Hindawi
Mathematical Problems in Engineering
Volume 2021, Article ID 9934726, 17 pages
https://doi.org/10.1155/2021/9934726

Research Article

Optimal Service Commission Contract Design of OTA to Create O2O Model by Cooperation with TTA under Asymmetric Information

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Received 16 March 2021; Revised 19 April 2021; Accepted 21 April 2021; Published 3 May 2021

Academic Editor: Ming Bao Cheng

This paper studies the service commission contract of an online travel agency (OTA) to integrate the online to offline (O2O) model by cooperation with a traditional travel agency (TTA) under asymmetric information. The principal-agent models are established with symmetric and asymmetric service information, respectively. Further, the impacts of asymmetry information on the revenue of the OTA, TTA, and the whole O2O model and the properties of optimal commission contract are analyzed. The paper notes management implications: (1) OTA designs service commission contracts by weighing the fixed payment and service commission coefficient for different incentives to TTAs with different serviceabilities and (2) because the existence of asymmetric information always leads to the damage of OTA's expected revenue, OTA should encourage the TTA to disclose private service information.

1. Introduction

With the rapid development of Internet and information technology, it is a popular and convenient way for tourists to buy more diverse tourism products and services through online travel agencies (OTAs) [1–3]. However, online tourism product homogenization makes OTAs reduce the service quality to attract more tourists, such as cashback and low price, forcing consumption in the experience, which seriously increase tourists' complaints and hinder the healthy development of online tourism [4–6]. To improve competitive advantage and realize differentiation, some OTAs (e.g., Ctrip) open up offline stores to achieve online to offline (O2O) model for providing personal information and advice to tourists, and some cooperate with traditional travel agencies (TTAs), such as Uzai (http://www.uzai.com/) and ZhongXin TTA, Lvmama (http://www.lvmama.com), and JinJiang TTA [4]. In the process of cooperation between OTAs and TTAs, it is difficult for OTAs to observe TTAs' service information, which makes the cooperation and incentive problem more complicated. Therefore, how to design the commission contract of TTAs strategically for OTAs is an urgent problem to implement O2O strategy.

The O2O model, as a new e-commerce business model, combines online trading and offline experience and has become an important strategy for the development of enterprises in recent years [7]. With the rapid development of OTAs, the online channel plays a crucial role in tourism and hospitality, and the tourism O2O model achieved by the cooperation between OTAs and hotels or airlines is a common phenomenon. Therefore, there is a growing popularity on the cooperation problem between OTAs and hotels or airlines and they have gotten some effective cooperation strategies [1, 8–11]. However, to seek better business opportunities, OTAs have to attach importance to the offline service to achieve differentiation. Although some scientific researchers have demonstrated the importance of TTAs' advice-offering and OTAs' attributes in travelers' booking, little literature in the hospitality and tourism fields has studied the service contract problem of cooperation between OTAs and TTAs.

To fill this gap and provide some suggestions for OTAs and TTAs managers on establishing the O2O model through service cooperation, this paper proposes a cooperation model to describe decision interactions of an OTA and a TTA. The OTA and TTA play a principal-agent model in which the OTA, as the principal player, determines the service commission and the TTA, as the agent, determines service effort. In addition, in the O2O model, because the OTA and TTA are relatively independent, TTA's private information is difficult to disclose and it often hides its own service information to obtain higher revenue. By comparing the case of information symmetry and asymmetry, the impacts of asymmetry information on OTA's service contract, TTA's information value, and the revenue of OTA and TTA are analyzed.

The rest of this paper is organized as follows. Section 2 reviews the related literature. Section 3 describes the service cooperation between an OTA and a TTA. Section 4 analyzes and compares equilibriums of symmetric and asymmetric information and further analyzes equilibriums when TTA's ability is continuous. Section 5 presents the results of numerical analyses. Section 6 concludes this paper by summarizing some of the managerial implications obtained.

2. Literature Review

According to the purpose of studying the service cooperation contract design of OTAs and TTAs, this section reviews three distinct of literature studies about the O2O model, service cooperation, and cooperation between tourism enterprises and OTAs.

2.1. O2O Model. Since Alex Rampel put forward the concept of the O2O model, it has attracted wide attention in academia. Although the concept and classification of the O2O model are different because of the scholars' different research perspectives, it is a business model for the effective integration of online and offline stores [4, 7]. It is believed that O2O is a new business model, which can disclose product information, change consumer brand awareness, and mitigate the adverse effects of product uncertainty on consumers' shopping decisions [12]. By using 311 respondent data from O2O e-commerce users in Greater Jakarta Area, Savila et al. showed that both multichannel integration and trust have a significant effect on both customer online loyalty and customer offline loyalty that drive customer repurchase intention [13].

According to the existing research about the O2O model, it can be divided into two categories: one is to purchase online and then experience offline, which can also be called online to offline; the other is to experience offline and then purchase online, which can also be called offline to online [14]. In the hospitality and tourism industry, because tourists have to experience tourism products offline, the O2O model achieved by the cooperation between OTAs and hotels or airlines is a common phenomenon. From the perspective of the supply chain, scholars more emphasize the sale cooperation between the OTAs and hotels or airlines and have gotten some effective cooperation strategies [1, 8–11]. In the retail industry, as the major characteristic feature of a product is tangible, it can be touched and tried out. The O2O model, achieved by cooperating with others or opening by oneself [14, 15], becomes the main research direction. Considering that the service cost and effort information of the showroom are asymmetry, Jin et al. study the design of the commission contract of offline to online, which is considered that the showroom and online retailer have impacts on consumers' purchasing decisions, respectively [15]. In practice, online sale efforts and offline services will affect the demand for each other. Therefore, it is difficult to highlight the integrity of the online retailer and store cocreating O2O model by splitting online and offline demand.

Despite the impact of technology and the advent of online bookings, offline channels play a pivotal role in the tourism supply chain. Unlike the general retail product, the tourism product of a travel agency cannot be touched, transported, stored, or returned. The functions of offline channels are different between general retailer and travel agency. The offline channels of general retailer provide touching, trying, and even online return service for consumers. The offline channels of travel agency provide scene experience, personal and professional information, and advice to meet travelers' demands on a continuous basis by gathering and organizing information [16, 17]. The O2O model of travel agency in this paper is an integration of online and offline. Both online sale efforts and offline services will have an impact on the overall demand for the O2O model.

2.2. Service Cooperation. The existing literature on service cooperation is mostly concentrated in the supply chain field. Service cooperation not only reduces the competition between direct and retail channels but also improves supply chain revenue [18–21]. Unit service reward and service cost sharing are the main forms of service cooperation. To avoid channel conflict and improve service efficiency, Xiao, Dan, and Zhang studied after-sale service cooperation between direct channel and retailers in which direct channel pays unit service commission to retailers [18]. In the O2O retail market, the service cost sharing mechanism is introduced to coordinate conflicts and achieve a win-win strategy, thereby improving the performance of the entire O2O supply chain [19]. Due to the importance of presales services in purchasing decisions, Zhou et al. introduce that the service cost sharing contract can effectively stimulate the retailer to improve his service level while free riding occurred [20]. Considering that the retailer provides the same service level in both channels or not, Yang and Zhang compare the manufacturer's optimal profit and retailer's optimal profit under the condition of different services and the same service and provide differentiated services to enable the system to achieve the optimal profit [21]. However, the completely symmetrical assumptions in the above literature are not currently common practice. The adverse selection and moral hazard are always in the cooperation process [22].

2.3. Cooperation between Tourism Enterprises and OTAs. Clearly, the OTAs are an extremely important part of the tourism supply chain, recognized as an online distribution channel for hotels and airlines. A larger number of scholars have emerged to pay attention to the issue of the cooperation problem between hotels, airlines, and OTAs, such as pricing strategy, cooperation form, and coordination strategy [1, 8–11]. Koo et al. point out that the airlines are less likely to use OTA platforms if the airlines have a large loyal consumer base or if the OTA platform is highly competitive [8]. Ling et al. and Guo et al. study the optimal pricing strategy for tourism hotels when they operate their online channel by cooperation with an OTA [1, 9]. Considering the overbooking of hotels, Dong and Ling study the pricing and overbooking strategies of a hotel in the context of cooperation with multiple OTAs and analyze how these strategies influence the cooperation process [10]. The commonly used "first come first serve" form puts hotels in a disadvantageous position especially when the OTAs have much more market attractiveness than the hotels. Xu et al. propose a new form named "setting Online-Exclusive-Rooms" for a hotel to collaborate with a third-party website on room booking service [11].

To get a new business opportunity, the TTAs are increasingly aware of the need to open up online markets' cooperation with OTAs because of the low volume of visits and lack of e-commence operating experience of self-built website [3, 4]. Therefore, a few scholars have provided suggestions on the cooperation between TTA and OTA. Based on the resource-based view, Shi and Long analyze the complementary resources input decisions of OTAs and TTAs cocreating the O2O model, which do not propose a clear form of cooperation [3]. In a supplemental study, Long and Shi study the optimal pricing strategies of a tour operator and an OTA when they achieve the O2O business model through online sale and offline service cooperation to develop the advantage of complementary resources [4].

However, no study has addressed the problem of an OTA that wants to achieve its O2O model by cooperating with a TTA with private information. In this situation, the OTA has little information and experience regarding offline service and knows little about how to design a service contract to disclosure TTA's real information. To enrich the scientific literature and provide some suggestions to OTA on how to pursue offline service, this paper studies the optimal service contract of OTAs under asymmetric information through the analysis of a simple O2O model composed of an OTA and a TTA.

3. Problem Description and Assumptions

In this paper, the O2O model, combining both trading and offline service, achieved by service cooperation of an OTA and a TTA is considered herein. Table 1 summarizes the main notation and its definitions used in this paper.

The OTA makes some effort to induce customers to make reservations through its website, such as ranking position. According to the literature [1], $c(e_O)$ is a convex increasing function with $\mathrm{d}c(e_O)/\mathrm{d}e_O > 0$, $\mathrm{d}^2c(e_T)/\mathrm{d}e_T^2 > 0$, and $c(e_O) = 0$. The sale cost of OTA is $c(e_O) = \eta_O e_O^2/2$, where η_O is the OTA's sale cost coefficient, which is widely used in the cost management literature [23–26].

While the TTA provides offline services for tourism products, such as the scene experience and personalized and professional travel advice, the service effort is the cost of hiring salespersons by TTA. According to the literature [4, 25, 26], a strictly convex service function $c(e_T)$ is used to depict TTA's unit cost of service effort, $c(e_T) = \eta_T e_T^2/2$, where η_T is the TTA's service cost coefficient, $\mathrm{d}c(e_T)/\mathrm{d}e_T > 0$, and $\mathrm{d}^2c(e_T)/\mathrm{d}e_T^2 > 0$.

The demand for O2O model q is influenced by OTA's saleability s_O, sale effort e_O, TTA's serviceability s_T, service effort e_T, market scale θ , and market random factors ξ.

$$q = f(s_O, e_O) + g(s_T, e_T) + u(\theta) + \xi, \tag{1}$$

where $f_{s_O} > 0$, $f_{s_O}s_O \le 0$, $f_{e_O} > 0$, $f_{e_O,e_O} \le 0$, $g_{s_T} > 0$, $g_{s_Ts_T} \le 0$, $g_{e_T} > 0$, $g_{e_Te_T} \le 0$, $u_\theta > 0$, $u_{\theta\theta} \le 0$, and ξ follows a normal distribution $\xi \in N(0, \sigma^2)$.

In this paper, according to the literature [27], let $f(e_O) = s_Oe_O$, $g(e_T) = s_Te_T$, and $u(\theta) = \theta$. Thus, the demand for O2O model is $q = s_Oe_O + s_Te_T + \theta + \xi$. Assuming that the revenue of O2O model is proportional to its demand, the revenue of O2O model can be simplified into $\Pi(q) = s_Oe_O + s_Te_T + \theta + \xi$. Following the studies of Jin et al. [15] and He et al. [28], OTA provides service commission (a, b) to motivate TTA to make service effort, where a represents fixed payment and b denotes service commission coefficient or the rate of revenue sharing. Therefore, given (a, b), the service commission that OTA pays for TTA is $T(q) = a + b\Pi(q)$.

Based on the above assumptions, the OTA's revenue function is obtained as follows:

$$\Pi_O = \Pi(q) - T(q) - c(e_O) = (1-b)(s_Oe_O + s_Te_T + \theta + \xi) - a - \frac{\eta_O e_O^2}{2}. \tag{2}$$

Assuming that OTA is risk-neutral and its utility is equal to expected revenue, the OTA's expected revenue is

$$E\Pi_O = (1-b)(s_Oe_O + s_Te_T + \theta) - a - \frac{\eta_O e_O^2}{2}. \tag{3}$$

The TTA's revenue is

$$\Pi_T = T(q) - c(e_T) = a + b(s_Oe_O + s_Te_T + \theta + \xi) - \frac{\eta_T e_T^2}{2}. \tag{4}$$

Assuming that TTA is risk-neutral risk aversion, one form of the utility function dominant in both theoretical and applied work in areas of decision theory and finance is the exponential utility function. Following the literature [29], $U_T(\Pi_T) = -e^{-r\Pi_T}$, where r denotes TTA's risk aversion coefficient and $r > 0$, $r = 0$, and $r < 0$ are risk aversion, risk neutrality, and risk preference, respectively. By certainty equivalence method, the revenue of TTA is obtained as follows:

Table 1: Notation and definitions.

Notation	Definitions
s_O	Sale ability of OTA
e_O	Sale effort of OTA
$C(e_O)$	Sale cost of OTA
η_O	Sale cost coefficient of OTA
s_T	Serviceability of TTA
e_T	Service effort of TTA
η_T	Service cost coefficient of TTA
$C(e_T)$	Unit cost of service effort of TTA
Q	The demand for O2O model
θ	Market scale
ξ	Market random factors
$T(q)$	Service commission that OTA pays for TTA
A	Fixed payment
B	Service commission coefficient or the rate of revenue sharing
$\Pi(q)$, Π_O, Π_T	The revenue of O2O model, OTA, and TTA, respectively
$E\Pi_O$, $E\Pi_T$	The expected revenue of OTA and TTA, respectively
$U_T(E\Pi_T)$	The utility function of TTA
R	TTA's risk aversion coefficient
I	The state of TTA's serviceability, $i = H, L$
s_{Ti}	TTA's serviceability, $i = H, L$
ρ	The probability that the OTA believes that the TTA's serviceability is at a high state

Note that the superscript *denotes the optimal solutions.

$$E\Pi_T = a + b\left(s_O e_O + s_T e_T + \theta\right) - \frac{\eta_T e_T^2}{2} - \frac{r\sigma^2 b^2}{2}. \tag{5}$$

Due to the uncertainty of the O2O model market demand and equation (5), TTA's risk cost is $r\sigma^2 b^2/2$.

4. Equilibrium Solutions and Analysis

This paper mainly studies the service cooperation contract design of OTA creating O2O model by cooperating with TTA under symmetric and asymmetric information. Further, the contract model with continuous type of TTA's serviceability under information asymmetry is researched. Here, the superscripts "N," "S," and "C" represent the case of symmetric information, the discrete type, and continuous type of TTA's service capability under information asymmetry, respectively.

In the process of establishing service cooperation between an OTA and a TTA, the serviceability and effort are TTA's private information which OTA is difficult to observe. Similar to the study of Li et al. [30], it is assumed that there are two possibilities for TTA's serviceability: high serviceability s_{TH} and low serviceability s_{TL}, and $s_{TH} > s_{TL}$.

4.1. Equilibrium of Symmetric Information. In the case of symmetric information, the OTA fully knows the state of TTA's serviceability s_{Ti} $(i = H, L)$. The OTA designs a service contract (a_i^N, b_i^N) and sale effort e_{Oi}^N when the type of TTA's serviceability is i. Then the expected revenue of OTA $E\Pi_O(a_i^N, b_i^N)$ and TTA $E\Pi_{Ti}(a_i^N, b_i^N)$ and the optimization problem P1 is

$$\begin{cases} \max\limits_{a_i^N, b_i^N, e_{Oi}^N} E\Pi_O = \left(1 - b_i^N\right)\left(\left(s_O e_{Oi}^N + s_{Ti} e_{Ti}^N + \theta\right) - a_i^N - \dfrac{\eta_O e_{Oi}^{N2}}{2}\right), \\ \text{s.t.}\ (\text{IR} - i)\ a_i^N + b_i^N\left(s_O e_{Oi}^N + s_{Ti} e_{Ti}^N + \theta\right) - \dfrac{\eta_T e_{Ti}^{N2}}{2} - \dfrac{r\sigma^2\left(b_i^N\right)^2}{2} \geq \underline{\Pi_T}, \end{cases} \tag{6}$$

where

$$e_{Ti}^N = \arg\max_{e_T}\left(a_i^N + b_i^N\left(s_O e_{Oi}^N + s_{Ti} e_{Ti}^N + \theta\right) - \frac{\eta_T e_{Ti}^{N2}}{2} - \frac{r\sigma^2\left(b_i^N\right)^2}{2}\right). \tag{7}$$

In the above optimization problem P1, the OTA maximizes its revenue. Inequality (IR-i) is individual constraints, assuring that the TTA will join the service cooperation because of exceeding the reservation revenue $\underline{\Pi_T}$. Equation (7) denotes the TTA optimizes service effort by maximizing its revenue. The optimal decisions are found out by solving the above optimization problem P1 using the backward induction method.

Theorem 1. *In the case of symmetric information, given the type of TTA's serviceability as i, the OTA's optimal service contract (a_i^{N*} b_i^{N*}), sale effort e_{Oi}^{N*}, and the TTA's optimal service effort e_{Ti}^{N*} are*

$$\begin{aligned} b_i^{N*} &= \frac{s_{Ti}^2}{s_{Ti}^2 + \eta_T r\sigma^2}, \\ a_i^{N*} &= \underline{\Pi_T} - \left(\frac{s_O^2}{\eta_O} + \theta\right) b_i^{N*} + \frac{1}{2}\left(r\sigma^2 - \frac{s_{Ti}^2}{\eta_T}\right)\left(b_i^{N*}\right)^2, \\ e_{Oi}^{N*} &= \frac{s_O}{\eta_O}, \\ e_{Ti}^{N*} &= \frac{s_{Ti}^3}{\eta_T\left(s_{Ti}^2 + \eta_T r\sigma^2\right)} = \frac{s_{Ti}}{\eta_T} b_i^{N*}. \end{aligned} \tag{8}$$

Theorem 1 shows that, (1) with the TTA's service cost coefficient η_T, market uncertainty σ^2, and risk aversion coefficient r increasing, the service commission coefficient b_i^{N*} decreases; (2) when the market scale θ and OTA's sale ability decreasing s_O or OTA's sale cost coefficient η_O increasing, the OTA's fixed payment increases a_i^{N*}, so as to encourage TTA to participate in cooperation for cocreating the O2O model. In addition, s_O and η_O only affect OTA's fixed payment a_i^{N*} but have no effect on service commission coefficient b_i^{N*}; (3) the OTA's online sales effort e_{Oi}^{N*} is only related to its own saleability s_O and cost coefficient η_O and is directly proportional to s_O and inversely proportional to η_O; (4) with the service commission coefficient b_i^{N*} and TTA's serviceability s_{Ti} increasing or TTA's service cost coefficient η_T decreasing, the TTA's offline service effort e_{Ti}^{N*} increases.

4.2. Equilibrium of Asymmetric Information. In the case of asymmetric information, the TTA surely knows which of the two serviceability states will occur, while the OTA has only a subjective assessment about the likelihood of the two serviceability states. Let ρ be the probability that the OTA believes that the TTA's serviceability is at a high state and 1-ρ be the probability of the low state. Due to its parsimony and tractability for analysis, this type of asymmetric information has been commonly employed in supply chain contracting [15, 27, 30]. In this paper, the OTA is an uninformed party that acts as a principal, and the TTA is an agent that holds private information about its serviceability. The service contract design problem is investigated under asymmetric serviceability information. The goal of the OTA is to design a menu of service contracts so as to maximize its expected profit based on the revelation principle.

When the state of TTA's serviceability is i and OTA gives service contract (a_i^S, b_i^S) and sale effort e_{Oi}^S, the revenue of OTA and TTA is $E\Pi_O(a_i^S, b_i^S)$ and $E\Pi_{Ti}(a_i^S, b_i^S)$, respectively, and then the optimization problem P2 is

$$\begin{cases} \max\limits_{a_H^S, b_H^S, e_{OH}^S, a_L^S, b_L^S, e_{OL}^S} E\Pi_O = \left\{\rho\left(\left(1 - b_H^S\right)\left(s_O e_{OH}^S + s_{TH} e_{TH}^S + \theta\right) - a_H^S - \frac{\eta_O e_{OH}^{S2}}{2}\right) + \right. \\ \left. (1-\rho)\left(\left(1 - b_L^S\right)\left(s_O e_{OL}^S + s_{TH} e_{TL}^S + \theta\right) - a_L^S - \frac{\eta_O e_{OL}^{S2}}{2}\right)\right\} \\ \text{s.t.}\ (\mathrm{IC}-H) a_H^S + b_H^S\left(s_O e_{OH}^S + s_{TH} e_{TH}^S + \theta\right) - \frac{\eta_T e_{TH}^{S2}}{2} - \frac{r\sigma^2 b_H^2}{2} \geq \\ a_L^S + b_L^S\left(s_O e_{OS}^S + s_{TH} e_{TH}^L + \theta\right) - \frac{\eta_T e_{TH}^{L2}}{2} - \frac{r\sigma^2 b_L^2}{2} \\ (\mathrm{IC}-L) a_L^S + b_L^S\left(s_O e_{OL}^S + s_{TL} e_{TL}^S + \theta\right) - \frac{\eta_T e_{TL}^{S2}}{2} - \frac{r\sigma^2 b_L^2}{2} \geq \\ a_H^S + b_H^S\left(s_O e_{OH}^S + s_{TL} e_{TL}^H + \theta\right) - \frac{\eta_T e_{TL}^{H2}}{2} - \frac{r\sigma^2 b_H^2}{2}, \\ (\mathrm{IR}-H) a_H^S + b_H^S\left(s_O e_{OH}^S + s_{TH} e_{TH}^S + \theta\right) - \frac{\eta_T e_{TH}^{S2}}{2} - \frac{r\sigma^2 b_H^2}{2} \geq \underline{\Pi_T}, \\ (\mathrm{IR}-L) a_L^S + b_L^S\left(s_O e_{OL}^S + s_{TL} e_{TL}^S + \theta\right) - \frac{\eta_T e_{TL}^{S2}}{2} - \frac{r\sigma^2 b_L^2}{2} \geq \underline{\Pi_T}, \end{cases} \tag{9}$$

where

$$e_{TH}^{S} = \arg\max_{e}\left(a_H^S + b_H^S\left(s_O e_{OH}^S + s_{TH} e_{TH}^S + \theta\right) - \frac{\eta_T e_{TH}^{S2}}{2} - \frac{r\sigma^2 b_H^2}{2}\right), \tag{10}$$

$$e_{TL}^{S} = \arg\max_{e}\left(a_L^S + b_L^S\left(s_O e_{OL}^S + s_{TL} e_{TL}^S + \theta\right) - \frac{\eta_T e_{TL}^{S2}}{2} - \frac{r\sigma^2 b_L^2}{2}\right). \tag{11}$$

In the above optimization problem P2, the expected revenue of OTA $E\Pi_O$ is the sum of revenue under the cooperation of serviceability states of TTA. Inequalities (IC-i) are incentive compatibility constraints, assuring that the TTA does not pretend to choose the other serviceability state, where $e_{TH}^L(e_{TL}^H)$ indicates the optimal service effort level of TTA under service reward contract (a_L^S, b_L^S) $((a_H^S, b_H^S))$. Inequalities (IR-i) are individual rationality constraints, assuring that the TTA will join to cocreate O2O model because of exceeding the reservation revenue $\underline{\Pi_T}$. Equations (10) and (11) denote the TTA optimizes its service effort e_{Ti}^N by maximizing its revenue according to OTA's service cooperation contract $(a_i^S b_i^S)$ and sale effort e_{Oi}^S. The optimal decisions are found out by solving the above optimization problem P2 using the backward induction method.

Theorem 2. *Under asymmetric information, the OTA reveals TTA's serviceability by designing separation contracts. The OTA's service commission contract, optimal sale effort, and TTA's service effort are*

$$\begin{aligned}
a_H^{S*} &= \underline{\Pi_T} - \left(\frac{s_O^2}{\eta_O} + \theta\right) b_H^{S*} + \frac{1}{2}\left(r\sigma^2 - \frac{s_{TH}^2}{\eta_T}\right)\left(b_H^{S*}\right)^2 + \frac{1}{2\eta_T}\left(s_{TH}^2 - s_{TL}^2\right)\left(b_L^{S*}\right)^2,\\
b_H^{S*} &= \frac{s_{TH}^2}{s_{TH}^2 + \eta_T r\sigma^2},\\
a_L^{S*} &= \underline{\Pi_T} - \left(\frac{s_O^2}{\eta_O} + \theta\right) b_L^{S*} + \frac{1}{2}\left(r\sigma^2 - \frac{s_{TL}^2}{\eta_T}\right)\left(b_L^{S*}\right)^2,\\
b_L^{S*} &= \frac{(1-\rho)s_{TL}^2}{s_{TL}^2 - 2\rho s_{TL}^2 + \rho s_{TH}^2 + (1-\rho)\eta_T r\sigma^2},\\
e_{OH}^{S*} &= e_{OL}^{S*} = \frac{s_O}{\eta_O},\\
e_{TH}^{S*} &= \frac{s_{TH}^3}{\eta_T\left(s_{TH}^2 + \eta_T r\sigma^2\right)},\\
e_{TL}^{S*} &= \frac{(1-\rho)s_{TL}^3}{\left(s_{TL}^2 - 2\rho s_{TL}^2 + \rho s_{TH}^2 + (1-\rho)\eta_T r\sigma^2\right)\eta_T}.
\end{aligned} \tag{12}$$

Theorem 2 shows the following:

(1) When $r \longrightarrow +\infty$, $b_H^{S*} = b_L^{S*} = 0$ and $a_H^{S*} = a_L^{S*} = \underline{\Pi_T}$ can be obtained. That is, when TTA has no risk tolerance, its revenue could only be equal to its reservation revenue. When $r \longrightarrow 0$, $b_H^{S*} = 1$ and $b_L^{S*} = (1/1 + \rho(s_{TH}^2 - s_{TL}^2/(1-\rho)s_{TL}^2)) < 1$. That is, when the TTA tends to be risk-neutral, TTA with high serviceability will obtain the total revenue and if the difference between the two types of TTA's serviceability or the probability of TTA with high serviceability is greater, the OTA's service commission coefficient for TTA with low serviceability is lower. When $r > 0$, with the increase of TTA's risk aversion coefficient, the service commission coefficient decreases correspondingly, indicating that risk aversion can offset the incentive effect of the service commission coefficient.

(2) According to $(\partial b_H^{S*}/\partial s_{TH}) \geq 0\,(\partial b_L^{S*}/\partial s_{TL}) \geq 0$, the service commission coefficient will increase with the increasing TTA's serviceability.

(3) The service effort of the TTA with low serviceability has no effort on the service commission coefficient the TTA with high serviceability obtains. However, the difference between service effort of TTA with high and low service will affect the service commission coefficient TTA with low serviceability obtains, and the greater the difference is, the smaller the service commission coefficient is.

(4) According to $(\partial b_H^{S*}/\partial \rho) = 0\,(\partial b_L^{S*}/\partial \rho) \leq 0$, the probability ρ has no effect on service commission coefficient that the TTA with high serviceability obtains. However, with the increase of ρ, the service commission coefficient that the TTA with high serviceability obtains decreases.

(5) The relationship between service commission coefficient and TTA's service cost coefficient η_T, the degree of market uncertainty σ^2, the degree of risk aversion r, and the relationship between fixed payment and OTA's saleability and sale cost coefficient are the same under symmetric information, which is omitted here.

Corollary 1. *For TTA with different serviceability, the optimal service commission contract parameters have the relationships $b_H^{S*} \geq b_L^{S*}$ and $a_H^{S*} \leq a_L^{S*}$.*

Corollary 1 shows that the motivation purpose of OTA service contract is different for TTA with different serviceability. This means that the OTA should balance the motivation cooperation and the incentive of improving service effort for TTA when designing service commission contract. If the TTA is of a low serviceability type, the OTA will give TTA a larger fixed payment to ensure TTA's initiative in cocreating the O2O model. If the TTA is of a high serviceability state, the OTA will give a larger service commission coefficient. And according to $b_H^{S*} - b_L^{S*} = ((s_{TH}^2 - s_{TL}^2)(\rho s_{TH}^2 + (1-\rho)\eta_T r\sigma^2)/(s_{TH}^2 + \eta_T r\sigma^2)(s_{TL}^2 - 2\rho s_{TL}^2 + \rho s_{TH}^2 + (1-\rho)\eta_T r\sigma^2)) \geq 0$, the greater the difference between service efforts of TTA with high and low service, the bigger the difference of service commission coefficient.

4.3. Comparison of Results under Symmetric and Asymmetric Information

4.3.1. Validity of Separation Service Contract. By introducing the results of Theorem 2 into incentive compatibility constraints (IC-i) and comparing the TTA's revenue of TTA false and truthfulness reporting serviceability, it is obtained as

$$\begin{aligned} E\Pi_{TH}\left(a_H^{S*}, b_H^{S*}\right) - E\Pi_{TH}\left(a_L^{S*}, b_L^{S*}\right) &= 0, \\ E\Pi_{TL}\left(a_L^{S*}, b_L^{S*}\right) - E\Pi_{TL}\left(a_H^{S*}, b_H^{S*}\right) &= \frac{\left(b_H^{S*} - b_L^{S*}\right)\left(b_H^{S*} + b_L^{S*}\right)\left(s_{TH} + s_{TL}\right)}{2\eta_T} > 0. \end{aligned} \tag{13}$$

When the TTA with low serviceability pretends to be the TTA with high serviceability, the revenue is strictly lower than that when TTA truthfully reports serviceability $(E\Pi_{TL}(a_H^{S*}, b_H^{S*}) < E\Pi_{TL}(a_L^{S*}, b_L^{S*}))$. Therefore, the TTA with low serviceability has no motivation to disguise the TTA with high serviceability. In addition, if the TTA is of a high serviceability type, its false report will not affect its revenue $(E\Pi_{TH}(a_H^{S*}, b_H^{S*}) = E\Pi_{TH}(a_L^{S*}, b_L^{S*}))$. Therefore, the TTA with high serviceability has no motivation to disguise TTA with low serviceability. It can be seen that separation of service contract has the characteristics of "self-selection" in the OTA and TTA cocreating O2O model. That is, the TTA with high or low serviceability needs to choose the service contract corresponding to its serviceability type.

Corollary 2. *By comparing the expected revenue and the reservation revenue with different serviceability types, it is obtained as*

$$\begin{aligned} E\Pi_T\left(s_{TL}\right) &= \underline{\Pi_T}, \\ E\Pi_T\left(s_{TH}\right) &= \underline{\Pi_T} + \frac{\left(s_{TH}^2 - s_{TL}^2\right)}{2\eta_T} b_L^{S*2}. \end{aligned} \tag{14}$$

Corollary 2 shows that when the TTA is of a low serviceability type, TTA's revenue is reservation revenue after accepting the service commission contract. However, when the revenue of TTA with high serviceability is greater than reservation revenue, the difference $((s_{TH}^2 - s_{TL}^2)/2\eta_T)b_L^{S*2}$ shows that, in order to obtain private information of TTA's serviceability, the OTA needs to pay TTA information sharing fees. If the OTA does not pay the information fee, TTA may lie about its serviceability and damage the OTA's expected revenue.

4.3.2. The Impact of Information Asymmetric on Service Contract and Expected Revenue. According to Theorems 1 and 2, by comparing and analyzing the service contract, TTA's optimal service effort, and the revenues of the partners under symmetric and asymmetric information conditions, Theorems 3 and 4 are obtained.

Theorem 3. *The optimal service contract, sale effort, and TTA optimal service effort under symmetry and asymmetry information have the following relationships:*

(1) $a_H^{S*} \geq a_H^{N*}, b_H^{N*} = b_H^{S*}$
(2) $a_L^{S*} \geq a_L^{N*}, b_L^{S*} \leq b_L^{N*}$
(3) $e_{TH}^{N*} = e_{TH}^{S*}, e_{TL}^{S*} < e_{TL}^{N*}$
(4) $e_{Oi}^{N*} = e_{Oi}^{S*}$

In Theorem 3, (1) and (2) show that the OTA should pay a higher fixed payment to mobilize TTA to participate in co-creating the O2O model under asymmetric information. If the TTA is of a low serviceability type, the OTA lacks motivation to encourage TTA to provide higher service effort, and the service commission coefficient is "distorted downward." If the TTA is of a high serviceability type, the OTA will provide a higher service commission coefficient to encourage the TTA to provide higher service effort under asymmetrical information. Here, the TTA can obtain additional information rent by "upward distorted" fixed payment. This also means that, due to the existence of asymmetric information, the service contract design of OTA needs to adjust the fixed payment and service commission coefficient to ensure that TTA can participate in cooperation and choose the appropriate level of service efforts that are beneficial to OTA. From (3), the service effort of TTA with the high serviceability is the same in symmetrical and asymmetrical information, and the service effort of TTA with the low serviceability is lower in asymmetrical information than that in symmetrical information. Therefore, the OTA is dominant in encouraging low serviceability type TTA to participate in cooperation, which will also provide incentives to participate in cooperation and service efforts to TTA with high serviceability state. (4) shows that the OTA's optimal sale effort is the same in symmetrical and asymmetrical information. This is straightforward because the OTA knows its own saleability information.

Theorem 4. *There is the following relationship between OTA's and TTA's expected revenue under symmetry and asymmetry information:*

(1) $E\Pi_{Oi}^{S*} \leq E\Pi_{Oi}^{N*}$
(2) $E\Pi_{TH}^{S*} \geq E\Pi_{TH}^{N*}$
(3) $E\Pi_{TL}^{S*} = E\Pi_{TL}^{N*}$

Theorem 4 shows that the information disadvantage of OTA is detrimental to its expected revenue; the information advantage of TTA does not necessarily generate information rent. When the TTA is the high serviceability type, the increase of fixed payment cost and constant service commission coefficient make OTA pay higher service commission. Therefore, the TTA with high serviceability can get additional information rent from the increased fixed payment. When the TTA is of a low serviceability type, the asymmetric information makes the service commission coefficient tilt downward and fixed payment cost rise, and the rise of fixed payment can make up for the loss of TTA caused by the decline of service commission coefficient. Therefore, the expected revenue of TTA with low serviceability remains unchanged.

4.4. Strategic Analysis When TTA's Service Ability Is Continuous. Assuming that TTAs' service capability is continuously distributed and satisfied $s_T \in H = [\underline{s_T}, \overline{s_T}]$, $F(s_T)$ and $f(s_T)$ are TTA's cumulative distribution and distribution density function, respectively, and $f(s_T) > 0$.

Due to the fact that ξ is not related to s_T, the expected revenue of risk-neutral OTA can be obtained as

$$E\Pi_O(s_T) = \int_{\underline{s_T}}^{\overline{s_T}} \left\{ \left(1 - b^C(s_T)\right)\left(s_O e_O^C(s_T) + s_T^C e_T^C(s_T) + \theta\right) - a^C(s_T) - \frac{\eta_O e_O^{C2}(s_T)}{2} \right\} f(s_T) \mathrm{d}s_T. \tag{15}$$

The expected revenue of TTA is

$$E\Pi_T(s_T) = a^C(s_T) + b^C(s_T)\left(s_O e_O^C(s_T) + s_T^C e_T^C(s_T) + \theta\right) - \frac{\eta_T e_T^{C2}(s_T)}{2} - \frac{r\sigma^2 b^{C2}(s_T)}{2}. \tag{16}$$

Firstly, determine the service effort level of TTA $e_T^C(s_T)$; that is, $\forall s_T \in H$, $e_T^C(s_T) = \mathrm{argmax}_e E\Pi_T(s_T) = = (s_T^C b^C(s_T)/\eta_T)$.

Bringing $e_T^C(s_T)$ to equation (16), it is obtained as

$$E\Pi_T(s_T) = a^C(s_T) + \left(s_O e_O^C(s_T) + \theta\right) b^C(s_T) + \frac{1}{2}\left(\frac{s_T^2}{\eta_T} - r\sigma^2\right) b^{C2}(s_T). \tag{17}$$

Furthermore, when s_T is continuous, the optimization problem P3 is

$$\max_{a^C, b^C} \int_{\underline{s_T}}^{\overline{s_T}} \left\{ \left(1 - b^C(s_T)\right)\left(s_O e_O^C(s_T) + s_T^C e_T^C(s_T) + \theta\right) - a^C(s_T) - \frac{\eta_O e_O^{C2}(s_T)}{2} \right\} f(s_T) \mathrm{d}s_T \tag{18}$$

$$\text{s.t. (IC)} \dot{b}^C(s_T) \geq 0,$$

$$\text{(IC)} \dot{a}^C(s_T) + s_O \dot{e}_O^C(s_T) b^C(s_T) + \left(s_O e_O^C(s_T) + \theta\right) \dot{b}^C(s_T) + \left(\frac{s_T^{C2}}{\eta_T} - r\sigma^2\right) \dot{b}^C(s_T) = 0, \tag{19}$$

$$(\mathrm{IR})a^{C}(s_T)+\left(s_O e_O^C(s_T)+\theta\right)b^{C}(s_T)+\frac{1}{2}\left(\frac{s_T^2}{\eta_T}-r\sigma^2\right)b^{C2}(s_T)\geq \underline{\Pi_T}, \tag{20}$$

where $e_T^C(s_T)=(s_T^C b^C(s_T)/\eta_T)$.

Theorem 5. *When* $(d/ds_T)(1-F(s_T)/s_T f(s_T))<0$,

$$\begin{aligned}
a^{C*}(s_T)&=\underline{\Pi_T}-\left(\frac{s_O^2}{\eta_O}+\theta\right)b^{C*}(s_T)-\frac{1}{2}\left(\frac{s_T^2}{\eta_T}-r\sigma^2\right)b^{C*2}(s_T)+\int_{\underline{s_T}}^{s_T}\frac{\omega}{\eta_T}b^{C2}(\omega)\mathrm{d}\omega,\\
b^{C*}\left(s_T^C\right)&=\frac{1}{1+\left(\eta_T r\sigma^2/s_T^{C2}\right)+\left(2\left(1-F\left(s_T^C\right)\right)/s_T^C f\left(s_T^C\right)\right)},\\
e_O^{C*}&=\frac{s_O}{\eta_O},\\
e_T^{C*}(s_T)&=\frac{s_T^C b^{C*}(s_T)}{\eta_T}.
\end{aligned} \tag{21}$$

Theorem 5 shows that when the serviceability of TTA is continuous, $(\mathrm{d}/\mathrm{d}s_T)(1-F(s_T)/s_T f(s_T))<0$ is the precondition for the existence of a service commission separation contract. At this time, $b^{C*}(s_T)$ is strictly increasing, and all TTA can choose appropriate service contracts corresponding to its serviceability type.

Corollary 3. $E\Pi_T(s_T)-\underline{\Pi_T}=\int_{\underline{s_T}}^{s_T}(\omega/\eta_T)b^{C*2}(\omega)d\omega$.

Corollary 3 shows that, apart from the TTA with the worst serviceability, all other types of TTA can get strict information rent. With the increase of TTA's serviceability, the information rent and the excepted revenue of TTA increase, which is consistent with the conclusion when TTA's serviceability is discrete.

5. Numerical and Sensitivity Analysis

The impacts of the risk aversion coefficient, serviceability, and asymmetric information on OTA service contract and both TTA and OTA's revenue are analyzed so as to get more management implications. Considering that the references on cooperation between the TTA and OTA are less and numerical examples are usually hypothetical, the values of parameters are assigned according to Jin et al. [15]. A selected set of parameters is as follows: $s_O=0.3$, $\eta_O=0.1$, $\eta_T=0.3$, $s_{TH}=0.5$, $s_{TL}=0.5$, $\rho=0.5$, $\theta=0$, $\sigma^2=4$, and $\underline{\Pi_T}=5$. In order to study the impacts of TTA's risk aversion coefficient r and serviceability s_{Ti} on the service commission and revenue of both TTA and OTA, take s_{Ti} as the horizontal axis; that is, when $s_{TH}=0.5$ and $s_{TL}\in(0.2,0.5)$ or when $s_{TL}=0.5$ and $s_{TH}\in(0.5,1)$, fixed payment, service commission coefficient, and revenue under symmetric information and asymmetric information are plotted, respectively, with $r=0.1$, $r=0.5$, and $r=0.9$. The results of numerical examples are summarized in Figures 1–3.

5.1. Analysis of the Parameters of Service Commission Contract. Figure 1 shows that (1) when TTA's serviceability s_{Ti} increases, fixed payment of a_i^{S*} and a_i^{N*} always decreases, but $a_i^{S*}>a_i^{N*}$. This is straightforward because OTA needs to give TTA more fixed payment to stimulate its initiative to cooperate and create an O2O model under asymmetric information; (2) when r takes different values, the influence of asymmetric information on fixed payment increases with the increase of the difference between TTA's serviceability, which indicates that the smaller the difference between TTA's different serviceability, the smaller the influence of asymmetric information on fixed payment; (3) no matter the serviceability type of TTA is, a_i^{S*} and a_i^{N*} increase and the distance between fixed payment curves decreases with the increase in r, indicating that r can alleviate the impact of asymmetric information on fixed payment.

Figure 2 shows that (1) when TTA's serviceability s_{Ti} increases, service commission coefficient of b_i^{S*} and b_i^{N*} always increases, and $b_H^{S*}=b_H^{N*}$ and $b_L^{S*}<b_L^{N*}$. This indicates that the existence of asymmetric information does not affect the service commission coefficient of OTA paid for TTA with high serviceability, but it will reduce the service commission coefficient of OTA paid for TTA with low serviceability; (2) no matter the serviceability type of TTA is, b_i^{S*} and b_i^{N*} decrease with the increase in r, indicating that r can offset the incentive effect of service commission coefficient on TTA; (3) Figure 2(b) shows the distance between service commission coefficient curves decreases with r or s_{TL} increases, which indicates that r can alleviate the impact of asymmetric information on service commission coefficient and the smaller the difference between TTA's different serviceability, the smaller the influence of asymmetric information on service commission coefficient.

5.2. Revenue Analysis of Both TTA and OTA. Figure 3 shows that (1) no matter the serviceability type of TTA is, there is $\Delta E\Pi_{Oi}^{SN*}<0$, indicating that the existence of asymmetric

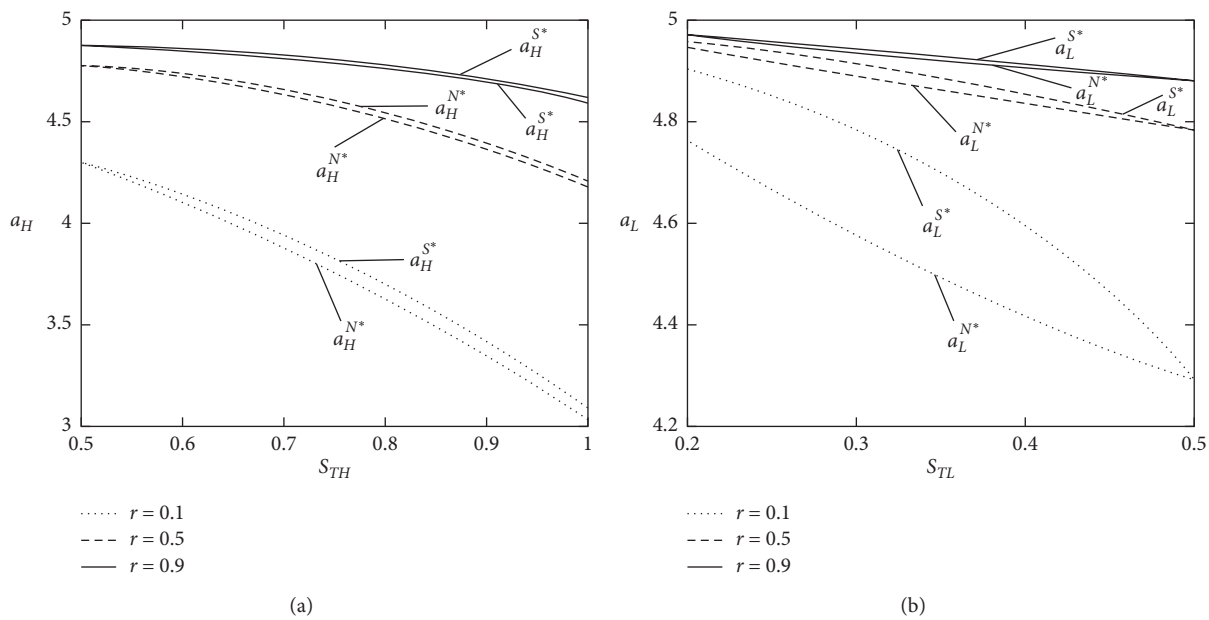

Figure 1: Impacts of r and s_{Ti} on fixed payment. (a) $s_{TL} = 0.5$. (b) $s_{TH} = 0.5$.

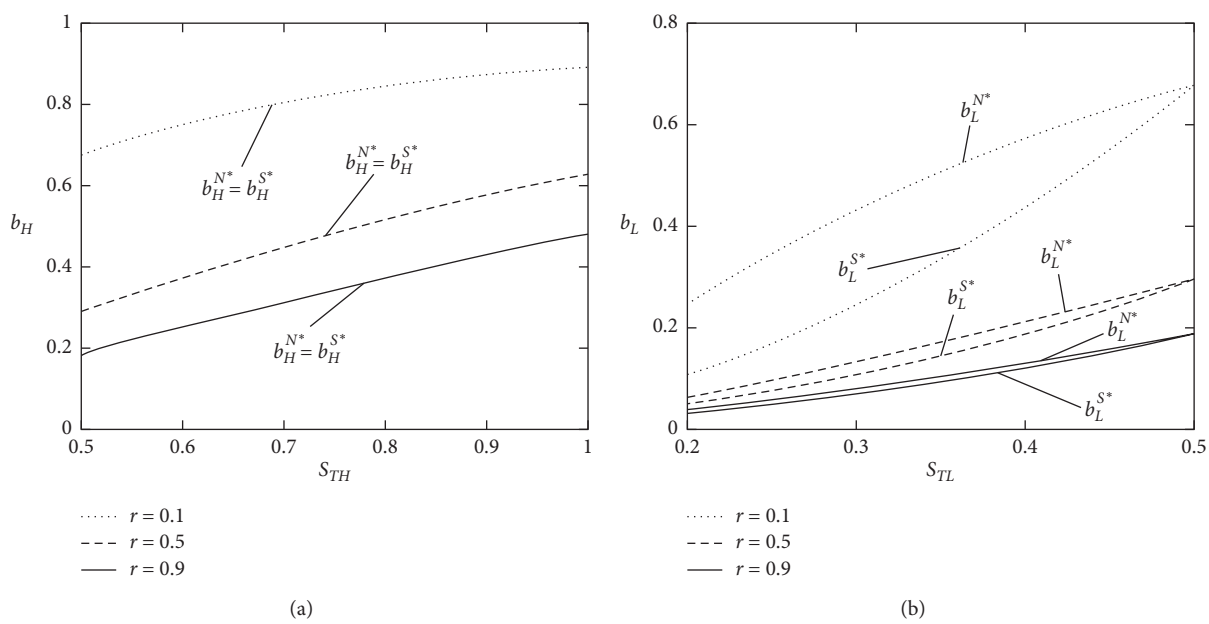

Figure 2: Impacts of r and s_{Ti} on service compensation coefficient. (a) $s_{TL} = 0.5$. (b) $s_{TH} = 0.5$.

information always leads to loss of OTA expected revenue. $\Delta E\Pi_{TH}^{SN*} > 0$ and $\Delta E\Pi_{TL}^{SN*} = 0$ show that only TTA with high serviceability can obtain additional information rent. $\Delta E\Pi_{TH}^{SN*}$ and $\Delta E\Pi_{OH}^{SN*}$ are symmetric with respect to the 0 value curve, which shows that, in the O2O model composed by TTA and OTA, the existence of asymmetric information transfers part of revenue from OTA to TTA with high service capability; (2) when s_{TH} increases, $\Delta E\Pi_{Oi}^{SN*}$ firstly decreases and then increases. The changing trend of $\Delta E\Pi_{OH}^{SN*}$ depends on whether OTA's revenue from the improvement of TTA's serviceability can compensate for the cost of information value; (3) $|\Delta E\Pi_{Oi}^{SN*}|$ decreases with r increases, which shows that r can alleviate the

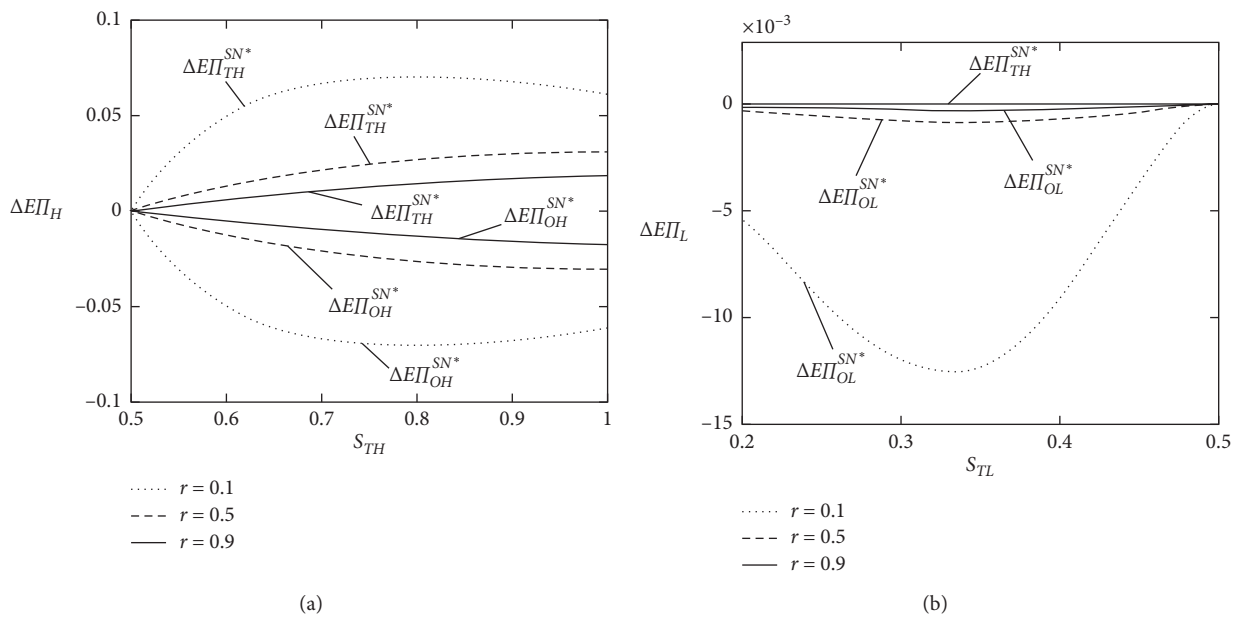

Figure 3: Impacts of r and s_{Ti} on $\Delta E\Pi_{Ti}^{SN*}$ and $\Delta E\Pi_{Oi}^{SN*}$. (a) $s_{TL} = 0.5$. (b) $s_{TH} = 0.5$.

adverse effect of OTA's information disadvantage. $\Delta E\Pi_{TH}^{SN*}$ decreases with r increases, which indicates that r can inhibit the information advantage of TTA with high serviceability.

6. Conclusion and Future Research

The rationality of the OTA service commission contract is an important factor to ensure the efficient operation of the O2O model in the establishment of service cooperation between OTA and TTA. Considering the serviceability information asymmetry, the OTA designs reasonable service commission contracts to differentiate TTA serviceability and motivate TTA to improve service effort level. Some suggestions for establishing a cooperation contract are provided:

(1) When an OTA has low saleability or high sale cost, the OTA will increase the fixed payment to the TTA to support the cocreation of the O2O model. The incentive effect of the service commission coefficient can be offset by the TTA's service effort cost coefficient, risk aversion coefficient, and the degree of market uncertainty.

(2) When the type of TTA's serviceability is continuous, the precondition of separation contract is $(\mathrm{d}/\mathrm{d}s_T)(1 - F(s_T)/s_T f(s_T)) < 0$. At this time, the TTA can choose the appropriate contract corresponding to its serviceability type.

(3) In cocreating the O2O model, the existence of asymmetric information always results in the loss of OTA's expected revenue. Except for TTA with the lowest serviceability, all other types of TTA can obtain strict information rent. The stronger the TTA serviceability is, the more information rent it obtains and the greater its expected revenue is.

(4) The OTA designs service contracts by weighing the different incentives of fixed payments and service commission coefficient to the TTA. When the TTA is a high serviceability type, the OTA sets a high service commission coefficient to encourage the TTA to make more service. When the TTA is of a low serviceability type, the OTA sets a larger fixed payment, stimulating its enthusiasm for participating in cocreating the O2O model.

Due to some of its basic assumptions, there are still some limitations of this paper. Firstly, in this paper, the service commission contract is considered as a linear form. In future research, it can be extended by other service cooperation forms, for example, service cost-sharing contract. Secondly, this study only considers that an OTA establishes service cooperation with a TTA or multiple TTAs. The next step is to extend this model, in which two or more OTAs achieve the O2O model by service cooperation with multiple TTAs. Thirdly, the optimal service commission contract is studied from a short-term perspective. However, in some cases, long-term cooperation is more conducive to the stable development of both. For example, He et al. studied sustainable tourism by using evolutionary game models [31, 32]. Although it is more complex and challenging, service cooperation could be discussed from a long-term perspective. Finally, our paper mainly utilizes an analytical approach. Thus, another future research direction is to conduct empirical research to validate our analytical findings.

Appendix

Proof of TTA's revenue

Assuming that the random variable x follows normal distribution $x \sim N(m, n^2)$, its utility function are the same as TTA's: $U(x) = -e^{-rx}$, and its expected utility is

$$\mathrm{EU}(x) = \int_{-\infty}^{+\infty} -e^{-rx} \frac{1}{\sqrt{2\pi n}} e^{-\left((x-m)^2/2n^2\right)} \mathrm{d}x = -e^{-r\left(m - rn^2/2\right)}. \tag{A.1}$$

According to certainty equivalence method $EU = U(CE)$, $-e^{-r(\mathrm{CE})} = -e^{-r(m-rn^2/2)}$ can be obtained and also $\mathrm{CE} = m - (rn^2/2)$ can be get. According to $\xi \in N(0, \sigma^2)$, $E\Pi_T = a + b(s_O e_O + s_T e_T + \theta) - (\eta_T e_T^2/2)$, $\mathrm{Var}(\Pi_T) = b^2\sigma^2$. The TTA's revenue Π_T is regarded as a random variable x, its certainty equivalent revenue is $a + b(s_O e_O + s_T e_T + \theta) - (\eta_T e_T^2/2) - (r\sigma^2 b^2/2)$.

Proof of Theorem A.1. The optimization problem P1 is solved by using reverse induction and K-T method. The process is solved in two steps.

① The TTA's response function is $e_{Ti}^N = (s_{Ti} b_i^N/\eta_T)$, with a given service contract $(a_i^N b_i^N)$, and sale effort e_{Oi}^N.

② Solving OTA's optimal service contract and sale effort.

Plugging e_{Ti}^N back to optimization problem P1, it is easy to know that the OTA's expected revenue $E\Pi_O$ is linear function of a_i^N and a joint concave of b_i^N and e_{Oi}^N. Therefore, there are corner solution a_i^N and interior solution b_i^N and e_{Oi}^N under the constraint equation (IR). That is, there exists a unique optimal solution. The Lagrange function is constructed as

$$\begin{aligned} L\left(a_i^N, b_i^N, e_{Oi}^N\right) &= \left(1 - b_i^N\right)\left(\left(s_O e_{Oi}^N + s_{Ti} e_{Ti}^N + \theta\right) - a_i^N - \frac{\eta_O e_{Oi}^{N2}}{2}\right) \\ &+ \chi\left(a_i^N + b_i^N\left(s_O e_{Oi}^N + s_{Ti} e_{Ti}^N + \theta\right) - \frac{\eta_T e_{Ti}^{N2}}{2} - \frac{r\sigma^2\left(b_i^N\right)^2}{2} - \underline{\Pi_T}\right). \end{aligned} \tag{A.2}$$

Let $(\partial L/\partial a_i^N) = (\partial L/\partial b_i^N) = (\partial L/\partial e_{Oi}^N) = 0$, $(\partial L/\partial \chi) \geq 0, \chi \geq 0$ and $\chi(\partial L/\partial \chi) = 0$

The only set of solutions can be obtained $(a_i^{N*} b_i^{N*} e_{Oi}^{N*})$. □

Proof of Theorem A.2. The optimization problem P2 is solved by using reverse induction and K-T method. The process is solved in two steps.

① The TTA's response function can be obtained $e_{Ti}^S = (s_{Ti} b_i^S/\eta_T)$, with a given service contract $(a_i^S b_i^S)$, and sale effort e_{Oi}^S.

② Solving OTA's optimal service contract and sale effort.

Plugging e_{Ti}^S back to optimization problem P2, it is easy to know that the OTA's expected revenue $E\Pi_O$ is linear function of a_i^S and a joint concave of b_i^S and e_{Oi}^S. Therefore, there are corner solution a_i^S and interior solution b_i^S and e_{Oi}^S under the constraint equation (IR-i). It is easy to prove that (IC-H) and (IR-L) are tight constraints, so the above optimization problem P2 can be rewritten as follows P2′

$$\begin{cases} \max\limits_{a_H^S, b_H^S, e_{OH}^S, a_L^S, b_L^S, e_{OL}^S} E\Pi_O = \left\{\rho\left(\left(1 - b_H^S\right)\left(s_O e_{OH}^S + \dfrac{b_H^S s_{TH}^2}{\eta_T} + \theta\right) - a_H^S - \dfrac{\eta_O e_{OH}^{S2}}{2}\right) + (1-\rho) \times \right. \\ \left.\left(\left(1 - b_L^S\right)\left(s_O e_{OL}^S + \dfrac{b_L^S s_{TL}^2}{\eta_T} + \theta\right) - a_L^S - \dfrac{\eta_O e_{OL}^{S2}}{2}\right)\right\} \\ \text{s.t.}\ (\mathrm{IC}-H) a_H^S + b_H^S\left(\left(s_O e_{OH}^S + \theta\right) + \dfrac{\left(b_H^S s_{TH}\right)^2}{2\eta_T} - \dfrac{r\sigma^2 b_H^2}{2} \geq \right. \\ a_L^S + b_L^S\left(s_O e_{OL}^S + \theta\right) + \dfrac{\left(b_L^S s_{TH}\right)^2}{2\eta_T} - \dfrac{r\sigma^2 b_L^2}{2} \\ (\mathrm{IR}-L) a_L^S + b_L^S\left(s_O e_{OL}^S + \theta\right) + \dfrac{\left(b_L^S s_{TL}\right)^2}{2\eta_T} - \dfrac{r\sigma^2 b_L^2}{2} \geq \underline{\Pi_T}. \end{cases} \tag{A.3}$$

The Lagrange function is constructed as

$$L(a_H, b_H, e_{OH}, a_L, b_L, e_{OL}, \chi_1, \chi_2) = \rho\left(\left(1-b_H^S\right)\left(s_O e_{OH}^S + \frac{b_H^S s_{TH}^2}{\eta_T} + \theta\right) - a_H^S - \frac{\eta_O e_{OH}^{S2}}{2}\right) + (1-\rho)\times$$
$$\cdot\left(\left(1-b_L^S\right)\left(s_O e_{OL}^S + \frac{b_L^S s_{TL}^2}{\eta_T} + \theta\right) - a_L^S - \frac{\eta_O e_{OL}^{S2}}{2}\right) + \chi_1\left(a_L^S + b_L^S\left(s_O e_{OL}^S + \theta\right) + \frac{\left(b_L^S s_{TL}\right)^2}{2\eta_T} - \frac{r\sigma^2 b_L^{S2}}{2} - \underline{\Pi_R}\right)$$
$$+\chi_2\left(a_H^S + b_H^S\left(s_O e_{OH}^S + \theta\right) + \frac{\left(b_H^S s_{TH}\right)^2}{2\eta_T} - \frac{r\sigma^2 b_H^{S2}}{2} - a_L^S - b_L^S\left(s_O e_{OL}^S + \theta\right) - \frac{\left(b_L^S s_{TH}\right)^2}{2\eta_T} + \frac{r\sigma^2 b_L^{S2}}{2}\right). \tag{A.4}$$

The Kuhn-Tucker condition is obtained as

$$\frac{\partial L}{\partial a_i^S} = \frac{\partial L}{\partial b_i^S} = \frac{\partial L}{\partial e_{Oi}^S} = 0, \quad \frac{\partial L}{\partial \chi_1} \geq 0, \frac{\partial L}{\partial \chi_2} \geq 0, \tag{A.5}$$

where $\chi_1 \geq 0$ and $\chi_1(\partial L/\partial \chi_1) = 0$, $\chi_2 \geq 0$ and $\chi_2(\partial L/\partial \chi_2) = 0$.

In $\chi_1 = 1, \chi_2 = \rho a_H^{S*} b_H^{S*} e_{OH}^{S*}, a_L^{S*}$, b_L^{S*} and e_{OL}^{S*} can be obtained. □

Proof of Corollary A.1.

$$b_H^{S*} - b_L^{S*} = \frac{\left(s_{TH}^2 - s_{TL}^2\right)\left(\rho s_{TH}^2 + (1-\rho)\eta_T r\sigma^2\right)}{\left(s_{TH}^2 + \eta_T r\sigma^2\right)\left(s_{TL}^2 - 2\rho s_{TL}^2 + \rho s_{TH}^2 + (1-\rho)\eta_T r\sigma^2\right)} \geq 0,$$
$$a_H^{S*} - a_L^{S*} = \left(\left(\frac{s_O^2}{\eta_O} + \theta\right) - \frac{1}{2}\left(r\sigma^2 - \frac{s_{TH}^2}{\eta_T}\right)\left(b_L^{S*} + b_H^{S*}\right)\right)\left(b_L^{S*} - b_H^{S*}\right). \tag{A.6}$$

When $r \leq 0$, it is easy to get $a_H^{S*} < a_L^{S*}$.

When $r > 0$, let

$$G(r) = \left(\frac{s_O^2}{\eta_O} + \theta\right) - \frac{1}{2}\left(r\sigma^2 - \frac{s_{TH}^2}{\eta_T}\right)\left(b_L^{S*} + b_H^{S*}\right) = \left(\frac{s_O^2}{\eta_O} + \theta\right) + \frac{s_{TH}^2}{2\eta_T}\left(b_L^{S*} + b_H^{S*}\right) - \frac{1}{2}r\sigma^2\left(b_L^{S*} + b_H^{S*}\right), \tag{A.7}$$

where $(s_{TH}^2/2\eta_T)(b_L^{S*} + b_H^{S*})$ is about r monotonically decreasing.

$$\frac{1}{2}r\sigma^2\left(b_L^{S*} + b_H^{S*}\right) = \frac{1}{2}r\sigma^2\left(\frac{s_{TH}^2}{s_{TH}^2 + \eta_T r\sigma^2} + \frac{(1-\rho)s_{TL}^2}{s_{TL}^2 - 2\rho s_{TL}^2 + \rho s_{TH}^2 + (1-\rho)\eta_T r\sigma^2}\right)$$
$$= \frac{1}{2\eta_T}\left(s_{TH}^2 + s_{TL}^2 - \frac{s_{TH}^4}{s_{TH}^2 + \eta_T r\sigma^2} - \frac{(1-\rho)s_{TL}^2\left(s_{TL}^2 - 2\rho s_{TL}^2 + \rho s_{TH}^2\right)}{s_{TL}^2 - 2\rho s_{TL}^2 + \rho s_{TH}^2 + (1-\rho)\eta_T r\sigma^2}\right), \tag{A.8}$$

$(1/2)r\sigma^2(b_L^{S*}+b_H^{S*})$ is about r monotonically increasing.

Therefore, $G(r)$ is about r monotonically decreasing, which maximizes $r \longrightarrow 0$ at and minimizes at $r \longrightarrow +\infty$.

$$G(+\infty)=\left(\frac{s_O^2}{\eta_O}+\theta\right),$$

$$G(0)=\left(\frac{s_O^2}{\eta_O}+\theta\right)+\frac{s_{TH}^2}{2\eta_T}\left(1+\frac{(1-\rho)s_{TL}^2}{s_{TL}^2-2\rho s_{TL}^2+\rho s_{TH}^2}\right). \tag{A.9}$$

Therefore, $G(r)>0$ and $a_L^{S^*}\geq a_H^{S^*}$, only when $r \longrightarrow +\infty$, $a_L^{S^*}=a_H^{S*}$. □

Proof of Theorem A.3. (1) $a_H^{S^*}-a_L^{S^*}=(1/2\eta_T)(s_{TH}^2-s_{TL}^2)(b_L^{S^*})^2\geq 0$;

(2) $b_L^{S^*}-b_L^{N^*}=(\rho s_{TL}^2(s_{TL}^2-s_{TH}^2)/(s_{TL}^2-2\rho s_{TL}^2+\rho s_{TH}^2+(1-\rho)\eta_T r\sigma^2)(s_{TL}^2+\eta_T r\sigma^2))\leq 0$;

$$a_L^{S^*}-a_L^{N^*}=\left(b_L^{N^*}-b_L^{S^*}\right)\left(\left(\frac{s_O^2}{\eta_O}+\theta\right)-\frac{1}{2}\left(r\sigma^2-\frac{s_{TL}^2}{\eta_T}\right)\left(b_L^{N^*}+b_L^{S^*}\right)\right). \tag{A.10}$$

The process of solving value of $(a_L^{S^*}-a_L^{N^*})$ is similar to the proof of Corollary 1.

The proofs of (3) and (4) of theorem are easy, so they are omitted. □

Proof of Theorem A.4.

(1) $\Delta E\Pi_{OH}^{SN^*}=E\Pi_{OH}^{S^*}-E\Pi_{OH}^{N^*}=(1/2\eta_T)(s_{TL}^2-s_{TH}^2)(b_L^{S^*})^2\leq 0$

$$\begin{aligned}\Delta E\Pi_{OL}^{SN^*}&=E\Pi_{OL}^{S^*}-E\Pi_{OL}^{N^*}=\left(b_L^{S^*}-b_L^{N^*}\right)\left(\frac{s_{TL}^2}{\eta_T}-\frac{1}{2}\left(\frac{s_{TL}^2}{\eta_T}+r\sigma^2\right)\left(b_L^{N^*}+b_L^{S^*}\right)\right)\\&=\frac{1}{\eta_T}\left(b_L^{S^*}-b_L^{N^*}\right)\left(s_{TL}^2-\frac{s_{TL}^2}{2b_L^{N*}}\left(b_L^{N^*}+b_L^{S^*}\right)\right)=\frac{s_{TL}^2}{2\eta_T}\left(b_L^{S^*}-b_L^{N^*}\right)\left(1-\frac{b_L^{S^*}}{b_L^{N^*}}\right)\\&=-\frac{\left(s_{TL}^2+\eta_T r\sigma^2\right)}{2\eta_T}\left(b_L^{S^*}-b_L^{N^*}\right)^2\leq 0.\end{aligned} \tag{A.11}$$

(2) $\Delta E\Pi_{TH}^{SN^*}=E\Pi_{TH}^{S^*}-E\Pi_{TH}^{N^*}=(1/2\eta_T)(s_{TH}^2-s_{TL}^2)(b_L^{S^*})^2\geq 0$

$$\Delta E\Pi_{TH}^{SN^*}=E\Pi_{TL}^{S^*}-E\Pi_{TL}^{N^*}=0. \tag{A.12}$$

□

Proof of Theorem A.5. According to the display principle, when analyzing the validity of continuous variables, the analysis restriction can be displayed $\{a(\overleftrightarrow{s_T}),b(\overleftrightarrow{s_T})\}$ directly. Therefore, $\forall(s_T,\overleftrightarrow{s_T})\in H$, there is

$$\begin{aligned}&a^C(s_T)+\left(s_O e_O^C(s_T)+\theta\right)b^C(s_T)+\frac{1}{2}\left(\frac{s_T^2}{\eta_T}-r\sigma^2\right)b^{C2}(s_T)\geq\\&a^C\left(\overleftrightarrow{s_T}\right)+\left(s_O e_O^C\left(\overleftrightarrow{s_T}\right)+\theta\right)b^C\left(\overleftrightarrow{s_T}\right)+\frac{1}{2}\left(\frac{s_T^2}{\eta_T}-r\sigma^2\right)b^{C2}\left(\overleftrightarrow{s_T}\right).\end{aligned} \tag{A.13}$$

According to In equation (A.13), there is

$$a^C(s_T)+\left(s_O e_O^C(s_T)+\theta\right)b^C(s_T)+\frac{1}{2}\left(\frac{s_T^2}{\eta_T}-r\sigma^2\right)b^{C2}(s_T)\geq$$
$$a^C(s_T')+\left(s_O e_O^C(s_T')+\theta\right)b^C(s_T')+\frac{1}{2}\left(\frac{s_T^2}{\eta_T}-r\sigma^2\right)b^{C2}(s_T'), \tag{A.14}$$

$$a^C(s_T')+\left(s_O e_O^C(s_T')+\theta\right)b^C(s_T')+\frac{1}{2}\left(\frac{s_T'^2}{\eta_T}-r\sigma^2\right)b^{C2}(s_T')\geq$$
$$a^C(s_T)+\left(s_O e_O^C(s_T)+\theta\right)b^C(s_T)+\frac{1}{2}\left(\frac{s_T'^2}{\eta_T}-r\sigma^2\right)b^{C2}(s_T). \tag{A.15}$$

In equations (A.14) and (A.15) are added and simplified as

$$\left(s_T-s_T'\right)\left(b^C(s_T)-b^C(s_T')\right)\geq 0. \tag{A.16}$$

So $b^C(s_T)$ is no decreasing, which shows $b^C(s_T)$ is differentiable everywhere in the interval $[\underline{s_T},\overline{s_T}]$, and $\dot{b}^C(s_T)\geq 0$. In addition, the first-order condition for s_T is obtained $\dot{a}^C(\overleftrightarrow{s_T})+s_O\dot{e}_O^C(s_T)b^C(s_T)+(s_O e_O^C(s_T)+\theta)\dot{b}^C(s_T)+((s_T^2/\eta_T)-r\sigma^2)\dot{b}^C(s_T)=0$ from In equation (A.13).

According to the direct display mechanism, $\forall s_T^C\in H$ there is

$$\dot{a}^C(s_T)+s_O\dot{e}_O^C(s_T)b^C(s_T)+\left(s_O e_O^C(s_T)+\theta\right)\dot{b}^C(s_T)+\left(\frac{s_T^2}{\eta_T}-r\sigma^2\right)\dot{b}^C(s_T)=0. \tag{A.17}$$

In equations (18) and (19) are incentive compatibility constraints to ensure that the TTA has no motivation to deviate from the service reward contract provided by OTA. In equation (20) is the constraint condition for the TTA to participate in cooperation and cannot be lower than its reserved revenue.

Derivatives of equation (17), and further simplified according to equation (19)

$$E\dot{\Pi}_T(s_T)=\frac{s_T}{\eta_T}b^{C2}(s_T). \tag{A.18}$$

Bring $E\dot{\Pi}_T(s_T)$ into equation (15), the above optimization problem P3 can be rewritten as follows P3′

$$\max_{a^C,b^C}\int_{\underline{s_T}}^{\overline{s_T}}\left\{s_O e_O^C(s_T)+\frac{s_T^2 b^C(s_T)}{\eta_T}+\theta-\frac{1}{2}\left(\frac{s_T^2}{\eta_T}+r\sigma^2\right)b^{C2}(s_T)-E\Pi_T(s_T)-\frac{\eta_O e_O^{C2}(s_T)}{2}\right\}f(s_T)\mathrm{d}s_T, \tag{A.19}$$

s.t. in equation (18) and (A.18), $E\Pi_T(s_T)\geq\underline{\Pi_T}$

Let $E\Pi_T(\underline{s_T})\geq\underline{\Pi_T}$, the solution of integral equation (A.18) is obtained

$$E\Pi_T(s_T)=\int_{\underline{s_T}}^{s_T}\frac{\omega}{\eta_T}b^{C2}(\omega)\mathrm{d}\omega+\underline{\Pi_T}. \tag{A.20}$$

According to. $\int_{\underline{s_T}}^{\overline{s_T}}[\int_{s_T}^{\overline{s_T}}(\omega/\eta_T)b^{C2}(\omega)\mathrm{d}\omega]f(s_T)\mathrm{d}s_T=\int_{\underline{s_T}}^{\overline{s_T}}[\int_{s_T}^{\overline{s_T}}f(\omega)\mathrm{d}\omega](s_T/\eta_T)b^{C2}(s_T)\mathrm{d}s_T=\int_{\underline{s_T}}^{\overline{s_T}}(1-F(s_T)/f(s_T))(s_T/\eta_T)b^{C2}(s_T)f(s_T)\mathrm{d}s_T$

Then the objective function of P3 is

$$\max_{a^C,b^C}\int_{\underline{s_T}}^{\overline{s_T}}\left\{s_O e_O^C(s_T)+\frac{s_T^2 b^C(s_T)}{\eta_T}+\theta-\frac{1}{2}\left(\frac{s_T^2}{\eta_T}+r\sigma^2\right)b^{C2}(s_T)-\frac{1-F(s_T)}{f(s_T)}\frac{s_T}{\eta_T}b^{C2}(s_T)-\underline{\Pi_T}-\frac{\eta_O e_O^{C2}(s_T)}{2}\right\}f(s_T)\mathrm{d}s_T. \tag{A.21}$$

The optimal solution is

$$e_O^{C*} = \frac{s_O}{\eta_O},$$

$$b^{C*}\left(s_T^C\right) = \frac{1}{1+\left(\eta_T r\sigma^2/s_T^{C2}\right)+\left(2\left(1-F\left(s_T^C\right)\right)/s_T^C f\left(s_T^C\right)\right)}, \tag{A.22}$$

Where, $b^{C*}(\underline{s_T}) = (1/1 + (\eta_T r\sigma^2/\underline{s_T}) + (2/\underline{s_T}\, f(\underline{s_T})))$, $b^{C*}(\overline{s_T}) = (1/1 + (\overline{\eta_T} r\sigma^2/\overline{s_T}^2))$

When $s_T = \underline{s_T}$, according to equation (16) and $E\Pi_T(\underline{s_T}) = \underline{\Pi_T}$, $a^{C*}(\underline{s_T})$ can be obtained as

$$a^{C*}\left(\underline{s_T}\right) = \underline{\Pi_T} - \left(\frac{s_O^2}{\eta_O}+\theta\right)b^{C*}\left(\underline{s_T}\right) - \frac{1}{2}\left(\frac{\underline{s_T}^2}{\eta_T} - r\sigma^2\right)b^{C*2}\left(\underline{s_T}\right). \tag{A.23}$$

Bring $b^{C*}(s_T^C)$ into equation (A.20), $E\Pi_T(s_T)$ can be obtained as

$$E\Pi_T\left(s_T\right) = \int_{\underline{s_T}}^{s_T} \frac{\omega}{\eta_T} b^{C*2}(\omega)\mathrm{d}\omega + \underline{\Pi_T}. \tag{A.24}$$

Bring equation (A.24) into equation (17), $a^{C*}(s_T)$ can be obtained as

$$a^{C*}\left(s_T\right) = \underline{\Pi_T} - \left(\frac{s_O^2}{\eta_O}+\theta\right)b^{C*}\left(s_T\right) - \frac{1}{2}\left(\frac{s_T^2}{\eta_T} - r\sigma^2\right)b^{C*2}\left(s_T\right) + \int_{\underline{s_T}}^{s_T} \frac{\omega}{\eta_T} b^{C2}(\omega)\mathrm{d}\omega. \tag{A.25}$$

□

Data Availability

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

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

This work was supported by the Research Fund for the Scientific Research Foundation of Chongqing University of Technology and the Humanities and Social Sciences Research Project of Chongqing Education Commission (2020CJR06).

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