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Research Article

Pricing Policy Selection in a Platform Service Supply Chain with Online Reviews

Jing Tian,[1] **Xiaodong Wang**,[1] **Jinhuan Meng**,[1] **and Pengfei Ma**[2]

[1]*Department of Management Engineering, Inner Mongolia Vocational and Technical College of Communications, Chifeng, Inner Mongolia 024005, China*
[2]*Development and Planning Department, CCTEG Shenyang Research Institute, Fushun, Liaoning 113112, China*

Correspondence should be addressed to Pengfei Ma; mapengfei@syccri.com

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In the operation of service-sharing platforms, online review information is crucial to attracting consumers. Considering consumers' preference for online review information, this paper discusses the pricing policy selection for a service-sharing platform providing vertically differentiated services in sharing economy, which is worth studying. In this paper, a platform service supply chain composed of a high-quality service provider, a low-quality service provider, and a service-sharing platform is considered. For the two pricing policies of a platform: service provider pricing and platform pricing, the profit-maximizing models are constructed, and the optimal high-quality and the low-quality service prices are obtained. This paper also analyzes the effects of online review information on the profits of service providers, platform profits, consumer surplus, and social welfare under the two policies. The results show that under the platform pricing policy, the platform can gain more profits, while the surplus of consumers and service providers may decrease. When the online review information exceeds a threshold, the high-quality service provider profit under the service provider pricing policy is larger than that under the platform pricing policy. Under the platform pricing policy, the low-quality service provider can earn more profit. We also find that the low-quality service provider is more motivated to encourage consumers to provide online reviews regardless of the pricing policy.

1. Introduction

With the development of information network technology and social media, service-sharing platforms have flourished in just a few years [1]. For example, these platforms include Airbnb, Uber, Upwork, TaskRabbit, and Thumbtack [2]. Service providers rent their idle capacity to consumers through online platforms, thus saving social resources and increasing total welfare [3]. According to a PwC report, the global revenue of service-sharing platforms will reach $335 billion [4]. Therefore, with the rapid development of the platform economy and the increase in Internet users, service sharing has attracted the interest of academia, professionals, and the public [5–7].

In P2P service-sharing markets, service providers' service quality is uneven [8], and consumers are unaware of this. As a result, there is information asymmetry between service providers and consumers, which makes it difficult for consumers to obtain accurate quality information before booking services [1]. Some drivers of ride-hailing platforms such as Uber and Didi may not be familiar with the roads or have detour issues. For example, some hosts on the house-sharing platforms of Booking.com and Airbnb may falsely advertise their houses' location and facilities, which may lead to dissatisfaction among consumers and potential security risks [9]. Some consumers will be reluctant to use P2P sharing services due to concerns about the quality of P2P services. Low-quality services have reduced the attractiveness of P2P services to consumers, which will further affect the revenue of the entire P2P service-sharing market [10].

Since consumers cannot access services before renting, they feel great uncertainty about service quality when booking services through online platforms [11]. Therefore, they often use consumers' online reviews as a reliable source

of information [12]. It is worth noting that online consumer reviews are generated by consumers when they trade and interact with platform enterprises for multiple periods. Online consumer reviews can alleviate consumers' concerns about quality uncertainty or product suitability, which significantly affects consumers' decision making and has become the focus of extensive research in recent years [13–16]. According to a survey by Bright Local in 2019, 82% of online consumers read online reviews before making a purchase decision [17]. This survey indicates that consumers will refer to other people's experiences in online reviews to help them make rental decisions [18]. In fact, the existence of a large number of online reviews on Airbnb has become one of the main factors for its success. In the case of online consumer reviews, platforms and service providers should not only consider how the review information affects consumers but also consider its impact on them. Moreover, platforms and service providers usually cannot control the effect of review information on consumers. From the platform's perspective, the effect of the online consumer review information on the platform profit has become significant. Therefore, it is worth exploring how online consumer reviews affect the platform's decisions.

Pricing decisions, as one of the most critical decisions for a platform, play a decisive role in creating profits for a platform. The platform influences the interaction between service providers and consumers by selecting the pricing policy. In practice, the platforms adopt different pricing policies, and we observe two types of policies: service provider pricing and platform pricing. Under the platform pricing policy, a platform sets service prices to maximize its profits. For example, Uber and Lyft set service prices to match passengers and drivers. Under the service provider pricing policy, the platform has no pricing power and service providers set the service price. For example, hosts on Airbnb, TaskRabbit, and Thumbtack set the service price. The platform generates revenue by taking commission fees from each transaction. In the service-sharing market, it is difficult for service providers to determine the price due to the uncertainty of demand and competition. For example, landlords on Airbnb are inefficient in setting prices for their services to maximize profits [19]. The service price has a considerable impact on the platform's profit. Higher service prices will lead to fewer transactions but higher profit margins, while lower prices may increase the number of transactions but erode profits [20]. At present, it is not clear which pricing policy is more beneficial to the platform.

Based on the above practical background, the strategic interaction between online review information disclosure and pricing decisions is complex. Online review information affects consumers' willingness to pay, and the service price limits the demand of consumers to join the platform. Due to the interaction between online review information and platform pricing decisions, in which pricing policy can be profitable for a platform to choose, it is necessary to conduct in-depth research. Therefore, this study fills the above gap by answering the following questions:

(1) How do online consumer reviews affect the selection of the pricing policy for a sharing platform?

(2) Can a sharing platform and service providers benefit from online reviews?

(3) How do online consumer reviews affect the profits, consumer surplus, and social welfare?

This paper studies the above questions from the perspective of platform operation management to provide reference and theoretical support for the operational decision making of the sharing platform. To solve the above problems, we build a game theory model. In the model, we consider a platform service supply chain composed of a high-quality service provider, a low-quality service provider, a platform, and consumers. There are two pricing policies for the platform: service provider pricing and platform pricing. Online consumer reviews affect consumers' rental choices. First, the profit-maximizing models of the platform and two service providers under each pricing policy are constructed, and the optimal service prices are obtained by solving the models. Then, through the comparative analysis of service provider profits, platform profits, consumer surplus, and social welfare under the two policies, this paper discusses which pricing policy is more beneficial for the platform and the service providers. Further, three extended studies are provided. The first is to consider that a platform or two service providers manipulate online reviews, the second is to consider that commission rates are endogenous, and the third is to consider the effects of the number of online reviews.

The main contributions of this study lie in three aspects. First, this paper investigates the pricing policy selection of a service-sharing platform considering online consumer reviews. This paper also examines how online consumer reviews affect market equilibrium, that is, the service price, market share, and profits. As far as we know, this has not been explored in the existing research. Therefore, this study makes up for the limitations of existing studies that only focus on the pricing policy selection of one platform [19, 21]. Second, this paper not only obtains the conditions for the optimal pricing policy of the platform but also reveals the effects of online review information on the platform profit, service provider profits, consumer surplus, and social welfare, which can provide a crucial basis for the operation decision of the platform. Third, unlike existing studies (e.g., [19, 21]), we find several new conclusions. For example, under the platform pricing policy, the platform can gain large profits, but under certain conditions, it may damage consumer surplus and social welfare.

The rest of this paper is organized as follows. Section 2 reviews the relevant literature. Section 3 describes the problem. Section 4 gives the model settings and optimal results under the two policies. Next, in Section 5, we compare the service prices, profits, consumer surplus, and social welfare under the two policies. Section 6 gives three extended studies. Section 7 summarizes this paper's conclusions and management insights and gives the future research. All proofs are provided in the Appendix.

2. Literature Review

This study is closely related to two streams of the literature: the pricing policy of a supply chain and online consumer reviews.

The first stream of the literature studies the pricing policy of a supply chain, and we can see that some scholars have done some research work. Feng et al. [22] studied pricing strategies for new products by using different choice behaviors of two types of consumers. Liu et al. [23] considered a problem of two-period pricing and strategy choice for a supply chain consisting of a supplier and a retailer in the presence of uncertain basic market demand and uncertain product review. Wu et al. [24] showed that when product competition is strong and no consumer switching behavior occurs, competing retailers always adopt symmetric sampling strategies to allow consumers to resolve such uncertainty before purchase. Moreover, the most relevant to our work is the pricing policy of P2P service-sharing platforms. Cachon et al. [25] studied the pricing mechanism of a service-sharing platform: fixed wage, fixed price, and peak pricing. They found that the peak pricing strategy benefits service providers and consumers under certain conditions. Liu et al. [3] studied the effects of the matching ability, the scale of service providers, and the differentiated services on the platform's service prices and wages. Taylor [26] studied how a service platform sets the service price charged to consumers and the wage paid to service providers. The results showed that with the increase in delay sensitivity, the service price will increase while the salary will decrease. Benjaafar et al. [27] studied how a sharing platform determines the service price and the wage. They found that the low wage will damage the service provider surplus. Gibbs et al. [28] used the feature pricing model to study the impacts of multiple variables on Airbnb's service price. They indicated that the room characteristics, location, and host characteristics significantly affect the service price. Zhao et al. [29] studied the differentiated pricing strategy of a ride-sharing platform and pointed out the specific conditions for adopting each strategy. Additionally, most relevant to our research, Pavlov and Berman [19] studied the pricing mechanism of a P2P platform in the sharing economy: platform pricing and service provider pricing. They showed that the platform pricing mechanism is not always optimal. Unlike the above research, this paper considers a platform service supply chain composed of a high-quality service provider, a low-quality service provider, and a service-sharing platform. The effect of online reviews on platform pricing policy selection is studied. For the two policies of a platform: service provider pricing and platform pricing, we discuss which pricing policy is beneficial for the platform. This study fills the gaps of existing research.

The second stream of the literature studies online consumer reviews. For this aspect of research, online consumer reviews are regarded as information tools to reveal the quality or applicability of products. Kwark et al. [14] pointed out that providing product information with different dimensions may soften or intensify upstream competition. Liu et al. [15] focused on online reviews and sales information. They showed that the two types of information mutually promote the company's profit. Chen et al. [30] studied the impact of online consumer review information on the platform profit. They found that when the consumer heterogeneity is low, providing online consumer review information will intensify the competition of service providers and damage the platform profit. Moreover, Xiao et al. [31] showed that only when online consumer reviews are sufficiently positive do online consumer reviews raise overall prices and profits for manufacturers and the entire supply chain, which is always harmful to retailers. Huang et al. [32] explored whether and when a company should adopt reviews from a supply chain perspective. Ren et al. [33] studied the impact of online reviews on the pricing of the home-sharing platform Airbnb, and they found that the number of online reviews positively correlates with the service price. Wang and Nicolau [34] analyzed the determinants of the service price of the home-sharing platform in the sharing economy. They found that the higher the average score of customers, the higher the service price. Moreover, the number of online reviews negatively affects the service price. It should be pointed out that one of the most significant features of service-sharing platforms is online review information, which is rarely studied in existing research. Unlike the above studies, we investigate the pricing policy selection of a P2P service-sharing platform based on online consumer reviews. We also explore the impacts of different pricing policies on the platform profit, service provider profits, consumer surplus, and social welfare. Additionally, in the extended studies, we also analyze the situation in which online reviews are manipulated and the impacts of the number of online reviews. This study makes up for the limitations of the existing studies. Table 1 shows how our study differs from the most relevant literature.

3. Problem Description

This paper considers a platform service supply chain composed of a high-quality service provider, a low-quality service provider, and a service-sharing platform (hereinafter "platform"). The high-quality and low-quality service providers control many assets and provide vertically differentiated services to consumers through the platform. The platform has two pricing policies: service provider policy (hereinafter "Policy S") and platform pricing (hereinafter "Policy C"). Under Policy S, each service provider determines the service price to maximize its profit; under Policy C, service providers deposit their service products on the platform, and the platform determines the service price to maximize its profit. Under each pricing policy, the platform shares the profit with service providers in a predetermined proportion for each transaction. Then, consumers decide whether to rent or not, and if so, whether to rent high-quality or low-quality service based on the service price. The market structure is shown in Figure 1.

In this paper, we focus on the impact of online review information on consumers' rental decisions. To examine the effects of online reviews on pricing decisions and profits, we only consider the stable state of online reviews that have

Table 1: The differences between our study and relevant literature.

	Zhang et al. [35]	Feng et al. [22]	Liu et al. [23]	Pavlov and Berman [19]	Chi et al. [1]	This study
Pricing decisions	✓	✓	✓	✓	✓	✓
Pricing policy	✗	✗	✗	✓	✓	✓
Online reviews	✓	✗	✓	✗	✗	✓
Differentiated service quality	✗	✗	✗	✓	✗	✓
Platform service supply chain	✗	✓	✗	✗	✗	✓

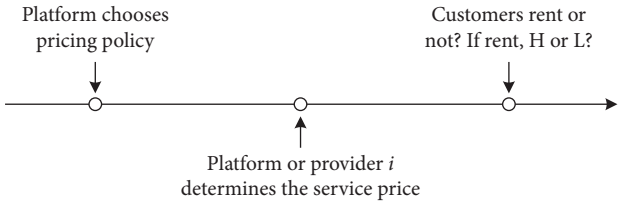

Figure 1: Market structure.

accumulated on the platform [36]. Each consumer gets the same information from online reviews, which can be positive or negative. This assumption can be used in the research of online reviews. Further, in reality, each service provider has the motivation to make online review information beneficial to it, or the platform should control misleading information to improve consumer surplus. Then, we consider the situation for manipulating online reviews in extended studies. Additionally, referring to [37], we first assume that the commission rate is exogenous and then consider the situation where the commission rate is endogenous in the extended studies.

In this paper, $i = H$ and L represent the high-quality and low-quality services, respectively, $j = S$ denotes Policy S, and $j = C$ denotes Policy C. The relevant symbols and variables involved in this paper are shown in Table 2.

4. Models

The service quality of the two service providers is q_H and q_L, respectively, and $q_H > q_L$. When there are no online reviews on the platform, the utility obtained by a consumer choosing the service provider i ($i = H, L$) is $\theta q_H - p_H^j$ and $\theta q_L - p_L^j$, respectively. θ is the valuation of the service by consumers, where $\theta \sim U[0,1]$. We use $f(\theta)$ to represent the probability density function of consumers' valuation. p_H^j represents the price of the high-quality service, and p_L^j represents the price of the low-quality service, where $p_H^j > p_L^j$. Meanwhile, consumers do not obtain sufficient information before purchasing services through short-term rental platforms, and online reviews displayed on the platform can reduce consumers' uncertainty about service quality. To examine the impacts of online reviews on pricing decisions and profits, we only consider the stable state of accumulated online reviews on the platform [36]. Referring to [35], q_R is defined as the common belief reflected by online reviews (or the information disclosed by online reviews), where $-1 \le q_R \le 1$. Specifically, if the consumers perceive a positive evaluation signal from the reviews, then $q_R > 0$, and vice versa. In addition, online reviews provide more information about service attributes that can only be obtained after consumption. Therefore, online reviews will affect the demands of each service provider. Referring to the minimum variance estimation method in [14], a consumer's expected posterior beliefs about the utility of the high-quality and low-quality services become $u_H^j = \theta(1-r)q_H + rq_R - p_H^j$ and $u_L^j = \theta(1-r)q_L + rq_R - p_L^j$, respectively. r represents the weight of online reviews in service evaluation, where $0 < r < 1$. The larger r is, the more the consumers pay attention to the information disclosed by online reviews. Therefore, consumers are more willing to adjust their quality evaluation according to online reviews. If $u_H^j > u_L^j$, consumers will choose high-quality services; if $u_H^j \le u_L^j$ and $u_L^j \ge 0$, consumers will select low-quality services. $\theta_1 = (p_L^j - rq_R/(1-r)q_L)$ can be obtained by solving $u_L^j = 0$. $\theta_2 = (p_H^j - p_L^j/(1-r)(q_H - q_L))$ can be obtained by solving $u_H^j = u_L^j$. D_H^j and D_L^j represent the demands of the high-quality service provider and the low-quality service provider, respectively. Therefore, the demand functions of the two service providers are

Table 2: Summary of notations.

Symbol	Definitions
Decision variable	
p_i^j	The service price
Parameter	
q_i	The service quality
θ	Consumers' valuation of services, $\theta \sim U[0,1]$
k	The commission rate for service providers
q_R	Information disclosed by online consumer reviews (hereinafter "review information"), $-1 < q_R < 1$
r	The weight of online consumer reviews in service evaluation
D_i^j	The demand
Π_i^j	The service provider profit
Π_p^j	Platform profit
CS^j	Consumer surplus
SW^j	Social welfare

$$D_H^j = \int_{\theta_2}^{1} f(\theta)\mathrm{d}\theta, \quad = 1 - \frac{p_H^j - p_L^j}{(1-r)(q_H - q_L)}, \tag{1}$$

$$D_L^j = \int_{\theta_1}^{\theta_2} f(\theta)\mathrm{d}\theta = \frac{q_L\left(p_H^j - p_L^j\right) - (q_H - q_L)\left(p_L^j - rq_R\right)}{q_L(1-r)(q_H - q_L)}. \tag{2}$$

This linear demand model has also been widely used and proved in the existing research. The difference is that to make it easier to get the impact of online reviews, we only consider the situation where the demands of both service providers are non-negative. That is, we have the following inequality constraint: $p_H^j \le \min\{p_L^j + (1-r)\quad(q_H - q_L), p_L^j q_H - rq_R(q_H - q_L)/q_L\}$.

Next, we will consider the service provider pricing and the platform pricing, respectively. For the convenience of analysis, we first assume that the commission rate is exogenous. Then, Section 6.2 analyzes the situation where the commission rate is endogenous.

4.1. Service Provider Pricing. When the platform adopts Policy *S*, service providers provide services to consumers. The high-quality and low-quality service providers determine their own service prices, respectively. For each transaction, the platform will charge a predetermined commission from each transaction.

Under Policy *S*, the profits of the high-quality and the low-quality service providers and the platform profit are as follows:

$$\max_{p_H^S} \ \Pi_H^S = (1-k)p_H^S D_H^S, \tag{3}$$

$$\max_{p_L^S} \ \Pi_L^S = (1-k)p_L^S D_L^S, \tag{4}$$

$$\Pi_P^S = k\left(p_H^S D_H^S + p_L^S D_L^S\right). \tag{5}$$

We can obtain the following lemma by solving equations (3) and (4).

Lemma 1. *Under Policy S, the optimal price of the high-quality service is* $p_H^{S*} = ((q_H - q_L)(2q_H - 2rq_H + rq_R)/4q_H - q_L)$*, and the optimal price of the low-quality service is* $p_L^{S*} = (q_H - q_L)(q_L - rq_L + 2rq_R)/4q_H - q_L$.

From Lemma 1 and equations (1)–(5), the demand and profit of the high-quality service provider are $D_H^{S*} = 2q_H - 2rq_H + rq_R/(1-r)(4q_H - q_L)$ and $\Pi_H^{S*} = (1-k)(q_H - q_L)(2q_H - 2rq_H + rq_R)^2/(1-r)(4q_H - q_L)^2$, respectively. The demand and profit of the low-quality service provider are $D_L^{S*} = q_H(q_L - rq_L + 2rq_R)/q_L(1-r)\quad(4q_H - q_L)$ and $\Pi_L^{S*} = q_H(1-k)(q_H - q_L)\ (q_L - rq_L + 2rq_R)^2/q_L(1-r)(4q_H - q_L)^2$. The platform profit is $\Pi_P^{S*} = k(q_H - q_L)\{(4q_H + q_L)[q_H q_L(1-r)^2 + r^2 q_R^2] + 8q_H q_L\ \ rq_R\ \ (1-r)\}/q_L(1-r)(4q_H - q_L)^2$.

From Lemma 1, we can find that the optimal results of Policy *S* depend not only on q_H and q_L but also on the online review information (q_R) and the weight (r). Therefore, the online review information and the weight play an important role in decision makers' pricing decisions. In service sharing, service providers should evaluate the online review information and the weight, increasing the difficulty of their decisions.

Corollary 2. *Under Policy S, the impacts of main parameters on the optimal results are shown in Table 3.*

Corollary 2 shows that the more the information disclosed by online reviews is (hereinafter "online review information"), the higher the service price p_i^{S*} is and the more profits the service provider i and the platform earn. This is because online reviews play a leading role in consumers' purchase decisions. Online reviews can improve consumers' understanding of the valuation of service quality, and consumers' valuation of the high-quality and low-quality services is more heterogeneous. Therefore, the competition between the two service providers is mitigated, leading to an increase in service price and profit. Further, the platform profit will also increase. We can also find that if the online review information is small, the service price, the service providers' profit, and the platform profit first decrease and then increase in the weight of online reviews. This is because when consumers' purchasing decisions are quality-oriented and the online review information is small, the weight of online reviews plays a leading role in reducing the quality difference between the two services. That is, the intensified competition between the two service providers leads to a decline in prices and profits of service providers. Otherwise, when the weight of online reviews exceeds a certain threshold, the competition will slow down, increasing service prices and service providers' profits.

The following corollary can be obtained by analyzing the service prices, demands, and profits under Policy *S*.

Corollary 3. *If* $q_R \ge -q_L(1-r)/2r$*, two service providers can coexist.*

Corollary 3 gives the conditions for the coexistence of two competing service providers ($D_H^{S*} \ge 0$ and $D_L^{S*} \ge 0$). Corollary 3 also shows that if the online review information of the two service providers is enough, the two service providers can coexist. This means that when online review information is small, the two service providers will be driven out of the market. In this paper, we focus on the competition between two service providers, namely, they can coexist.

Therefore, positive or negative online reviews can encourage consumers to purchase services, and negative online reviews may not harm service providers. Sufficiently negative online reviews will reduce the profits of low-quality service providers. Specifically, service providers may gain higher profits when online review information exceeds a threshold. For example, house-sharing platforms such as Airbnb will display online reviews for each service, and

Table 3: The impacts of key parameters on the optimal results under Policy S.

	p_H^{S*}	p_L^{S*}	Π_H^{S*}	Π_L^{S*}	Π_P^{S*}
q_R	↑	↑	↑	↑	↑
r	If $q_R < 2q_H$, then ↓; otherwise, ↑	If $q_R < q_L/2$, then ↓; otherwise, ↑	If $q_R < 4\kappa q_H$, then ↓; otherwise, ↑	If $q_R < \kappa q_L$, then ↓; otherwise, ↑	If $q_R < q_R'$, then ↓; otherwise, ↑

$q_R' = (1-r)[\sqrt{q_H q_L (8q_H - 4rq_L + rq_L)(4rq_H + 2q_L - rq_R)} - q_H q_L (1-r)]/r(2-r)(4q_H + q_L)$, $\kappa = 1 - r/2(2-r)$.

consumers can learn more information by reading the comment text or images.

Corollary 4. *(i)* $\partial p_H^{S*}/\partial q_R < \partial p_L^{S*}/\partial q_R$, $\partial D_H^{S*}/\partial q_R < \partial D_L^{S*}/\partial q_R$, $\partial \Pi_H^{S*}/\partial q_R < \partial \Pi_L^{S*}/\partial q_R$; *(ii)* $\partial p_H^{S*}/\partial r < \partial p_L^{S*}/\partial r$, $\partial D_H^{S*}/\partial r < \partial D_L^{S*}/\partial r$, $\partial \Pi_H^{S*}/\partial r < \partial \Pi_L^{S*}/\partial r$.

Corollary 4 shows that the online review information (or the weight of online reviews) has less impact on the price, demand, and the high-quality service provider profit than on the price, demand, and profit of the low-quality service provider profit. That is, the low-quality service provider is more sensitive to changes in online review information (or the weight of online reviews). These results show that service providers can benefit more from an increase in online review information (or the weight of online reviews).

In other words, service providers can take measures (such as giving small gifts and coupons) to motivate consumers to provide more comprehensive online reviews. Specifically, the increase in online review information may increase service providers' profits and attract many consumers to purchase services. Therefore, service providers can promote transactions between themselves and consumers by providing high-quality services to consumers.

Referring to [38], consumer surplus can be expressed as $\mathrm{CS}^S = (1-r)[q_H (D_H^{S*})^2 + 2q_L D_H^{S*} D_L^{S*} + q_L (D_L^{S*})^2]/2$. Substituting D_H^{S*} and D_L^{S*} into CS^S, we can obtain

$$\mathrm{CS}^S = \frac{q_H\left\{(4q_H + 5q_L)\left[q_H q_L (1-r)^2 + r^2 q_R^2\right] + 2q_L r q_R (1-r)(8q_H + q_L)\right\}}{2q_L (1-r)(4q_H - q_L)^2}. \tag{6}$$

Social welfare can be expressed as $\mathrm{SW}^S = \Pi_H^{S*} + \Pi_L^{S*} + \Pi_P^{S*} + \mathrm{CS}^S$, namely,

$$\mathrm{SW}^S = \frac{2\left(6q_H^2 - q_L^2\right)\left[q_H q_L (1-r)^2 + r^2 q_R^2\right] + r q_H q_L q_R [2(1-r)(16q_H - 7q_L) - rq_R] - q_H^2 q_L^2 (1-r)^2}{2q_L (1-r)(4q_H - q_L)^2}. \tag{7}$$

Further, we can obtain the following corollary.

Corollary 5. *(i)* $\partial CS^S/\partial q_R > 0$, $\partial SW^S/\partial q_R > 0$; *(ii) if* $q_R < (1-r)[\sqrt{q_L^2 (8q_H + q_L)^2 + rq_L (2+r)(q_H - q_L)(4q_H - q_L)^2} - q_L (1-r)(8q_H + q_L)]/r(2-r)(4q_H + 5q_L)$, *then* $\partial CS^S/\partial r < 0$; *otherwise,* $\partial CS^S/\partial r \geq 0$; *if* $q_R < (1-r)[\sqrt{(16q_H - 7q_L)^2 q_H^2 q_L^2 + q_H q_L r(2-r)(9q_H - 4q_L)(q_H - q_L)(4q_H - q_L)^2} - q_H q_L (1-r)(16q_H - 7q_L)]/r(2-r)(12q_H^2 - q_H q_L - 2q_L^2)$, *then* $\partial SW_P^S/\partial r < 0$; *otherwise,* $\partial SW_P^S/\partial r \geq 0$.

Corollary 5 (i) shows that the impacts of online reviews on consumer surplus and social welfare are complex. That is, with the increase of online review information, both consumer surplus and social welfare will increase. This is because online reviews slow down the competition between the two service providers. With the increase of online review information, consumers can buy services at a lower mismatch cost. The matching between consumers' preferences and services may improve the efficiency of the online market, which in turn will increase consumer surplus and social welfare.

Corollary 5 (ii) indicates that consumer surplus and social welfare first decrease and then increase in the weight of online reviews when the online review information is small. This is because when online review information is small, consumers can purchase the service at a lower price and may incur mismatching costs. Therefore, consumer surplus and social welfare will decrease, and social welfare will also decrease.

This finding effectively explains why some house-sharing platforms, such as Airbnb and HomeAway, offer landlords smart pricing tools. Even if the platform's profit declines, shared services will become increasingly popular because of consumer surplus and social welfare improvement.

4.2. Platform Pricing. Under Policy C, the platform determines both high-quality and low-quality service prices to maximize its profit. The platform collects a predetermined commission fee from each transaction. We construct the profit-maximizing model of the platform as

$$\max_{p_H^C, p_L^C} \Pi_P^C = k\left(p_H^C D_H^C + p_L^C D_L^C\right). \tag{8}$$

Furthermore, the profit function of the high-quality service provider is $\Pi_H^C = (1-k)p_H^C D_H^C$, and the profit function of the low-quality service provider is $\Pi_L^C = (1-k)p_L^C D_L^C$.

By solving equation (8), Lemma 6 can be obtained.

Lemma 6. *Under Policy C, the optimal price of the high-quality service is* $p_H^{C*} = q_H - rq_H + rq_R/2$, *and the optimal price of the low-quality service is* $p_L^{C*} = q_L - rq_L + rq_R/2$.

Further, the demand and the profit of the high-quality service provider are $D_H^{C*} = 1/2$ and $\Pi_H^{C*} = (1-k)\ (q_H - rq_H + rq_R)/4$. The demand and profit of the low-quality service provider are $D_L^{C*} = rq_R/2q_L(1-r)$ and $\Pi_L^{C*} = rq_R\ (1-k)\,(q_L - rq_L + rq_R)/4q_L(1-r)$. The platform profit is $\prod_P^{C*} = k[r^2 q_R^2 + 2rq_L q_R(1-r) + q_H q_L\ (1-r)^2]/4q_L(1-r)$.

Corollary 7. *Under Policy C, the impacts of key parameters on the optimal results are shown in Table 4.*

Corollary 7 shows that the more the online review information is (i.e., q_R), the higher the service prices are (i.e., p_H^{C*} and p_L^{C*}) and the more profits the service provider i and the platform earn. Further, the platform profit will also increase. We can also find that if the weight of online reviews (i.e., r) is small, the service price, the service providers' profit, and the platform profit first decrease and then increase in the weight of online reviews. These findings are consistent with the results of Corollary 2.

We obtain the following corollaries by analyzing the service price, the demand, and the profit under Policy *C*.

Corollary 8. *If* $q_R \geq 0$, *two service providers can coexist.*

Corollary 8 gives the conditions for the coexistence of two service providers (i.e., $D_H^{C*} \geq 0$ and $D_L^{C*} \geq 0$). From Corollary 8, we can see that if the online review information obtained by consumers is positive, the two service providers can coexist. This means that when $q_R < 0$, the low-quality service provider will be driven out of the market. This means that the low-quality service provider will not benefit from online reviews. This is because consumers will likely not purchase the low-quality service if they receive negative online review information. That is, low-quality services will limit consumers from joining the platform. However, no matter whether the online review information obtained by consumers is positive or negative, it will not affect the market demand for high-quality services. Therefore, the effect of online reviews is significant. This conclusion can bring some management implications to the platform. For a platform, online reviews can be an effective means to improve service quality and platform revenue. From the platform's sustainable development perspective, the platform can also assign other policies and rules (such as punitive measures and reputation management) to strengthen supervision and control over the low-quality service provider. Here, we focus on the situation where two service providers constantly compete, that is, they can coexist.

Corollary 9. *(i)* $\partial p_H^{C*}/\partial q_R = \partial p_L^{C*}/\partial q_R$, $\partial D_H^{C*}/\partial q_R = \partial D_L^{C*}/\partial q_R$, $\partial \Pi_H^{C*}/\partial q_R < \partial \Pi_L^{C*}/\partial q_R$; *(ii)* $\partial p_H^{C*}/\partial r < \partial p_L^{C*}/\partial r$, $\partial D_H^{C*}/\partial r < \partial D_L^{C*}/\partial r$, $\partial \Pi_H^{C*}/\partial r < \partial \Pi_L^{C*}/\partial r$.

From Corollary 9, we can find that the impact of online review information on the price and demand of the high-quality service is equal to the impact on the price and demand of the low-quality service. In contrast, the impact of online review information on the profit of the high-quality service provider is less than the impact on the profit of the low-quality service provider. This is because, under Policy *C*, the platform determines the high-quality and low-quality service prices to maximize its profit while there is no competition between providers. Therefore, the impact of online review information on the price and demand of the high-quality and the low-quality services remains unchanged. The results and potential mechanisms of Corollary 9 (ii) are consistent with Corollary 4 (ii), and we omitted more details here.

Similar to Policy *S*, consumer surplus can be expressed as

$$\mathrm{CS}^C = \frac{(1-r)\left[q_H\left(D_H^{C*}\right)^2 + 2q_L D_H^{C*} D_L^{C*} + q_L\left(D_L^{C*}\right)^2\right]}{2}. \tag{9}$$

Social welfare is the sum of the profits of two service providers, the platform profit, and consumer surplus. Further, Social welfare can be expressed as

$$\mathrm{SW}^C = \frac{3\left[q_H q_L(1-r)^2 + 2r(1-r)q_L q_R + r^2 q_R^2\right]}{8(1-r)q_L}. \tag{10}$$

Corollary 10. *(i)* $\partial CS^C/\partial q_R > 0$, $\partial SW^C/\partial q_R > 0$; *(ii) if* $q_R < (1-r)[\sqrt{(1-r)q_L^2 + r(2-r)q_H q_L} - q_L(1-r)]/r(2-r)$, *then* $\partial CS^C/\partial q_R < 0$, $\partial SW^C/\partial q_R < 0$; *otherwise,* $\partial CS^C/\partial r \geq 0$, $\partial SW^C/\partial r \geq 0$.

Corollary 10 indicates that consumer surplus and social welfare will increase with the increase of online review information. Moreover, when there is less online review information, consumer surplus and social welfare first decrease and then increase as the weight of online reviews increases. This finding is consistent with the result of Corollary 5. When online review information is small, it is not beneficial for consumer surplus and social welfare. When the online review information is sufficient and positive, online reviews benefit consumer surplus and social welfare. Therefore, the platform can encourage consumers to provide more online reviews by adopting incentive measures (such as coupons) to improve consumer surplus and social welfare.

5. Analysis and Discussion

In this section, by comparing the platform profits, the service provider profits, consumer surpluses, and social welfare under Policies *S* and *C*, we obtain the following propositions. We also use numerical analysis to visualize our results and

Table 4: Impacts of key parameters on the optimal results under Policy C.

	p_H^{C*}	p_L^{C*}	Π_H^{C*}	Π_L^{C*}	Π_P^{C*}
q_R	↑	↑	↑	↑	↑
r	If $q_R < q_H$, then ↓; otherwise, ↑	If $q_R < q_L$, then ↓; otherwise, ↑	If $q_R < q_H$, then ↓; otherwise, ↑	↑	If $q_R < q_R''$, then ↓; otherwise, ↑

$q_R'' = (1-r)[\sqrt{q_L^2 + rq_L(2-r)(q_H - q_L)} - q_L(1-r)]/r(2-r)$.

obtain some new findings. Referring to [35], the values of some parameters are set to $q_H = 0.8$, $q_L = 0.6$, $r = 0.5$, and $k = 0.9$. These parameter settings can ensure that the conditions of the optimal results are satisfied and will not affect the comparison results.

Proposition 11. *(i)* $D_H^{S*} > D_H^{C*}$, $D_L^{S*} > D_L^{C*}$; *(ii)* $p_H^{S*} < p_H^{C*}$, $p_L^{S*} < p_L^{C*}$.

Proposition 11 shows that the demand of the high-quality (low-quality) service provider under Policy S is higher than that under Policy C, and the price of the high-quality (low-quality) service provider under Policy S is lower than that under Policy C. This is because, under Policy S, when the high-quality service provider and the low-quality service provider compete in price, the demand of both service providers is high. Policy S helps market segmentation to ease the competition between service providers. Under Policy S, the demand is higher when service providers compete in price. This result is intuitive. We usually believe that when a platform adopts Policy C, it weakens competition among service providers and increases the service prices.

Figures 2 and 3 visually display the above results and demonstrate the impact of the weight of online reviews on platform pricing decisions and consumer demand.

From Figures 2 and 3, we can see that regardless of whether the platform adopts Policy S or C, as consumers increase their weight on online reviews, they are more willing to purchase services. These findings can provide a reference for the pricing decisions of platforms and service providers. The platforms and service providers can make pricing decisions to attract more potential consumers.

Proposition 12. *(i) If* $q_R < \overline{q}_R$, *then* $\Pi_H^{S*} \le \Pi_H^{C*}$, $\Pi_L^{S*} > \Pi_L^{C*}$; *(ii) if* $\overline{q}_R < q_R < \widehat{q}_R$, *then* $\Pi_H^{S*} \le \Pi_H^{C*}$, $\Pi_L^{S*} \le \Pi_L^{C*}$; *(iii) if* $q_R > \widehat{q}_R$, *then* $\Pi_H^{S*} > \Pi_H^{C*}$, $\Pi_L^{S*} \le \Pi_L^{C*}$, *where* $\overline{q}_R = (1-r)\,[(4q_H - q_L)\sqrt{q_L(8q_H + q_L)} - q_L(8q_H + q_L)]/2r(8q_H + q_L)$ *and* $\widehat{q}_R = (1-r)[(4q_H - q_L)\sqrt{q_L(8q_H + q_L)} + q_L(8q_H + q_L)]/8r\,(q_H - q_L)$.

Proposition 12 indicates that when the online review information is small, the high-quality service provider profit under Policy C is higher than that under Policy S. On the contrary, the low-quality service provider gains more profit under Policy S. When the online review information is moderate, Policy C benefits the high-quality and the low-quality service providers. When the online review information is large, the high-quality service provider profit under Policy S is higher than that under Policy C, while the low-quality service provider profit is high. That is, when the online review information is small, the high-quality service provider is more willing to determine the service price by the platform. In contrast, the low-quality service provider is more inclined to have pricing power. When the online review information is large, the high-quality service provider is more willing to decide the service price, while the low-quality service provider is more willing to determine the price by the platform. This is because, when the online review information is small, the low-quality service provider can attract consumers by lowering the service price. With the increase of the online review information, it is beneficial to the low-quality service provider, but it will damage the high-quality service provider profit. Figure 4 visualizes the results of Proposition 12.

We also analyze the effects of the weight of online reviews and the commission rate on the profits of high-quality and low-quality service providers, as shown in Figures 5 and 6. We can see from Figure 5 that under Policy S or C, the profit of the high-quality service provider decreases in the weight. Under Policy S, the profit of the low-quality service provider increases in the weight. Under Policy C, the profit of the low-quality service provider decreases first and then increases in the weight. We can see from Figure 6 that the commission rate negatively affects the profits of the high-quality and low-quality service providers.

Proposition 13. $\Pi_P^{S*} < \Pi_P^{C*}$.

Proposition 13 indicates that the platform profit under Policy C is higher than that under Policy S. This is because, under Policy C, platform pricing weakens the competition between the two service providers and increases the service price. If the quality of the service provider on the platform is uncertain and when the online review information is negative, the platform should transfer the pricing power to the service provider, which is beneficial to the platform.

This result has important management implications for the P2P service-sharing industry. This indicates that the platform has greater flexibility in influencing the number of consumers. For example, the online review system established by the platform promotes interaction between both parties and further encourages more consumers to purchase services. This finding validates Airbnb's approach in reality. Airbnb is a well-run platform in an emerging industry, but its landlords (i.e., service providers) have lower efficiency in setting prices to maximize profits. Therefore, Airbnb launched a smart pricing tool based on internal algorithms in 2015. If landlords can use the platform's pricing tools appropriately, they can earn 40% more profits. From Proposition 12 and 13, we find that regardless of the pricing policy adopted by the platform, service quality and online review information are

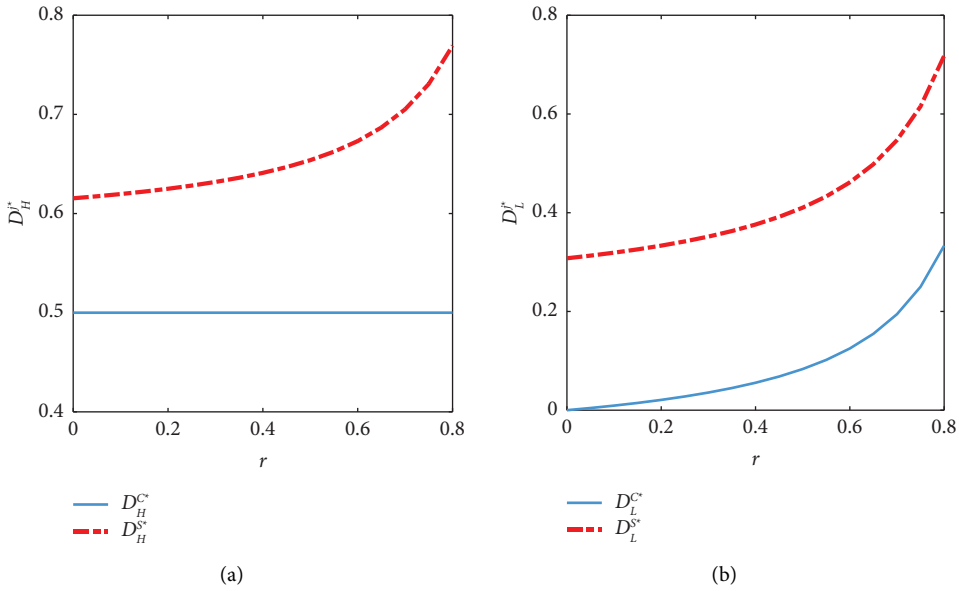

FIGURE 2: Comparison of consumer demands under two pricing policies. (a) Comparison of D_H^{C*} and D_H^{S*}. (b) Comparison of D_L^{C*} and D_L^{S*}.

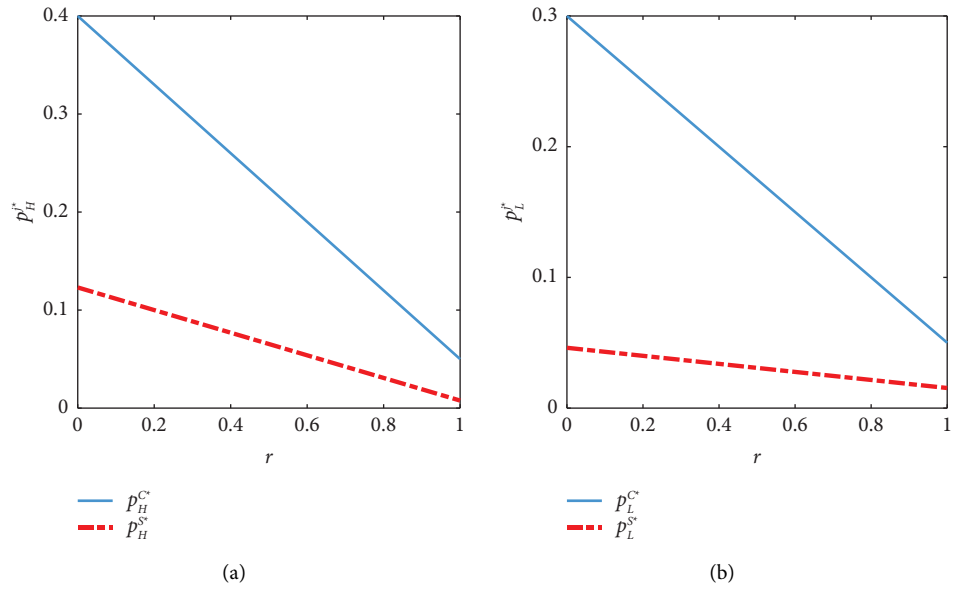

FIGURE 3: Comparison of service prices under two pricing policies. (a) Comparison of p_H^{C*} and p_H^{S*}. (b) Comparison of p_L^{C*} and p_L^{S*}.

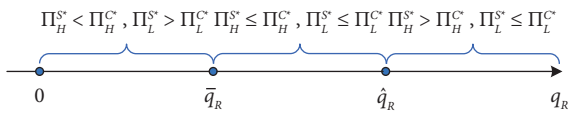

FIGURE 4: Comparison of service provider profits under two pricing policies.

important factors affecting the rapid development of the platform. Figure 7 visualizes the results of Proposition 13. Moreover, we can see from Figure 7 that under Policy S or C, platform profit decreases in the weight and increases in the commission rate.

Proposition 14. *(i) If* $q_R < (1-r)q_H q_L / r(2q_H - q_L)$, *then* $D_H^{S*} > D_L^{S*}$; *otherwise,* $D_H^{S*} \le D_L^{S*}$; *if* $q_R < (1-r)q_L/r$, *then* $D_H^{C*} > D_L^{C*}$; *otherwise,* $D_H^{C*} \le D_L^{C*}$. *(ii) If* $q_R < (1-r)\sqrt{q_H q_L}/r$, *then* $\Pi_H^{S*} > \Pi_L^{S*}$, $\Pi_H^{C*} > \Pi_L^{C*}$; *otherwise,* $\Pi_H^{S*} \le \Pi_L^{S*}$, $\Pi_H^{C*} \le \Pi_L^{C*}$.

Proposition 14 (i) indicates that when the online review information is small (i.e., $q_R < (1-r)q_H q_L / r(2q_H - q_L)$ or $q_R < (1-r)q_L/r$), the high-quality service provider can gain more consumer demand than the low-quality service provider under Policy S or C; otherwise, the low-quality service provider can obtain more consumer demand. Proposition 14 (ii) indicates that when the online review information is

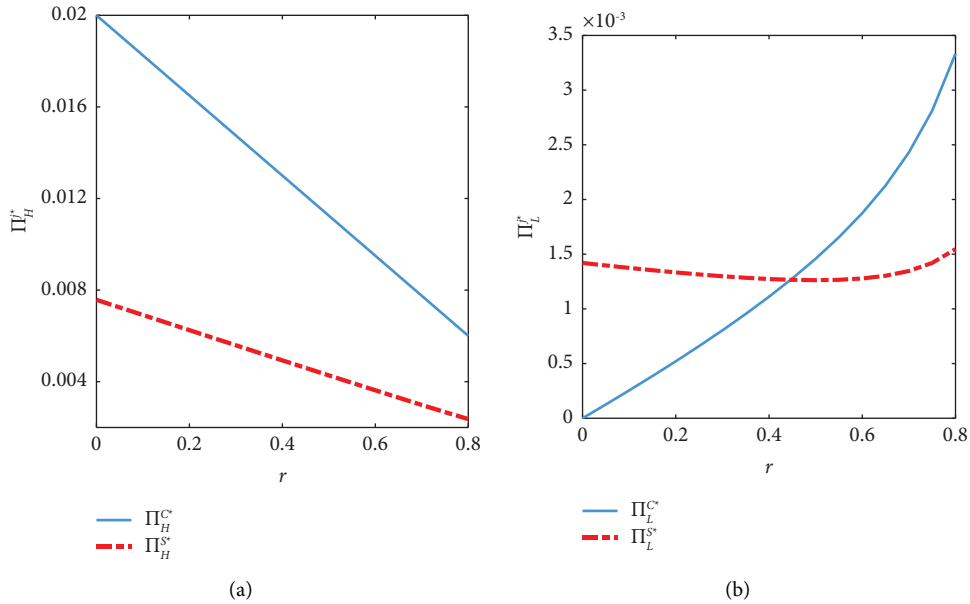

FIGURE 5: Effects of the weight of online reviews on the profit of the high-quality service provider. (a) Effects of r on Π_H^{j*}. (b) Effects of r on Π_L^{j*}.

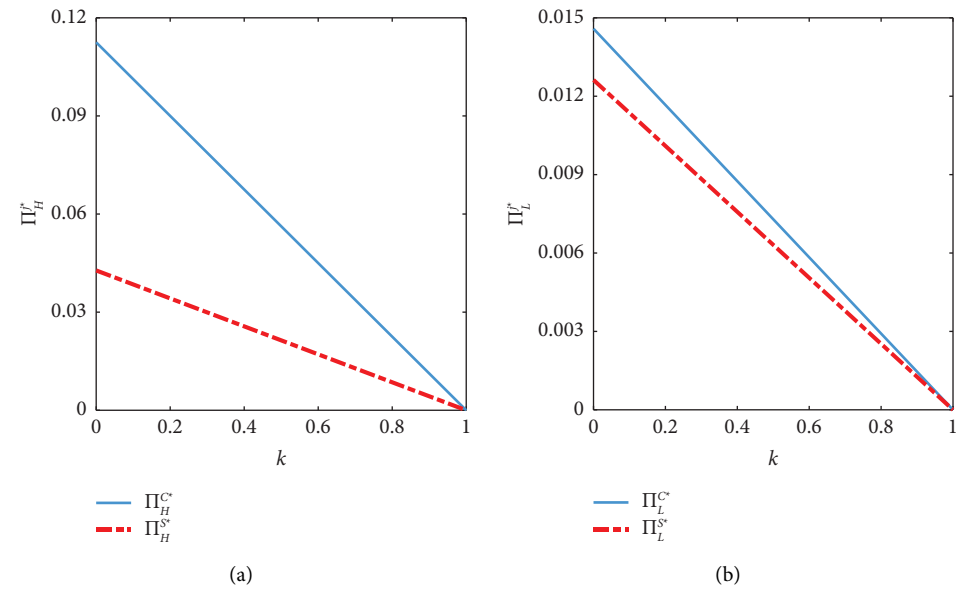

FIGURE 6: Effects of the commission rate on the profit of the high-quality service provider. (a) Effects of k on Π_H^{j*}. (b) Effects of k on Π_L^{j*}.

small (i.e., $q_R < (1-r)\sqrt{q_H q_L}/r$), the high-quality service provider can gain more profit than the low-quality service provider under Policy S or C; otherwise, the low-quality service provider can obtain more profit. The reason behind this can be explained as follows. Consumers can learn about the difference in service quality through online reviews. The information in online reviews enables consumers to understand the service better. After consumers understand the difference in service quality, they are more concerned about the degree to which the high-quality or low-quality service matches their preferences. For the low-quality service, the larger the online review information, the more consumers can understand their service quality and matching degree and thus increase their willingness to pay for the low-quality service. Thus, an increase in online review information can increase the demand and profit of the low-quality service provider. That is, the increase of the online review information can improve the advantages of the low-quality service provider. Hence, the increase of the online review information benefits the low-quality service provider and harms the profits of the high-quality service provider. These results can provide some practical management implications for operational decisions of service providers and platforms. For service providers, the increase in online review

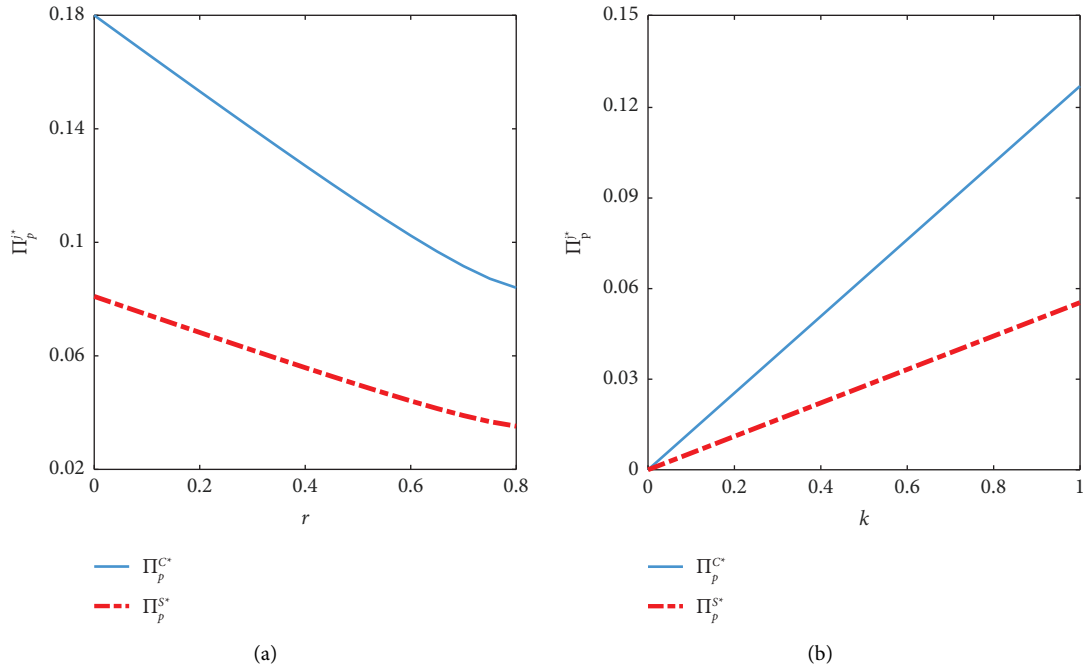

FIGURE 7: Comparison of platform profits under two pricing policies. (a) Effects of r on Π_p^{j*}. (b) Effects of k on Π_p^{j*}.

information plays a vital role in improving transactions between service providers and consumers. When consumers pay more attention to review information, a service provider has more incentive to improve the review information of its service in order to compete with competitors and attract more consumers. For a platform, it can motivate consumers to provide higher quality online reviews (such as evaluating room facilities, cleanliness, service quality, and safety of shared housing services) to alleviate competition between two service providers and thus increase their own profits.

We use Figures 8 and 9 to illustrate the results of Proposition 14. We can also see from Figures 8 and 9 that under Policy S, the profits and demand of the high-quality and low-quality service providers increase in the online review information, respectively. Under Policy C, the profit and demand of low-quality service providers increase in the online review information, and the profit of high-quality service providers increases in the online review information, while the demand of the high-quality service provider is not affected by the online review information.

Proposition 15. *(i)* $CS^S > CS^C$; *(ii)* $SW^S > SW^C$.

Proposition 15 (i) indicates that consumer surplus under Policy S is higher. This is because, under Policy S, service providers compete in price, the consumer demand is higher, and consumers can purchase services at lower prices. This is beneficial for consumers but disadvantageous for service providers. Under Policy C, the platform replaces the service provider to determine the price. If the service price is high, the total demand will be lower than that under Policy S. Therefore, consumer surplus will increase under Policy S.

Proposition 15 (ii) indicates that social welfare under Policy S is also higher. This is because Policy S may increase the profits of high-quality and low-quality service providers and the platform profit at the expense of sacrificing consumer surplus. Moreover, online review information provides a better match between consumers and services and reduces the mismatch cost in the entire market. As a result, social welfare has increased. This finding can also explain why some house-sharing platforms (such as Airbnb, Roomorama, and Tujia) are determined by service providers for prices.

We use Figure 10 to visualize the results of Proposition 15 and analyze the impact of the weight of online reviews on consumer surplus and social welfare. From Figure 10, we can see that as the weight of online reviews increases, consumer surplus and social welfare also increase under each pricing policy. This is because the increase in the weight of online reviews under each pricing policy leads to a decrease in service prices and platform profits, which in turn benefits consumers and increases social welfare. In this situation, consumers care more about online review information, and therefore, platforms can increase consumer surplus and social welfare by incentivizing consumers to provide more reviews.

The results of Proposition 15 and Figure 10 can provide some reference for the decision making of the platform. The platform needs to pay attention to the online review information to maximize its profit without decreasing consumer surplus and the profits of two service providers. Moreover, the platform needs to make a trade-off between attracting more consumers and making more profit.

6. Extensions

In this section, three extended studies are given to check the robustness of the above results and obtain some new conclusions. First, we study how service providers and platforms

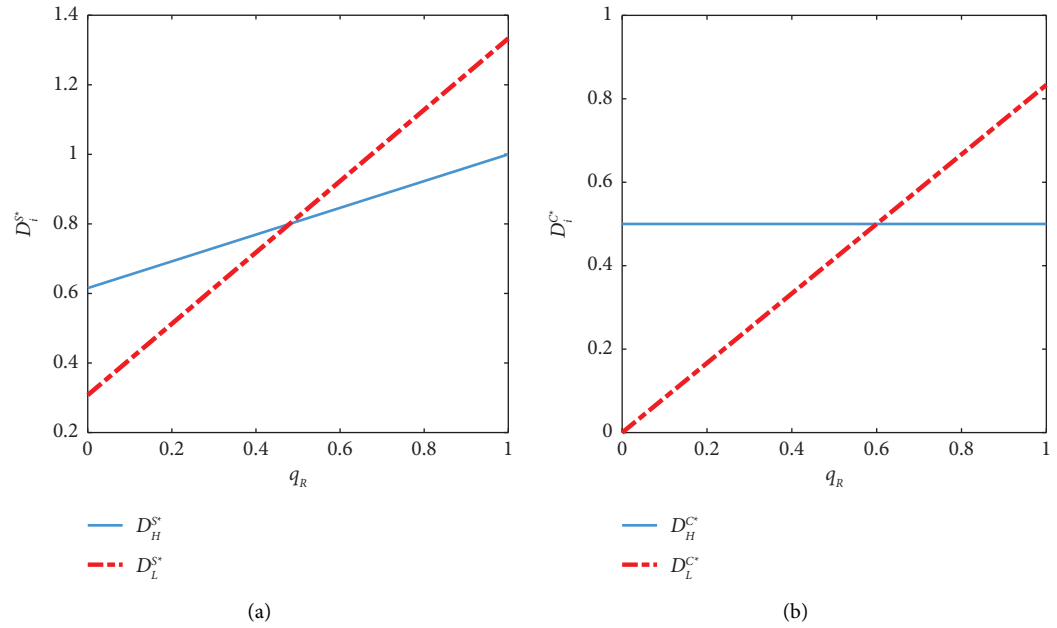

FIGURE 8: Comparison of consumer demand for high-quality and low-quality services under each pricing policy. (a) Comparison of D_H^{S*} and D_L^{S*}. (b) Comparison of D_H^{C*} and D_L^{C*}.

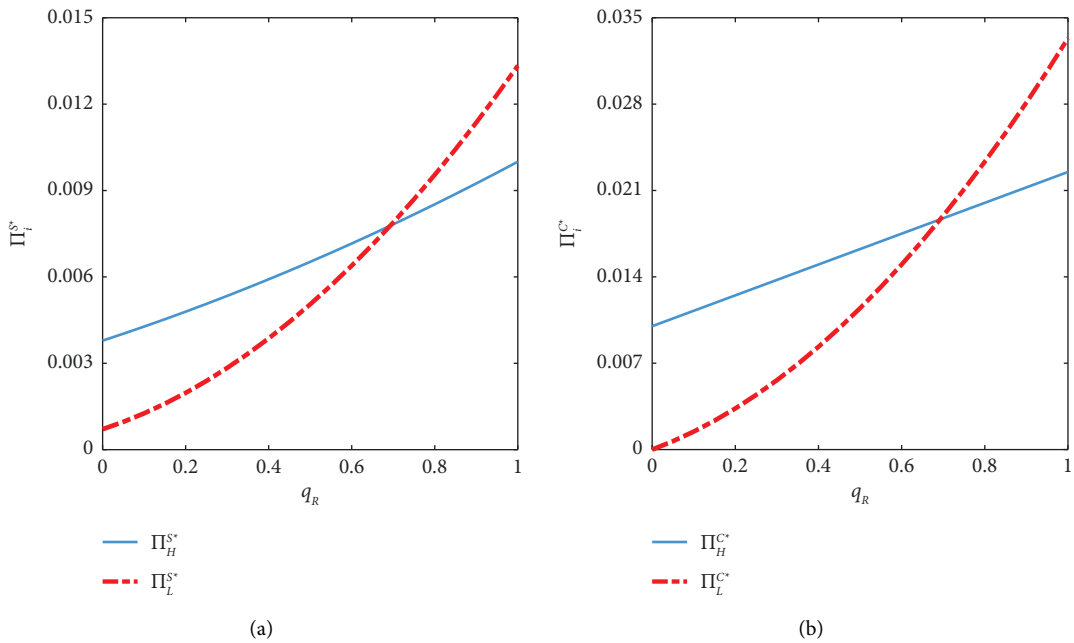

FIGURE 9: Comparison of the high-quality and low-quality service provider profits under each pricing policy. (a) Comparison of Π_H^{S*} and Π_H^{C*}. (b) Comparison of Π_H^{C*} and Π_L^{C*}.

manipulate online reviews. Second, we analyze the case where the commission rate is endogenous. Third, we analyze the effect of the number of online reviews.

6.1. Online Review Manipulation. Online review information affects the surpluses of service providers and consumers. According to the conclusion of Section 5, if the online review information is small or negative, the low-quality service provider will be driven out of the market. It is assumed that the service providers have the motivation to make the online review information beneficial to themselves. Alternatively, the platform should manipulate misleading information to improve consumer surplus. Next, referring to [39], we analyze the situation that two service providers manipulate online reviews under Policy *S*, and the platform manipulates online reviews under Policy *C*.

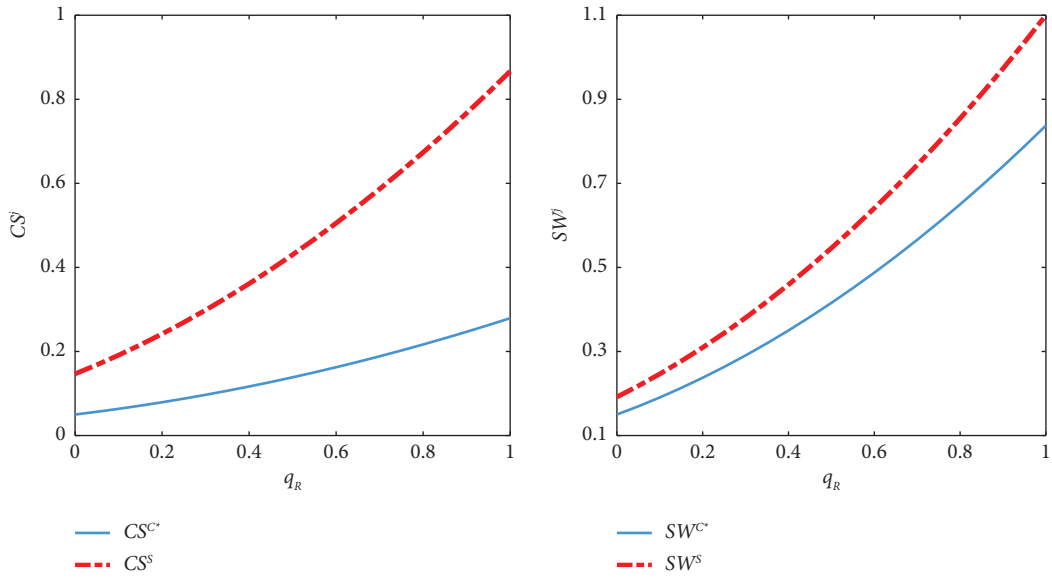

FIGURE 10: Comparison of consumer surplus and social welfare under each pricing policy. (a) Comparison of CS^C and CS^S. (b) Comparison of SW^C and SW^S.

We regard q_R as the result of online reviews manipulated by service providers or the platform. A service provider can invest more to encourage consumers to praise the service to get a higher quality evaluation than another service provider. This paper assumes that the manipulation efforts for online reviews of the high-quality the low-quality services are q_{R1} and q_{R2}, respectively, where $q_R = q_{R1} - q_{R2}$. We use the quadratic cost functions cq_{R1}^2 and cq_{R2}^2 to describe the cost of manipulating online reviews.

Under Policy S, we can construct the profit functions of two service providers as follows:

$$\Pi_H^S = \frac{(1-k)(q_H - q_L)\left[2q_H - 2rq_H + r(q_{R1} - q_{R2})\right]^2}{(1-r)(4q_H - q_L)^2} - cq_{R1}^2, \tag{11}$$

$$\Pi_L^S = \frac{q_H(1-k)(q_H - q_L)\left[q_L - rq_L + 2r(q_{R1} - q_{R2})\right]^2}{q_L(1-r)(4q_H - q_L)^2} - cq_{R2}^2. \tag{12}$$

When the manipulation cost coefficient is sufficiently large, i.e., $c > 4r^2(1-k)(q_H - q_L)/(1-r)(4q_H - q_L)^2$, there is an equilibrium solution. By solving equations (11) and (12), we can obtain $q_{R1}^{S*} = 2rq_H(1-k)(q_H - q_L)\ [r^2(1-k)(q_H - q_L) - cq_L(4q_H - q_L)\quad (1-r)]/c(4q_H - q_L)[r^2(1-k)(q_H - q_L)(4q_H + q_L) - cq_L(4q_H - q_L)^2(1-r)]$ and $q_{R2}^{S*} = 2rq_H(1-k)(q_H - q_L)[r^2(1-k)\ (q_H - q_L) + cq_L(4q_H - q_L)(1-r)]/c(4q_H - q_L)[r^2(1-k)(q_H - q_L)(4q_H + q_L) - cq_L(4q_H - q_L)^2(1-r)]$.

Under Policy C, the platform's profit function can be expressed as

$$\prod_P^C = \frac{k\left[r^2q_R^2 + 2rq_L(q_{R1} - q_{R2})(1-r) + q_Hq_L(1-r)^2\right]}{4q_L(1-r)} - cq_{R1}^2 - cq_{R2}^2. \tag{13}$$

When the manipulation cost coefficient is sufficiently large, i.e., $c > kr^2/2(1-r)q_L$, there is an equilibrium solution. By solving equation (13), we can obtain $q_{R1}^{C*} = q_{R2}^{C*} = krq_L(1-r)/2(kr^2 + 2crq_L - 2cq_L)$, i.e., $q_R = q_{R1}^{2*} - q_{R2}^{2*} = 0$. This will enable consumers to obtain a minimum surplus.

We obtain the following proposition by comparing the optimal manipulation efforts under the two policies.

Proposition 16. *(i)* $q_{R1}^{S*} < q_{R2}^{S*}$; *(ii)* $q_{R1}^{C*} = q_{R2}^{C*}$.

Proposition 16 points out that under Policy *S*, the low-quality service provider will pay more manipulation efforts to attract more consumers, which makes online reviews disclose more favorable information. Under Policy *C*, the platform makes the same manipulation efforts for the two services. That is, the platform can control misleading information, increase the matching degree between consumers and services, and improve consumer surplus. With the increase of the manipulation cost, the profits of the platform and the high-quality service provider will decrease, while the low-quality service provider can obtain more profit. That is, the platform manipulates online reviews, which are more beneficial to low-quality service providers. Therefore, manipulating online reviews is a useful tool that can reduce the credibility of online reviews. Without online reviews, consumers will face great uncertainty about the service. Online reviews significantly reduce the uncertainty between service providers and consumers. We find that reducing uncertainty is not always beneficial for platforms.

6.2. Endogenous Commission Rate. In this subsection, referring to [37], we regard the commission rate (i.e., k) as an endogenous variable, which will be affected by the external selection of service providers.

We define the reservation profit of the service provider i as μ_i. The reservation profit means that the service provider does not provide services to consumers through the platform, that is, the service provider offers rental services to consumers through other channels.

Since the service quality of the high-quality service provider is larger than that of the low-quality service provider, we assume that $\mu_H > \mu_L$. Under each policy, the platform first determines the commission rate, and then the service provider or the platform determines the service price.

Under Policy *S*, the profit functions of the high-quality service provider and the low-quality service provider are shown in equation (3) and (4), respectively. The profit function needs to satisfy that the profit of the high-quality and low-quality service providers should not be less than their reservation profits. By solving the profit functions (see Appendix), we obtain the optimal commission rate as follows:

$$k^{S*} = \frac{\left(4q_H^2 - q_L^2 - 3q_Hq_L\right)\left[q_Hq_L(1-r)^2 + r^2q_R^2\right] + \Gamma}{(q_H - q_L)\left\{(4q_H + q_L)\left[q_Hq_L(1-r)^2 + r^2q_R^2\right] + 8rq_Hq_Lq_R(1-r)\right\}}, \tag{14}$$

where $\Gamma = 8q_Hq_L(1-r)[rq_R(q_H - q_L) - (2q_H + q_L)(\mu_H + \mu_L)] - q_L^3(1-r)(\mu_H + \mu_L)$.

Under Policy C, the profit function of the platform is shown in equation (8), where k is an endogenous variable. Similarly, the profit function also needs to satisfy that the profits of the high-quality and low-quality service providers should not be less than their reservation profits. By solving the profit function, we can obtain the optimal commission rate as follows:

$$k^{C*} = \frac{q_Hq_L(1-r)^2 + r^2q_R^2 + 2q_L(1-r)\left[rq_R - 2(\mu_H + \mu_L)\right]}{q_Hq_L(1-r)^2 + rq_R\left[2q_L(1-r) + rq_R\right]}. \tag{15}$$

Through analysis, we can find that, first, under Policy *S*, the larger the online review information or the weight of online reviews, the higher the commission rate. Second, under Policy *C*, with the increase of the online review information, the commission rate is high. Additionally, the commission rate is also related to the weight of online reviews. When $r < 1 - q_R\sqrt{q_R^2 - 2q_Lq_R + q_Hq_L}/q_R^2 - 2q_L\ q_R + q_Hq_L$, the commission rate decreases in the weight of online reviews; otherwise, the commission rate increases in the weight of online reviews. Third, the commission rate under Policy *S* is smaller than that under Policy *C*. This is also why the platform profit under Policy *C* is larger than that under Policy *S*. Based on the above discussion, this extension can guide the platform to determine the commission rate when considering online reviews. Based on the above discussion, the extension can guide the platform to determine the commission rate when considering online reviews.

6.3. The Effects of the Number of Online Reviews. The number of online reviews is also one of the most important characteristics that affect consumers' willingness to purchase [40]. Online reviews provide consumers with more information about services when searching for them. 79% of consumers follow the number of online reviews. Most consumers believe that the number of online reviews is a sign of product popularity. Next, we analyze the impact of the number of online reviews on platform pricing policy selection and optimal pricing decisions.

Similar to Section 3, the service qualities of the two service providers are q_H and q_L, respectively. To examine the impact of online reviews on pricing decisions and profits, we only consider the stable state of online reviews that have accumulated on the platform [30]. We use n_i to denote the number of online reviews about service provider i's rental business, and we use β to denote the sensitivity of consumers to the number of online reviews. Since online reviews may positively or negatively affect consumers, we assume $-1 < \beta < 1$. The utility of a consumer choosing the high-quality service is $\widehat{u}_H^j = \theta q_H + \beta n_H - \widehat{p}_H^j$, and the utility of a consumer choosing the low-quality service is $\widehat{u}_L^j = \theta q_L + \beta n_L - \widehat{p}_L^j$. If $\widehat{u}_H^j > \widehat{u}_L^j$, the consumer will choose

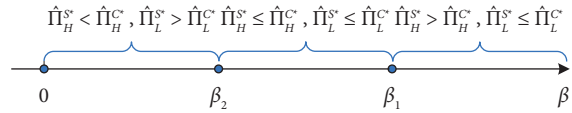

Figure 11: Comparison of the service provider profits under two policies.

the high-quality service. If $\hat{u}_H^j \le \hat{u}_L^j$ and $\hat{u}_L^j \ge 0$, the consumer will choose the low-quality service. When $\hat{u}_L^j = 0$, $\theta_1{}' = (\hat{p}_L^j - \beta n_L)/q_L$ can be obtained. When $\hat{u}_H^j = \hat{u}_L^j$, we can obtain $\theta_2' = \hat{p}_H^j - \hat{p}_L^j - \beta(n_H - n_L)/q_H - q_L$. We use $\hat{D}_H^j$ and $\hat{D}_L^j$ to represent the demands of the high-quality and the low-quality service providers, respectively. Therefore, the demand functions of two service providers are $\hat{D}_H^j = \int_{\theta_2'}^{1} f(\theta)\mathrm{d}\theta = 1 - (\hat{p}_H^j - \hat{p}_L^j - \beta(n_H - n_L)/q_H - q_L)$ and $\hat{D}_L^j = \int_{\theta_1'}^{\theta_2'} f(\theta)\ \ \mathrm{d}\theta = (\beta(n_L q_H - n_H q_L) + \hat{p}_H^j q_L - \hat{p}_L^j q_H/(q_H - q_L)\ q_L)$, where $j \in \{S, C\}$.

Under Policy S, the profit-maximizing models of the high-quality and the low-quality service providers are $\max_{\hat{p}_H^S} \hat{\Pi}_H^S = (1-k)\hat{p}_H^S \hat{D}_H^S$ and $\max_{p_L^S} \hat{\Pi}_L^S = (1-k)\hat{p}_L^S \hat{D}_L^S$. By solving the models, we can obtain the following lemma.

Lemma 17. *Under Policy S, the optimal price of the high-quality service is* $\hat{p}_H^{S*} = (\beta n_H + 2q_H)(4q_H - q_L) - q_H[\beta(2n_H + n_L) + 6q_H]/4q_H - q_L$, *and the optimal price of the low-quality service is* $\hat{p}_L^{S*} = 2\beta q_H n_L - \beta q_L(n_H + n_L) + (q_H - q_L)q_L/4q_H - q_L$.

From Lemma 17, we can obtain the demand of the profit of the high-quality service provider as $\hat{D}_H^{S*} = 2q_H(q_H - q_L) + \beta(2n_H q_H - n_L q_H - n_H q_L)/(4q_H - q_L)(q_H - q_L)$ and $\hat{\Pi}_H^{S*} = (1-k)[\beta n_L q_H - \beta n_H(2q_H - q_L) - 2q_H(q_H - q_L)]^2/(4q_H - q_L)^2(q_H - q_L)$. The demand of the profit of the low-quality service provider is $\hat{D}_L^{S*} = q_H[2\beta n_L q_H - \beta q_L(n_H + n_L) + q_L(q_H - q_L)]/q_L(4q_H - q_L)(q_H - q_L)$ and $\hat{\Pi}_L^{S*} = (1-k)q_H[\beta q_L(n_H + n_L) - 2\beta n_L q_H - q_L(q_H - q_L)]^2/q_L(4q_H - q_L)^2(q_H - q_L)$. The platform profit is $\hat{\Pi}_P^{S*} = k\{[\beta n_L q_H - \beta n_H(2q_H - q_L) - 2q_H(q_H - q_L)]^2 + q_H[\beta q_L(n_H + n_L) - 2\beta n_L q_H - q_L(q_H - q_L)]^2\}/q_L(4q_H - q_L)^2(q_H - q_L)$.

Under Policy C, the profit-maximizing model of the platform is $\max_{p_H^C, p_L^C} \hat{\Pi}_P^C = k(\hat{p}_H^C \hat{D}_H^C + \hat{p}_L^C \hat{D}_L^C)$. By solving the model, we can obtain the following lemma.

Lemma 18. *Under Policy C, the optimal price of the high-quality service is* $\hat{p}_H^{C*} = q_H + \beta n_H/2$, *and the optimal price of the low-quality service is* $\hat{p}_L^{C*} = q_L + \beta n_L/2$.

Furthermore, we can obtain the demands of the high-quality and the low-quality service as $\hat{D}_H^{C*} = \beta(n_H - n_L) + (q_H - q_L)/2(q_H - q_L)$ and $\hat{D}_L^{C*} = \beta(n_L q_H - n_H q_L)/2q_L(q_H - q_L)$. The platform profit is $\hat{\Pi}_P^{C*} = k\{q_L(\beta n_H + q_H)[\beta(n_H - n_L) + q_H - q_L] + \beta(\beta n_L + q_L)(n_L q_H - n_H q_L)\}/4q_L(q_H - q_L)$. The profits of the high-quality and the low-quality service providers are $\hat{\Pi}_H^{C*} = (1-k)(\beta n_H + q_H)[\beta(n_H - n_L) + q_H - q_L]/4(q_H - q_L)$ and $\hat{\Pi}_L^{C*} = \beta(1-k)(\beta n_L + q_L)(n_L q_H - n_H q_L)/4q_L(q_H - q_L)$, respectively.

By comparing the profits of service providers and platform profit under two pricing policies, we can obtain the following proposition. We also use numerical analysis to visualize our findings.

Proposition 19. *(i) If* $\beta < \beta_2$, *then* $\hat{\Pi}_H^{S*} \le \hat{\Pi}_H^{C*}$, $\hat{\Pi}_L^{S*} > \hat{\Pi}_L^{C*}$; *(ii) if* $\beta_2 < \beta < \beta_1$, *then* $\hat{\Pi}_H^{S*} \le \hat{\Pi}_H^{C*}$, $\hat{\Pi}_L^{S*} \le \hat{\Pi}_L^{C*}$; *(iii) if* $\beta > \beta_1$, *then* $\hat{\Pi}_H^{S*} > \hat{\Pi}_H^{C*}$, $\hat{\Pi}_L^{S*} \le \hat{\Pi}_L^{C*}$, *where* $\beta_1 = n_L q_H\{4q_H[\sqrt{q_L(8q_H + q_L)} - 2q_L] - q_L[q_L + \sqrt{q_L(8q_H + q_L)}]\} - t_1/2[4n_L^2 q_H^2 - 8n_H^2 q_H q_L + n_H(3n_H + n_L)q_L^2]$, $t_1 = n_H q_L\{4q_H\sqrt{q_L(8q_H + q_L)} + q_L[q_L + \sqrt{q_L(8q_H + q_L)}] - q_H(16q_H - 6q_L)\}$, $\beta_2 = n_L q_H\{q_L[7q_L - \sqrt{q_L(8q_H + q_L)}] + 4q_H[\sqrt{q_L(8q_H + q_L)} - 4q_L]\} - t_2/2[n_L^2 q_H(8q_H - 3q_L) - 4n_H^2 q_H q_L - q_L^2 n_H n_L]$, $t_2 = n_H q_L\{8q_H^2 - 4q_H\sqrt{q_L(8q_H + q_L)} + q_L[q_L + \sqrt{q_L(8q_H + q_L)}]\}$.

Proposition 19 indicates that when the sensitivity coefficient (i.e., β) is small, the high-quality service provider will earn more profits under Policy C, while the low-quality service provider will earn more profits under Policy S. When the sensitivity coefficient (i.e., β) is moderate, it is advantageous for both the high-quality and the low-quality service providers under Policy S. When the sensitivity coefficient (i.e., β) is high, the high-quality service provider gains more profits under Policy S, while the low-quality service provider gains more profit under Policy C. Intuitively, two service providers benefit from an increase in the number of online reviews because they provide more information about shared services, thus weakening price competition between the two providers. This is because when the number of online reviews is low, the low-quality service provider can attract consumers by lowering the price. Figure 11 visualizes the results of Proposition 19.

Proposition 20. $\hat{\Pi}_P^{S*} < \hat{\Pi}_P^{C*}$.

Proposition 20 indicates that the platform profit under Policy S is higher than that under Policy C. This is because the competition between two service providers is weakened and service prices are increased. This finding is consistent with the result of Proposition 13. Therefore, the main results and management implications we obtained are still robust. Moreover, Figure 12 visualizes the result of Proposition 20. We can also see from Figure 12 that the platform profit increases in the sensitivity coefficient (i.e., β). Intuitively, two

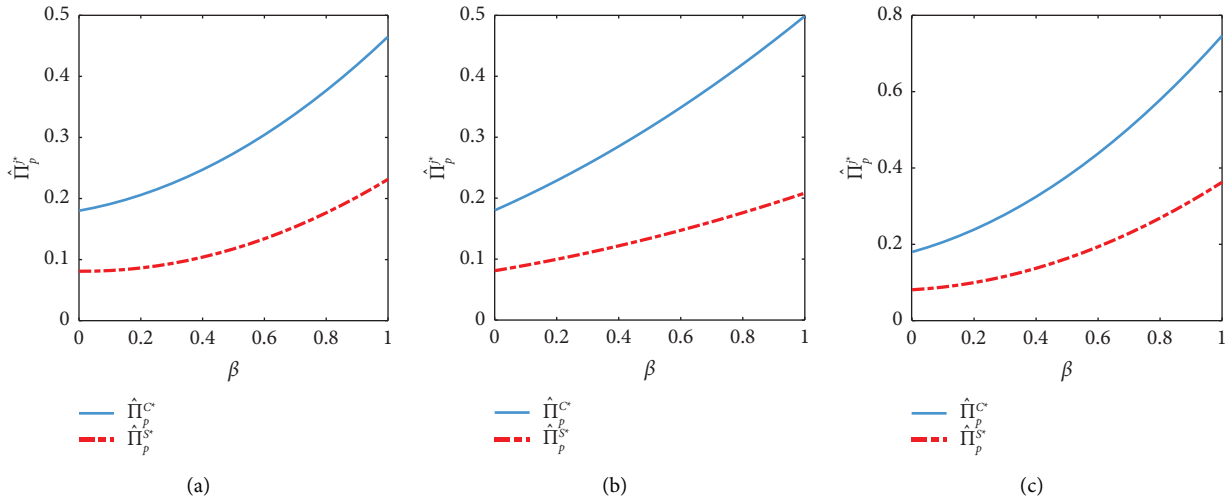

FIGURE 12: Comparison of platform profits under two pricing policies ($k = 0.9$). (a) $n_H = 0.2$ and $n_L = 0.5$. (b) $n_H = 0.2$ and $n_L = 0.5$. (c) $n_H = 0.8$ and $n_L = 0.5$.

service providers benefit from an increase in the number of online reviews because they provide more information about shared services.

7. Conclusions

This paper studies the pricing policy selection of a service-sharing platform based on online consumer reviews. A platform service supply chain composed of a high-quality service provider, a low-quality service provider, and a sharing platform is considered. For the two pricing policies of the platform: service provider pricing and platform pricing, we give the optimal results for each policy. This paper also examines the impacts of online consumer reviews on the pricing strategies, profits, consumer surplus, and social welfare under different pricing policies. We also give three extended studies. The first is to consider the situation of manipulating online reviews, the second is to consider the situation where the commission rate is endogenous, and the third is to consider the effect of the number of online reviews on the platform's pricing policy selection.

The important findings of this study are summarized below. First, under each pricing policy, the impact of online review information on the high-quality service provider profit is always smaller than the low-quality service provider profit. The low-quality service provider is more sensitive to changes in online review information. With the increase of online review information, consumer surplus and social welfare will increase. Second, when the online review information is small, the high-quality service provider obtains more profits under Policy *C*, while the low-quality service provider gets more profits under Policy *S*. When the online review information is moderate, both the high-quality the low-quality service providers are profitable under Policy *C*. When the online review information is large, the high-quality service provider obtains more profits under Policy *S*, while the low-quality service provider gets more profits under Policy *C*. Third, under Policy *C*, the price of high-quality (low-quality) service provider is high, and the demand is small. Moreover, the platform profit is large, while the consumer surplus and social welfare are small.

Additionally, we also discuss the model assumptions extensively. First, we analyze the situation where the service providers or the platform manipulates online reviews. That is, consumers get different review information from online reviews of the high-quality and the low-quality services. We find that under Policy *S*, a low-quality service provider will manipulate more to attract more consumers, which can make online reviews show more favorable information. Under Policy *C*, the platform makes the same manipulation effort for both services, that is, the platform will control misleading information. Second, under the situation of endogenous commission rate, we find that under Policy *C*, the larger the weight of online reviews or online review information, the higher the commission rate. Under Policy *C*, with the increase of online review information, the commission rate will also increase. The commission rate decreases first and then increases with the increase of online review information. Moreover, the commission rate under Policy *S* is smaller than that under Policy *C*. Third, we consider the effect of the number of online reviews on the profits of platforms and service providers. The results show that when the sensitivity coefficient is moderate, it is advantageous for both high-quality and low-quality service providers under Policy *S*. That is, both service providers benefit from an increase in the number of online reviews.

This study also provides some management implications for service providers and P2P service platforms. First, the platform adopts various technologies to reduce consumers' uncertainty and match them with their favorite services. For example, the platform has developed the online review systems and the service recommendation systems. Two service providers and platforms can benefit from online reviews, and platforms should encourage consumers to provide online reviews. For example, the platform can

provide consumers with some templates to guide them to give online review information. Second, when the platform adopts the service provider pricing, it is beneficial to consumers, and more consumers join the platform. Social welfare brought by the service provider pricing is higher than the platform pricing. Therefore, a platform in the early stage of development should let service providers price if it is willing to sacrifice some profits for a large market share. In contrast, a mature platform should determine the service price according to profit maximization. In reality, Airbnb's pricing strategy verifies this finding. When Airbnb was first established, the landlords determined the price. Later, they launched a price suggestion service. The introduction of this intelligent pricing brings Airbnb closer to setting the price by the platform.

Future research can be carried out in two aspects. First, this paper considers that the platform can only choose one pricing policy. It will be an interesting question if the platform can adopt two pricing policies simultaneously. Second, there is competition among some P2P service-sharing platforms in the market. Therefore, it is interesting to explore the decision making of multiple platforms in a competitive environment.

Appendix

A. Proof of Lemma 1

Substituting equations (1) and (2) into equations (3) and (4), equations (3) and (4) can be further expressed as

$$\max_{p_H^S} \Pi_H^S = (1-k)p_H^S\left[1-\frac{p_H^S-p_L^S}{(1-r)(q_H-q_L)}\right], \tag{A.1}$$

$$\max_{p_L^S} \Pi_L^S = \frac{(1-k)p_L^S\left[q_L\left(p_H^S-p_L^S\right)-(q_H-q_L)\left(p_L^S-rq_R\right)\right]}{q_L(1-r)(q_H-q_L)}. \tag{A.2}$$

According to equation (A.1), the first-order and the second-order conditions of equation (A.1) with p_H^S are

$$\frac{\partial\Pi_H^S}{\partial p_H^S} = \frac{-(1-k)p_H}{(1-r)(q_H-q_L)} + \frac{(1-k)\left[(1-r)(q_H-q_L)-\left(p_H^S-p_L^S\right)\right]}{(1-r)(q_H-q_L)},$$

$$\frac{\partial^2\left(\Pi_H^S\right)}{\partial\left(p_H^S\right)^2} = \frac{-2(1-k)p_H}{(1-r)(q_H-q_L)}. \tag{A.3}$$

According to equation (A.2), the first-order and the second-order conditions of equation (A.2) with p_L^S are

$$\frac{\partial\Pi_L^S}{\partial p_L^S} = \frac{-(1-k)p_L^Sq_H}{q_L(1-r)(q_H-q_L)} + \frac{(1-k)\left[q_L\left(p_H^S-p_L^S\right)-(q_H-q_L)\left(p_L^S-rq_R\right)\right]}{q_L(1-r)(q_H-q_L)},$$

$$\frac{\partial^2\Pi_L^S}{\partial\left(p_L^S\right)^2} = \frac{-2(1-k)q_H}{q_L(1-r)(q_H-q_L)}. \tag{A.4}$$

Obviously, $\partial^2\Pi_H^S/\partial(p_H^S)^2<0$ and $\partial^2\Pi_L^S/\partial(p_L^S)^2<0$. Therefore, equations (A.1) and (A.2) have the maximum values. By solving $\partial\Pi_H^S/\partial p_H^S=0$ and $\partial\Pi_L^S/\partial p_L^S=0$, we obtain $p_H^{S*}=(q_H-q_L)(2q_H-2rq_H+rq_R)/4q_H-q_L$ and $p_L^{S*}=(q_H-q_L)(q_L-rq_L+2rq_R)/4q_H-q_L$.

Hence, Lemma 1 holds.

B. Proof of Corollary 2

The first conditions of p_H^{S*}, p_L^{S*}, Π_H^{S*}, Π_L^{S*}, and Π_p^{S*} with respect to q_R are $\partial p_H^{S*}/\partial q_R=r(q_H-q_L)/4q_H-q_L$, $\partial p_L^{S*}/\partial q_R=2r(q_H-q_L)/4q_H-q_L$, $\partial\Pi_H^{S*}/\partial q_R=2r(q_H-q_L)(1-k)(2q_H-2rq_H+rq_R)/(4q_H-q_L)^2(1-r)$, $\partial\Pi_L^{S*}/\partial q_R=4rq_H(q_H-q_L)(1-k)(q_L-rq_L+2rq_R)/q_L(4q_H-q_L)^2(1-r)$, and $\partial\Pi_p^{S*}/\partial q_R=2kr(q_H-q_L)[4q_Hq_L(1-r)+4rq_Hq_L+rq_Lq_R]/q_L(4q_H-q_L)^2(1-r)$, respectively. Obviously, we know $\partial p_H^{S*}/\partial q_R>0$, $\partial p_L^{S*}/\partial q_R>0$, $\partial\Pi_H^{S*}/\partial q_R>0$, $\partial\Pi_L^{S*}/\partial q_R>0$, and $\partial\Pi_p^{S*}/\partial q_R>0$.

The first conditions of p_H^{S*}, p_L^{S*}, Π_H^{S*}, Π_L^{S*}, and Π_p^{S*} with respect to r are $\partial p_H^{S*}/\partial r=-(2q_H-q_R)(q_H-q_L)/4q_H-q_L$, $\partial p_L^{S*}/\partial r=-(q_L-2q_R)(q_H-q_L)/4q_H-q_L$, $\partial\Pi_H^{S*}/\partial r=-(q_H-q_L)(1-k)[(2-r)q_R-2(1-r)q_H][2(1-r)q_H+rq_R]/(4q_H-q_L)^2(1-r)^2$, $\partial\Pi_L^{S*}/\partial r=-q_H(q_H-q_L)(1-k)[(2-r)q_R-2(1-r)q_L][(1-r)q_L+2rq_R]/q_L(4q_H-q_L)^2(1-r)^2$, $\partial\Pi_p^{S*}/\partial r=2kr(q_H-q_L)[4q_Hq_L(1-r)+4rq_Hq_L+rq_Lq_R]/q_L(4q_H-q_L)^2(1-r)$, and $\partial\Pi_p^{S*}/\partial r=k(q_L-q_H)\{4q_H^2q_L(1-r)^2-(2-r)rq_L q_R^2+q_H[q_L^2(1-r)^2-8q_Lq_R(1-r)^2-4rq_R^2(2-r)]\}/q_L(4q_H-q_L)^2(1-r)^2$, respectively. Obviously, we know if $q_R<2q_H$, then $\partial p_H^{S*}/\partial r<0$; otherwise, $\partial p_H^{S*}/\partial r>0$. If $q_R<q_L/2$, then $\partial p_H^{S*}/\partial r>0$; otherwise, $\partial p_H^{S*}/\partial r<0$. If $q_R<4\kappa q_H$, then $\partial\Pi_H^{S*}/\partial r>0$; otherwise, $\partial\Pi_H^{S*}/\partial r>0$. If $q_R<\kappa q_L$, then $\partial\Pi_L^{S*}/\partial r<0$; otherwise, $\partial\Pi_L^{S*}/\partial r>0$. If $q_R<q_R'$, then $\partial\Pi_p^{S*}/\partial r<0$; otherwise, $\partial\Pi_p^{S*}/\partial r>0$ where $q_R'=(1-r)[\sqrt{q_Hq_L(8q_H-4rq_L+rq_L)(4rq_H+2q_L-rq_R)}-q_Hq_L(1-r)]/r(2-r)(4q_H+q_L)$ and $\kappa=1-r/2(2-r)$.

The proof process of the remaining corollaries is similar to that of Corollary 2, which is not discussed here.

C. Proof of Lemma 6

Substituting equations (1) and (2) into equation (8), equation (8) can be further expressed as

$$\max_{p_H^C, p_L^C} \Pi_P^C = k p_H^C \left[1 - \frac{p_H^C - p_L^C}{(1-r)(q_H - q_L)}\right] + k p_L^C \left[\frac{q_L\left(p_H^C - p_L^C\right) - (q_H - q_L)\left(p_L^C - r q_R\right)}{q_L(1-r)(q_H - q_L)}\right]. \tag{C.1}$$

For equation (C.1), we can obtain the first-order conditions for p_H^C and p_L^C, i.e.,

$$\frac{\partial \Pi_P^C}{\partial p_H^C} = \frac{k\left[(1-r)(q_H - q_L) - 2\left(p_H^C - p_L^C\right)\right]}{(1-r)(q_H - q_L)}, \qquad \frac{\partial \Pi_P^C}{\partial p_L^C} = \frac{k\left[2p_H^C q_L - 2p_L^C q_H + (q_H - q_L) r q_R\right]}{q_L(1-r)(q_H - q_L)}. \tag{C.2}$$

Furthermore, we can obtain $\partial^2 \Pi_P^C / \partial (p_H^C)^2 = -(2k/(1-r)(q_H - q_L))$, $\partial^2 \Pi_P^C / \partial (p_L^C)^2 = -(2k q_H / q_L (1-r)(q_H - q_L))$, and $\partial^2 \Pi_P^C / \partial p_H^C \partial p_L^C = \partial^2 \Pi_P^C / \partial p_L^C \partial p_H^C = 2k/(1-r)(q_H - q_L)$. Then, we can obtain the Hessian matrix of equation (C.1) as

$$H = \begin{bmatrix} -\dfrac{2k}{(1-r)(q_H - q_L)} & \dfrac{2k}{(1-r)(q_H - q_L)} \\ \dfrac{2k}{(1-r)(q_H - q_L)} & -\dfrac{2k q_H}{q_L(1-r)(q_H - q_L)} \end{bmatrix}. \tag{C.3}$$

Obviously, $\partial^2 \Pi_P^C / \partial (p_H^C)^2 < 0$ and $\partial^2 \Pi_P^C / \partial (p_L^C)^2 < 0$. Furthermore, $|H| = 4k^2 / q_L (q_H - q_L)(1-r)^2 > 0$ can be obtained. Therefore, Π_P^C is the concave function of p_H^C and p_L^C. By solving $\partial \Pi_P^C / \partial p_H^C = 0$ and $\partial \Pi_P^C / \partial p_L^C = 0$, we can obtain $p_H^{C*} = q_H - r q_H + r q_R / 2$ and $p_L^{C*} = q_L - r q_L + r q_R / 2$.

Hence, Lemma 6 holds.

D. Proof of Proposition 11

(i) From Lemmas 1 and 6, we can obtain $D_H^{S*} - D_H^{C*} = q_L - r q_L + 2 r q_R / 2(4q_H - q_L)(1-r)$ and $D_L^{S*} - D_L^{C*} = 2q_H - 2r q_H + r q_R / 2(4q_H - q_L)(1-r)$. Obviously, we know $D_H^{S*} > D_H^{C*}$ and $D_L^{S*} > D_L^{C*}$.

(ii) From Lemmas 1 and 6, we can obtain $p_H^{S*} - p_H^{C*} = -(3q_H q_L (1-r) + 2 r q_H q_R + r q_R q_L / 2 \quad (4q_H - q_L))$ and $p_L^{S*} - p_L^{C*} = -(q_L \quad (2q_H + q_L - 2 r q_H - \quad r q_L + 3 r q_R) / 2(4q_H - q_L))$. Obviously, we know $p_H^{S*} < D_H^{C*}$ and $p_L^{S*} < p_L^{C*}$.

Hence, Proposition 11 holds.

The proof process of the remaining propositions is similar to that of Proposition 11, which is not discussed here.

E. Proof in Section 6.2

Under Policy *S*, from the results in Section 4.1, we can obtain $\Pi_H^{S*} = (1-k)(q_H - q_L)(2q_H - 2 r q_H + r q_R)^2 / (1-r)(4q_H - q_L)^2$ and $\Pi_L^{S*} = q_H (1-k) \quad (q_H - q_L)(q_L - r q_L + 2 r q_R)^2 / q_L (1-r)(4q_H - q_L)^2$.

The profit-maximizing model of the platform is $\Pi_p^S(k^S) = \Pi_H^{S*} - \mu_H + \Pi_L^{S*} - \mu_L$. By solving $\partial \Pi_p^S(k^S) / \partial k^S = 0$, we can $k^{S*} = (4q_H^2 - \quad q_L^2 - 3 q_H q_L)\Gamma + 8 q_H q_L \quad (1-r) \quad [r q_R (q_H - q_L) - (2q_H + q_L)(\mu_H + \mu_L)] - \quad q_L^3 (1-r) \quad (\mu_H + \mu_L) / (q_H - q_L)[(4q_H + q_L)\Gamma + 8 r q_H q_L q_R (1-r)]$, where $\Gamma = q_H q_L (1-r)^2 + r^2 q_R^2$. It is easy to obtain $\partial k^{S*} / \partial q_R > 0$ and $\partial k^{S*} / \partial r > 0$.

Under Policy C, from the results in Section 4.2, we can obtain $\Pi_H^{C*} = (1-k)(q_H - r q_H + r q_R)/4$ and $\Pi_L^{C*} = r q_R (1-k)(q_L - r q_L + r q_R) / 4 q_L (1-r)$.

The profit-maximizing model for the platform is $\Pi_p^C = \Pi_H^{C*} - \mu_H + \Pi_L^{C*} - \mu_L$. By solving $\partial \Pi_p^C(k^C) / \partial k^C = 0$, we can obtain $k^{C*} = q_H q_L (1-r)^2 + \quad r^2 q_R^2 + 2 \quad q_L (1-r)[r q_R - 2(\mu_H + \mu_L)] / q_H q_L \quad (1-r)^2 + r q_R [2 q_L \quad (1-r) + r q_R]$.

It is easy to obtain $\partial k^{C*} / \partial q_R > 0$; if $r < 1 - q_R \sqrt{q_R^2 - 2 q_L q_R + q_H q_L} / q_R^2 - 2 q_L q_R + q_H q_L$, then $\partial k^{C*} / \partial r < 0$; otherwise, $\partial k^{C*} / \partial r \geq 0$.

F. Proof of Lemma 17

The profit-maximizing models of two service providers can be further expressed as

$$\max_{\widehat{p}_H^S} \widehat{\Pi}_H^S = (1-k)\widehat{p}_H^S \left[1 - \frac{\widehat{p}_H^S - \widehat{p}_L^S - \beta(n_H - n_L)}{q_H - q_L}\right], \tag{F.1}$$

$$\max_{\widehat{p}_L^S} \Pi_L^S = \frac{(1-k)\widehat{p}_L^S\left[\beta(n_L q_H - n_H q_L) + \widehat{p}_H^S q_L - \widehat{p}_L^S q_H\right]}{(q_H - q_L) q_L}. \tag{F.2}$$

The second-order condition of equation (F.1) with $\widehat{p}_H^S$ is $\partial^2 \Pi_H^S / \partial (\widehat{p}_H^S)^2 = -2(1-k)/q_H - q_L$, and the second-order condition of equation (F.2) is $\partial^2 \widehat{\Pi}_L^S / \partial (\widehat{p}_L^S)^2 = -2 q_H (1-k) / q_L (q_H - q_L)$. Obviously, $\partial^2 \widehat{\Pi}_H^S / \partial (\widehat{p}_H^S)^2 < 0$ and $\partial^2 \widehat{\Pi}_L^S / \partial (\widehat{p}_L^S)^2 < 0$. Therefore, equations (C.1) and (F.1) have the maximum values. By solving $\partial \widehat{\Pi}_H^S / \partial \widehat{p}_H^S = 0$ and $\partial \widehat{\Pi}_L^S / \partial \widehat{p}_L^S = 0$, we obtain $\widehat{p}_H^{S*} = (\beta n_H + 2 q_H)(4q_H - q_L) - q_H[\beta(2n_H + n_L) + 6 q_H] / 4 q_H - q_L$ and $\widehat{p}_L^{S*} = 2\beta q_H n_L - \beta q_L (n_H + n_L) + (q_H - q_L) q_L / 4 q_H - q_L$.

Hence, Lemma 17 holds.

G. Proof of Lemma 18

The profit-maximizing model of the platform can be further expressed as

$$\max_{\widehat{p}_H^C,\widehat{p}_L^C} \widehat{\Pi}_P^C = k\left\{\widehat{p}_H^C\left[1-\frac{\widehat{p}_H^C-\widehat{p}_L^C-\beta(n_H-n_L)}{q_H-q_L}\right]+\widehat{p}_L^C\left[\frac{\beta(n_Lq_H-n_Hq_L)+\widehat{p}_H^Cq_L-\widehat{p}_L^Cq_H}{(q_H-q_L)q_L}\right]\right\}. \tag{G.1}$$

From equation (G.1), we can obtain the first-order conditions for $\widehat{p}_H^C$ and $\widehat{p}_L^C$, i.e.,

$$\frac{\partial\widehat{\Pi}_P^C}{\partial\widehat{p}_H^C}=\frac{-k\left[2\left(\widehat{p}_H^C-\widehat{p}_L^C\right)-(q_H-q_L)-\beta(n_H-n_L)\right]}{q_H-q_L},$$

$$\frac{\partial\widehat{\Pi}_P^C}{\partial\widehat{p}_L^C}=\frac{k\left[2\widehat{p}_H^Cq_L-2\widehat{p}_L^Cq_H-\beta n_Hq_L+\beta n_Lq_H\right]}{q_L(q_H-q_L)}. \tag{G.2}$$

Furthermore, we can obtain $\partial^2\widehat{\Pi}_P^C/\partial(\widehat{p}_H^C)^2=-2k/q_H-q_L$, $\partial^2\widehat{\Pi}_P^C/\partial(\widehat{p}_L^C)^2=-(2kq_H/q_L(q_H-q_L))$, and $\partial^2\widehat{\Pi}_P^C/\partial\widehat{p}_H^C\partial\widehat{p}_L^C=\partial^2\widehat{\Pi}_P^C/\partial\widehat{p}_L^C\partial\widehat{p}_H^C=2k/q_H-q_L$. Then, we can obtain the Hessian matrix of equation (G.1) as

$$H=\begin{bmatrix}-\dfrac{2k}{q_H-q_L} & \dfrac{2k}{q_H-q_L}\\ \dfrac{2k}{q_H-q_L} & -\dfrac{2kq_H}{q_L(q_H-q_L)}\end{bmatrix}. \tag{G.3}$$

Obviously, $\partial^2\widehat{\Pi}_P^C/\partial(\widehat{p}_H^C)^2<0$ and $\partial^2\widehat{\Pi}_P^C/\partial(\widehat{p}_L^C)^2<0$. Furthermore, $|H|=4k^2/q_L(q_H-q_L)>0$ can be obtained. Therefore, $\widehat{\Pi}_P^C$ is the concave function of $\widehat{p}_H^C$ and $\widehat{p}_L^C$. By solving $\partial\widehat{\Pi}_P^C/\partial\widehat{p}_H^C=0$ and $\partial\widehat{\Pi}_P^C/\partial\widehat{p}_L^C=0$, we can obtain $\widehat{p}_H^{C*}=q_H+\beta n_H/2$ and $\widehat{p}_L^{C*}=q_L+\beta n_L/2$.

Hence, Lemma 18 holds.

Data Availability

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

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Jing Tian was responsible for review and editing. Xiaodong Wang was responsible for writing, methodology, visualization, formal analysis, and investigation. Jinhuan Meng was responsible for methodology and review and editing. Pengfei Ma was responsible for supervision, conceptualization, and review and editing.

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