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*Research Article*

# Using Distribution Alliance to Signal the Seller's Service Quality in Online Retailing Platforms

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Signal plays a significant role in the online retailing market, especially where the service quality of sellers is unobservable. In the current study, a game-theoretical model was formulated to help examine whether the new delivery service called distribution alliance in the electronic market can serve as a superior signal in revealing online seller's service quality. Our results showed that the certification accuracy and the application fee are closely related to the signaling effect of the distribution alliance. Specifically, we found a concrete analytical boundary where a certain high level of certification accuracy is required to guarantee the existence of market equilibrium, and a corresponding application fee can convoy the signal's effectiveness. In addition, the potential extensions and limitations of this research were also discussed.

## 1. Introduction

For nearly two decades, e-commerce has changed the landscape of retailing worldwide. On 03 May 2021, the United Nations Conference of Trade and Development (UNCTAD) released a report announcing the global online retailing sales rise from 16% of total retail sales in 2019 to 19% in 2020 driven by COVID-19, which equals 30% of global GDP in 2019 (1 UNCTAD, "Estimates of global e-commerce 2019 and preliminary assessment of COVID-19 impact on online retail 2020," https://unctad.org/node/32767, 2021-07-27). The development of online retailing platforms provides several opportunities for small businesses to establish online storefronts to capture more potential consumers [1]. In such a marketplace, the platforms sell not only their own products but also the web pages for other sellers (i.e., the contractual sellers) to peddle commodities. In fact, allowing contractual sellers to merchandise in an online platform creates significant uncertainty about the overall level of seller's service quality at the time of purchase [2]. To improve the situation where such uncertainty of the service quality might deteriorate consumer's shopping experience, the platform introduces the distribution alliance (DA), a platform-organized logistics service, to deliver merchandise to consumers for its contractual sellers.

DA is a logistics innovation to achieve economic efficiency in delivering products through flexible capacity, benefiting the online retailing platforms at both the strategic level and the operational level. In terms of the corporate strategy, DA is one of the tentative directions of green supply chain development where green production [3, 4], protection of the environment [5, 6], and recycling process [7, 8] are the common topics to follow up with the trend of sustainability [9]. It is a feasible solution for manufacturers and retailers to increase profits by improving service quality, reducing operational costs by covering the product returns, and performing environmental-friendly by adapting to the uncertainty in the demand side, simultaneously [10]. On the other hand, the operation mechanism of DA comes from inspirations of sharing economy, which is mainly based on a two-sided market structure. Online retailing platforms initiate and organize transportation resources by recruiting social capacity such as third-party logistics to provide delivery service between online sellers and consumers. For the delivery side, the platform posts recruitment conditions and the corresponding subsidy to attract full-time deliverers or some drivers preferring part-time tasks. For the user's side, DA is packaged as an optional delivery service, behind which is a well-integrated logistics and information flow from the platform, aiming to improve the consumer experience during the process from shopping to after-sales service [11]. Through DA, online sellers hope to collect more visits, and consumers are seeking better services, and all of these expectations ultimately conclude on whether DA can signal out the seller's private information on service quality. In this paper, we study how DA can signal the service quality of contractual sellers in the online retailing platform where consumers cannot directly identify the service quality before purchase.

We interpret service quality generally to the online seller's performance on providing after-sale support. Such performance is things like order fulfillment, logistics, and availability of after-sale service, which could be only revealed after purchase. As the storefronts share the platform's corporate image, this results in the fact that the contractual seller's service quality, in turn, would influence the platform's reputation [12] (e.g., consumers tend to expect "amazon-style" services from the contractual sellers on Amazon.com; once they experience inadequate services, they might blame it on Amazon). As a large number of literature have shown, the uncertainty caused by information asymmetry would drive some potential consumers out of the market and preclude any gain from transactions [2, 13, 14]. In addition, signals have proven to be significant to reduce information friction and help consumers learn the service quality in online retailing markets [15]; however, the current signaling strategies seem to lose efficacy in differentiating contractual seller's service quality due to the low cost of imitating the storefront setting and service descriptions from each other [16]. Therefore, the platform is using DA to differentiate its contractual sellers in their service quality. That is, what DA is trying to signal is the correspondence between the expected service quality and what is offered by the contractual sellers. The typical DA offers standard logistics service, including the details of order fulfillment and a guarantee of the delivery time. Accordingly, it requires that the sellers who intend to join DA should offer quality service at the level declared by the platform and pay a fee of application. Currently, DA has been operated by some giant online retailing platforms, such as the service of Amazon Flex called Fulfillment by Amazon (FBA), Walmart's Spark Delivery, and Alibaba's Cainiao Alliance.

Our objective is to show that DA can be a valuable signal to reveal the contractual seller's service quality. In the process, the critical issue we address is to find the market equilibrium where only the sellers with quality service will join DA. To better understand the signaling mechanism, we build a static signaling model to shape the utility of consumers and the expected profits of the sellers. On this basis, achieving such equilibrium is to determine the consumer's belief in sellers' service quality in DA and the seller's decision to apply for a given DA service. When the equilibrium is achieved, consumers believe that a separation exists among the contractual sellers where the sellers joining in DA will provide high-quality service. At the same time, those being left outside DA will offer low-quality service. Besides, the equilibrium should also be stable for any contractual seller, which indicates that each deviation of this separation turns out unprofitable. However, there exists the fact that high-quality sellers might be rejected by DA, or low-quality ones might be included in DA, which will hurt the seller's profit or compromise the consumer's perceived utility. Such misidentification might eventually lead to the DA breakdown and calls for advisable mechanisms to ensure DA functioning as a signal. The direct way to reduce misidentification is to improve the accuracy of certification. The certification accuracy refers to the probability of the platform accurately distinguishing whether the seller's service quality meets the requirements. For a given accuracy, if the certification is successful, sellers with good service quality will gain their due profit, while those with low-quality service will lose their application investment. On the contrary, if it failed, the high-quality sellers will gain nothing but bear the cost of providing quality service and applying for DA, while the low-quality ones will obtain speculative profits. It follows that the higher the accuracy is, the more the high-quality sellers prefer to join DA. As seen in practice, however, it is not easy to standardize the service quality, which makes it challenging to eliminate the misidentification. On this basis, if the application is at no cost, there will always be a part of low-quality sellers who can get positive net profits through speculation, indicating that DA is invalid as a signal. Therefore, the application fee is necessary to perfect the signaling effect of DA. The platform charges an application fee collected at the application time which is nonrefundable to each applied seller according to the certification accuracy announced by itself. Specifically, the application fee should at least keep the sellers with low service quality from profiting from pretending high-quality sellers and applying for DA; however, if the platform charges too much, DA will be abandoned as it prevents sellers from any gain in joining in DA.

Additionally, DA has the characteristic of being a signal. First, a seller joining in DA will obtain an easy-to-observe digital label that can be confidently judged by the market participants. This observability has been proved to be the essential condition of a signal in prior studies [2, 17]. Second, DA is operated by the platform, possessing the platform's reputation endorsement. When consumers are willing to purchase products on one platform, DA can inherit the consumers' trust [18]. In addition, when a seller applies for DA service, the platform must examine its service quality. Such service quality is set as the seller's private information in this study which needs to be signaled out. As [14] states that quality can be identified by a unique separating equilibrium under a certain certification accuracy (called reputation therein), it suggests that a separating equilibrium may exist when the pricing of DA is sufficient to benefit the high-quality sellers and discourage the low-quality sellers.

Some issues related to the market equilibrium where DA works effectively as a signal are also included. First, the platform's revenue should be taken seriously. Previous researches have shed much light on our investigation of platform profitability, including the construction of the platform's payoffs and the methods of equilibrium derivation. A profit function was used to characterize the platform's revenue in this paper, which is similar to those in most studies in the field of marketing and operational management. One recent example comes from [19], which proposed an optimal decision model with an objective function to maximize an enterprise's profit in a different context. The classical solution method in game theory (i.e., backward induction) was adopted to find the market equilibrium in this article, the guidance of which can be found in [20, 21], which provided standard game-theoretical analysis process in a business environment. In our scenario about DA, if the expected equilibrium is achieved, a set of combinations of application fee and certification accuracy will be generated, resulting in pricing issues. Therefore, it is of significant meaning, both theoretically and practically, to investigate the pricing strategies for providing DA service so that the platform can achieve optimal profits while driving DA to be an effective signal.

This study belongs to the literature on the signaling theory of service quality. Signaling theory provides a framework that explains how visible features are used to transfer limited quality information to promote an interaction [22]. In transaction-based relationships, signaling theory has been applied to distinguish the signals produced by the party with private information to reduce information asymmetry [23]. Consumers often lack information to accurately assess unfamiliar sellers' service quality before purchasing [16]. Therefore, they need signals to help identify the actual quality of sellers and their services. The standard to judge a signal's performance in reducing information asymmetry is to see whether it benefits good sellers while excluding poor sellers. That is, an efficient signal can lead to a separating equilibrium [24]. In contrast, a signal will lose efficacy when failing in separating the sellers [25]. In the current study, we concentrate on the DA's signaling effect in revealing the service quality of online contractual sellers, and the signaling theory provides an available method. Unlike most of the existing literature in this field, we characterize the payoffs of the game players by constructing profit functions instead of using the traditional utility functions, which makes it more intuitive to discuss the motivations of deviating the market equilibrium when considering distribution alliances. The pattern of profit-based modeling also helps business-level discussions and discover management insights. Besides, since the classical signal results from an observable effort made by players with private information, identifying DA—one service provided by a platform—as a signal is an innovative attempt of integrated applying of the signaling theory and secondary price discrimination in the theoretical field.

In e-commerce, signal theory can offer new insight for researches into seller's service quality [26]. Signals have been widely used to convey information about the quality of sellers and their services to consumers. The prior researches focused on the signaling effect of after-sales service [27, 28], brands [29–31], labels [17, 32], and return policies [33–35]. Specifically, the "touch and feel" experience is difficult to replicate online, creating uncertainty for consumers about seller quality and service quality [36, 37]. However, the lower entry cost in online markets and similar technology used in operating online shops have incurred additional uncertainty as the current signals become less costly to produce [16]. The service quality defined in this study is such a thing that is hard to perceive before purchasing and can be disclosure via a certain signal. Compared with the related researches, our study highlights the significant role of logistics service by concluding the signaling effect of DA, which contributes to both the fields of service quality and e-commerce. For service quality, the introduction of DA as a signal provides new operational guidance for sellers to differentiate their services. It also links the seller's selection of logistics service partners to its own service levels, providing a new path of interpretation to demonstrate online sellers' service quality. For literature about e-commerce, the results of the current paper could improve the operational efficiency of the online retailing marketplace in the practical context of developing the green supply chain, and the profitability of online platforms organizing DA was also discussed.

This study also contributes to the literature on parcel delivery systems. Nowadays, online retailing platforms are launching quality delivery services to improve consumer satisfaction [38], including establishing distribution alliances to deal with the "last mile" delivery. One of the first attempts to identify distribution alliances is [39] which investigates sufficient practical enterprises of distribution platforms. Then, a game-theoretic model aiming to analyze the operational mechanism of distribution alliance is proposed [40]. The results indicate that DA can play a role in pricing regulation and platform management. Following this stream, [10] presents a series of scenario-based pricing models for the platform to design pricing strategies, which complements and refines the existing researches about DA at the operational level. Compared to these researches, our paper explores the contribution of DA in reducing information asymmetry in online retailing marketplaces from the perspective of signaling effects, which enriches the content of platform operational strategies beyond pricing governance. In addition, it also confirms that DA can serve as an effective signal to convey the service quality of online sellers under certain conditions. Besides, it has been proved that consumers will feel more satisfied when offered quality delivery services [41, 42], which indicates that DA might obtain good responses from consumers.

In summary, this paper contributes to and extends the current literature in several ways. First, it extends the application of signaling theory by recognizing DA as a new signal in online retailing markets. Second, it develops a framework to help the platform make certification accuracy selection and pricing decisions. Third, we examine the signaling effect of DA, which shows the profitability of operating DA and the potential value of the platform's reputation. Finally, we make some comments on the platforms' and DA's operation.

We organize the remainder of this paper as follows. Section 2 introduces the methodology applied in this paper briefly and presents the model settings. Section 3 reports the principal results, and Section 4 states managerial implications and limitations of the current study. Section 5 concludes the paper. Some supplements are in the Appendix.

## 2. Methodology

This paper aims to formulate the decision problem of online retailing platforms that offer distribution alliance services using the mathematical modeling. The problem is described as a constrained extreme value model based on a game-theoretic framework. With concerns of examining the signaling effect, our mathematical model of the game-theoretic optimization problem includes formulas that also have been discussed in the signaling games. The equations describing prices and profits are set for helping find a purely strategic Nash equilibrium satisfying signaling constraints.

*2.1. The Service Quality.* We start by considering an online retailing platform operating the DA service, enabling the DA a monopoly position. Meanwhile, the platform is populated by many sellers and consumers, which creates a perfectly competitive market environment. To simplify the impact of returns on the seller's expected profit, our model setting on the product is according to [14], where the value of products to sellers is normalized to zero. Similarly, the value of the products themselves is assumed to be zero to help to concentrate on the seller's service quality. Then, the product's value to consumers depends on the seller's service quality $\theta \in \{\theta_b, \theta_g\}$, which is determined by sellers privately. For the same product, sellers can provide the service of low-quality $\theta_b$ at no cost, which is worth 0 for consumers. Alternatively, they can offer quality service worth 1 to consumers and bear an extra cost $\lambda$, which is set as the seller's private information to keep in line with the common knowledge. We refer to $\lambda$ as the "type" of the sellers and assume that $\lambda$ follows a uniform distribution on $[0, 1]$ to highlight their heterogeneity. Obviously, providing quality service is profitable for any seller, even if they differ in how costly they choose high quality. In a signaling theory framework, when the service quality is public information, the market turns to be full of high-quality sellers. Conversely, if service quality is private information, they have to abandon the potential profit and choose low quality irrespective of their cost. As a result, the information asymmetry obstructs the market efficiency, which calls for useful signals. This fact incentivizes us to investigate the signaling effect of DA.

*2.2. The Certification Processes.* When a seller applies for DA service, the platform should conduct a quality test on its service. As the Cainiao Alliance and Amazon have done in operation, if a seller is allowed to join DA, he will obtain an observed label as DA. By contrast, sellers who are not in DA can only provide third-party logistics delivery service, which might be marked as TP. Denote by $q$ the certification accuracy of DA, which refers to the probability that a seller's service quality is correctly recognized. This gives the following conditional distributions of the seller's service quality in DA:

$$\begin{aligned} \Pr(\mathrm{DA}|\theta_g) &= \Pr(\mathrm{TP}|\theta_b) = q, \\ \Pr(\mathrm{DA}|\theta_b) &= \Pr(\mathrm{TP}|\theta_g) = 1 - q. \end{aligned} \tag{1}$$

Besides, the platform charges an application fee $\phi$. In signaling theory, $\phi$ can be recognized as the signaling costs. As well as in practice, it is analogous to the idea of slotting fee or entry fee. We make two related assumptions on the application fee. First, we impose that the fee is only charged for sellers. This assumption catches the fact that most platforms provide free access to consumers to attract more users. That is, the consumers' decisions are only based on the expected value of products obtained in different delivery services. Second, in line with common practice, we assume that the fee should be paid upfront and not be refunded. This precludes the incentives for DA to conspire with sellers. Moreover, it increases the signaling cost and helps reduce the possibility that the seller with low quality sends a wrong signal.

*2.3. The Consumer Decision.* The consumers own a belief about the proportion of sellers with high service quality in DA. Denote by $\alpha$ this belief, and $\alpha$ can be verified in the market equilibrium. In such a market, the consumers can obtain products valued $\alpha * 1 + (1 - \alpha) * 0 = \alpha$ from the DA-labeled sellers and obtain zero when choosing the TP service. It indicates that consumers will choose DA as long as they have a positive belief in DA ($\alpha > 0$). We denote by $d \in \{0, 1\}$ the consumer's demand for DA, which is characterized by $\alpha$ such that

$$\begin{cases} d = 1, & \text{if } \alpha > 0, \\ d = 0, & \text{otherwise.} \end{cases} \tag{2}$$

*2.4. The Sequence of Events.* The game develops as follows:

(1) The platform publishes the application fee $\phi$ and claims the certification accuracy $q$.
(2) Privately, sellers learn their cost $\lambda$ and determine the service quality $\theta$.
(3) Sellers decide whether to join DA or not.
(4) If a seller applies for the DA service, the platform tests the seller's service quality with a certification accuracy $q$ and produces a label in {DA, TP} observable to all participants.
(5) Consumers purchase products.

The related notations are listed in Table 1.

## 3. Analysis and Results

We derive the equilibrium from studying how application fee and certification accuracy affect the decisions made by all the participants, as well as the platform's profit. The solving process draws upon a backward induction method. As discussed above, the consumers' issues are evident and brief.

Table 1: Notations used in the paper.

| Variables | Description |
|---|---|
| $\theta$ | The seller's service quality, $\theta \in \{\theta_b, \theta_g\}$ |
| $\lambda$ | The seller's extra cost for providing high service quality, $\lambda \in U[0,1]$ |
| $\overline{\lambda}$ | The amount of sellers applying for distribution alliance with high service quality |
| $q$ | The certification accuracy of the distribution alliance |
| $\Phi$ | The application fee for joining distribution alliance |
| $\alpha$ | The consumer's belief about the proportion of sellers with high service quality in distribution alliance |
| $d$ | The consumer's demand for distribution alliance |
| $\gamma$ | The fraction of sellers with low service quality who apply for distribution alliance |
| $D$ | The seller's demand for distribution alliance |
| $D_T$ | The total market demand for distribution alliance |
| $\pi$ | The platform's expected profit of operating distribution alliance |

Besides, the certification process requires no other decision. Therefore, we start with the sellers' movements.

*3.1. The Seller's Demand for DA.* A seller's decision on service quality and applying for DA can be jointly acquired in equilibrium. If the seller does not use DA service, he must choose low quality since providing quality service is both of high cost and unobservable. As a result, TP-labeled sellers can only price their products at zero. It suggests that sellers with high quality always prefer DA service and get expected profit $q - \lambda - \phi$ per product. Alternatively, sellers might try to cheat the certification system by applying DA with low quality. They certainly obtain zero when the actual quality is revealed. However, if it works, they may get the expected payoff $1 - q - \phi$ per product. Indeed, the seller can also stand away and get zero. To sum up, sellers will choose to provide high-quality service when and only when

$$q - \lambda - \phi \geq \max\{0,\ 1 - q - \phi\}. \tag{3}$$

Therefore, a critical value $\overline{\lambda}$ exists satisfying that below which each seller provides high service quality and prefers to join DA, while those above $\overline{\lambda}$ provide low service quality. Whether the sellers with poor service quality soliciting DA depends on their profitability. When $1 - q - \phi \geq 0$, they will adventure sending the fake signal to gain the speculative profit. In particular, these opportunistic sellers also contribute to the purchase of DA. To identify this demand, we denote by $\gamma$ the fraction of sellers with low service quality who apply for DA. $\gamma$ is determined by

$$\begin{cases} \gamma = 1, & \text{if } 1 - q - \phi \geq 0, \\ \gamma = 0, & \text{otherwise.} \end{cases} \tag{4}$$

Then, the sellers' demand for DA is

$$D = \overline{\lambda} + \gamma(1 - \overline{\lambda}). \tag{5}$$

By deriving the perfect Bayesian equilibrium, we obtain Propositions 1 and 2.

**Proposition 1.** *For any given certification accuracy $q \leq 1/2$, a unique perfect Bayesian equilibrium exists: (1) If $\phi \leq 1 - q$, then $\overline{\lambda} = 0$, $\gamma = 1$, and $D = 1$. (2) If $\phi > 1 - q$, then $\overline{\lambda} = 0$, $\gamma = 0$, and $D = 0$.*

Proposition 1 describes the perfect Bayesian equilibrium on the condition that the certification accuracy is low ( $q \leq 1/2$). It shows that when the application fee is pricey ($\phi > 1 - q$), there are no demands of sellers for the DA, which means that all kinds of sellers choose third-party logistics delivery services. By contrast, if the application for the DA is not costly ($\phi \leq 1 - q$), all sellers will burst in it ($D = 1$). From Proposition 1, we find that all sellers make the same choice between the DA and the TP according to whether the application fee is low or not if the certification accuracy of the DA is low. It means that the DA with a low certification accuracy fails as a signal in conveying service quality, which indicates the significance of the certification accuracy in operating the DA service.

**Proposition 2.** *For a given certification accuracy $q > 1/2$, a unique perfect Bayesian equilibrium exists: (1) If $\phi \leq 1 - q$, then $\overline{\lambda} = 2q - 1$, $\gamma = 1$, and $D = 1$. (2) If $1 - q < \phi < q$, then $\overline{\lambda} = q - \phi$, $\gamma = 0$, and $D = q - \phi$. (3) If $\phi \geq q$, then $\overline{\lambda} = 0$, $\gamma = 0$, and $D = 0$.*

Proposition 2 shows the perfect Bayesian equilibrium on the condition under a high-level certification accuracy ($q > 1/2$). When the certification fee for the DA is extremely high ($\phi \geq q$) or extremely low ($\phi \leq 1 - q$), all sellers will adopt the TP or the DA, which is similar to the situation with a low certification accuracy ($q \leq 1/2$) in Proposition 1. It is different from the situation above in that it is a market with a middle application fee for the DA, and some sellers prefer the DA while others the TP ($D = q - \phi$). In addition, sellers with low quality all abandon the DA ($\gamma = 0$). Therefore, we find that the DA serves as the signaling effect and can perfectly separate sellers with different service quality when the application fees of the DA are in the middle level ($1 - q < \phi < q$). However, the exorbitant and undervalued price will both lead to the emergence of pooling equilibrium and ruin the signaling effect of the DA. Then, we concern more about the existence of separating equilibrium, since it provides a possibility of the DA as an efficient signal. When the application fee is respectively high ($\phi > 1 - q$), sellers with low-quality service are excluded from applying the DA, since the higher cost ($\lambda > q - \phi$) precludes any gain from their speculation. Meanwhile, some high-quality sellers prefer the DA, and the number of those sellers declines with the increase in application fee. Particularly, as $\phi$ increases over $q$, all sellers stand away due to the costly application fees.

The main conclusions in Propositions 1 and 2 are illustrated in Figures 1 and 2. Figure 1 shows the participation of sellers under the given certification accuracy ($q$), which clearly presents that the eligible separation equilibrium exists when and only when $q > 1/2$ and $1 - q < \phi < q$. Meanwhile, Figure 2 is formulated in an operation-friendly way to recognize the seller's demand for DA in different situations. The existing equilibriums have been divided into four areas according to $q$ and $\phi$. Specifically, Area I refers to the equilibrium where all sellers choose to join DA and provide low service quality, Area II refers to the equilibrium where all sellers use TP service while providing low-quality service, and Area IV refers to the equilibrium where all sellers will apply for DA. Still, only some will choose good service, and Area III shows the separation equilibrium where sellers with high service quality join DA, while those with low quality choose TP.

*Proof of Propositions 1 and 2.* The perfect Bayesian equilibrium is characterized by $(\lambda, \gamma)$ such that

$$\bar{\lambda} = \max\{0, \min\{2q - 1, q - \phi\}\},$$
$$\begin{cases} \gamma = 1, & \text{if } 1 - q - \phi \geq 0, \\ \gamma = 0, & \text{otherwise.} \end{cases} \tag{6}$$

The consumer's belief about the proportion of sellers with high service quality in DA, $\alpha$, is given by

$$\alpha = \frac{\bar{\lambda}}{D}. \tag{7}$$

We find the equilibria by solving each candidate situation obtained from equation (6) and equation (7). When $0 > 2q - 1 > q - \phi$, it implies $\phi > (1 - q) > 1/2 > q$ and hence $\bar{\lambda} = \gamma = 0$. If $\bar{\lambda} = \gamma = 0$ satisfy the requirement of one equilibrium, then everyone gains nothing in such situation, and the profit from deviating to applying for DA is $q - \lambda - \phi$ if the seller chooses high-quality service and $1 - q - \phi$ if he chooses low-quality service. The seller with a quality service who gains most from deviating is the type $\lambda = 0$, and this seller will get a payoff $q - \phi < 0$. In contrast, a seller with low quality will get $1 - q - \phi < 0$ from deviating. That is, no profitable deviation exists. Therefore, $\bar{\lambda} = \gamma = 0$ can be one equilibrium if and only if $q < 1/2$. Then we get $D(\phi, q) = 0$, and $\alpha = 0$. That is, $\bar{\lambda} = 0$, $\gamma = 0$, $D = 0$, and $\alpha = 0$ might be part of the equilibrium. We examine 16 other situations following this method and summarize the equilibrium into Proposition 1 on the condition of $q \leq 1/2$. Similarly, Proposition 2 is shaped according to the constraint that $q > 1/2$. All the details are listed in Table 2. □

*3.2. The Total Demand for DA.* The priority in generating the pricing strategy of the application fees is to identify the total demand of DA. In each equilibrium, by examining consumer's belief about the proportion of sellers with high-quality service in DA, we obtain Proposition 3 to describe consumer's demand for DA. It is noteworthy that $\bar{\lambda}$ always performs zero in Proposition 1, suggesting a market without high-quality sellers. Therefore, we focus on the consumer's demand for DA when $q > 1/2$.

**Proposition 3.** *Given $q \leq 1/2$, the consumer's demand for DA is $d = 0$. Given $q > 1/2$, the consumer's demand for DA can be recognized as follows: (1) If $\phi \leq 1 - q$, then $\alpha = 2q - 1$, and $d = 1$. (2) If $1 - q < \phi < q$, then $\alpha = 1$, and $d = 1$. (3) If $\phi \geq q$, then $\alpha = 0$, and $d = 0$.*

Proposition 3 presents customers' demand for the DA under different situations. As shown in Figure 3, with the certification accuracy ($q$) and the application fee for the DA ($\phi$) varying, customers' beliefs for the proportion of high-quality sellers and the associating demand for DA are changing. When the certification accuracy is low ($q \leq 1/2$) or the application fee is very high ($\phi \geq q$), consumers believe there are no sellers with high service quality in DA; therefore, their demand for the DA turns to zero, as shown in Area I in Figure 3. If the certification accuracy is high ($q > 1/2$) and the application fee for the DA is moderate ($1 - q < \phi < q$), consumers believe that all sellers in the DA provide high-quality service ($\alpha = 1$). Then they all pursue the DA ($d = 1$), as shown Area II in Figure 3. As for the situation where the certification accuracy of the DA is high ($q > 1/2$) while the application fee is low ($\phi \leq 1 - q$), all consumers will choose DA ($d = 1$) even though only part of the sellers in DA might provide high service quality ($\alpha = 2q - 1$).

It is commonsense that consumers do not need the DA if its certification accuracy is low because they could not distinguish high-quality sellers from low-quality ones by the DA label. In addition, when the application fee for the DA is very high, no seller will apply for the DA, so that no consumer will need the DA service. When the DA could perfectly separate sellers with high-quality service and those with low-quality service, consumers certainly need the DA. It is surprising that although high-quality sellers cannot be perfectly distinguished from low-quality ones by the DA, consumers all prefer the DA. Because of the high certification accuracy, consumers give a high-level belief about the DA as a signal of a high-quality seller. Therefore, all consumers are willing to pay for the DA. From Proposition 3, we can find that the certification accuracy of the DA is crucial for consumers, and it largely determines whether consumers need the DA or not.

*Proof of Proposition 3.* The consumer's demand is described as $d = 1$ if $\alpha > 0$ and $d = 0$ in other situations. Combining this with the proof of Propositions 1 and 2, we can reformulate the conditions related to $\alpha$ with the expressions of $d$. Thus, the consumer's demand for DA can be presented as

$$\begin{cases} \text{if } \phi \leq 1 - q, & \text{then } d = 0, \\ \text{if } \phi > 1 - q, & \text{then } d = 0, \end{cases} \quad \text{when } q \leq 1/2,$$
$$\begin{cases} \text{if } \phi \leq 1 - q, & \text{then } d = 1, \\ \text{if } 1 - q < \phi < q, & \text{then } d = 1 \quad \text{when } q > 1/2. \\ \text{if } \phi \geq q, & \text{then } d = 0 \end{cases} \tag{8}$$

Then Proposition 3 is proved. □

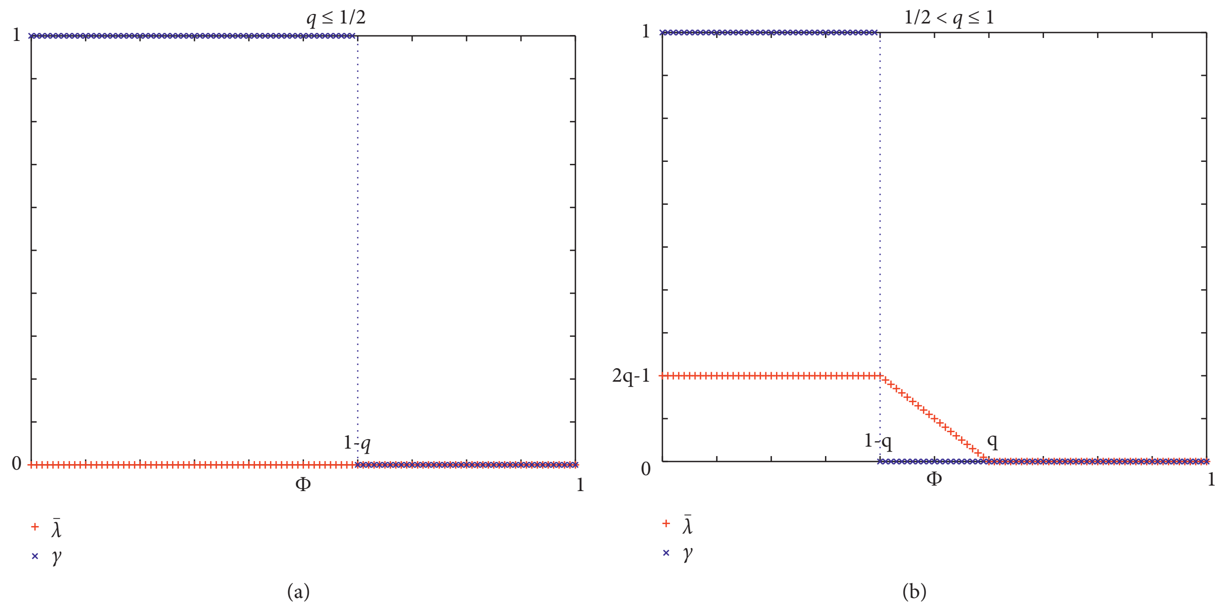


FIGURE 1: The impact of application fee on the participation of sellers under the given certification accuracy: (a) in the situation of $q = 0.4 \leq 1/2$; (b) in the situation of $1/2 < q = 0.6 \leq 1$.

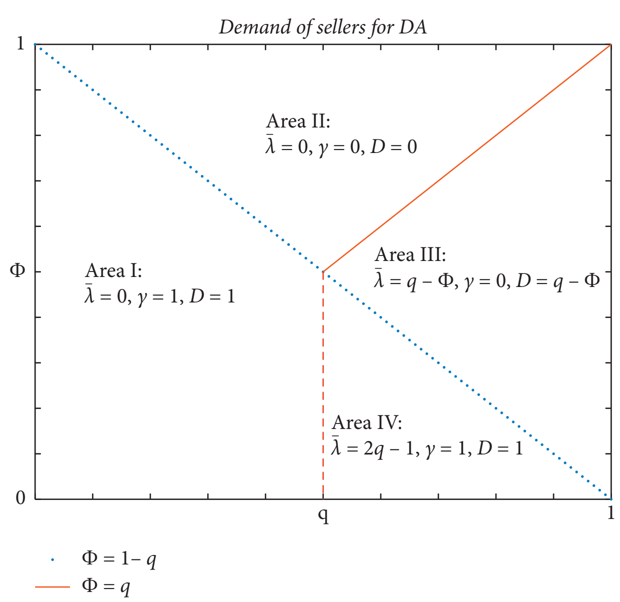


FIGURE 2: The impact of application fee and certification accuracy on the seller's demand for DA.

According to the seller's demand and consumer's demand for DA discussed above, we denote by $D_T = d \times D(\phi, q)$ the total demand for DA. The operational character $'' \times ''$ turns out $D_T = d * D(\phi, q)$ if and only if $d > 0, D(\phi, q) > 0$; otherwise, $D_T = 0$; and the total demand for DA then reads

$$D_T = \begin{cases} 1 & q > 1/2 \text{ and } \phi \leq 1 - q, \\ q - \phi & q > 1/2 \text{ and } 1 - q < \phi < q, \\ 0 & \text{otherwise.} \end{cases} \quad (9)$$

□

*3.3. Pricing of the Application Fee.* The expression of total demand for DA in equation (9) helps generate the expected profit of the platform operating DA. The profit function is presented as

$$\max \pi(\phi) = \phi D_T = \begin{cases} \phi & q > 1/2 \text{ and } \phi \leq 1 - q, \\ \phi(q - \phi) & q > 1/2 \text{ and } 1 - q < \phi < q, \\ 0 & \text{otherwise.} \end{cases} \quad (10)$$

Then we derive the optimal application fee via a standard method in the pricing decision. From equation (10), the expected profit of DA has the following properties:

(1) If $q > 1/2$ and $\phi \leq 1 - q$, a price increase raises the DA's profit, which indicates that $\phi = 1 - q$ might be a point to achieve the local maximum profit.

(2) If $q > 1/2$ and $1 - q < \phi < q$, a price increase decreases the total demand, which suggests the existence of $\phi^*$ to maximize the profit.

The local optimal solutions of the extremum problem in equation (10) are listed in Table 3.

We plot the optimal application fee, total market demand, and the platform's optimal profit in Figure 4 to visualize the effect of certification accuracy on such an optimal state. The decision space has been divided into four zones according to the range of $q$ and the constraints of $\phi$ in (a). The relationships between $\phi$ and $\pi$ are illustrated separately under different levels of $q$: (b) in the range of $1/2 < q \leq 2/3$; (c) in the range of $2/3 < q \leq 2\sqrt{2} - 2$; (d) in the range of $2\sqrt{2} - 2 < q \leq 1$.

It can be seen that the platform's decision on whether to launch DA service depends on its expected profits. According to the locally optimal results of equation (10), the maximum profit of DA can be rewritten as

Table 2: List of equilibria in all candidate situations.

| Situation | Condition | Equilibrium |
|---|---|---|
| $0 > 2q - 1 > q - \phi$ | $q < 1/2, q < (1-q) < \phi$ | $\overline{\lambda} = 0,\ \gamma = 0,\ D = 0,\ \alpha = 0$ |
| $0 > 2q - 1 = q - \phi$ | $q < 1/2, q < (1-q) < \phi$ | $\overline{\lambda} = 0, \gamma = 1,\ D = 1,\ \alpha = 0$ |
| $0 = 2q - 1 > q - \phi$ | $q < 1/2, q < (1-q) < \phi$ | $\overline{\lambda} = 0,\ \gamma = 0,\ D = 0,\ \alpha = 0$ |
| $0 = 2q - 1 = q - \phi$ | $q < 1/2, q < (1-q) < \phi$ | $\overline{\lambda} = 0, \gamma = 1,\ D = 1,\ \alpha = 0$ |
| $0 > q - \phi > 2q - 1$ | $q < 1/2,\ q < \phi < (1-q)$ | $\overline{\lambda} = 0, \gamma = 1,\ D = 1,\ \alpha = 0$ |
| $0 > q - \phi = 2q - 1$ | $q < 1/2,\ q < \phi < (1-q)$ | $\overline{\lambda} = 0, \gamma = 1,\ D = 1,\ \alpha = 0$ |
| $0 = q - \phi > 2q - 1$ | $q < 1/2,\ q < \phi < (1-q)$ | $\overline{\lambda} = 0, \gamma = 1,\ D = 1,\ \alpha = 0$ |
| $2q - 1 > 0 > q - \phi$ | $q > 1/2,\ (1-q) < q < \phi$ | $\overline{\lambda} = 0,\ \gamma = 0,\ D = 0,\ \alpha = 0$ |
| $2q - 1 > 0 = q - \phi$ | $q > 1/2,\ (1-q) < q < \phi$ | $\overline{\lambda} = 0,\ \gamma = 0,\ D = 0,\ \alpha = 0$ |
| $2q - 1 = 0 > q - \phi$ | $(q = 1/2,\ (1-q)) = q < \phi$ | $\overline{\lambda} = 0,\ \gamma = 0,\ D = 0,\ \alpha = 0$ |
| $2q - 1 > q - \phi > 0$ | $q > 1/2,\ (1-q) < q < \phi$ | $\overline{\lambda} = 0,\ \gamma = 0,\ D = 0,\ \alpha = 0$ |
| $2q - 1 > q - \phi = 0$ | $q > 1/2,\ (1-q) < q < \phi$ | $\overline{\lambda} = q - \phi,\ \gamma = 0,\ D = q - \phi,\ \alpha = 1$ |
| $2q - 1 = q - \phi > 0$ | $q > 1/2,\ (1-q) < q < \phi$ | $\overline{\lambda} = 0,\ \gamma = 0,\ D = 0,\ \alpha = 0$ |
| $q - \phi > 0 > 2q - 1$ | $q < 1/2, \phi < q < (1-q)$ | $\overline{\lambda} = 2q - 1,\ \gamma = 1,\ D = 1,\ \alpha = 2q - 1$ |
| $q - \phi > 0 = 2q - 1$ | $q < 1/2, \phi < q < (1-q)$ | $\overline{\lambda} = 0, \gamma = 1,\ D = 1,\ \alpha = 0$ |
| $q - \phi = 0 > 2q - 1$ | $q < 1/2, \phi < q < (1-q)$ | $\overline{\lambda} = 0, \gamma = 1,\ D = 1,\ \alpha = 0$ |
| $q - \phi > 2q - 1 > 0$ | $q > 1/2,\ \phi < (1-q) < q$ | $\overline{\lambda} = 2q - 1,\ \gamma = 1,\ D = 1,\ \alpha = 2q - 1$ |
| $q - \phi > 2q - 1 = 0$ | $q > 1/2,\ \phi < (1-q) < q$ | $\overline{\lambda} = 0, \gamma = 1,\ D = 1,\ \alpha = 0$ |
| $q - \phi = 2q - 1 > 0$ | $q > 1/2,\ \phi < (1-q) < q$ | $\overline{\lambda} = 2q - 1,\ \gamma = 1,\ D = 1,\ \alpha = 2q - 1$ |

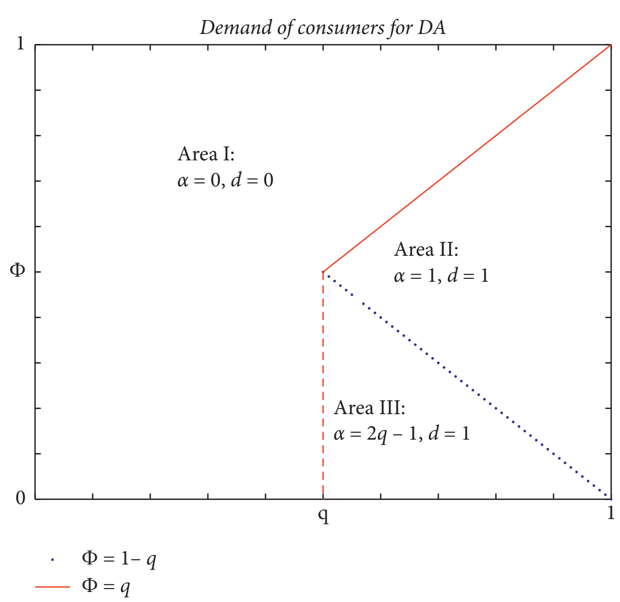


Figure 3: The impact of application fee and certification accuracy on the consumer's demand for DA.

$$\pi^*\left(\phi^*\right) = \phi^* D_T^* = \begin{cases} 1 - q & q > 1/2 \text{ and } \phi \leq 1 - q, \\ q^2/4 & q > 1/2 \text{ and } 1 - q < \phi < q, \\ 0 & \text{otherwise.} \end{cases} \tag{11}$$

By discussing the possible situations in equation (11), we summarize the global optimal pricing strategy of the application fee in Proposition 4.

**Proposition 4.** *The following pricing strategy ensures DA achieving the maximum profits: (1) If $q \in [0, 1/2]$, then $\phi^* = 0$, $D_T^* = 0$, and $\pi^* = 0$. (2) If $q \in (1/2, 2\sqrt{2} - 2]$, then $\phi^* = 1 - q$, $D_T^* = 1$, and $\pi^* = 1 - q$. (3) If $q \in (2\sqrt{2} - 2, 1]$, then $\phi^* = q/2$, $D_T^* = q/2$, and $\pi^* = q^2/4$.*

Proposition 4 shows the platform's optimal decisions and profits under different levels of certification accuracy of the DA. In line with Propositions 1 and 2, the low accuracy ($q \in [0, 1/2]$) demotivates sellers to provide quality service and shrinks the demand of DA ($D_T^* = 0$), which results in the incapacitation of the platform ($\pi^* = 0$). However, the increase of certification accuracy does not indicate that the DA can convey the information of service quality precisely. When the certification accuracy is not high enough ($q \in (1/2, 2\sqrt{2} - 2)$), the platform can obtain a certain profit by the DA ($\pi^* = 1 - q$), but it still hinders identifying the seller's types ($\gamma = 1$). Therefore, a more accurate certification process is required to guarantee that the DA works efficiently as a signal. We have proven that the high-level certification accuracy of the DA ($q \in (2\sqrt{2} - 2, 1]$) can help the platform get a sufficient signal ($\gamma = 0$) and the highest profits at the same time ($\pi^* = q^2 > 4 - 4q$).

The main results of Proposition 4 are illustrated in Figure 5.

In Figure 5, we present the optimal application fee for the DA, and corresponding demand and maximal profit vary with the certification accuracy ($q$). We can find that the platform can get the highest profit by pricing the DA application highly when the accuracy remains in a middle level. In addition, with a middle-level certification accuracy, the optimal application fee for the DA drops down with the increasing certification accuracy of the DA, as well as the optimal profit, while the demand remains at a high level ($D_T^* = 1$). However, when the accuracy reaches a pretty high level, the optimal application fee for the DA and corresponding demand and profit all improve with the increasing accuracy of the DA. It is interesting that, from Figure 5, we can see that a high-level certification accuracy does not mean a high profit for the platform. When the accuracy is very

Table 3: The local optimal application fee, total market demand, and profits under different levels of certification accuracy.

| | Constraints | The range of certification accuracy | | | |
|---|---|---|---|---|---|
| | | $q < 1/2$ | $1/2 < q \leq 2/3$ | $2/3 < q \leq 2\sqrt{2} - 2$ | $q \geq 2\sqrt{2} - 2$ |
| $\Phi^*$ | $\phi \leq 1 - q$ | 0 | $1 - q$ | $1 - q$ | $1 - q$ |
| | $1 - q < \phi < q$ | 0 | $1 - q$ | $q/2$ | $q/2$ |
| | $\phi \geq q$ | 0 | 0 | 0 | 0 |
| $D_T^*$ | $\phi \leq 1 - q$ | 0 | 1 | 1 | 1 |
| | $1 - q < \phi < q$ | 0 | $2q - 1$ | $q/2$ | $q/2$ |
| | $\phi \geq q$ | 0 | 0 | 0 | 0 |
| $\pi^*$ | $\phi \leq 1 - q$ | 0 | $1 - q$ | $1 - q$ | $1 - q$ |
| | $1 - q < \phi < q$ | 0 | $(1 - q)(2q - 1)$ | $q^2/4$ | $q^2/4$ |
| | $\phi \geq q$ | 0 | 0 | 0 | 0 |

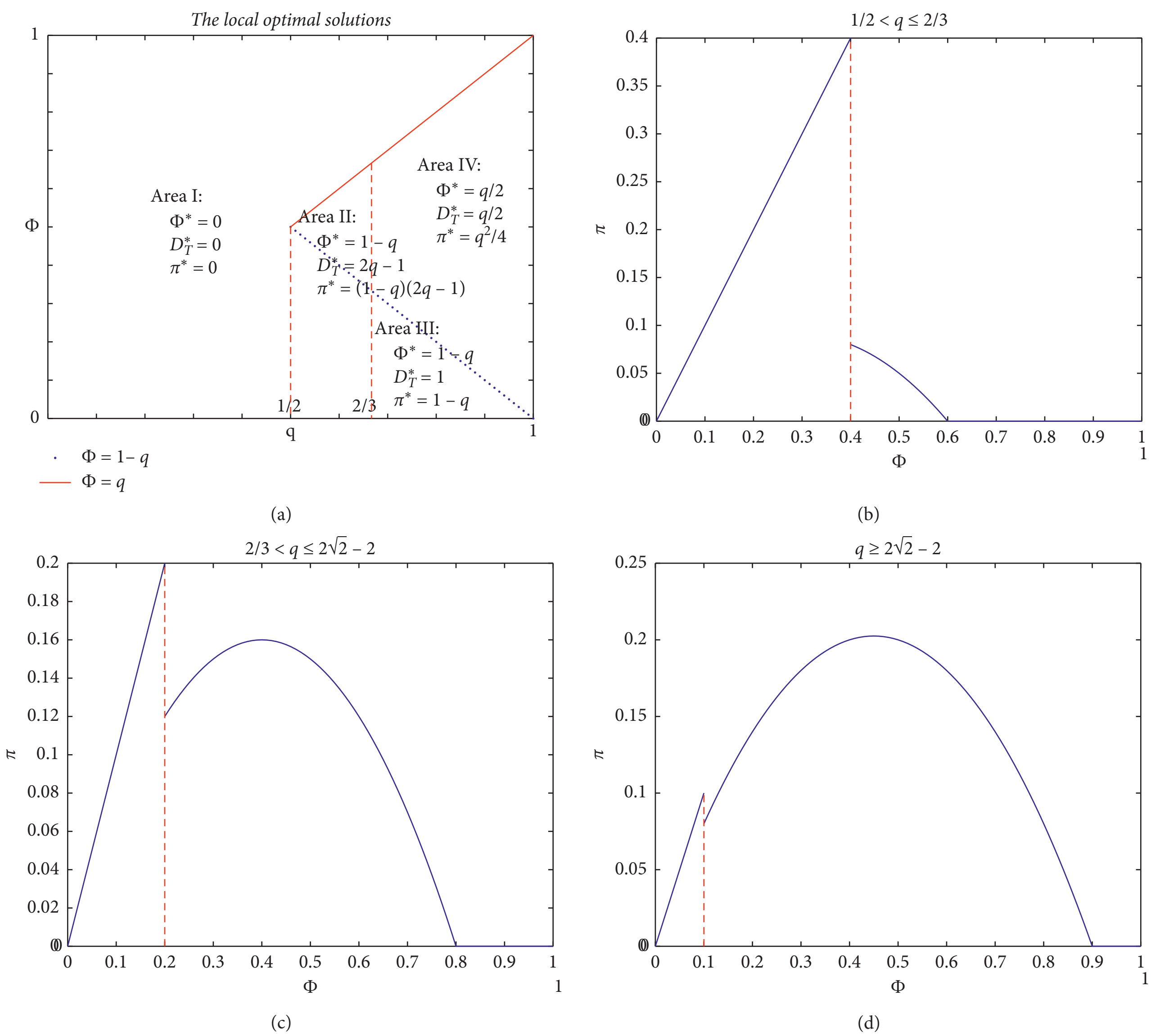


Figure 4: The local optimal solutions in different situations of certification accuracy: (a) details of decision space; (b) in the situation of $1/2 < q = 0.6 \leq 2/3$; (c) in the situation of $2/3 < q = 0.8 \leq 2\sqrt{2} - 2$; (d) in the situation of $2\sqrt{2} - 2 < q = 0.9 \leq 1$.

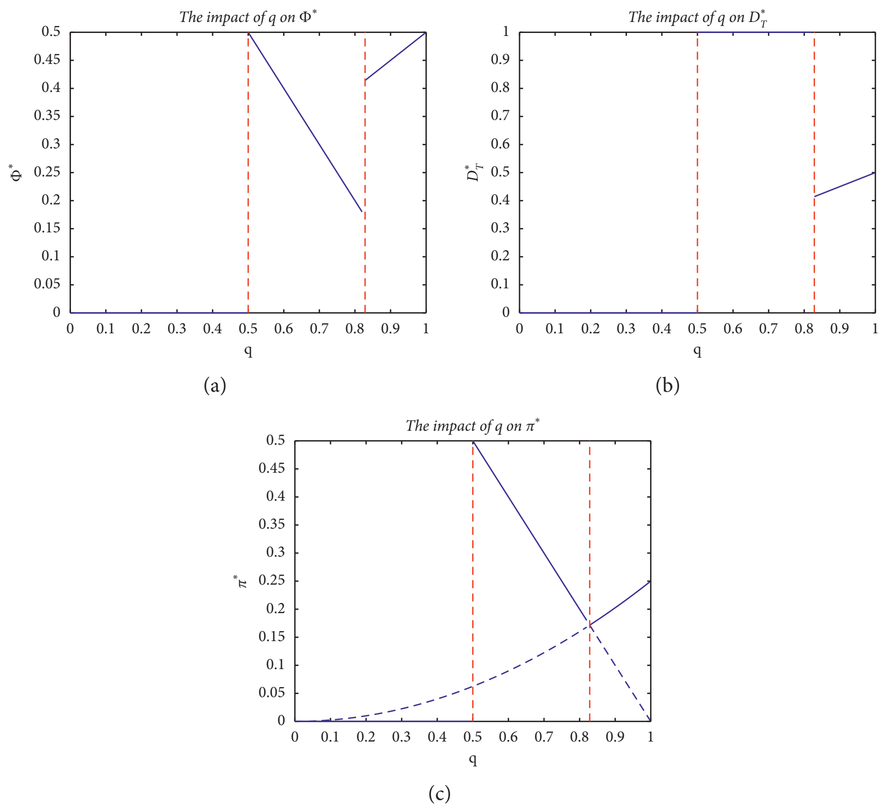


Figure 5: The impact of certification accuracy on (a) the global optimal application fee, (b) the total market demand, and (c) the platform's optimal profits.

high, the demand decrease results in the DA service being less profitable than that in a middle-level accuracy for the platform. This result clarifies the fact that not all sellers in DA provide high-quality service on a platform.

*Proof of Proposition 4.* When $q \in [0, 1/2]$, it is evident that $\pi^* = 0$ because there is no demand for DA. Assume that $f(q) = q^2/4 - (1-q)$. Let $f(q) = 0$. We obtain that $q = -2 - 2\sqrt{2}$ and $q = -2 + 2\sqrt{2}$. The former does not satisfy the set of $q$. Then, it shows that $q^2/4 \le (1-q)$ when $q \in (1/2, 2\sqrt{2} - 2]$, and $q^2/4 > (1-q)$ when $q \in (2\sqrt{2} - 2, 1]$. It suggests that the platform should price $\phi \le 1 - q$ when claiming $q \in (1/2, 2\sqrt{2} - 2]$, the optimal price is $\phi^* = 1 - q$, and the optimal profit is $\pi^* = 1 - q$. Alternatively, the platform can price $1 - q < \phi < q$ when claiming $q \in (2\sqrt{2} - 2, 1]$, and then the maximal profit $\pi^* = q^2/4$ can be reached at $\phi^* = q/2$.

Then Proposition 4 is proved. □

## 4. Discussion

*4.1. Managerial Implications.* This study provides both theoretical and practical contributions. In the academic aspect, the examination of DA's signaling effect can contribute to our understanding of how the platform's certification accuracy can influence both sellers' and consumers' participating in DA and inform us about the pricing strategies to regularize the DA's operation. In the practical aspect, our findings can help inform online enterprises (both sellers and platforms) about the effect of DA on the consumer's perceptions.

For platform enterprises, while it has been proven that DA can help consumers differentiate the service quality of sellers and improve the welfare of society, profitability is the primary concern to launch DA services. Therefore, our investigation has been devoted to showing that platforms can be profitable through DA for given different market equilibrium. From an operational viewpoint, if a platform plans to implement DA service, it still needs to accumulate enough sellers and consumers to maintain the user volume and reserve enough quality capacity resources to ensure that DA is competent. According to the network externality of the two-sided market structure, more consumers will attract more sellers and vice versa. When the delivery service is promoted, a new similar market structure led by DA emerges. In this marketplace, DA links high- quality-service sellers and delivery resources, and the numbers of such sellers and deliverers are in line with the basic law of network externality. Hence, more high-quality deliverers can bring more sellers with high service quality, which attracts more consumers; the new joining consumers can help the platform attract more high-quality sellers and then quality deliverers to join DA.

Besides the operational implications for online retailing platforms, there are still two issues that can be discussed in depth. The first one is how the platforms price DA service. Given that both sellers and consumers accept DA service, the platform should provide appropriate pricing contracts to promote the healthy development of the DA system. In practice, the platform generally charges only sellers and offers free options to consumers to maintain market share. Considering the context in which we are operating, things might change so that the platform should be charging consumers rather than sellers. As DA conveys private information about the service quality of sellers while providing new delivery service, it adds value to products sold on the platform, which allows for charging to the consumers. Meanwhile, the platform also has options to adopt types of pricing strategies for consumers, such as membership projects, transaction-based prices, or two-part tariff prices. The other issue that deserves to be discussed is how to regulate the pricing behavior of the platform to consolidate the target equilibrium. A separated equilibrium where DA can signal the different service quality sellers is expected. However, in our results, the platform seems to gain more profit in some other equilibriums. In order to prevent the platform from making undue profits at the expense of service quality, market oversights (i.e., reputational mechanisms) and government actions (i.e., regulatory mechanisms) should be introduced. As we state that DA possesses the platform's reputation endorsement, if the low precision cannot identify service quality but ensures the platform gets a certain potential profit, this might motivate the platform to deviate from its claimed certification accuracy, which results in a moral hazard. When it is true, the reputation mechanism is required to regulate the platform's operation. The reputation of the platform eventually turns out to be the signal, whose efficiency can only be examined via the proportion of quality sellers in DA. The regulatory mechanism operates on similar logic to the reputational mechanism, except that, at a technical level, it moves from a goal to be achieved by the platform to a constraint that must be obeyed.

For logistics service providers, how to develop a cooperation plan with the platform is the most significant issue. As a logistics manager, determining whether the signal of DA works efficiently is a priority, which could be guided by the current paper. The next step is how to allocate the available capacity resources to make the logistics enterprise operate most efficiently. Here we give three basic principles for participating in DA. First, distribution alliances that rely on the platform for customer acquisition can provide sufficient orders to ensure profitability; second, the profit level of participating in distribution alliances can cover the costs associated with developing new capacity resources (procurement costs, human resources costs, etc.); third, according to the daily situation, when the trucks are not fully loaded, they can take orders from distribution alliances to reduce the average cost. These three problems correspond to the market assessment problem, the return-on-investment problem, and the project selection problem which can be solved by referring to the literature and experience in related fields.

In addition, the methodology in this paper provides effective tools for examining new potential signals which can be explored further. For example, online reviews and repeat purchase rates are emerging as new factors influencing consumers' online purchasing behavior. Our approach should be evaluated further to determine whether they can serve as signals to convey private information about sellers and platforms and whether their signaling effects in an online marketplace can be validated.

*4.2. Limitations.* The first limitation of our model is the setting of the game period. The results of static gaming analysis can only present the short-term profits; that is, the platform obtains certain profit from the process of turning the distribution alliance into an adequate signal. When it comes to long-term consideration, the potential motivation of deviating from our target separation equilibrium appears due to the fact that the expected profits outside the equilibrium path are larger than the optimal ones in a period. Specifically, with the reputational concerns in a finite-stage repeated game, the platform might deviate the equilibrium via choosing a lower certification accuracy, and the corresponding application fee at the last stage (extremely like the situation where $q$ is slightly more than 1/2, $\phi^* = 1 - q$, $\pi^* = 1 - q$) or a new equilibrium will be found to guide the platform's decision. To overcome the limitations of the proposed model, we encourage future researchers to consider two-stage game-theoretical models and (or) infinite-horizon evolutionary gaming models, both of which will benefit understanding and analyzing the decision behaviors of platform firms in the medium-to-long term. Regardless of which recommended model is adapted, it is necessary to design a reputation mechanism for platforms which allows consumers and sellers to update their beliefs about the announced certification accuracy when joining DA as the game goes on. The key point of making DA a signal here is to introduce the unobservable effort invested by the platform in certification accuracy.

The other limitation of our model lies in the model setting about the cost. The cost of the certification process has been omitted for the purpose of simplification. The certification accuracy is assumed to be cost-free by now, which suggests that the platform can provide the highest precision, $q = 1$, to create a frictionless market where service quality is public information. In practice, it is rare because the platform should bear the related cost of quality detection. Our model can explain this situation to some extent. As presented in Proposition 2 that a more accurate certification is associated with a higher application fee, covering the cost of quality testing can be thought of. However, in other situations, this cost might grow even faster as the certification accuracy increases. We recommend an alternative method for future researches to catch this fact, in which a cost function in a quadratic form related to the certification accuracy is introduced (i.e., $c = kq^2$, where $c$ represents the cost of the certification process and $k$ is a parameter). The consideration of certification cost requires the platform to make decisions on $q$ and $\phi$ simultaneously, which increases the designing complexity of DA. In this situation, the market equilibrium in our model might be broken, and the platform must balance the certification cost and the expected profit in operating DA service.

Some other future directions of the current study are listed as follows. First, the signal design of DA could be more complex. For the concerns of abstract representation, only two levels of service quality, high and low, are presented in our model. In fact, when combined with other information, DA can signal more types of seller's service quality. For instance, a product on Amazon.com might be labeled as "sold by and ships from Amazon" or "ships from Amazon" or might have no label, which might help identify three kinds of sellers. Another similar example comes from Jingdong.com, one of the most popular e-commerce platforms in China, whose labels also include "sold by Jingdong," "only ships from Jingdong," and "sold by third-party sellers." Second, the applications of some studies in the field of certification can be introduced into the signaling mechanism of DA, such as credit ratings, scoring systems, and recommendation mechanisms.

## 5. Conclusions

In this study, we proposed a game-theoretical model to examine the signaling effect of DA in an online platform marketplace where online sellers have their private information on the service quality. Considering the operability of the potential results, we introduced profit functions to describe the game players' payoffs. In the discussed market equilibriums, the certification accuracy and application fees are two key factors influencing each participant's behavior. Theoretically, the certification accuracy should be set high enough to preclude sellers with low service quality from applying DA speculatively. Meanwhile, a proper setting of the application fee also ensures the validity of DA's signal effect; it should be neither too low to allow low-service-quality sellers to realize undue profits nor too high to prevent any gain from transactions. Based on the model settings, the boundary conditions of the target equilibrium have been presented in our results.

The major contribution of the paper is to launch a game-theoretical model to identify the signaling effect of distribution alliance. DA is a new and good innovation in logistics and e-commerce whose organizational characteristics make it a lubricant in the traditional supply chain structure. Meanwhile, DA becomes a signal conveying the service quality of online sellers and complements the existing signal theory and marketing theory, indicating that new signals belonging to the new consumption have emerged. In addition, the methodology in this paper can be applied to the identification of other potential signals in similar situations, which enriches the application scenarios of mathematical modeling method, signal theory, and game-theoretical methods.

We also recommended some directions for future researches. The current static finite-period game-theoretical model could be promoted to a dynamic infinite repeated gaming to help illustrate the platform's long-term decisions while considering a certification cost. Also, it could be developed in a complex situation where there are three or more types of sellers needed to be identified.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

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

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