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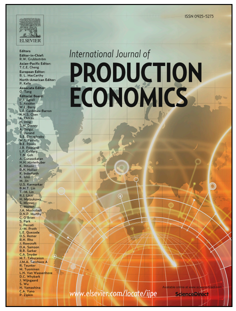

Opaque distribution channels for service providers with asymmetric capacities: Posted-price mechanisms

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PII: S0925-5273(18)30052-5

DOI: 10.1016/j.ijpe.2018.01.022

Reference: PROECO 6937

To appear in: *International Journal of Production Economics*

Received Date: 18 December 2016

Revised Date: 22 September 2017

Accepted Date: 21 January 2018

Please cite this article as: Mao, Z., Liu, W., Feng, B., Opaque distribution channels for service providers with asymmetric capacities: Posted-price mechanisms, *International Journal of Production Economics* (2018), doi: 10.1016/j.ijpe.2018.01.022.

Opaque distribution channels for service providers with asymmetric capacities: posted-price mechanisms

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Opaque distribution channels for service providers with asymmetric capacities: posted-price mechanisms

Abstract: A new e-commerce model called online-to-offline (O2O) e-commerce has attracted significant managerial and academic attention. One of the most recent applications of the O2O model in the travel industry is opaque selling, which enables service providers to offer a new channel to potential customers. This study uses game models to analyze whether service providers with asymmetric capacities should contract with an intermediary to introduce an opaque distribution channel using a posted-price mechanism to sell opaque services. We construct models for both single-channel and dual-channel cases, and derive the optimal pricing strategies. A revenue sharing contract is established between service providers and an intermediary when the decision is made to use an opaque distribution channel. We then compare the profits obtained in the two cases and find some interesting results driven by asymmetric capacities and other related factors.
Keywords: Opaque Selling; Posted Price; Revenue Sharing Contract; Optimal Pricing; Stackelberg Game

1. Introduction

The rapid development of information technology has made it much easier for customers to book services online and then collect them from brick-and-mortar stores. This practice is called "online-to-offline (O2O) e-commerce" and is exemplified by Priceline and Hotwire in the travel industry and Didi and Uber in the transportation industry (Xiao and Dong 2015). Opaque selling is a newly emerging O2O channel whereby service providers sell opaque services to customers online and then the customers consume the service offline. Opaque selling is widely used in travel-related industries such as hotel accommodation, airline travel, and car rental, and provides a new distribution channel in addition to the traditional industry channels. For instance, it is currently being promoted by Hotwire and Priceline in America, as well as Qunar and Ctrip in China. In opaque distribution channels, posted price (PP) is a popular selling mechanism that has now been adopted by Hotwire.

In practice, many hotels, such as the Hilton, Home Inn, and Sheraton chains, have started to collaborate with intermediaries such as Hotwire, CheapTickets, Priceline, and OneTravel. This provides a dual-channel system for the hotels whereby the hotel operates the traditional channel while the intermediary operates the opaque distribution channel. The hotel sells its regular services to customers through the traditional channel, so that a customer has all the necessary information about the hotel and can choose the hotel he or she prefers. In the opaque distribution channel, the intermediary hides some of the service attributes from the customer, only revealing them after the customer has paid for their booking. For example, before making a booking, the customer might only know the hotel's star rating, its general location within the destination city, and the room rate, but the hotel's brand, exact location, facilities, and other information may be concealed. Thus, a customer may end up booking a room in a hotel he or she dislikes (Xie et al. 2015). Figure 1 shows an example of an opaque product offered on Hotwire.

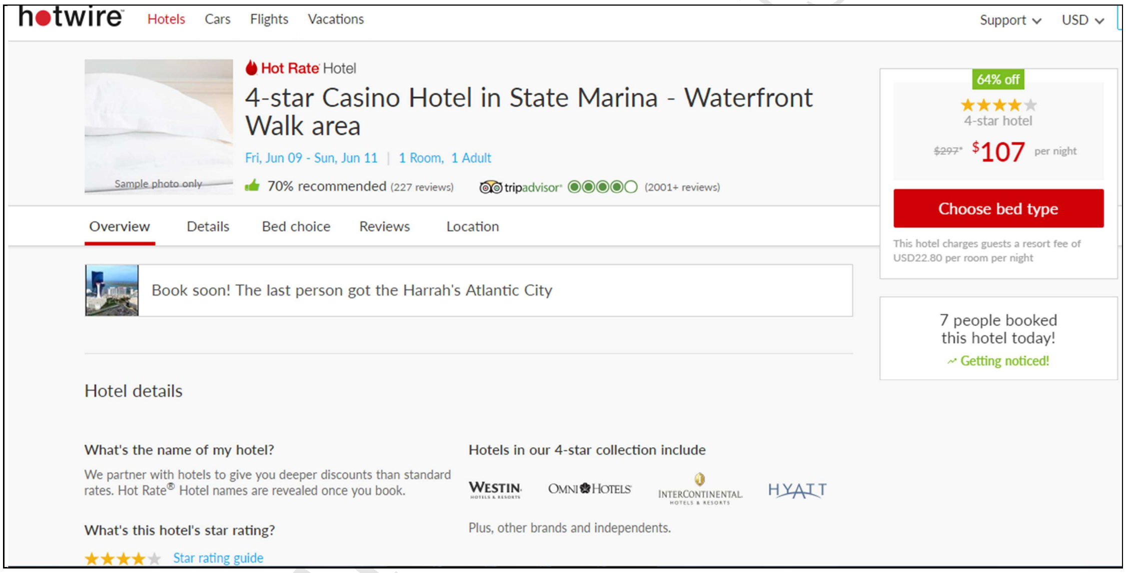

Figure 1 The Opaque Distribution Channel Operated by Hotwire

In these cases, service providers operating a single traditional channel should decide whether they should contract with an intermediary to introduce an additional opaque distribution channel. An opaque distribution channel helps service providers to employ price discrimination and customer segmentation (Smith et al. 2007). It also enables service providers to generate incremental revenue by selling excess capacity cheaply without disrupting existing distribution channels. However, the opaque distribution channel also competes with the traditional channel (Fay 2008). Another critical issue is that asymmetric capacities of collaborative service providers may influence their decision to contract with the intermediary. If one service provider has more capacity than the other, they can use their own pooling effect to balance any mismatch between supply and demand. However, the collaborative service providers may suffer reduced profits from using an opaque distribution channel. Therefore, it is important to analyze whether service providers should contract with an intermediary to set up an opaque distribution channel when they have asymmetric capacities.

This study uses game-based models to investigate the problem of opaque distribution channel choice for service providers with asymmetric capacities using PP mechanisms. The service providers can either belong to the same parent company or can simply be two collaborative partners. For instance, the Hilton, Home Inn, and Sheraton hotel chains collaborate with intermediaries, such as Hotwire, CheapTickets, Priceline, and OneTravel. Thus, hotel chains under the parent companies Hilton, Home Inn, or Sheraton are collaborative service providers. Conversely, our study also examines the case in which service providers are in partnership. For example, Home Inn and Hanting are two hotel chains in China with three-star ratings. They cooperate with each other and have contracted with an intermediary, Qunar, to distribute their surplus capacity to maximize their profits. We first construct models representing the single-channel and dual-channel cases, and then derive the optimal pricing strategies under different scenarios based on changes in the service providers' capacities. Stackelberg game models are used to characterize the revenue sharing contract[1] between the service providers and the intermediary in the dual-channel case, in which the service providers negotiate the proportion of the intermediary's income that is allocated to them (Binmore et al. 1986). The equilibrium solution to the Stackelberg game is derived and the optimal profit for the service provider is obtained. Finally, we compare the optimal profits of the service providers in the single-channel and dual-channel cases and find some interesting results driven by the service providers' asymmetric capacities and other related factors.

This paper contributes to the opaque selling literature and also provides important insights for managers of service providers. First, to the best of our knowledge, this study is the first to address the impact of asymmetric capacities of collaborative service providers on their choice of an additional opaque distribution channel. Previous studies have found that a dual-channel system always benefits collaborative service providers with the same capacity, and thus they should always

[1] This means that when an intermediary contracts with a service provider, it should distribute a fixed proportion of its income to the service provider (Cachon and Kök 2010 and Feng and Lu 2012).

enter into a contract with an intermediary. However, our findings show that the degree of capacity asymmetry of collaborative service providers influences their choice regarding an opaque distribution channel. A high degree of asymmetry in service providers' capacities may result in non-cooperation with the intermediary when a PP mechanism is used.

Second, our study provides a comprehensive framework to analyze the role of a service provider's capacity in the contracting process. The capacity of collaborative service providers has a significant impact on their optimal profit levels. In the single-channel case, as the capacity of collaborative service providers increases, their optimal price will decrease but their profits will increase. Consequently, in the dual-channel case, collaborative service providers should allocate their surplus capacity to the intermediary when their capacity is relatively high. The opaque distribution channel can help the service providers to employ price discrimination and customer segmentation by setting different prices in different channels. Therefore, collaborative service providers should not contract with the intermediary when their capacity is relatively low.

Finally, the relative patience of collaborative service providers also affects their strategic choices. Service providers should not contract with the intermediary when their relative patience is relatively low. This means that a low level of relative patience in the Stackelberg bargaining game will induce service providers to accept less profit from the intermediary.

The remainder of the paper is organized as follows. Section 2 presents a literature review. Section 3 describes the problem. The single-channel case is developed in Section 4, and the dual-channel case is developed in Section 5. We compare the single-channel case with the dual-channel case in Section 6. Section 7 presents the main findings and conclusions. All proofs are given in the appendices.

2. Literature Review

The early literature on opaque selling mainly focused on the name-your-own-price (NYOP)[2] bidding mechanism (see, for example, Fay and Laran 2009; Cai et al. 2009; Fay and Lee 2015; Li et al. 2016; Liu et al. 2016, Stoel and Muhanna 2016; Wang et al. 2016), in particular whether an

[2] Under the NYOP mechanism, a customer is successful in securing a booking if their bid price is above the intermediary's reservation price.

intermediary should allow the customer to bid for a second time. While previous studies only examined the NYOP mechanism, the issue of how the level of service opacity affects the market size was first discussed by Fay (2008). He investigated the effects of introducing opaque selling to the market and found that an opaque service can help to achieve better customer segmentation, leading to market expansion and affecting the price competition. By expanding Fay’s (2008) model from two retailers to numerous retailers, Shapiro and Shi (2008) proved that the opaque channel can help service providers to employ price discrimination among both leisure customers who are sensitive to service characteristics and loyal customers who are not. Further, Fay et al. (2015) investigated the effect of opaque selling on the optimal product mix, and Geng (2016) studied opaque selling in a congestion-susceptible environment. Feng et al. (2017) compared two kinds of selling from the perspective of the service providers, and Granados et al. (2017) provided evidence of the effect of opaque selling on revenue. However, the above literature only considers the situation when the service providers are symmetrical in terms of capacity. It does not consider the effect of service providers’ asymmetric capacities, nor of contracting between service providers and intermediaries.

There are three research streams relating to capacity, asymmetry, and contracts. The first stream studies the influence of capacity on service providers. Anderson and Xie (2014) built a stylized model of consumer choice that describes the role of opaque selling in market segmentation, in which the capacity of a monopoly service provider is considered. Chen et al. (2014) studied two competing service providers with capacity restrictions over two periods and compared the PP and NYOP mechanisms. However, even though these studies consider the effect of capacity on opaque selling, they only consider its effect on pricing strategies in the symmetrical case. By contrast, we study two service providers with different capacities, and investigate the effect of asymmetry on the service providers’ strategic choices.

Few studies have investigated the condition in which service providers are asymmetric in terms of capacity. By comparing the benefits of last-minute selling to the customer versus introducing opaque selling, Jerath et al. (2010) proved that direct last-minute selling is better than opaque selling when the customer’s valuation of the service is high or there is little service differentiation between competing retailers. Even though the retailers in that study are asymmetric in terms of capacity, our study is different. The aim of our study is to compare the single-channel and dual-channel cases by considering the asymmetric capacities and relative patience of service providers, and then designing a contract between the service provider and the intermediary. These aspects are not considered by Jerath et al. (2010). Similarly, Cai et al. (2013) proved that the equilibrium channel structure should be asymmetric, that is, one supplier reserves their own service while the others allocate the service to the intermediary. Furthermore, Zhang et al. (2015) studied opaque selling in quality-differentiated markets and proved that it can be used to dispose of excess capacity profitably. Even though they consider the situation in which the suppliers are asymmetric, their study differs from ours because we also design a contract between the service providers and an intermediary.

To the best of our knowledge, only one study has examined the contract between the service provider and the intermediary. Wang et al. (2009) discussed whether hotels should use an opaque channel and showed that it can help hotels to employ market segmentation and price discrimination when they enter a contract with an intermediary. They also showed that the more capacity the hotels have, the less likely it is that they will contract with an intermediary. Even though they consider contracts with intermediaries, their study differs from ours. We consider the PP mechanism used by Hotwire and the NYOP mechanism used by Priceline, and show that a service provider’s decision regarding contracting with an intermediary is affected by both the service provider’s capacity and their relative patience.

3. Problem Description

We consider two service providers and one intermediary in the market, and investigate whether the service providers should contract with the intermediary when they have asymmetric capacities. In the single-channel case, the service providers cooperate with each other to sell services and maximize their profit by observing their relative capacities. The structure of this system is shown in Fig. 2(a). In the dual-channel case, service providers may contract with the intermediary. The structure of this system is shown in Fig. 2(b). In this case, we need to determine the optimal proportion of revenue that the intermediary allocates from the opaque distribution channel to the service providers. This proportion is determined by a Stackelberg game between the service providers and the intermediary in which the service providers are the leaders and the intermediary is the follower. In the dual-channel case, α denotes the proportion of the intermediary's revenue that is allocated to the service providers, P_i represents the price of the service offered by provider $i, i \in \{1,2\}$, and P_3 is the PP in the opaque channel. At the same time, we assume that the relative patience of the service providers is δ_F and the relative patience of the intermediary is δ_I. Relative patience is very common in the Stackelberg game because it can provide an accurate measure of the relative bargaining power of the service providers and the intermediary.

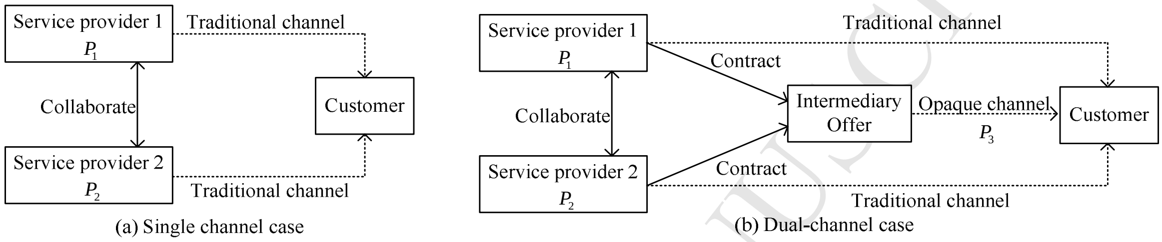

Figure 2 Structure of the Single-Channel and Dual-Channel Systems

The service providers face demand from leisure customers whose reservation price for the service is 1. The customers are uniformly distributed between the two service providers. Each leisure customer's location x implies the customer's ideal service, which means that leisure customers will buy the service from the closest provider. Service providers 1 and 2 are assumed to be located at the endpoints of the segment, i.e., at 0 and 1. Let t represent the fit cost loss coefficient from not receiving the customer's ideal service. $U_i(i=1,2,3)$ signifies the net utility of the leisure customer ordering from service providers 1 and 2 and the intermediary. Then, we can derive $U_1 = 1 - tx - P_1$ and $U_2 = 1 - t(1-x) - P_2$. We assume that when the leisure customer orders the service through the opaque channel, the probability of obtaining the service from either service provider 1 or service provider 2 is the same. Thus, the probability that a leisure customer orders the service from service provider 1 or 2 via the opaque channel is 0.5. We can derive the average distance of the leisure customer to service provider 1 or 2 as $0.5x + 0.5(1-x) = 0.5$. Then, we can derive the net utility of the leisure customer buying from the intermediary as $U_3 = 1 - t/2 - P_3$.

4. Single-Channel Case

In the single-channel case, the service provider does not cooperate with the intermediary. We now build the mathematical model for the single-channel case. As the service provider's capacity changes, the optimal solution may change, and thus we need to analyze them separately. Following the analysis under each condition, we derive the optimal profit of each service provider.

4.1 *Model in the Single-Channel Case*

First, the critical point at which it makes no difference to the customer whether they choose service provider 1 and 2 can be determined. Assume that the critical point is x_0, as illustrated in Fig. 3. Solving the equation $1-tx_0-P_1=1-t(1-x_0)-P_2$, we can derive the critical point $x_0=1/2+(P_2-P_1)/2t$. In addition, when the customer orders the service from provider i, $i=1,2$, we assume that the critical point at which the net utility of the customer is equal to 0 is x_i. Then, we can derive $x_1=(1-P_1)/t$ and $x_2=1-(1-P_2)/t$, which means that if the customer lies to the right of x_1, he or she will not order the service from provider 1 and if the customer lies to the left of x_2, he or she will not order the service from provider 2.

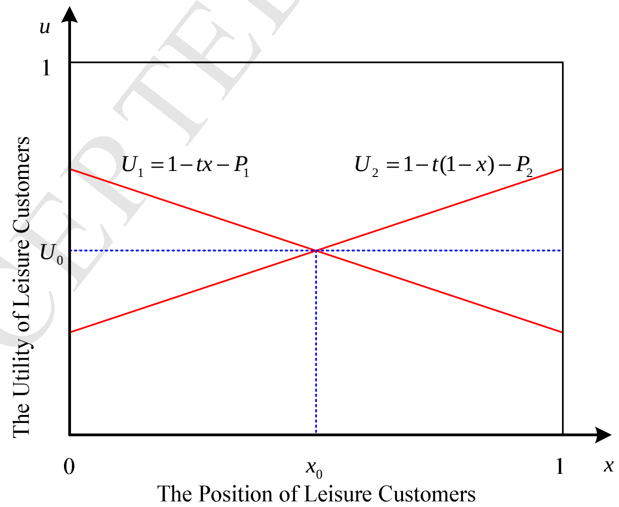

Figure 3 Net Utility of Leisure Customers in the Single-Channel Case

Assuming that the capacity of service provider i is k_i, and without loss of generality, we assume that $k_1 \le k_2$. Then, we need to compare the magnitudes among x_1, x_0 and k_1, and those among $1-x_2$, $1-x_0$ and k_2. This is because we need to consider whether the utility of the customer at position x_0 is non-negative. When the utility is non-negative, we should choose x_0 to build the model, otherwise we should choose x_1 and x_2. To combine these two situations, we take the minimum of either x_1 or x_0 and the minimum of either $1-x_2$ or $1-x_0$. Consequently, the customer demand for service providers 1 and 2 is $\min(x_1, x_0)$ and $\min(1-x_2, 1-x_0)$, respectively. Since the sales volume is the least value between the demand and capacity, the sales volume of service providers 1 and 2 is $\min(k_1, x_1, x_0)$ and $\min(k_2, 1-x_2, 1-x_0)$, respectively.

The optimal profits of the service providers are obtained as follows:

$$\max_{0\le P_1, P_2 \le 1} \pi_t = \min\{k_1, x_1, x_0\}P_1 + \min\{k_2, 1-x_2, 1-x_0\}P_2 .$$

4.2 *Analysis of the Single-Channel Case*

The profit of the service providers is unimodal, as shown by Lemma 1.

Lemma 1. The profit of the service providers in the single-channel case, π_t, is unimodal.

Lemma 1 is necessary for us to derive the optimal profit of the service providers because it ensures that the local optimal value is also the global optimal value. We then obtain the optimal pricing strategy and profit of the service providers in Proposition 1.

Proposition 1. In the single-channel case, the optimal pricing strategy of service provider $i, i=1,2$ is $P_i^* = 1-\min\{0.5, k_i\}t$, and the corresponding optimal profit of service provider i is $\pi_t^{i*} = (1-\min\{0.5, k_i\}t)\min\{0.5, k_i\}$.

In the single-channel case, as the service provider's capacity changes, both the optimal prices and profits of the service providers will change accordingly. When the capacity of the service provider is relatively small, an increase in capacity will cause the service provider's optimal price to decrease and its profit to increase. This is because the increased capacity can be used to satisfy the previously unsatisfied demand from leisure customers. These leisure customers may not be close to the service provider, which leads to a lower optimal price. However, once the capacity moves beyond the critical point, both the optimal price and optimal profit of the service provider will not change because the demand has been fully satisfied, and thus there will be surplus capacity. In addition, the service providers cannot employ price discrimination and customer segmentation in the single-channel case because the service providers must offer the same price to all potential customers. Therefore, the service providers may need to introduce other selling strategies to enable them to employ price discrimination and increase their profits.

5 Dual-Channel Case

In the dual-channel case, the service providers contract with an intermediary, and thus need to decide on the capacity that is allocated to the intermediary. We assume that the service providers will allocate all of their surplus capacity to the intermediary after satisfying the demand from leisure customers in the traditional channel. Thus, the capacity allocated to the intermediary is affected by the service providers' overall capacity and pricing strategy. We derive the capacity allocated to the intermediary after determining the optimal pricing strategy in the traditional channel. As the service provider's capacity changes, the optimal solution will change correspondingly. Thus, we need to build the model under different conditions and analyze the optimal solutions separately.

5.1 *Model in the Dual-Channel Case*

We assume that $y_i (i=1,2)$ is the critical point. In Figure 4, y_1, y_2 and $y_2 - y_1$ represent the customer demand for service providers 1 and 2 and the intermediary, respectively. We assume that n_i represents the capacity that provider i allocates to the intermediary, so $n_1 = \max\{k_1 - y_1, 0\}$, $n_2 = \max\{k_2 + y_1 - 1, 0\}$. $n_1 = \max\{k_1 - y_1, 0\}$ means that if the demand for service provider 1 is less than its capacity ($k_1 > y_1$), then service provider 1 should allocate the surplus capacity $k_1 - y_1$ to the intermediary, otherwise it should not allocate any capacity to the intermediary. Similarly, $n_2 = \max\{k_2 + y_1 - 1, 0\}$ means that if the demand for service provider 2 is less than its capacity ($k_2 > 1 - y_2$), then service provider 2 should allocate the surplus capacity $k_2 + y_1 - 1$ to the intermediary, otherwise it should not allocate any capacity to the intermediary. At the same time, since the sales volume is the least value between the demand and capacity, the sales volume of service providers 1 and 2 and the intermediary is $\min\{k_1, y_1\}$, $\min\{k_2, 1 - y_2\}$ and $\min\{n_1 + n_2, y_2 - y_1\}$, respectively.

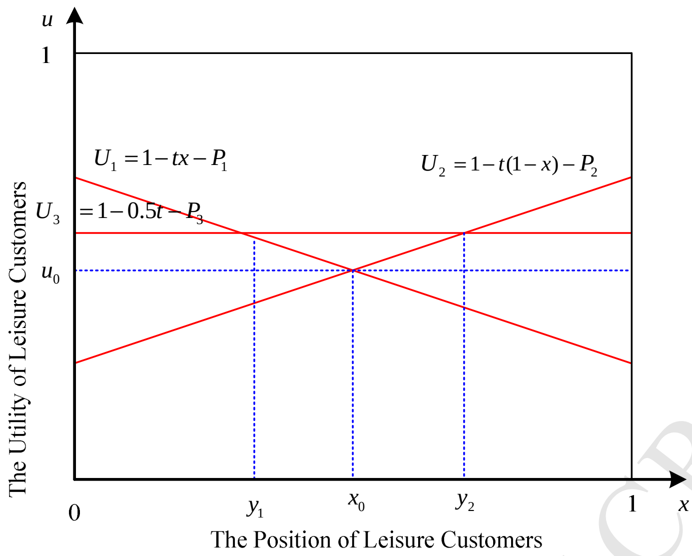

Figure 4 Net Utility of Leisure Customers in the Dual-Channel Case

The overall profits of the service providers and the intermediary are obtained as follows:

$$\max_{\substack{0 \le P_1, P_2 \le 1 \\ 0 \le P_3 \le 1-0.5t}} \pi^{PP} = \min\{k_1, y_1\}P_1 + \min\{n_1 + n_2, y_2 - y_1\}P_3 + \min\{k_2, 1 - y_2\}P_2,$$

where $n_1 = \max\{k_1 - y_1, 0\}, n_2 = \max\{k_2 + y_1 - 1, 0\}$.

5.2 *Analysis of the Dual-Channel Case*

Since the provider allocates capacity to the intermediary, it will obtain profit from the intermediary. The proportion of the intermediary's income that is allocated to the service providers is α, and if the proportions allocated to service providers 1 and 2 are based on their relative capacity, then they are given by $\alpha\beta$ and $\alpha(1-\beta)$, respectively, where $\beta = n_1 / (n_1 + n_2)$. We present the optimal profit and pricing strategy of the service provider in Proposition 2.

Proposition 2. In the dual-channel case:

(i) If either of the service providers' capacity is less than 0.25, the service provider will not contract with the intermediary.

(ii) If $0.25 < k_1$ and $0.25 < k_2$, the optimal pricing strategy is $P_1^* = P_2^* = 1 - 0.25t$, $P_3^* = 1 - 0.5t$, the optimal profit of the intermediary is $\pi_3^{PP*} = (1-\alpha)(1-0.5t)(min\{1, k_1 + k_2\} - 0.5)$, and the optimal profit of service providers 1 and 2 is

$\pi_1^{PP*} = \alpha\beta(1-0.5t)(min\{1, k_1 + k_2\} - 0.5) + 0.25(1-0.25t)$ and

$\pi_2^{PP*} = \alpha(1-\beta)(1-0.5t)(min\{1, k_1 + k_2\} - 0.5) + 0.25(1-0.25t)$, respectively.

Under Proposition 2(i), there will be at least one service provider that does not contract with the intermediary when the service providers' capacity is relatively small. In this case, the optimal solution is obtained when the service providers make full use of their capacity. As the service providers' capacity increases, their optimal profits will also increase because the additional capacity can be used to satisfy the excess demand from leisure customers.

Under Proposition 2(ii), when the service providers' capacity increases further, they will allocate any excess capacity to the intermediary to obtain additional profit from the intermediary after satisfying demand through the traditional channel. In this case, half of the demand is satisfied through the traditional channel, and all of the remaining customers will purchase through the opaque channel. When customers purchase through the traditional channel, they pay a higher price compared to that in the opaque channel even though they can always obtain positive surpluses when they buy from the traditional channel. This is because the customers close to the service provider have a higher willingness to pay than other customers, and thus it offers the service providers a chance to employ price discrimination and customer segmentation by setting different prices in the traditional and opaque channels.

5.3 *Stackelberg Bargaining between Service Providers and the Intermediary*

In the Stackelberg bargaining game that takes place between the service providers and the intermediary, the service providers act as a leader and the intermediary acts as a follower. The service providers offer take-it-or-leave-it contracts to the intermediary, who decides whether to accept the contract. The bargaining process is shown in Fig. 5. First, the service providers offer proportion α_F, and then the intermediary decides whether to accept. If not, the intermediary requests proportion α_I. α_F and α_I denote the proportion of revenue sharing that the intermediary allocates to the service providers.

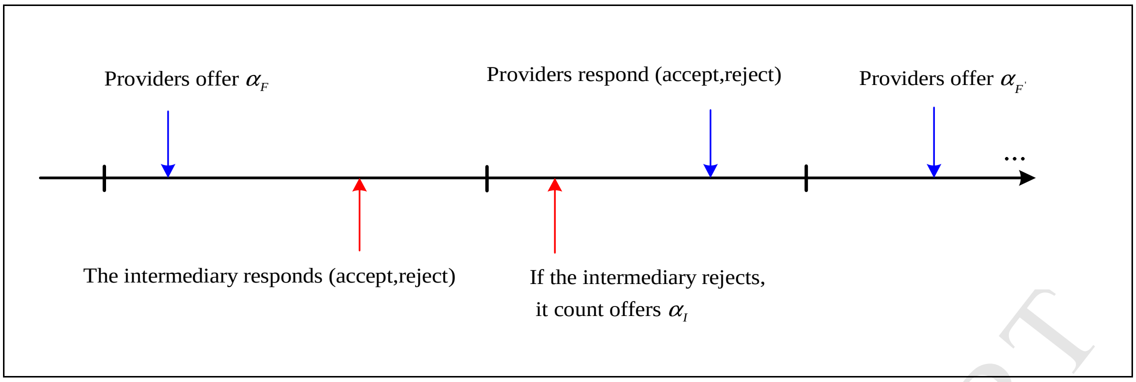

Figure 5 The Bargaining Process between the Service Providers and the Intermediary

Firstly, the service providers determine proportion α_F. The objective function is to maximize the service providers' profit obtained from the intermediary. The constraint should ensure that the profit the intermediary obtains in the first stage is no less than its maximum profit in the second stage. Then, we can derive the model in the first stage:

$$\omega_F = \max_{\alpha_F} \alpha_F (1-0.5t)(\min\{1, k_1 + k_2\} - 0.5)$$

subject to $\quad (1-\alpha_F)(1-0.5t)(\min\{1, k_1 + k_2\} - 0.5) \geq \delta_I \omega_I(\omega_F)$.

If the intermediary does not agree to accept proportion α_F, it determines proportion α_I in the second stage. The objective function is to maximize the intermediary's profit over α_I. The constraint should ensure that the profit the service provider obtains in the second stage is no less than its maximum profit in the first stage. Then, we can derive the model in the second stage:

$$\omega_I(\omega_F) = \max_{\alpha_I} (1-\alpha_I)(1-0.5t)(\min\{1, k_1 + k_2\} - 0.5)$$

subject to $\quad \alpha_I (1-0.5t)(\min\{1, k_1 + k_2\} - 0.5) \geq \delta_F \omega_F$.

We show the equilibrium position of the Stackelberg bargaining game in Proposition 3.

Proposition 3. When the service providers bargain with the intermediary, the equilibrium $\alpha = (1-\delta_I)/(1-\delta_I\delta_F)$, which is increasing in δ_F and decreasing in δ_I, and the profit allocated to the service providers is given by $\omega_F = (1-0.5t)(min\{1, k_1 + k_2\} - 0.5)(1-\delta_I)/(1-\delta_I\delta_F)$.

The equilibrium α is increasing in δ_F and decreasing in δ_I, which means that if the service providers have higher relative patience, they will obtain more profit. This is because if the service providers have enough time to bargain with the intermediary and are sufficiently patient, they have an advantage over an intermediary who is impatient. Consequently, the service provider will obtain more profit in this case. Therefore, the service providers should exercise patience because this will increase their bargaining power and profit.

6. Comparison between the Single-Channel and Dual-Channel Cases

Having derived the optimal profits of the service providers in the previous section, we can now compare their optimal profits in the single-channel case with those in the dual-channel case to determine whether they should contract with the intermediary. Since we have proved that the service providers will not contract with the intermediary when the capacity of either service provider is less than 0.25, we only need to discuss the situation in which the capacity of both service providers is greater than 0.25.

If a service provider wants to contract with an intermediary, it should ensure that the profit obtained in the single-channel case is less than that obtained in the dual-channel case. Thus, it should satisfy the following condition: $\pi_i^{PP*} > \pi^{i*}, i = 1, 2$.

That is:

$$\begin{cases} \alpha\beta(1-0.5t)(\min\{1, k_1+k_2\}-0.5)+0.25(1-0.25t) > (1-\min\{0.5, k_1\}t)\min\{0.5, k_1\} \\ \alpha(1-\beta)(1-0.5t)(\min\{1, k_1+k_2\}-0.5)+0.25(1-0.25t) > (1-\min\{0.5, k_2\}t)\min\{0.5, k_2\} \end{cases}.$$

To simplify this expression, we let

$$f(k_1, k_2) = \frac{(1-\min\{0.5, k_1\}t)\min\{0.5, k_1\}-0.25(1-0.25t)}{(1-0.5t)(\min\{1, k_1+k_2\}-0.5)}, \text{ and}$$

$$h(k_1, k_2) = \frac{(1-\min\{0.5, k_2\}t)\min\{0.5, k_2\}-0.25(1-0.25t)}{(1-0.5t)(\min\{1, k_1+k_2\}-0.5)}.$$

Then, the condition can be simplified to the following constraint:

$f(k_1, k_2)/\alpha < \beta < 1 - h(k_1, k_2)/\alpha$, where $\alpha = (1-\delta_I)/(1-\delta_I\delta_F)$.

We present the properties of $h(k_1, k_2)$ and $f(k_1, k_2)$ in Lemma 2.

Lemma 2. $0 < f(k_1, k_2) < 1$ and $0 < h(k_1, k_2) < 1$.

To further simplify our analysis, we let $g(k_1, k_2, t) = h(k_1, k_2) + f(k_1, k_2)$. This should satisfy

$g(k_1,k_2,t)<\alpha$, and thus ensure that the service providers can obtain more profit when they contract with the intermediary. We present the property of $g(k_1,k_2,t)$ in Proposition 4.

Proposition 4. The monotonicity of $g(k_1,k_2,t)$ is as follows:

(i) When $0.25<k_1<0.5$ and $0.25<k_2<0.5$, $g(k_1,k_2,t)$ is increasing in k_i at first, and then decreasing.

(ii) When $0.25<k_1<0.5$, $k_2>0.5$ and $k_1+k_2>1$, $g(k_1,k_2,t)$ is decreasing in k_2, and increasing in k_1 at first, and then decreasing.

(iii) When $k_1>0.5$ and $k_2>0.5$, $g(k_1,k_2,t)$ has nothing to do with $k_i(i=1,2)$.

Proposition 4(i) shows the situation in which the capacities of the two service providers are relatively small. In this case, the service providers cannot satisfy all of the demand, and an increase in their capacities means that the profits they obtain will increase in both the single-channel case and the dual-channel case. At first, the profit obtained in the single-channel case increases faster than that in the dual-channel case, so it becomes less likely that the service providers will contract with the intermediary. Consequently, $g(k_1,k_2,t)$ is increasing in the capacity when capacity is relatively small. However, when the capacity reaches the critical point, the profit obtained in the dual-channel case increases faster than that obtained in the single-channel case, and so it becomes more likely that the service providers will contract with the intermediary. As a result, $g(k_1,k_2,t)$ is increasing in the capacity when the capacity is relatively large.

Proposition 4(ii) shows the situation in which the capacity of service provider 2 increases further, which means that there is surplus capacity after satisfying demand. Compared to Proposition 4(i), $g(k_1,k_2,t)$ is always decreasing in the service provider 2's capacity. This is because the service providers can obtain more profit in the dual-channel case, but are unable to obtain extra profit in the single-channel case. Thus, it is more likely that the service providers will contract with the intermediary following an increase in the capacity of service provider 2.

Proposition 4(iii) shows the situation in which the capacities of the two service providers are both relatively large, which means that both service providers have excess capacity after satisfying demand. In contrast to Propositions 4(i) and 4(ii), in this case $g(k_1, k_2, t)$ has nothing to do with capacity. This is because the capacity of the two service providers is sufficient to meet demand. Thus, any increase in capacity will have no effect on the service providers' strategic choices. Based on Proposition 4, we present the strategic choices of the service providers in Proposition 5.

Proposition 5. As the service providers' relative patience and capacity change, their strategic choices are as follows:

(i) When the relative patience of the service providers is relatively low, they should not contract with the intermediary.

(ii) When the relative patience of the service providers is relatively high, it is less likely that they will contract with an intermediary if their capacities become more asymmetric.

Whether the service providers should contract with the intermediary is affected not only by their relative patience but also by the asymmetry in their capacities. When the relative patience of the service providers is relatively low, they should not contract with the intermediary. This is because low relative patience in the Stackelberg bargaining game will cause the service providers to obtain less profit from the intermediary. Consequently, they will obtain less profit than in the single-channel case. In contrast, when the relative patience of the service providers is relatively high, they can obtain more profit from the intermediary. Consequently, the service providers can obtain more profit by contracting with the intermediary.

7. Conclusions

Opaque selling is one of the most recent and popular applications of O2O in the travel industry and has been extensively adopted by agent platforms such as Hotwire. Opaque selling is critically important in enabling service providers such as Home Inn, Hanting, Hilton and Sheraton to utilize excess capacity because it offers a new channel to reach potential customers. In contrast to previous studies that only investigated two service providers with the same capacity, we considered the case in which two service providers have different capacities. To the best of our knowledge, this is the first study to consider the effect of asymmetric capacities on the decision to form a contract between two collaborative service providers and an intermediary. At the same time, we considered the effect of the service providers' relative patience on the likelihood of forming a contract. We derived some important findings and managerial insights related to service providers' asymmetric capacities and their relative patience.

The decision on whether the service providers should contract with the intermediary is mostly affected by the degree of asymmetry in their capacities. We showed that the greater the asymmetry between the two service providers' capacities, the lower the likelihood that they will contract with the intermediary. That is because one service provider will obtain less profit if the service providers' capacities are more asymmetric. The service providers' strategic choice is also affected by their relative patience. When the service providers' relative patience is low, they will not contract with the intermediary. This implies that a low level of relative patience in the Stackelberg bargaining game will induce the service providers to obtain less profit from the intermediary. Nevertheless, when the relative patience of the service providers is high, it is less likely that they will contract with the intermediary if their capacities become more asymmetric.

There are several potential directions for future research into opaque selling in a dynamic environment. In many situations, the service providers dynamically allocate capacity to an intermediary based on the market they face. For example, a hotel needs to decide how many rooms it will allocate to the agent platform every day because demand is constantly changing. In addition, the situation should be examined from the perspective of the intermediary with a view to determining what kind of opaque selling strategy the intermediary should introduce. This would help the travel industry to take full advantage of the potential of opaque selling.

References

Anderson, C. K., X. Xie. 2014. Pricing and market segmentation using opaque selling mechanisms. European Journal of Operational Research 233(1) 263–272.

Binmore, K., A. Rubinstein, A. Wolinsky. 1986. Optimal pricing of seasonal products in the presence of forward looking consumers. Rand Journal of Economics 17(2) 176–188.

Cachon, G. P., A. G. Kök. 2010. Competing manufacturers in a retail supply chain: On contractual form and coordination. Management Science 56(3) 571–589.

Cai, G., X. Chao, J. Li. 2009. Optimal reserve prices in the name-your-own price auctions with bidding and channel options. Production and Operation Management 18(6) 653–671.

Cai, G., Y. Chen, C. Wu, L. Hsiao. 2013. Probabilistic selling, channel structure, and supplier competition. Decision Science 44(2) 267–296.

Chen, R. R., E. Gal-Or, P. Roma. 2014. Opaque distribution channels for competing service providers: Posted price vs. name-your-own-price mechanisms. Operations Research 62(4) 733–750.

Fay, S. 2008. Selling an opaque product through an intermediary: The case of disguising ones product. Journal of Retailing 84(1) 59–75.

Fay, S., J. Laran. 2009. Implications of expected changes in the sellers price in name-your-own-price auctions. Management Science 55(11) 1783–1796.

Fay, S., S. H. Lee. (2015). The role of customer expectations in name-your-own-price markets. Journal of Business Research 68(3) 675-683.

Fay, S., J. Xie, C. Feng. 2015. The effect of probabilistic selling on the optimal product mix. Journal of Retailing 91(3) 451–467.

Feng, B., W. Liu, Z. Mao. 2017. Expanding traditional channel to opaque selling channel for service providers. Available at SSRN: https://ssrn.com/abstract=2999031.

Feng, Q., L. X. Lu. 2012. The strategic perils of low cost outsourcing. Management Science 58(6) 1196–1210.

Geng, X. 2016. Opaque selling in congested systems. Operations Research Letters 44(6) 737-741.

Granados, N., K. Han, D. Zhang. 2017. Demand and Revenue Impacts of an Opaque Channel: Evidence from the Airline Industry. 10.1111/poms.12704.

Green, C. E., M. V. Lomanno. 2012. Distribution channel analysis: A guide for hotels. Tech. rep., The American Hotel & Lodging Association (AH&LA) and STR Special Report, Washington, DC.

Huang, X., G. Sošić, Kersten. 2014. Selling through priceline? On the impact of name-your-own price in competitive market.Working paper.

Jerath, K., S. Netessine, S. K. Veeraraghavan. 2010. Revenue management with strategic customers: Last-minute selling and opaque selling. Management Science 56(3) 430–448.

Jiang, Y. 2007. Price discrimination with opaque products. Journal of Revenue Pricing Management 6(2) 118–134.

Li, J., Q. Wang, H. Yan, S. X. Zhu. 2016. Optimal Remanufacturing and Pricing Strategies Under Name-Your-Own-Price Auctions and Stochastic Demand. Asia-Pacific Journal of Operational Research 33(01).

Liu, J., R. Dai, X. Wei, Y. Li. 2016. Information revelation and customer decision-making process of repeat-bidding name-your-own-price auction. decision support systems 46-55.

Shapiro, D., X. Shi. 2008. Market segmentation: The role of opaque travel agencies. Journal of Economics & Management Strategy 17(4) 803–837.

Smith, B. C., R. Darrow, J. Elieson, D. Gunther, B. V. Rao, F. Zouaoui. 2007. Travelocity becomes a travel retailer. Interfaces 37(1) 68–81.

Stoel, M. D., W. A. Muhanna. 2016. Online word of mouth: Implications for the name-your-own-price channel. decision support systems 37-47.

Wang, Q., J. Li, H. Yan, S. X Zhu. 2016. Optimal remanufacturing strategies in name-your-own-price auctions with limited capacity. International Journal of Production Economics, 113-129.

Wang, T., E. Gal-Or, R. Chatterjee. 2009. The name-your-own-price channel in the travel industry: An analytical exploration. Management Science 55(6) 968–979.

Working, H., H. Hotelling. 1929.Applications of the theory of error to the interpretation of trends. Journal of the American Statistical Association 24(165A) 73–85.

Xiao, S, M. Dong. 2015. Hidden semi-markov model-based reputation management system for online to offline (o2o) e-commerce markets. Decision Support Systems 77(C) 87–99.

Xie, X., R. Verma, C. K. Anderson. 2015. Demand Growth in Services: A Discrete Choice Analysis of Customer Preferences and Online Selling. Decision Sciences 47(3) 473-491.

Zhang, Z., K. Joseph, R. Subramaniam. 2015. Probabilistic selling in quality-differentiated markets. Management Science 61(8) 1959–1977.

Appendix

A. Proofs in the Single-Channel Case

A.1. Proof of Lemma 1

The optimal profit of the service providers is given by

$$\max_{0\le P_1,P_2\le 1} \pi_t = \min\{k_1, x_1, x_0\}P_1 + \min\{k_2, 1-x_2, 1-x_0\}P_2,$$

where $x_0 = 1/2 + (P_2 - P_1)/2t$, $x_1 = (1-P_1)/t$, $x_2 = 1-(1-P_2)/t$.

It is easy to show that $k_1P_1, x_1P_1, x_0P_1, k_2P_2, (1-x_2)P_2, (1-x_0)P_2$ are all concave in P_1 and P_2 because their Hessian matrixes are negative. Then, $\min\{k_1P_1, x_1P_1, x_0P_1\}$ and $\min\{k_2P_2, (1-x_2)P_2, (1-x_0)P_2\}$ are both concave in P_1 and P_2. Consequently, we can derive that $\pi_t = \min\{k_1, x_1, x_0\}P_1 + \min\{k_2, 1-x_2, 1-x_0\}P_2$ is concave. Thus, π_t is unimodal.

A.2. Proof of Proposition 1

We prove Proposition 1 in the following four situations.

(i) When $k_1 > 0.5$ and $k_2 > 0.5$, each service provider will have excess capacity because capacity exceeds demand. We assume that each service provider obtains half of the overall profit when capacity exceeds demand because any capacity in excess of demand is useless. The optimal profit is derived by $\pi^* = 1-0.5t$. Each service provider obtains profit $\pi^{i*} = 0.5(1-0.5t)$. The optimal solution is found in the middle position between service providers 1 and 2, thus the optimal pricing strategy is $P_i^* = 1-0.5t$.

(ii) When $0 < k_1 < 0.5$ and $0 < k_2 < 0.5$, capacity is less than the demand. The service providers have no excess capacity and there are customers who are unable to purchase the service. We assume that the profit of the service provider is based on its capacity. Thus, the optimal profit is given by $\pi^* = (1-k_1t)k_1 + (1-k_2t)k_2$, and hence the profit of service provider i is $\pi^{i*} = (1-k_it)k_1$. The optimal profit is found at the position where $x_1 = k_1$ and $x_2 = 1-k_2$, so the optimal pricing strategy is $P_i^* = 1-k_it$.

(iii) When $0 < k_1 < 0.5$, $0.5 < k_2$ and $k_1 + k_2 < 1$, capacity is less than the demand and service provider 2 has no excess capacity. The profit of the service provider is based on the capacity of the service provider, which means that the service provider obtains more profit the more it sells. Thus, the optimal profit is given by $\pi_t^* = (1-k_1 t)k_1 + 0.5(1-0.5t)$. Hence, the profit of service provider 1 is $\pi_t^{1*} = (1-k_1 t)k_1$ and the profit of service provider 2 is $\pi_t^{2*} = 0.5(1-0.5t)$. The optimal profit is obtained at the position where $x_1 = k_1$ and $x_2 = 0.5$, so the optimal pricing strategy is $P_1^* = 1-k_1 t, P_2^* = 1-0.5t$.

(iv) When $k_1 < 0.5, k_1 + k_2 > 1$, capacity is greater than the demand. Thus, the optimal profit is given by $\pi^* = (1-k_1 t)k_1 + 0.5(1-0.5t)$. The optimal profit is obtained at the position where $x_1 = k_1$ and $x_2 = 0.5$, so the optimal pricing strategy is $P_1^* = 1-k_1 t, P_2^* = 1-0.5t$.

In conclusion, the optimal profit is obtained at the position where $x_1 = \min\{0.5, k_1\}$ and $x_2 = 1 - \min\{0.5, k_2\}$, and the corresponding optimal pricing strategy of service provider i is $P_i^* = 1 - \min\{0.5, k_i\}t.$ The optimal overall profit is given by

$$\pi_t^* = (1-\min\{0.5,k_1\}t)\min\{0.5,k_1\} + (1-\min\{0.5,k_2\}t)\min\{0.5,k_2\}.$$

The optimal profit of service provider $i, i = 1,2$ is given by $\pi_t^{i*} = (1-\min\{0.5,k_i\}t)\min\{0.5,k_i\}$.

B. Proofs in the Dual-Channel Case

B.1. Proof of Proposition 2

(1) Before solving the model, we should judge whether the objective function is concave in P_1, P_2 and P_3.

Since the Hessian matrix $H_{\pi^{PP}} = \begin{pmatrix} -2/t & 0 & 2/t \\ 0 & -2/t & 2/t \\ 2/t & 2/t & -4/t \end{pmatrix} \le 0$,

π^{PP} is jointly concave for P_1, P_2 and P_3, which means that π^{PP} is unimodal.

Then, we are able to derive the derivatives of π^{PP} for P_1, P_2 and P_3 as follows:

$$\begin{cases} \dfrac{\partial \pi^{PP}}{\partial P_1} = \dfrac{0.5(t+4p_3-4p_1)}{t} \\ \dfrac{\partial \pi^{PP}}{\partial P_2} = \dfrac{0.5(t+4p_3-4p_2)}{t} \\ \dfrac{\partial \pi^{PP}}{\partial P_3} = -\dfrac{2(p_1+p_2-2p_3)}{t} > 0 \end{cases},$$

since π^{PP} is increasing in P_3. Since $0 \le P_3 \le 1-0.5t$, we have $P_3^* = 1-0.5t$.

Then, we can obtain the optimal prices $\begin{cases} P_1 = 1-0.25t \\ P_2 = 1-0.25t \\ P_3 = 1-0.5t \end{cases}$,

and the optimal profit is given by $\pi^{PP*} = (1-0.5t)0.5 + 0.5(1-0.25t) = 1-0.375t$.

The capacity allocated by service provider 1 to the intermediary is $n_1 = k_1 - 0.25$ and the capacity allocated by service provider 2 to the intermediary is $n_2 = k_2 - 0.25$. Since a service provider's profit comes from both its own channel and the intermediary, we are able to determine the profits of service providers 1 and 2.

The optimal profit of service provider 1 is $\pi_1^{PP*} = 0.5\alpha\beta(1-0.5t) + 0.25(1-0.25t)$, while the optimal profit of service provider 2 is $\pi_1^{PP*} = 0.5\alpha(1-\beta)(1-0.5t) + 0.25(1-0.25t)$.

After receiving its allocation from service providers 1 and 2, the intermediary will obtain a profit of $\pi_3^{PP*} = 0.5\alpha(1-0.5t)$.

(2) Similar to the previous analysis, before solving the model, it can easily be seen that the objective function is concave for P_1, P_2 and P_3.

Using a similar method to that used previously, the optimal profit is derived by $\pi^{PP*} = (1-0.5t)(k_1+k_2-0.5) + 0.5(1-0.25t)$.

The capacity allocated by service provider i to the intermediary is $n_i = k_i - 0.25$. The optimal profit for service provider 1 is $\pi_1^{PP*} = 0.5\alpha\beta(1-0.5t) + 0.25(1-0.25t)$, and that for service provider 2 is $\pi_1^{PP*} = 0.5\alpha(1-\beta)(1-0.5t) + 0.25(1-0.25t)$. The intermediary obtains profit $\pi_1^{PP*} = 0.5(1-\alpha)(1-0.5t)$.

B.2. Proof of Proposition 3

We use backward induction to solve the problem.

Firstly, solving the model in stage 2, we obtain

$$\alpha_I \ge \frac{\delta_F}{\omega_F(1-0.5t)(\min\{1, k_1+k_2\}-0.5)},$$

and the profit of the intermediary is given by

$$\omega_I(\omega_F) = (1-\alpha_I)(1-0.5t)(\min\{1, k_1+k_2\}-0.5).$$

Applying $\omega_I(\omega_F)$ to the model in stage 1, we obtain

$$\alpha_F \leq 1 - \frac{\delta_I}{\omega_I(\omega_F)(1-0.5t)(\min\{1, k_1+k_2\}-0.5)}.$$

After simplification, we derive the equilibrium solution as follows:

$$\alpha_F = (1-\delta_I)/(1-\delta_I\delta_F),$$

$$\omega_F = (1-0.5t)(\min\{1, k_1+k_2\}-0.5)(1-\delta_I)/(1-\delta_I\delta_F);$$

$$\alpha_I = \delta_F(1-\delta_I)/(1-\delta_I\delta_F),$$

$$\omega_I = (1-0.5t)(\min\{1, k_1+k_2\}-0.5)\delta_F(1-\delta_I)/(1-\delta_I\delta_F).$$

In conclusion, when the service provider decides to allocate proportion $\alpha = (1-\delta_I)/(1-\delta_I\delta_F)$, the intermediary will agree to the deal.

C. Proofs in the Comparison between the Single-Channel and Dual-Channel Cases

C.1. Proof of Lemma 2

Since $0.25(1-0.25t)$ is the profit of service providers 1 and 2 when one-quarter of the demand is met through the traditional channel and $\pi_i^{PP*}(i=1,2)$ is the optimal profit of service provider i when the capacity of both service providers is greater than one-quarter of the demand, it is obvious that $\pi_i^{PP*} \geq 0.25(1-0.25t)$. Then, $f(k_1,k_2)$ and $h(k_1,k_2)$ are both non-negative.

In addition, π^{PP*} represents the overall profit in the dual-channel case and π_t^* represents the profit of the service provider in the single-channel case, thus the former is larger than the latter. Then, we have

$$\begin{cases} (1-0.5t)(\min\{1, k_1+k_2\}-0.5) > (1-\min\{0.5, k_1\}t)\min\{0.5, k_1\} - 0.25(1-0.25t) \\ (1-0.5t)(\min\{1, k_1+k_2\}-0.5) > (1-\min\{0.5, k_2\}t)\min\{0.5, k_2\} - 0.25(1-0.25t) \end{cases}.$$

Thus, $f(k_1,k_2) < 1$ and $h(k_1,k_2) < 1$.

In conclusion, $0 < f(k_1,k_2) < 1$ and $0 < h(k_1,k_2) < 1$, thus Lemma 2 is proved.