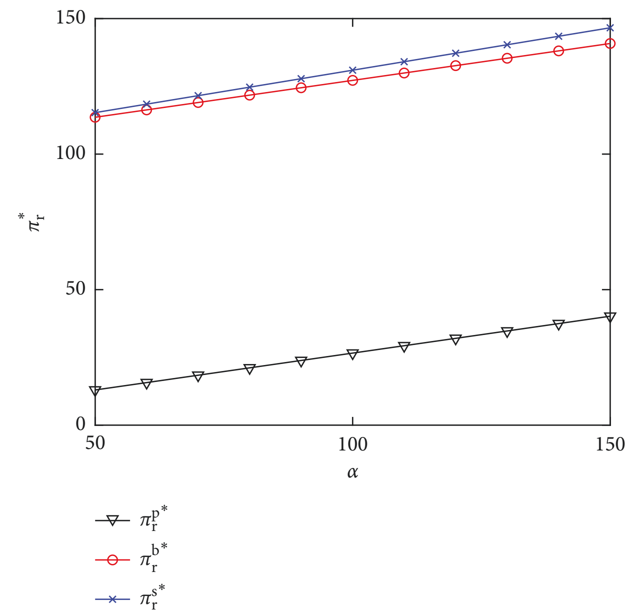

Figure 11: Impact of change in α on the rider's optimal profit.

catering business under the SDM exceeds that in the PDM and BSM. With the increase of market size, the profit difference between SDM and PDM will be larger. This represents that PDM is the best choice for the catering business with small market size. For catering businesses with large market size, they can choose SDM mode, which is more beneficial to obtaining greater profits.

As observed in Figure 11, the optimal profit of the rider increases with the market size under both modes. The optimal profit under SDM is the largest. The bigger the market size is, the higher the profit gap between the SDM and the BSM is. This reveals that the rider can get higher profits by choosing SDM and BSM mode. Meanwhile, with the increase of market size, SDM mode should be chosen. In addition, it represents that the rider prefers the mode with fixed wage.

6. Managerial Insights

Due to the increasing demand of consumers for online ordering and offline dining, managers are provided with the following suggestions to improve services and ultimately increase profits.

(a) The takeout platform should cooperate with more catering businesses and adopt different revenue sharing rates considering the catering businesses with different market sizes.

(b) The takeout platform can optimize its service quality effort by appropriately adjusting the revenue sharing rate.

(c) The catering business should properly consider the market size and choose the corresponding operation mode to achieve sustainable profit growth.

(d) Considering the characteristics of online and offline, the catering business can adopt different online and offline prices, and obtain more profits by dynamically adjusting online and offline prices.

(e) The rider who chooses to join the self-built platform mode can get more revenue.

7. Conclusions

This paper considers an O2O takeout service supply chain consisting of an O2O takeout platform, a catering business, and a rider. By establishing a mathematical model, this research analyzes and compares the optimal quality effort and the optimal profit under platform distribution, business self-distribution, and business self-built platform + distribution. The above results show that the optimal platform's service quality effort is positively correlated with revenue sharing rate; the optimal catering business's service quality effort is negatively correlated with revenue sharing rate. In addition, the online price is positively correlated with revenue sharing rate, while the offline price is negatively correlated with revenue sharing rate. Specifically, online and offline prices are different in the three operation modes, and the online price is slightly lower than the offline price. Obviously, the optimal profit of all supply chain members increases with the market size.

With the continuous improvement of economy, the takeout industry is developing rapidly. In the future development process, members of the takeout service supply chain should actively provide consumers with more high-quality services. The takeout platform should improve consumer satisfaction by appropriately extracting the revenue sharing rate. The catering business should focus on formulating different online and offline prices to obtain more economic profits. The rider should cooperate with appropriate platforms or businesses to improve the service quality and win better customer experience.

In further research, the different sensitivities of consumers to the service quality of platforms, catering businesses, and riders can be explored. In addition, the model adopts the traditional linear demand function. However, there is a certain gap between this linear demand function and reality.

Appendix

A. Acronym for Equilibrium Solution

$$
\begin{aligned}
A_1 &= q_r\left[b_2^2 q_p q_b(\lambda_1-2)^2+4b_1^2 q_p q_b(\lambda_1-1)+\beta^4\lambda_1(\lambda_1-1)-2\beta^2 b_1(\lambda_1-1)\left(q_p+q_b\lambda_1\right)\right],\\
A_2 &= q_p\left\{q_r\left[b_1(m\lambda_1-2c)-\alpha\theta(\lambda_1-2)\right]+m\beta^2(\lambda_1-2)(\lambda_2-1)\right\}+\beta^2 q_r\left[2m\lambda_2+\lambda_1(c-m-m\lambda_2)\right],\\
A_3 &= -cb_2^2 q_p q_r(\lambda_1-2),\\
A_4 &= m\beta^4(\lambda_2-1),\\
A_5 &= m\beta^2(\lambda_2-1),\\
A_6 &= \alpha\beta^2\theta+b_2\left\{c\beta^2+q_b\left[\alpha(\theta-1)+b_2(c-m-m\lambda_2)\right]\right\},\\
A_7 &= b_1\left\{m\beta^2 q_r+q_b\left[(2\alpha\theta+cb_2)q_r-2A_5\right]\right\}-2mb_1^2 q_b q_r,\\
B_1 &= b_1\left\{q_b\left\{q_r\left[(2\alpha\theta+cb_2)\lambda_1-2\alpha\theta\right]-2m\beta^2(\lambda_1-1)(\lambda_2-1)\right\}+m\beta^2 q_r(\lambda_1-\lambda_2-1)\right\}+m\beta^4(\lambda_1-1)(\lambda_2-1),\\
B_2 &= q_p\left\{m\beta^2(\lambda_1-2)(\lambda_1-1)(\lambda_2-1)+q_r\{\lambda_1\left[mb_1(\lambda_1+\lambda_2-1)\right]-\alpha\theta(\lambda_1-3)\}-2\alpha\theta\right\}-m\beta^2 q_r\lambda_1(\lambda_1-1)(1+\lambda_2),\\
B_3 &= 2mb_1^2 q_b q_r(1+\lambda_2-\lambda_1)+q_r\left\{b_2\left[\alpha q_b(\theta-1)(2-\lambda_1)-c\beta^2(\lambda_1-1)\right]-\alpha\beta^2\theta(\lambda_1-1)+mb_2^2 q_b(\lambda_1-2)(1+\lambda_2)\right\},\\
B_4 &= cb_2^2 q_p q_b q_r(2-\lambda_1),\\
C_1 &= \left[\beta^4+4b_1^2 q_p q_b-4b_2^2 q_p q_b-2\beta^2 b_1\left(q_p+q_b\right)\right]q_r,\\
C_2 &= \alpha\theta q_r-m\beta^2(\lambda_2-1),\\
C_3 &= \alpha\beta^2\theta+b_2\left\{c\beta^2+2q_b\left[\alpha(\theta-1)+mb_2(\lambda_2-1)\right]\right\},\\
C_4 &= c\beta^2+\left[\alpha(\theta-1)-cb_1\right]q_b,\\
C_5 &= c\beta^2-2q_b\left[\alpha-\alpha\theta+mb_2(1+\lambda_2)\right],\\
C_6 &= m\beta^4(\lambda_2-1)-2mb_1^2 q_b q_r(1+\lambda_2),\\
C_7 &= m\beta^2\left(2b_1 q_b-\beta^2\right)q_r\lambda_2,
\end{aligned}
\tag{A.1}
$$

B. Process of Proof

Proof. Appendix B

From (3) and (5), the authors obtain $d^2\pi_p^p/de_p^2 = -q_p < 0$, and $d^2\pi_r^p/de_r^2 = -q_r < 0$, and then, π_p^p is a concave function of e_p and π_r^p is a concave function of e_r. According to (4), the Hessian matrix of π_b^p is as follows:

$$H = \begin{bmatrix} \frac{\partial^2 \pi_b^p}{\partial e_b^2} & \frac{\partial^2 \pi_b^p}{\partial e_b \partial p_{on}} & \frac{\partial^2 \pi_b^p}{\partial e_b \partial p_{off}} \\ \frac{\partial^2 \pi_b^p}{\partial p_{on} \partial e_b} & \frac{\partial^2 \pi_b^p}{\partial p_{on}^2} & \frac{\partial^2 \pi_b^p}{\partial p_{on} \partial p_{off}} \\ \frac{\partial^2 \pi_b^p}{\partial p_{off} \partial e_b} & \frac{\partial^2 \pi_b^p}{\partial p_{off} \partial p_{on}} & \frac{\partial^2 \pi_b^p}{\partial p_{off}^2} \end{bmatrix} \tag{B.1}$$

$$= \begin{bmatrix} -q_b & 0 & \beta \\ 0 & -2b_1(1-\lambda_1) & b_2 + b_2(1-\lambda_1) \\ \beta & b_2 + b_2(1-\lambda_1) & -2b_1 \end{bmatrix}.$$

We can get $H_1 < 0, H_2 > 0$, if $q_b[b_2(2-\lambda_1)]^2 > 2b_1(\beta^2 - 2b_1q_b)(\lambda_1 - 1)$, then $H_3 < 0$, and π_b^p is a concave function of e_b, p_{on}, and p_{off}.

Let $d\pi_p^p/de_p = d\pi_b^p/de_b = d\pi_b^p/dp_{\mathrm{off}} = d\pi_b^p/dp_{\mathrm{on}} = d\pi_r^p/de_r = 0$, the authors obtain $e_p^{p*}, e_b^{p*}, e_r^{p*}, p_{\mathrm{on}}^{p*}, and\ d\ p_{\mathrm{off}}^{p*}$ shown in (6)–(10). Replace $e_p^{p*}, e_b^{p*}, e_r^{p*}, p_{\mathrm{on}}^{p*}, and\ d\ p_{\mathrm{off}}^{p*}$ in (3)–(5), the authors obtain $\pi_p^{p*}, \pi_b^{p*}, and\ d\ \pi_r^{p*}$. □

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declared that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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