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# Charging model of scientific and technological achievements transformation platform considering platform system attractiveness

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**Abstract** With the proliferation of the Internet, advancements in big data technology, and the widespread adoption of cloud computing, numerous digital trading platforms have emerged across various industries, revolutionizing the marketing of scientific and technological (S&T) achievements by enabling their listing as specialized commodities. Consequently, this has significantly accelerated the commercialization of S&T achievements, fostering a more efficient and dynamic market for technological innovation. In this paper, we construct a platform-based supply chain system consisting of the platform, S&T achievements providers, and demanders. The platform is considered to have two operation models, demand-side charging and supply-side charging, and the corresponding game-theoretic models are built based on them. We further compare the equilibrium results under the two charging

models. It was found that the platform's preference for the charging model is influenced by the value of the S&T achievements and the strength of the platform's attractiveness effect. Interestingly, providers of S&T achievements consistently prefer the demand-side charging model, as it allows them to achieve higher profits. In addition, the demand-side charging model is more profitable for the platform-based supply chain system. The research work enriches the operations management theory of digital platforms and guides the business practice of S&T achievements transformation platforms.

**Keywords** scientific and technological achievements, platform, charging model, attractiveness effect

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## 1 Introduction

In the era of the digital economy, many digital trading platforms have emerged, which have the characteristics of linking multilateral markets and benefit from the network effect to develop rapidly (Bonina et al., 2021). Among all kinds of digital trading platforms, the most representative is e-commerce, the head of the e-commerce platform enterprises such as Amazon, Alibaba, and eBay. These platforms primarily target the essential consumer needs related to daily living (Xiao et al., 2020), contracts and channels are the aspects of such platforms that have garnered significant attention from scholars (Gilbert et al., 2024). In addition, with the wide application of digital platforms, online peer-to-peer services based on digital platforms have given rise to service-sharing platforms in the past few years, which do not own the assets that serve as the basis for transactions but rely on individuals to provide them (Gerwe et al., 2022), such as Airbnb, Turo, and TaskRabbit. With the continuous growth of the industry and the underutilization of some assets, asset owners who previously had limited direct

communication with demanders began to join the platform (Chen et al., 2025). These platforms share a common feature of combining online searching and booking of a product or service with consumption in a brick-and-mortar store, also referred to as O2O (online-to-offline) e-commerce platforms (Wan and Chen, 2019). O2O platforms, seen as a new approach to innovation that may bring about major changes in many industries (Govindan and Malomfalean, 2019), seem to provide access to services or products for those who might not otherwise have access to them. For example, in terms of innovation, the target users of these platforms, although have not disappeared, the barrier to accessing the platforms seems to have been lowered, enabling them to achieve specific goals (Bonina et al., 2021).

In recent years, many digitalized service platforms for the transformation of scientific and technological (S&T) achievements have emerged in the field of S&T innovation (Song et al., 2023), such as Yet2.com. Especially in China, S&T innovation has been elevated to a pivotal national development strategy, with the country currently embarking on a comprehensive drive to promote initiatives such as “Innovation China” “InnoMatch” and “Zhong-guancun Technology Achievement Transformation and Technology Transaction”. Figure 1 shows the interface of the platform “Innovation China,” on which several technology demand projects have been released.

From a platform network perspective, the transformation of S&T achievements necessitates the collaborative participation of multiple stakeholders, thereby fostering a relational network. Still, the widely dispersed structural loopholes in this network separate the network members from each other, hindering the mobilization of knowledge (Liu, 2024), limited by the specificity of the transaction

object (i.e., S&T achievements), the platform’s difficulty in matching the supply and demand is more significant compared to common e-commerce and ride-sharing platforms. Specifically, users can be quickly matched to vehicles through the ride-sharing platform by formulating an order allocation strategy, and the demand is relatively easy to satisfy (Shi and Li, 2024). However, on the S&T achievements transformation service platform, it is not easy for the demand-side to find the required S&T achievements, which is caused by the complexity, technological nature, and the uncertainty of the transformation of S&T achievements. For instance, the supply-demand matching efficiency of the platform Keyi is only 28.99% (He et al., 2020). Therefore, the level of digital intelligence of the platforms becomes crucial, and the technological capability determines the competitive advantage of each platform. Superior technology enables the platforms to attract more users, thus forming a strong platform ecosystem (Jung et al., 2019). Relying on a higher level of digital intelligence, platforms can provide more comprehensive and timely information to the demand side and make the intangible technology solutions more three-dimensional, which helps to enhance the demander’s confidence in purchasing and improve the platform’s transaction success rate and satisfaction. Fig. 2 shows the online transaction process of the service platform for the transformation of S&T achievements.

Given the characteristics of the S&T achievements transformation platform, the issue of the platform’s fee-charging model has attracted the attention of this paper. In the practice of the technology brokerage industry, different charging models usually exist, mainly including two models of charging service fees to the S&T achievements demander and charging service fees to the S&T

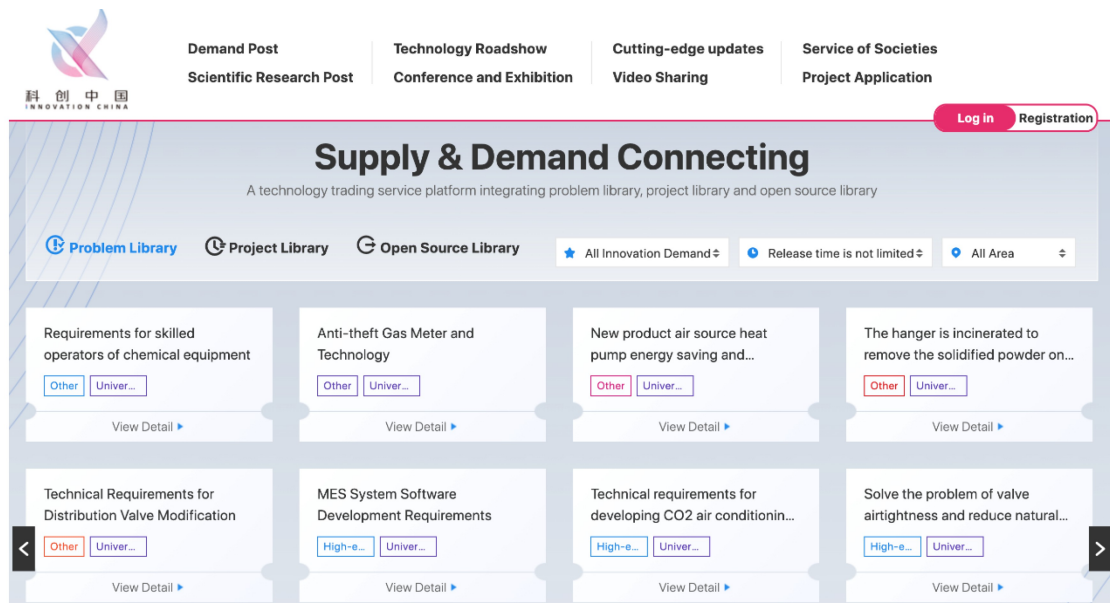


Fig. 1 The webpage of the platform “Innovation China”.

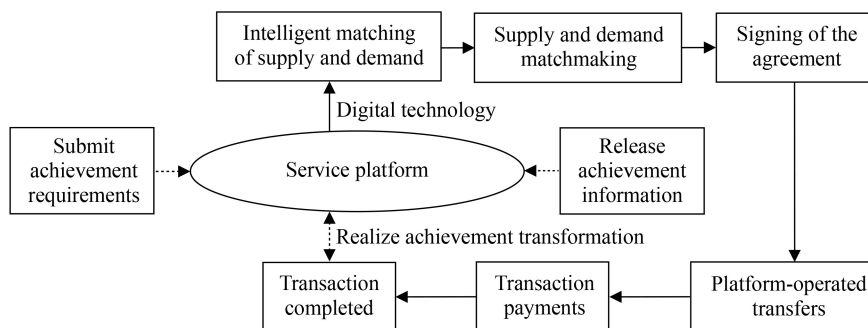


Fig. 2 The process of transaction for the S&T achievements transformation.

achievements provider. For example, in January 2022, the Guidance on Commission Charges for Technology Brokerage Services issued by Shanghai Municipality of China suggested that professional consulting services should be charged at around 1,000 RMB per session. Therefore, to solve the problem of choosing the charging model of the service platform for the transformation of S&T achievements, this paper defines the following two charging models according to “to whom to charge” and “how to charge”: (i) Demand-side charging model, that is, the platform charges the demand-side users a unit transaction service fee. (ii) Supply-side charging model, that is, the platform charges the S&T achievements providers a unit transaction service fee.

The main innovations and contributions of this paper are summarized as follows: (i) The concept of attractiveness is introduced to portray the platform system attractiveness. In a platform supply chain system, users will be attracted to more than one stakeholder group (Rossmannek et al., 2022). This paper considers two key stakeholders’ attractiveness, that is, the platform attractiveness and the provider attractiveness. In particular, platform attractiveness consists of lower prices and higher levels of digital intelligence, and provider attractiveness consists of lower prices and higher levels of offline supporting services. (ii) We express platform demand as a Cobb-Douglas form function of platform attractiveness, provider attractiveness, and platform scale. Furthermore, we analyze the demand scenarios under three platform charging models: demand-side charging, supply-side charging, and two-sided charging. This study identifies the dominant charging model scenarios for the S&T achievement transformation platform and derives the optimal operational strategies for the members of the platform system.

The remaining sections of the article are organized as follows. A review of related literature is discussed in Section 2, and the problem description and basic assumptions of the model in Section 3. In Section 4, the model is built and solved to obtain the equilibrium solutions. Results are discussed through the numerical illustration and sensitivity analysis in Section 5. In Section 6, the model of charging both the supply and demand sides of

the platform was expanded. Finally, Section 7 defines the main findings results, managerial insights, limitations, and guidelines for future research.

## 2 Literature review

This study adopts a game-theoretic model to solve the problem of the charging model of the S&T achievements transformation platform based on the attractiveness of the platform system. Furthermore, we aim to help platforms and S&T achievement providers formulate optimal pricing strategies and optimal supporting service strategies under two different charging models. The literature is comprehensively summarized in the subsequent subsections for clarity and ease of understanding.

### 2.1 Transformation of S&T achievements

Innovation is the first driving force of development, to enhance the power of industrial development, it is necessary to transform the S&T innovation achievements effectively (Cheng et al., 2020; Xu, 2022), and the transformation of S&T achievements is an effective combination of science and technology and the economy (Cheng et al., 2023), which has become an indispensable part of the national S&T innovation structure (Wang et al., 2024). However, in the process of transformation, there are problems such as difficulty in promoting information on S&T achievements, low trust between the two parties, and lack of corresponding service platforms, which has given rise to the research and development, and design of the S&T achievements transformation system covering the functions of user management and S&T achievements transaction (Song et al., 2023; Wang et al., 2024), which connects the bilateral market of supply and demand and matches services and transactions, effectively improving the transformation and enhancing the efficiency of S&T achievements (Song et al., 2023). As the main providers of S&T achievements, the transformation efficiency of S&T achievements of universities is positively correlated with the development of a low-carbon economy (Li and

Zhang, 2021) and correlated with the development of a regional economy (Cheng et al., 2023). However, some scholars have found that the overall level of transformation of S&T achievements of universities is at a medium level, especially in some colleges and universities located in economically underdeveloped regions (Li and Xu, 2022). There is still a lot of room for improvement in the transformation capacity of S&T achievements of universities (Wu and Chen, 2023). Except for Zhao and Ni (2024), who discuss the issue of pricing models for technology-trading platforms using a two-stage game model, little literature has focused on the operational model of the S&T achievements transformation service platform. This study considers a digital service platform connecting the supply and demand sides, this paper aims to decide on a dominant charging model for the platform, which can improve the efficiency of the transformation of S&T achievements.

## 2.2 Online-to-offline e-commerce

Online-to-offline (O2O) refers to a new type of e-commerce that combines online order acquisition and offline on-demand order fulfillment services (Dai et al., 2023; Tao et al., 2023), which is characterized by physical experience, integration of online and offline information (Yang et al., 2020), and resource sharing (Wan X et al., 2023), and has received great attention from both academia and practice. Research on O2O often focuses on the elements of product, price, and service, and the wholesale price and product design strategies of participants in an O2O supply chain are influenced by online consumer reviews (Li et al., 2021) and consumer reference effects (Ma et al., 2021). Appropriate service strategies can mitigate the competition between online and offline, retailers prefer to have full control and pay the full cost for their offline services (Amrouche et al., 2023), and retailers generally regard “buy online, pick up in store” (BOPS) services as an important omnichannel initiative (Song et al., 2020), and they encourage consumers to purchase products online and utilize offline channel services as sales aids to satisfy consumers’ experience utility (Ma et al., 2021), BOPS strategy has been widely used in a variety of contexts as it attracts both existing and potential customers, but it is not appropriate to introduce BOPS when service levels are high across all channels because when the cost of improving online service levels is high, the all channels will rather reduce the service level when BOPS is introduced (Fan et al., 2022), so there are researches focusing on the smart dual channel (online to offline) strategy in order for it to provide the most appropriate service to the customers (Choi et al., 2022). In the field of e-commerce, there have been a large number of research results on O2O, however, few studies on digital science and technology service platforms have

considered O2O. Based on the specificity of S&T achievements transactions, it is more important to highlight the O2O multi-channel integration. Therefore, this study considers integrating the S&T achievements transformation service platform into the O2O operational model, which has not been studied before.

## 2.3 Platform charging strategy

Platform charging decision is a fundamental issue that every platform must thoroughly address (Chen et al., 2022; Zhao and Ni, 2024), platforms connect supply-side and demand-side, and different platform charging strategies affect the behaviors of both supply-side and demand-side (Chen and Xu, 2024). Some platforms charge supply-side service fees (Zhang et al., 2019; Chen et al., 2020; Nie et al., 2022; Muthers and Wismer, 2022; Chen and Xu, 2024; Avinadav and Levy, 2025), and platforms offer two common charging models to the supply-side, one is revenue-sharing (i.e., commission charges), and the other is fixed-fee charges (Zhang et al., 2019), simulating the interaction between the three stakeholders and solving the problem of pricing strategy selection of the supply side (Nie et al., 2022), when the platform does not participate in the competition, designing a charging mechanism that includes a combination of fixed-fee and variable commission to the supply side can maximize the utility of the three parties (Chen et al., 2020). When the platform participates in the competition, charging the supply side a percentage of the commission can increase the attractiveness of the platform (Muthers and Wismer, 2022). Avinadav and Levy (2025) found that under circumstances where the platform holds an informational advantage, adopting a fixed-fee charging model for interactions is more beneficial than a commission-rate charging model. In addition, the quality of the product offered by the supply side and the market heterogeneity also affect the platform’s charging strategy choice (Chen and Xu, 2024).

Some platforms charge for the demand side (Chen et al., 2022; Mishra and Sarkar, 2023; Tang et al., 2023; Amaldoss et al., 2024; Li et al., 2023; Tan et al., 2024), and platforms can adopt either a uniform pricing strategy or a tiered pricing strategy for consumers (Amaldoss et al., 2024), when dual-platforms compete, the degree of cross-network effect and the degree of functionality matching of the free version affect the Nash equilibrium strategies of the two platforms, and if the platforms are in the early stage of development, they should prioritize the strategy of charging the demanders (Tang et al., 2023). In addition, under the service-oriented model of sharing economy platforms, there are mixed charging models such as on-time charging, monthly charging, and the coexistence of two charging methods, and there are optimal pricing strategies for all three charging methods that maximize the revenue of the enterprise (Tan et al., 2024).

In addition to the aforementioned charging models, there is also a platform, such as on-demand service platform, which adopts a business model of charging its customers of demand-side and paying wages to its independent service providers of supply-side (Taylor, 2018; Bai et al., 2019). Other platforms, such as rental platforms that charge both the supply side and the demand side. This platform needs to choose between supply-side charges and supply-demand charges (Wang et al., 2020), and in markets where demand-side competition is more intense than supply-side competition, the fixed-fee scheme generates the highest profits for the platforms, and conversely, in markets where supply-side competition is more intense, the dynamic commission rate scheme generates the highest profits (Zhang et al., 2022). Most of their research focuses on the diversity of platform charging schemes and lacks a direct comparison between the supply-side and demand-side charging models. This is the problem that this paper aims to solve, that is, the platform is guided to choose the dominant charging strategy after comparing two charging models.

#### 2.4 S&T platform supply chain

In recent years, although the issue of supply chain collaboration has seen improvement, the traditional supply chain environment has undergone significant changes (Kumar et al., 2023), and the digital network platform has also become a part of the supply chain decision-making, for example, analyze the relationship between the manufacturer and platforms cooperative decision-making problem (Yu et al., 2023). With the gradual development of digital commercial platforms, platform supply chain management has received extensive attention from scholars, and the issues that need to be solved in platform supply chains usually include pricing decisions, service decisions, data sharing decisions, contract management decisions, and so on. The decision-making problems of all parties in the platform supply chain, such as the big data discriminatory pricing problem of service platforms (Liu et al., 2021) and the user privacy data leakage problem (Arora and Jain, 2024) have repeatedly appeared in the platform supply chain, and how to effectively govern the platform supply chain has become an important research topic.

Typically, scholars researching the supply chains of goods or services-based platforms pay considerable attention to the platform's service investment strategies. This is because users can directly perceive the service level of the platform when they access it. Consequently, the service strategy represents one of the crucial decisions for the platform, exerting a significant impact on the platform's profit (Zhang et al., 2021). Some scholars also focus on the decision-making behaviors of retailers on the platform. They hold the view that online sellers

should not be confined to selling on the platform alone, but should also set up physical retail stores offline (Jin et al., 2022). In addition, issues such as the platform's advertising strategy (Gal-Or et al., 2018), green strategy (Du et al., 2019), contract management (Zhang et al., 2022), and platform competition (Cohen and Zhang, 2022) are also topics of great concern in the field of platform supply chain.

Distinct from the relatively well-studied platform supply chain for goods (services), this paper considers the S&T achievement transformation platform. The most significant difference of this platform lies in the particularity of its trading objects, namely S&T achievements. After a transaction of S&T achievements is concluded on the platform, the providers of these achievements need to offer offline technical guidance to the demand-side of the achievements, supporting the demand-side to complete the industrial transformation of the achievements. This implies that the level of offline supporting services provided by the S&T achievements providers (not the platform) is one of the important variables influencing the transaction. Precisely based on this, in the process of constructing the model, this study regards the level of offline supporting services as a decision-making variable for the providers, which will affect demand, the decision-making of members in the S&T platform supply chain, and their profits.

#### 2.5 Research gaps

Some of the literature discussed above studies the design and development of the service platform system for the transformation of S&T achievements and the relationship between economic growth and the transformation of S&T achievements. The perspective focuses more on the S&T achievements providers, with few studies on the demand side of S&T achievements and the operational models of the S&T achievements transformation platform. Some other literature has analyzed the dual-channel decision-making of O2O platforms (e.g., Fan et al., 2022; He et al., 2021; Du et al., 2023), but the types of platforms are limited to shopping, traveling, or catering industries, etc., and the O2O decision-making of S&T achievement transformation platforms has not been discussed. There is also some literature discusses the charging strategy of platforms, either supply-side charging or demand-side charging, and solves the problem of quality, service, or pricing strategy of supply-side or demand-side charging under different charging schemes, but it does not take into account the platform's pricing decision or service decision, and does not consider the decision of S&T achievements transformation platforms (e.g., Zhang et al., 2019; Nie et al., 2022; Chen and Xu, 2024). Many of these studies use game theory to solve the problem of coordinating the strategies of the platform parties, but

none of them constructs a model by considering the platform's technological capability or the level of digitization as a demand-influencing factor (e.g., Cohen and Zhang, 2022; Zhang et al., 2022).

In addition, the network effect is an important manifestation of the characteristics of platform bilateral markets (Armstrong, 2006; Rochet and Tirole, 2006), the existence of the network effect has a greater impact on the operational decisions of platform-based enterprises. Scholars in the field of platform-based operations management usually take network effects as one of the important research elements, e.g., Zhang et al. (2022), Cohen and Zhang (2022), Zhao and Ni (2024). Of course, some scholars ignore network effects (e.g., literature 1 to 7 in Table 1), and this paper is consistent with most platform research literature and considers the network effect in the model settings. Table 1 shows the comparative differences between the research of this paper and some other related studies. It is worth mentioning that only the study of Zhao and Ni (2024) belongs to the same category as the research object of this paper, both of which are centered on the service platform of S&T achievements, they focus on the optimal pricing problem for platforms with different operating models, while this paper aims to address the question of at which end of the market a platform should charge.

To summarize, the contribution of this paper to the literature in this field lies in: (i) Regarding the research object, we expand the research object in the field of platform operation and supply chain management to the S&T achievement transformation service platform; (ii) Regarding the platform charging model, we clarify the advantages and disadvantages of the demand-side charging and supply-side charging strategies; (iii) Regarding the research method, we adopt the classic leader-follower game theory, innovatively characterizes attractiveness functions of the platform and its system, and thereby derives the Cobb-Douglas form of the demand function,

which provides a reference for related research.

### 3 Problem description and basic assumptions

#### 3.1 The platform

Consider a digitalized S&T achievements transformation service platform, which provides online S&T achievements transfer and transaction services for S&T achievements providers and demanders (also referred to as demand-side users), to solve the contradiction between the supply and demand of S&T achievements, such as patented technologies, and to assist in the application of S&T achievements for commercial transfer and transformation. There is a total of  $n$  S&T achievements providers on the platform,  $n \geq 2$ ; for example, more than 10,000 S&T achievements are published on the platform "Zhongguancun Technology Achievement Transformation and Technology Transaction," which can be regarded as the number of providers on the platform. The platform and the  $n$  providers together form a platform supply chain system. The platform supply chain system relies on stakeholders to create value together, and its attractiveness needs to be shaped by the platform and the providers together.

There are two options for the platform's charging model  $j \in \{DM, SM\}$ . One is the demand-side charging model ( $j = DM$ ): the platform charges the demander a unit transaction fee  $P$ , and the other is the supply-side charging model ( $j = SM$ ): the platform charges the provider a unit transaction fee  $W$ . The type of charging model a platform operates with is its important business model, and this paper aims to study and solve the problem of choosing the charging model of the platform. It should be noted that for demanders, different charging models will lead to differences in the attractiveness of the platform, such that  $A^j$  denotes the attractiveness of the platform

**Table 1** Literature comparison

Literature	Types of platforms	Factors of influencing demand	Efforts of followers	Channel structure	Whether to consider network effects
Zhang et al. (2019)	Shopping Platform	Price + Quality	Product quality	Online	No
Ji et al. (2022)	Shopping Platform	Price + Quality + Socialization	Product quality	Online	No
Fan et al. (2022)	Shopping Platform	Price + Service	No followers	Online + Offline	No
He et al. (2021)	Shopping Platform	Price + Delivery fee	No additional effort	Online + Offline	No
Du et al. (2023)	Takeaway platform	Price + Delivery fee + Delivery service level	No additional effort	Online + Offline	No
Chen and Xu (2024)	Shopping Platform	Price + Quality	No additional effort	Online	No
Zhang et al. (2022)	Sharing platform	Price	No additional effort	Online + Offline	Yes
Cohen and Zhang (2022)	Sharing platform	Price + Quality	No additional effort	Online + Offline	Yes
Zhao and Ni (2024)	Technology-trading platform	Transaction fee + Registration fee	No additional effort	Online	Yes
Our paper	S&T achievements transformation platform	Level of digitization + Price + Service + Scale	Offline Supporting Services	Online + Offline	Yes

under the  $j$  charging model, and thus the attractiveness of the platform under the demand-side charging model can be denoted as  $A^{DM} = TP^{-\sigma}$ , which is determined by the platform's level of digitization  $T$  (which influences the efficiency of supply–demand matching), and the platform's charge to the demander  $P$ , where  $\sigma$  is the corresponding price elasticity; however, in the supply-side charging model, since the platform does not charge fees at the demand-side, the platform attractiveness in this model is directly expressed as  $A^{SM} = T$ , which means that the strength of the platform attractiveness at this time depends entirely on its digitization level  $T$ . In addition,  $C$  denotes the unit service operation cost of the platform and  $\pi_p^j$  denotes the profit of the platform. Note that here we consider cost  $C$  as the average unit cost.

### 3.2 The S&T achievements provider

The attractiveness  $a_i^j$  of provider  $i$  ( $i = 1, 2, \dots, n$ ) is expressed as  $a_i^j = s_i^j p_i^{-\delta}$ , where  $s_i^j$  is the offline supporting service level of the provider's S&T achievements transformation. Due to the special nature of the service and transaction content, the S&T achievements transformation platform is different from the general online shopping platform. It is difficult to facilitate the supply and demand sides to reach a deal just by displaying the information related to the S&T achievements online. It is often necessary to have further consultation offline and provide related technical support. Therefore, for the transformation of S&T achievements such as special commercial transactions, the level of offline supporting services given by the provider plays an important role in attracting demanders, because professional technical capabilities will have a direct impact on the efficiency and effectiveness of the transfer and transformation of S&T achievements (He et al., 2020). Specifically, when the demander conducts technology transactions online, he often encounters technical problems in the process of industrial transformation, and then the provider must give the demander relevant technical guidance and other supporting services offline to help the demander better apply the technology to realize the industrial transformation of S&T achievements. In short, the level of supporting services  $s_i^j$  provided by the provider is another important factor in addition to price. In the traditional e-commerce field, this model is called “order online, service offline” new retail. In the ride-sourcing market, it is similar to the quality of service provided by drivers to passengers (Li et al., 2022). According to Li et al. (2022), drivers' service quality is modeled as a random variable that follows a uniform distribution, capturing the variability in service outcomes within ride-sourcing platforms. In contrast, this paper treats offline supporting service quality as a decision variable controlled by S&T achievement providers, reflecting their strategic choices in optimizing service levels. In addition,  $p_i$  is the market price of the transformation of

S&T achievements. It should be noted that, unlike the reselling e-commerce platform, the S&T achievements transformation platform does not hold the pricing right of transformation of S&T achievements, and in reality, the market price of transformation is often negotiated between the provider and the demander, therefore, considering the importance of focusing on the platform's charging model, we set the market price  $p_i$  as an exogenous variable here.

Many studies have emphasized the role of the price factor in the bilateral market of platforms, and the coordination of bilateral users through price to solve the problem of “the chicken lays the egg and the egg lays the chicken” (Xie et al., 2021; Panico and Cennamo, 2022). Instead of focusing on the resource price, this paper emphasizes the operational decision of the provider's offline support services. The provider can decide the optimal level of supporting services by investing in its services, such as strategically investing in the hiring of science and technology specialists, personnel training, and the construction of its service system, in order to implement the most advantageous service strategy. When provider  $i$  decides to provide the supporting service level  $s_i^j$ , it needs to pay

the investment cost  $I(s_i^j) = \frac{h(s_i^j)^2}{2}$ , for example, deploying sufficiently experienced technical personnel (Musalem et al., 2023), and this investment cost function is widely used in the field of operations management research (Raj et al., 2021; Yu et al., 2023; Kumar et al., 2023). In addition, the attractiveness of the overall provider on the platform  $a^j$  is denoted as the sum of the attractiveness of all providers, i.e.,  $a^j = \sum_{i=1}^n a_i^j = \sum_{i=1}^n s_i^j p_i^{-\delta}$ . Note that, compared with traditional e-commerce platforms that sell daily consumer goods, the trading objects of S&T achievement transformation platforms, namely S&T achievements, possess a high degree of uniqueness. This can be manifested in the fact that they often hold technical patents, and there are significant technological differences among different achievements. In other words, the heterogeneous characteristics are remarkably prominent. Therefore, the overall attractiveness of providers on the platform will increase as the attractiveness of each provider strengthens. Let  $\pi_i^j$  denote the profit of provider  $i$ .

### 3.3 The demand

Denoting the demand  $D^j$  for S&T achievements (i.e., platform transaction volume) as  $D^j = (A^j)^\alpha (a^j)^\beta n^\gamma$  implies that there is a complementarity between the platform attractiveness  $A^j$ , the overall provider attractiveness on the platform  $a^j$ , and the number of providers  $n$ . Note that the functional expression is a standard Cobb-Douglas form. This function implies a constant elasticity of substitution between the different factors influencing demand. In our case, it indicates that as the platform

works on enhancing its attractiveness (through a higher level of digitization, etc.), or as the S&T achievement providers improve their attractiveness (by offering high-quality offline supporting services), or as the platform scale expands (launch more S&T achievements), the substitution among these factors in influencing demand remains consistent. The parameter  $\alpha$  indicates the importance of the demander's purchasing behavior attributed to the platform attractiveness, and a larger value of  $\alpha$  implies a greater intensity of the platform attractiveness effect; the parameters  $\beta$  and  $\gamma$  portray the intensity of the provider attractiveness effect and the provider scale effect, respectively. The substitution among these factors in influencing demand remains consistent. For example, if the platform invests in improving its attractiveness, the change in demand due to this improvement will interact with the other two factors in a way that is predictable based on the parameters  $\alpha$ ,  $\beta$ , and  $\gamma$ . Since the overall provider attractiveness  $a^j$  contains the number of providers, based on the microeconomics theory, it is determined whether there are increasing or decreasing returns to scale based on whether  $\beta + \gamma$  is greater than 1. In the digital platform scenario, this paper interprets these two parameters as important and specific economic meanings, that is,  $\beta + \gamma$  is less than 1 indicating that the platform exhibits a weakened network effect, and  $\beta + \gamma$  is greater than 1 indicating that the platform has a strengthened network effect. It is important to note that Panico and Cennamo (2022) argue that the marginal utility of demanders is decreasing as they get cheaper products and better services. Therefore, this paper considers demand  $D^j$  as a monotonically increasing concave function with respect to  $a^j$ , which implies  $\beta \in (0, 1)$ . In addition, this paper considers  $\alpha\sigma > 1$  and  $\beta\delta > 1$ , that is, the case where the price elasticity is greater than 1, in which the game model is guaranteed to have interior point solutions.

Drawing on the idea in the theory of attractiveness first proposed by Bell et al. (1975) that the market share of a resource provider within a platform is determined by the magnitude of its attractiveness relative to the attractiveness of the providers within the platform as a whole, the market share of each provider  $q_i^j$  is denoted as  $q_i^j = \frac{a_i^j}{a^j}$  in this paper.

### 3.4 The sequence of decision-making

The platform constructed in this paper acts as the leader in the game, while the providers act as the followers. Essentially, this belongs to a Stackelberg game, and the decision-making sequence of this game is shown in Fig. 3. In Stage 0, the platform needs to choose between demand-side charging model and supply-side charging model. (i) If the platform chooses demand-side charging model, then in Stage 1, the platform decides to charge demanders a fee of  $P$ , and then the provider decides the level of supporting service  $s_i^{DM}$  in Stage 2, and ultimately realizes the demand  $D^{DM}$  in Stage 3. (ii) If the platform chooses supply-side charging model, then in Stage 1, the platform decides to charge fees  $W$  from the provider, and then the provider decides the level of supporting service  $s_i^{SM}$  in Stage 2, and finally realizes the demand  $D^{SM}$  in Stage 3.

The symbols involved in this paper are summarized in Table 2.

## 4 Model development

This section constructs corresponding Stackelberg game models based on two different charging models, where the platform is the game leader and the provider is the game follower.

### 4.1 Demand-side (DM) charging model

Based on the description of the model background in the previous section, it can be seen that the platform's programming problem under the demand-side charging model with the objective of profit maximization can be expressed as follows

$$\max_P \pi_p^{DM}(P) = (P - C)D^{DM}. \tag{1}$$

The provider  $i$ 's programming problem, which also aims to maximize profits, can be expressed as follows

$$\max_{s_i^{DM}} \pi_i^{DM}(s_i^{DM}) = p_i q_i^{DM} D^{DM} - I(s_i^{DM}). \tag{2}$$

Substituting  $A^{DM} = TP^{-\sigma}$  and  $D^{DM} = (A^{DM})^\alpha (a^{DM})^\beta n^\gamma$

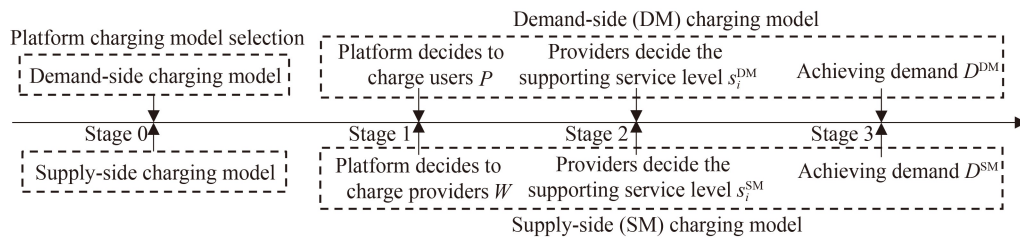


Fig. 3 Sequence of the events.

**Table 2** Notation and definition

Notation	Definition
Superscripts and subscripts	
$i$	The subscript $i$ denotes the provider, $i = 1, 2, \dots, n$
$j$	The superscripts $j = DM, SM$ denote the demand-side and supply-side charging models respectively
*	Market equilibrium
Parameters	
$T$	Level of digitization of the platform
$p_i$	Provider $i$ 's market price of S&T achievements
$n$	Total number of providers on the platform (size of the supply side of the platform)
$\alpha$	Influence coefficient of platform attractiveness on demand
$\beta$	Influence coefficient of provider attractiveness on demand
$\gamma$	Influence coefficient of provider size on demand
$C$	Unit service operation cost of the platform
Decision variables	
$P$	Unit transaction fees charged by platforms to demanders
$W$	Unit transaction fees charged by platforms to providers
$\lambda$	Commission rates charged by platforms to providers
$s_i^j$	Level of offline supporting services of provider $i$ under model $j$
Function	
$A^j$	Attractiveness of the platform under model $j$
$a_i^j$	Attractiveness of provider $i$ under model $j$
$a^j$	Overall provider attractiveness under model $j$ , $a^j = \sum_{i=1}^n a_i^j$
$D^j$	Demand for S&T achievements under model $j$ (platform transaction volume)
$q_i^j$	Market share of provider $i$ under model $j$
$\pi_p^j$	Profit of the platform under model $j$
$\pi_i^j$	Profit of provider $i$ under model $j$
$\Pi^j$	Profit of platform supply chain systems under model $j$

into the above programming problems and solving the Stackelberg game model according to backward induction (Gaula and Jha, 2024), Proposition 1 is obtained as follows (Refer to Appendix A for the proof of main conclusions).

**Proposition 1** Under the demand-side charging model, the optimal pricing for users and the optimal level of supporting services for providers of scientific and technological achievements by the service platform for the transformation of scientific and technological achievements are respectively

$$P^* = \frac{2\alpha\sigma C}{2(\alpha\sigma - 1) + \beta}, \tag{3}$$

$$s^{DM*} = \left[ p^{1-\delta\beta} T^\alpha n^{\gamma+\beta-2} h^{-1} (n + \beta - 1) \right]^{\frac{1}{2-\beta}} \left[ \frac{2\alpha\sigma C}{2(\alpha\sigma - 1) + \beta} \right]^{\frac{-\alpha\sigma}{2-\beta}}. \tag{4}$$

Proposition 1 gives the optimal pricing strategy  $P^*$  for the platform under the demand-side charging model, and

the optimal response strategy  $s^{DM*}$  for the provider in terms of the level of offline supporting services.

### 4.2 Supply-side charging model (SM)

Under the supply-side charging model, the platform's programming problem can be expressed as follows

$$\max_W \pi_p^{SM}(W) = (W - C) D^{SM}. \tag{5}$$

The provider  $i$ 's programming problem can be expressed as

$$\max_{s_i^{SM}} \pi_i^{SM}(s_i^{SM}) = (p_i - W) q_i^{SM} D^{SM} - I(s_i^{SM}). \tag{6}$$

Substituting  $A^{SM} = T$  and  $D^{SM} = T^\alpha (a^{SM})^\beta n^\gamma$  into the above programming problems, and similarly solving the game model based on backward induction yields Proposition 2 as follows.

**Proposition 2** Under the supply-side charging model,

the optimal pricing of the scientific and technological achievement transformation service platform for the achievement provider and the optimal supporting service level of the provider are respectively

$$W^* = \frac{p(2-\beta) + \beta C}{2}, \quad (7)$$

$$s^{SM*} = \left[ p^{-\delta\beta} T^\alpha n^{\gamma+\beta-2} \beta (2h)^{-1} (p-C)(n+\beta-1) \right]^{\frac{1}{2-\beta}}. \quad (8)$$

When the platform chooses the supply-side charging model, Proposition 2 gives the optimal pricing strategy  $W^*$  for the platform, whereby the provider develops the optimal level of supporting services  $s^{DM*}$  as a response strategy.

Further, the sales commission rate of the platform is denoted by  $\lambda$ , that is, the platform charges the commission from the S&T achievement provider in the proportion of  $\lambda$  of the sales revenue, which leads to Lemma 1.

**Lemma 1** Under the supply-side charging model, the commission rate charged to the provider by the S&T service platform at market equilibrium is  $\lambda^* = 1 - \frac{\beta(p-C)}{2p}$ .

Under the supply-side charging model, the platform takes the commission  $W^*$  from each transaction, which implies that the platform endogenously determines the commission rate  $\lambda^*$ . As in Lemma 1, which shows the level of the platform's commission rate at market equilibrium.

**Property 1** The following correlations exist between the commission rate and the main parameters:  $\frac{\partial \lambda^*}{\partial \beta} < 0$ ,  $\frac{\partial \lambda^*}{\partial p} < 0$ ,  $\frac{\partial \lambda^*}{\partial C} > 0$ .

According to Property 1, the commission rate is negatively correlated with the strength of the provider's attractiveness effect and the market price of transformation of S&T achievements, and positively correlated with the platform's unit service cost of the platform, which means that the stronger the provider's attractiveness effect and the higher the transaction price of the transformation of S&T achievements are, the lower the commission rate charged by the platform will be. In addition, the higher the platform's unit service cost is, the higher the commission rate charged by the platform will be. It is worth noting that, when the platform and the provider share revenues, the strength of the provider's attractiveness affects the revenues it shares. Specifically, if the attractiveness effect is stronger, the platform will share higher revenues with the provider; conversely, the provider will obtain lower shared revenues.

**Conclusion 1** (The platform's commission strategy) The platform should offer commission rate discounts to providers of high-value S&T achievements, charging lower commissions. Conversely, higher commissions

should be charged to providers of low-value S&T achievements. This measure indirectly filters out high-quality providers and prevents low-quality providers from "bad money drives out good." In the long-term, this charging mechanism is conducive to promoting the sustainable development of the platform.

## 5 Results and discussion

### 5.1 Comparison of optimal decisions

First, based on the equilibrium solution of the provider's optimal level of offline supporting services, by analyzing its correlation with the digitization level  $T$  of the platform, Property 2 can be obtained.

**Property 2** The following correlation exists between the provider's optimal level of offline supporting services and the platform's digitization level:  $\frac{\partial s^{j*}}{\partial T} > 0$ .

From Property 2,  $s^{j*}$  is positively correlated with  $T$ , that is, the higher the digitization level of the platform is, the higher the supporting service level that providers will be prompted to offer. It follows that digitization is not only beneficial to helping platforms improve the matching rate, but also helpful for motivating the providers of achievements to invest more in supporting services.

**Conclusion 2** (The provider's supporting service strategy) For providers of S&T achievements, they need to determine the level of offline supporting services offered to research users based on the digitization level of the platform they join. If the platform has a high level of digitization, the provider should also adopt a strategy of delivering high-quality supporting services. With the rapid development of digital technology, the technical level of supply and demand matching on platforms has undoubtedly increased significantly, which also brings pressure on providers to offer supporting services.

Furthermore, comparing the provider's optimal level of offline supporting services under the two charging models leads to Proposition 3.

**Proposition 3** (Comparison of supporting services levels) (i) If  $(P^*)^{-\alpha\sigma} > \frac{p-C}{2p}\beta$ , then  $s^{DM*} > s^{SM*}$ . (ii) If  $(P^*)^{-\alpha\sigma} < \frac{p-C}{2p}\beta$ , then  $s^{DM*} < s^{SM*}$ . (iii) If  $(P^*)^{-\alpha\sigma} = \frac{p-C}{2p}\beta$ , then  $s^{DM*} = s^{SM*}$ .

Proposition 3 gives the conditions under which the level of supporting services dominates under the two charging models, and Fig. 4 visualizes the dominant situation.

According to Fig. 4, it can be seen that  $s^{DM*}$  is always the largest in the Region ② under the two cases of the  $C$ -value, that is, demanders in this region can enjoy a higher level of offline supporting services under the

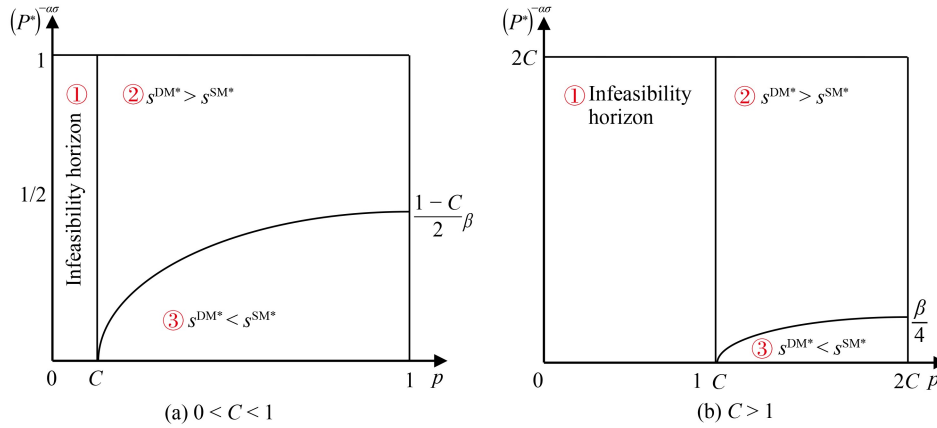


Fig. 4 Dominant scenarios of the level of supporting services under the two charging models.

demand-side charging model, which means that only in terms of the level of supporting services, when Region ② occurs, demanders will prefer the platform to implement the demand-side charging model, which from another angle also indicates that if demanders want to enjoy a higher level of supporting services, their willingness to pay service fees to the platform will also be higher. In addition, it is worth noting that in Region ③, demanders are the ones who don't want the platform to implement the demand-side charging model, because demanders need to pay the service fee to the platform and can only enjoy a lower level of supporting services, which is obviously a lower utility for demanders at this time. Comparing Figs. 4(a) and (b), it can be seen that as the value of  $C$  increases from less than 1 to more than 1, there is a significant decrease in the cases where the level of supporting services is favorable under the supply-side charging model, which means that if the unit operating cost of the platform is relatively high, it is more difficult for the demanders to enjoy a higher level of supporting services under the supply-side charging model.

Comparing the platform's pricing strategies for the bilateral market of S&T achievement providers-side and demanders-side under the two charging models leads to Proposition 4.

**Proposition 4** (Comparison of charges) (i) If  $X > 0$ , then  $P^* > W^*$ . (ii) If  $X < 0$ , then  $P^* < W^*$ . (iii) If  $X = 0$ , then  $P^* = W^*$ , where  $X = 4p(1-\beta) + 2\beta C - (p-C)[2\alpha\sigma(2-\beta) - \beta^2]$ .

Proposition 4 indicates that whether the pricing for providers or demanders is higher in the two charging models of the platform depends on the positivity or negativity of the  $X$ -value. When  $X > 0$ , the platform's pricing for demanders is higher than that for providers; whereas, when  $X < 0$ , the situation is reversed. Furthermore, to provide a more intuitive comparison of the charging levels on both sides of the platform, we represent the relationship between the platform's service cost ( $C$ ) and the price ( $p$ ) of S&T achievements on a two-dimensional coordinate axis, as shown in Fig. 5.

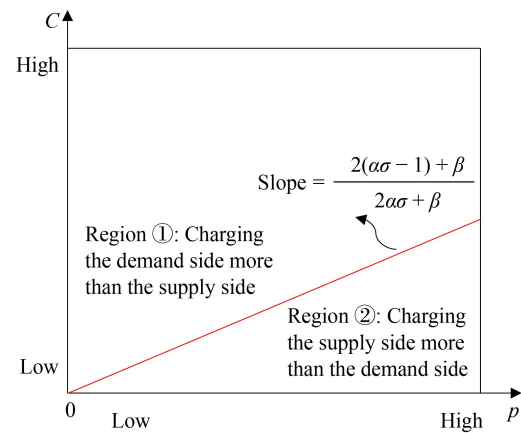


Fig. 5 Comparison of charging levels on both sides of the platform.

Fig. 5 intuitively illustrates the pricing strategies of S&T achievements transformation platforms with different cost structures. In most cases, the platform is more likely to charge higher fees to the demand side. However, if the platform's transaction service cost is relatively low, it will charge higher fees to the supply side.

### 5.2 Comparison of demand

Combining Propositions 1 and 2, it is easy to obtain the demand under the two charging models at market equilibrium as shown in Lemma 2.

**Lemma 2** In market equilibrium, the demand under two charging models, demand-side and supply-side, are respectively.

$$\begin{aligned}
 D^{DM*} &= (A^{UM*})^\alpha (a^{UM*})^\beta n^\gamma \\
 &= T^{\frac{2\alpha}{2-\beta}} p^{\frac{\beta(1-2\beta)}{2-\beta}} n^{\frac{2\gamma}{2-\beta}} [h^{-1}(n+\beta-1)]^{\frac{\beta}{2-\beta}} \left[ \frac{2\alpha\sigma C}{2(\alpha\sigma-1)+\beta} \right]^{-\frac{2\alpha\sigma}{2-\beta}}, \tag{9}
 \end{aligned}$$

$$D^{SM*} = T^\alpha (a^{SM*})^\beta n^\gamma = T^{\frac{2\alpha}{2-\beta}} p^{\frac{-2\beta}{2-\beta}} n^{\frac{2\gamma}{2-\beta}} \left[ \beta(2h)^{-1} (p-C)(n+\beta-1) \right]^{\frac{\beta}{2-\beta}}. \quad (10)$$

Based on Lemma 2, we can compare the level of demand under the two charging models.

**Proposition 5** (Comparison of demand) (i) If  $\frac{\beta(p-C)}{2p} < \left[ \frac{2(\alpha\sigma-1)+\beta}{2\alpha\sigma C} \right]^{\frac{2\alpha\sigma}{\beta}}$ , then  $D^{DM*} > D^{SM*}$ . (ii) If  $\frac{\beta(p-C)}{2p} > \left[ \frac{2(\alpha\sigma-1)+\beta}{2\alpha\sigma C} \right]^{\frac{2\alpha\sigma}{\beta}}$ , then  $D^{DM*} < D^{SM*}$ . (iii) If  $\frac{\beta(p-C)}{2p} = \left[ \frac{2(\alpha\sigma-1)+\beta}{2\alpha\sigma C} \right]^{\frac{2\alpha\sigma}{\beta}}$ , then  $D^{DM*} = D^{SM*}$ .

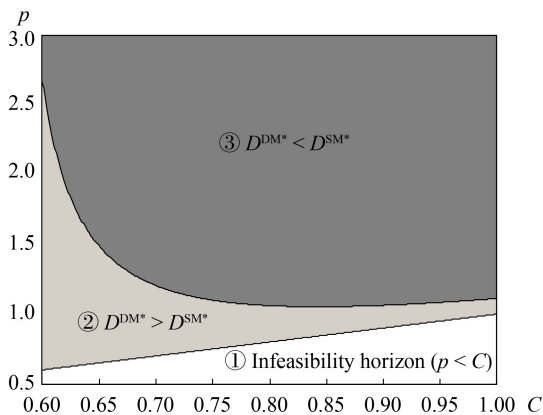
Proposition 5 gives the predominance of the demand under different charging models. To show more intuitively the platform’s performance in terms of demand under the two charging models, numerical simulation is used next for comparative analysis. The parameters involved in the full paper are assigned values as shown in Table 3.

Using MATLAB software, the relationship between the size of the demand in the two charging models is obtained as shown in Fig. 6.

As can be seen from Fig. 6, for the demand performance indicator, the demand-side charging model dominates in Region ② and the supply-side charging model dominates in Region ③. This shows that when the platform’s unit service cost and the market price of S&T achievements transformation are both low, the demand-side charging model can stimulate the market demand for S&T achievements transformation, while when the platform’s unit service cost and the market price of S&T achievements transformation are both high, the supply-side charging model has a stronger role in promoting the market

**Table 3** Parameter assignment

Parameter	$\alpha$	$\beta$	$\delta$	$\sigma$	$T$	$n$	$\gamma$	$h$	$p$	$C$
Value	1.2	0.6	2	1	2	10	0.5	0.1	2	0.6



**Fig. 6** Dominating user demand under the two charging models.

demand. In addition, if the market price of the transformation of S&T achievements is high enough, the platform should charge the supply-side providers rather than the demand-side users, which is consistent with reality.

5.3 Provider’s preference for charging models

Combining Propositions 1 and 2 and substituting the equilibrium solution into the profit function of the provider, the provider’s profit under the two charging models can be obtained. The trend of the provider’s profit with respect to the key parameters is further obtained through numerical simulation as shown in Fig. 7.

According to Fig. 7, in the process of gradual increase of market price of transformation of S&T achievements, unit service cost of platform, attractiveness effect strength of platform and attractiveness effect strength of provider, the profit of provider is always higher than that in demand-side charging model than in supply-side charging model. To a certain extent, this shows that the provider strictly prefers the demand-side charging model, that is, regardless of the market price of S&T achievements transformation and the unit service cost of the platform, as well as the intensity of the attractiveness effect of the platform and the provider, the provider always prefers the operation model in which the platform charges the demanders.

**Proposition 6** For both demand-side and supply-side charging models of the platform, the demand-side charging model is always preferred for S&T achievements providers.

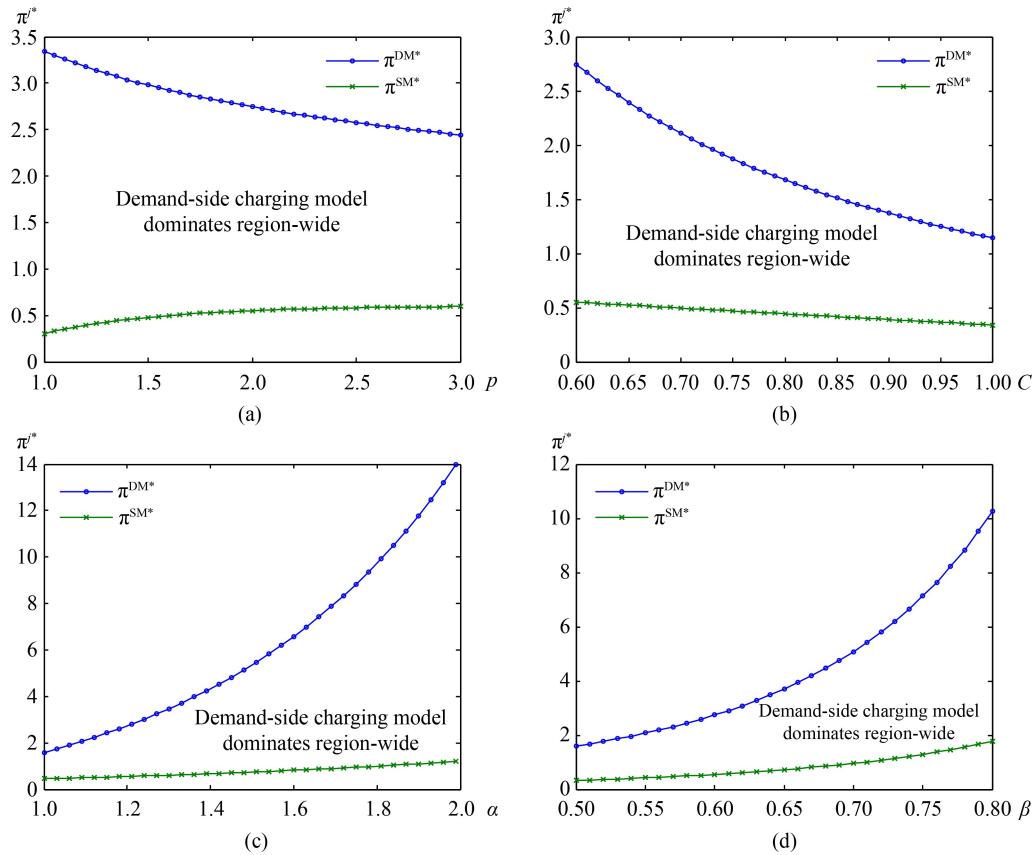
5.4 Platform’s preference for charging models

Combining Propositions 1 and 2 and substituting the equilibrium solution into the profit function of the platform, the platform’s profit under the two charging models can be obtained. Furthermore, the trend of the platform’s profit with the key parameters is obtained by numerical simulation as shown in Fig. 8.

As can be seen from Fig. 8(a), in the process of market price fluctuations related to the achievements transformation, no charging model is strictly dominant. Rather, both the demand-side charging model and the supply-side charging model have scenarios where they are advantageous or dominant. Furthermore, the dominant situation is determined by a certain market price threshold, when the price exceeds the threshold, the supply-side charging model is dominant, and when the price is lower than the threshold, the demand-side charging model is dominant.

**Proposition 7** When the market price of the transformation of S&T achievements is low, the platform should choose the demand-side charging model; when the market price is high, the platform should choose the supply-side charging model.

In addition, as can be seen from Fig. 8(b), when the



**Fig. 7** Impact of changes in key parameters on the provider's profit under the two charging models. (a) Impact of transfer market price on profit; (b) Impact of platform unit cost of services on profit; (c) Impact of the platform attractiveness on profit; (d) Impact of the provider attractiveness on profit.

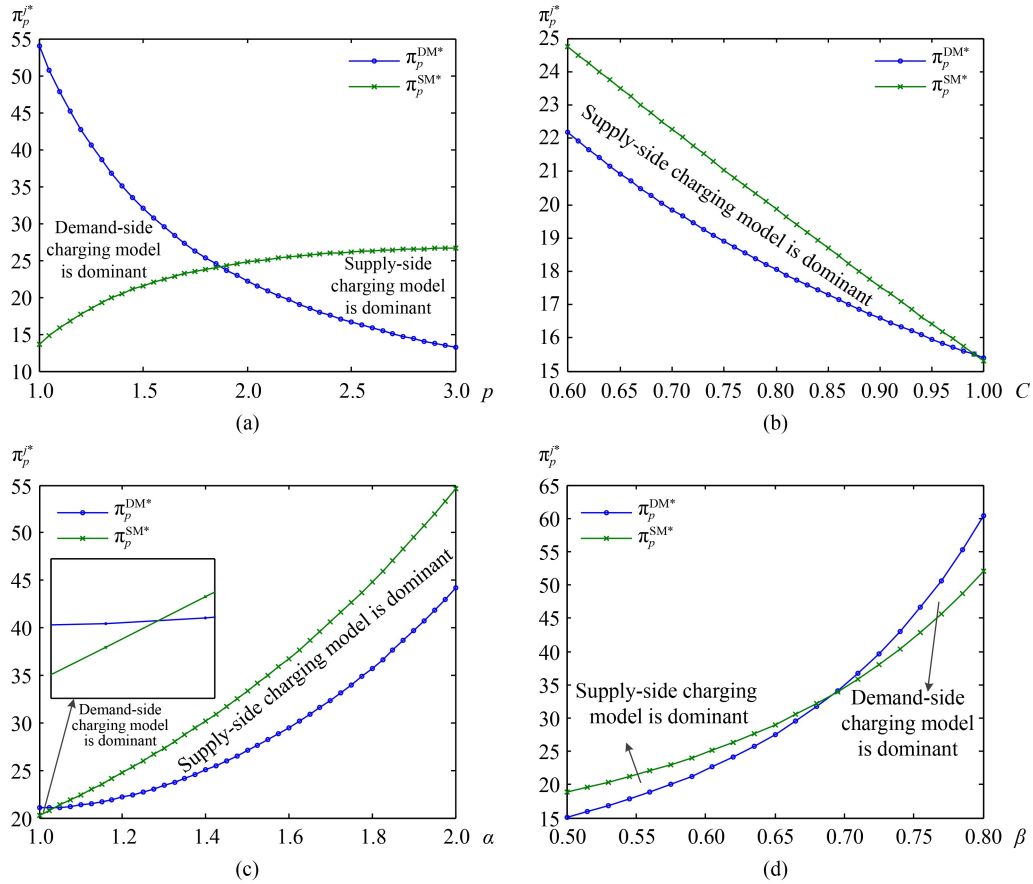
platform's unit service cost gradually increases from 0.6 to 1, the platform consistently achieves higher profits under the supply-side charging model compared to the demand-side charging model. According to Fig. 8(c), it can be seen that the supply-side charging model dominates in the vast majority of cases during the process of increasing the strength of the platform attractiveness effect from weak to strong, and the demand-side charging model dominates only when the strength of the platform attractiveness effect is weak enough. Fig. 8(d) indicates that when the strength of the provider attractiveness effect is weak, the supply-side charging model is dominant, whereas when it is strong, the demand-side charging model becomes dominant. This is another indication that the platform will shift from supply-side charging to demand-side charging as the provider attractiveness effect increases from weak to strong. In conjunction with Fig. 7, it is worth noting that the preferences of the platform and providers toward charging models are not identical.

**Proposition 8** When the strength of the provider attractiveness effect is weak, the platform prefers the supply-side charging model; whereas, when the strength of the provider attractiveness effect is strong, the platform prefers the demand-side charging model.

### 5.5 Comparison of profit of platform supply chain system

The profit of platform supply chain system  $\Pi^j$  is denoted as the sum of the platform profit and the profit of all providers on the platform, i.e.,  $\Pi^j = \pi_p^j + n\pi_i^j$ . Furthermore, the trend of the system's profit with the key parameters is obtained through numerical simulation as shown in Fig. 9.

According to Fig. 9, as the market price of S&T achievements transformation, platform's unit service cost, platform attractiveness effect, and provider attractiveness effect gradually increase, the profit of platform supply chain system is always higher under the demand-side charging model than under the supply-side charging model, which is similar to Fig. 7. Combining Figs. 7 and 9, it can be found that both the profit of platform supply chain system and providers are higher under demand-side charging model, which means that compared with supply-side charging model, demand-side charging model has better performance in these two profit indicators. In other words, from the perspective of optimizing the profit of the platform supply chain system, the demand-side charging model emerges as the dominant choice when comparing



**Fig. 8** Impact of changes in key parameters on the platform’s profit under the two charging models: (a) Impact of transfer market price on profit; (b) Impact of the platform’s unit cost of services on profit; (c) Impact of the platform attractiveness on profit; (d) Impact of the provider attractiveness on profit.

both charging models.

**Proposition 9** From the perspective of the platform supply chain system, the demand-side charging model is dominant over the supply-side charging model.

## 6 Model extension: Charging both the demand and supply sides

In this section, we extend our consideration to another charging model. The platform charges a unit service fee  $P^{ME}$  from the demand-side and at the same time charges a transaction commission  $\lambda^{ME}$  from the supply-side, which is the charging model for both the supply and demand sides. Note that we use the superscript ME to represent this extended model. Based on the settings of the previous basic model, the platform’s programming problem with the objective of profit maximization can be expressed as follows

$$\max_{P^{ME}, \lambda^{ME}} \pi_p^{ME}(P^{ME}, \lambda^{ME}) = (P^{ME} + \lambda^{ME} p_i - C) D^{ME}. \quad (11)$$

The provider  $i$ ’s programming problem, which also aims to maximize profits, can be expressed as follows

$$\max_{s_i^{ME}} \pi_i^{ME}(s_i^{ME}) = (1 - \lambda^{ME}) p_i q_i^{ME} D^{ME} - I(s_i^{ME}). \quad (12)$$

Substituting  $A^{ME} = T(P^{ME})^{-\sigma}$  and  $D^{ME} = (A^{ME})^\alpha (a^{ME})^\beta n^\gamma$  into the above programming problems and solving this game model according to backward induction, Proposition 10 is obtained.

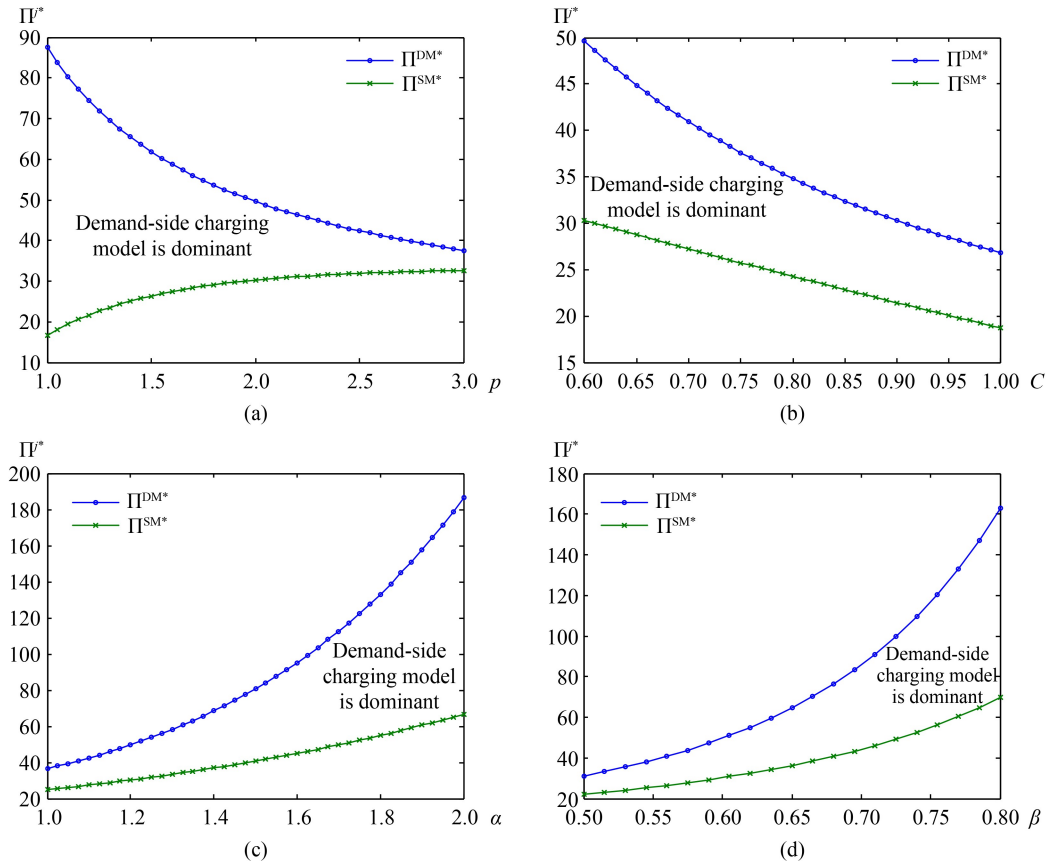
**Proposition 10** Under both the demand and supply sides charging model, the optimal pricing for charging users, the optimal commission rate for charging providers, and the optimal level of supporting services formulated by providers are respectively as follows:

$$P^{ME*} = \frac{2\alpha\sigma(2-\beta)(C-p)}{(3-\beta)(\beta-2+2\alpha\sigma)-2\alpha\sigma}, \quad (13)$$

$$\lambda^{ME*} = \frac{(\beta-2+2\alpha\sigma)[p(2-\beta)+C]-2\alpha\sigma C}{p[(\beta-2+2\alpha\sigma)(3-\beta)-2\alpha\sigma]}, \quad (14)$$

$$s_i^{ME*} = \left\{ \frac{T^\alpha n^{\gamma+\beta-2} (n+\beta-1) [(2-\beta)(C-p)]^{1-\alpha\sigma}}{hp^{\delta\beta} (2\alpha\sigma)^{\alpha\sigma} [(\beta-2+2\alpha\sigma)(3-\beta)-2\alpha\sigma]^{1-\alpha\sigma}} \right\}^{\frac{1}{2-\beta}}. \quad (15)$$

Apparently, under the charging model for both sides,



**Fig. 9** Impact of changes in key parameters on the profit of the platform supply chain system under two charging models. (a) Impact of transfer market prices on profit; (b) Impact of platform unit cost of services on profit; (c) Impact of the platform attractiveness on profit; (d) Impact of the provider attractiveness on profit.

the platform needs to formulate two pricing strategies simultaneously. We obtain Propositions 11 and 12 by conducting a comparative analysis of the equilibrium results under different charging models.

**Proposition 11** (Comparison of charging to demanders)

(i) If  $p < C \left\{ 1 - \frac{[(3-\beta)(\beta-2+2\alpha\sigma)-2\alpha\sigma]}{(2-\beta)[2(\alpha\sigma-1)+\beta]} \right\}$ , then  $p^{ME*} < P^*$ .

(ii) If  $p > C \left\{ 1 - \frac{[(3-\beta)(\beta-2+2\alpha\sigma)-2\alpha\sigma]}{(2-\beta)[2(\alpha\sigma-1)+\beta]} \right\}$ , then  $p^{ME*} > P^*$ .

(iii) If  $p = C \left\{ 1 - \frac{[(3-\beta)(\beta-2+2\alpha\sigma)-2\alpha\sigma]}{(2-\beta)[2(\alpha\sigma-1)+\beta]} \right\}$ , then  $p^{ME*} = P^*$ .

An important conclusion can be drawn from Proposition 11. For platforms dealing with S&T achievements of relatively low value, they will charge lower fees to demanders under the charging model for both supply and demand sides. For platforms dealing with S&T achievements of relatively high value, they will charge lower fees to demanders under the charging model only for the demand-side. This finding is of great significance for guiding the practical operation of platforms.

**Conclusion 3** (The platform’s pricing strategy for demanders) For platforms dealing with high-value S&T achievements, they should set higher prices for demanders under a dual charging model that includes both supply and demand sides. For platforms dealing with low-value S&T achievements, they should set higher prices for demanders under a charging model that targets only the demand side.

**Proposition 12** (Comparison of charging to providers)

(i) If  $p$  satisfies the condition that  $p < \frac{C}{\beta+2(\alpha\sigma-1)}$ , then  $\lambda^{ME*} < \lambda^*$ .

(ii) If  $p$  satisfies the condition that  $p > \frac{C}{\beta+2(\alpha\sigma-1)}$ , then  $\lambda^{ME*} > \lambda^*$ .

(iii) If  $p$  satisfies the condition that  $p = \frac{C}{\beta+2(\alpha\sigma-1)}$ , then  $\lambda^{ME*} = \lambda^*$ .

From Proposition 12, when the value of S&T achievements falls within different interval ranges, the optimal commission rates charged by the platform to providers under different charging models show differences. In other words, the platform should reasonably determine the commission rates under different charging models

according to the value level of S&T achievements. Specifically, for low-value S&T achievements, the platform sets a higher commission rate under the supply-side-only charging model. For high-value S&T achievements, the platform sets a higher commission rate under the two-sided charging model.

Additionally, we present the platform's commission rate strategy under varying combinations of the platform's service cost ( $C$ ) and the price ( $p$ ) of S&T achievements, as shown in Fig. 10. In Region ①, the platform's commission rate is higher under the supply-side-only charging model, while in Region ②, the platform's commission rate is higher under the two-sided charging model.

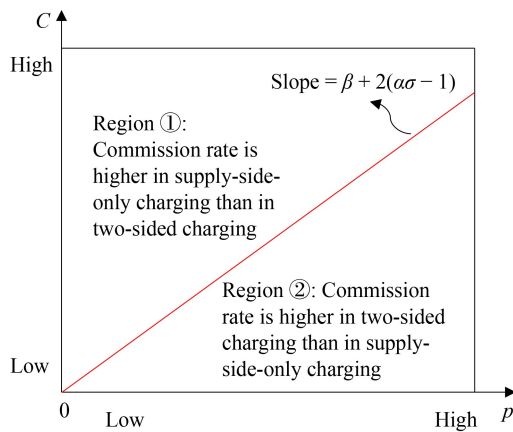


Fig. 10 Comparison of commission rates under the two charging models.

## 7 Conclusions

### 7.1 Main findings

We consider a platform-based supply chain system consisting of a digital service platform for achievement transformation and multiple S&T achievement providers, with the platform as the supply chain leader and the providers as the supply chain followers. The focus of this paper is to explore the charging model of the platform, that is, how the platform chooses between the demand-side charging model and the supply-side charging model. To answer this question, this paper adopts the Stackelberg theory to construct the game models between platforms and providers under the two charging models and obtains research conclusions by analyzing the game equilibrium results. The main findings are as follows. (i) If the platform's unit operating cost is relatively high, S&T achievements demanders are more likely to enjoy a higher level of offline supporting services under the demand-side charging model. (ii) When both the platform's unit service cost

and the market price of S&T achievements transformation are low, the demand-side charging model can stimulate the market demand for S&T achievements transformation. While when both the platform's unit service cost and the market price of S&T achievements transformation are high, the supply-side charging model has a stronger role in promoting the market demand. (iii) S&T achievements providers always prefer the demand-side charging model. However, for platforms, their preference for the charging model is different from that of providers. Impacts of the market price of S&T achievements transformation, the strength of attractiveness effect between platforms and providers and other factors, make a difference on the platform's preference of charging model. (iv) Compared with the supply-side charging model, the demand-side charging model is more profitable for both providers and the platform supply chain system. (v) When the platform changes to the charging model for both the supply and demand sides, its user service charging strategy and provider commission system will most likely change.

### 7.2 Managerial insights

Compared with the e-commerce online shopping platform (Chen et al., 2023; Zhuo et al., 2024) and service-sharing platform (Li et al., 2022; Anand et al., 2023; Liu et al., 2024) for general consumer goods or services, this paper chooses the platform of S&T achievements transformation as the research object. Main findings of the research can provide important management insights for the members of the platform supply chain system for the transformation of S&T achievements, mainly including the platform and the S&T achievements providers, and in particular, it has a strong significance of guiding the platform in the decision-making of the charging model of the operation practice.

For the service platform for the transformation of S&T achievements, when formulating the charging model, it should fully consider the market price of S&T achievements transformation, the unit operating cost of the platform, the respective attractiveness effect strength of the platform and providers, and so on, to make decisions. If the market price of S&T achievements is lower, the attractiveness effect strength of the platform is sufficiently weak, and the attractiveness effect strength of providers is relatively strong, the demand-side charging model is a better choice for the platform. Conversely, the platform should choose the supply-side charging model. Much of the platform operations management literature discusses only one model of platform charging to the supply side but only considers the issue of whether the platform should choose a commission system or a fixed fee system (Zhang et al., 2019; Zhang et al., 2022; Chen and Xu, 2024), which is still essentially a supply-side charging

model. However, this paper further expands to propose the model of platform charging to the demand side, which is one more optional charging model for S&T achievement transformation platforms.

For providers of S&T achievements, although they do not have the right to decide on the charging model of the platform and can only be the recipients of the charging model, they always have their preferred charging model from the perspective of economic interests. Specifically, when the market price of S&T achievements, the unit operating cost of the platform, and the strength of the respective attractiveness effect between the platform and providers are within a certain range, providers show their preference for the demand-side charging model. This suggests that the preferences of providers and the platforms for charging models are not completely opposed to each other and that there are cases in which providers and the platform achieve a win-win situation under the demand-side charging model.

### 7.3 Limitations and future research

Our research can be further expanded in two aspects. First, referring to the operational model of other types of e-commerce platforms, the merchants stationed on the platform have the pricing right for their products or services, and introducing it into the service platform for the transformation of S&T achievements means that the provider can endogenously decide the market transfer price of S&T achievements, so it is worthwhile to study how the platform decides on the charging model when it is in the game with the provider in such a situation. Secondly, the situation of platform competition can be further analyzed. When platforms compete, resource providers face the problem of platform ownership, and the influence of different ownership structures on the platform’s choice of charging model can be discussed. These extended studies in the future will not only contribute to the enrichment of the theory of platform-based operations management but also offer more comprehensive and targeted guidance for the operational practices of platform-based enterprises.

**Competing Interests** The authors declare that they have no competing interests.

## Appendix A

### Proof of Proposition 1

The profit function of provider  $i$  is  $\pi_i^{DM}(s_i^{DM}) = p_i(TP^{-\sigma})^\alpha n^\gamma \frac{s_i^{DM} p_i^{-\delta}}{(\sum_{k=1}^n s_k^{DM} p_k^{-\delta})^{1-\beta}} - \frac{h(s_i^{DM})^2}{2}$ , to find the first order derivative of  $\pi_i^{DM}(s_i^{DM})$  with respect to  $s_i^{DM}$  and get

$$\frac{p_i^{1-\delta}(TP^{-\sigma})^\alpha n^\gamma (\sum_{k=1}^n s_k^{DM} p_k^{-\delta})^{1-\beta} - (1-\beta)s_i^{DM} p_i^{-\delta} (\sum_{k=1}^n s_k^{DM} p_k^{-\delta})^{-\beta}}{(\sum_{k=1}^n s_k^{DM} p_k^{-\delta})^{2-2\beta}} - h s_i^{DM} = 0.$$

Consider the symmetry conditions, i.e.,  $p_i = p$ ,  $s_i^{DM} = s^{DM}$ ,  $i = 1, 2, \dots, n$ , so that the first order condition can be rewritten as  $p^{1-\delta}(TP^{-\sigma})^\alpha n^\gamma \frac{n s^{DM} p^{-\delta} - (1-\beta)s^{DM} p^{-\delta}}{(n s^{DM} p^{-\delta})^{2-\beta}} - h s^{DM} = 0$ , which in turn yields the optimal response of provider  $i$ 's level of supporting services as  $\hat{s}^{DM}(P) = [p^{1-\delta\beta}(TP^{-\sigma})^\alpha n^{\gamma+\beta-2} h^{-1} (n+\beta-1)]^{\frac{1}{2-\beta}}$ . The profit function of the platform is  $\pi_p^{DM}(P) = (P-C)(TP^{-\sigma})^\alpha n^\gamma (\sum_{i=1}^n s_i^{DM} p_i^{-\delta})^\beta$ , substituting  $\hat{s}^{DM}(P)$  and combining the symmetries, we get  $\pi_p^{DM}(P) = (P-C)P^{\frac{2\alpha\sigma}{2-\beta}} (n^\gamma T^\alpha)^{\frac{2}{2-\beta}} [p^{1-2\delta} h^{-1} (n+\beta-1)]^{\frac{\beta}{2-\beta}}$ , find the first-order derivative of  $\pi_p^{DM}(P)$  with respect to  $P$ , and obtain the first-order condition as  $P^{\frac{2\alpha\sigma}{2-\beta}} - \frac{2\alpha\sigma}{2-\beta} P^{\frac{2\alpha\sigma}{2-\beta}-1} (P-C) = 0$ . Thus, the demand-side optimal pricing of the platform at equilibrium is obtained as  $P^* = \frac{2\alpha\sigma C}{2(\alpha\sigma-1)+\beta}$ .

From  $\beta \in (0, 1]$  and  $\alpha\sigma > 1$ , it can be seen that  $\frac{2\alpha\sigma}{2(\alpha\sigma-1)+\beta} > 1$ , i.e.,  $P^* > C$  is established, which satisfies the model reality condition. Bringing  $P^*$  into  $\hat{s}^{DM}(P)$ , we can get the optimal service level of the provider is  $s^{DM*} = [p^{1-\delta\beta} T^\alpha n^{\gamma+\beta-2} h^{-1} (n+\beta-1)]^{\frac{1}{2-\beta}} \left[ \frac{2\alpha\sigma C}{2(\alpha\sigma-1)+\beta} \right]^{\frac{-\alpha\sigma}{2-\beta}}$ .

The proof is completed.

### Proof of Proposition 2

The profit function of provider  $i$  is  $\pi_i^{SM}(s_i^{SM}) = (p_i - W) T^\alpha n^\gamma \frac{s_i^{SM} p_i^{-\delta}}{(\sum_{k=1}^n s_k^{SM} p_k^{-\delta})^{1-\beta}} - \frac{h(s_i^{SM})^2}{2}$ , and the first order condition is  $(p_i - W) T^\alpha n^\gamma p_i^{-\delta} \frac{(\sum_{k=1}^n s_k^{SM} p_k^{-\delta})^{1-\beta} - (1-\beta)s_i^{SM} p_i^{-\delta} (\sum_{k=1}^n s_k^{SM} p_k^{-\delta})^{-\beta}}{(\sum_{k=1}^n s_k^{SM} p_k^{-\delta})^{2-2\beta}} - h s_i^{SM} = 0$ .

In the same way, according to the symmetry conditions  $p_i = p$  and  $s_i^{SM} = s^{SM}$ , the first-order condition can be rewritten as  $(p - W) T^\alpha n^\gamma p^{-\delta} \frac{n s^{SM} p^{-\delta} - (1-\beta)s^{SM} p^{-\delta}}{(n s^{SM} p^{-\delta})^{2-\beta}} - h s^{SM} = 0$ , which leads to the optimal response to the level of supporting services is  $\hat{s}^{SM}(W) = [(p - W) T^\alpha n^{\gamma+\beta-2} p^{-\delta\beta} h^{-1} (n+\beta-1)]^{\frac{1}{2-\beta}}$ . The profit function of the platform is  $\pi_p^{SM}(W) = (W - C) T^\alpha n^\gamma (\sum_{i=1}^n s_i^{SM} p_i^{-\delta})^\beta$ , substituting  $\hat{s}^{SM}(W)$  and combining with symmetry, we get  $\pi_p^{SM}(W) = (W - C)(p - W)^{\frac{\beta}{2-\beta}} (n^\gamma T^\alpha)^{\frac{2}{2-\beta}} [p^{-2\delta} h^{-1} (n+\beta-1)]^{\frac{\beta}{2-\beta}}$ . Finding the first order derivative of  $\pi_p^{SM}(W)$  with respect to  $W$ , the first order condition is obtained as  $(p - W)^{\frac{\beta}{2-\beta}} - \frac{\beta}{2-\beta} (W - C)(p - W)^{\frac{\beta}{2-\beta}-1} = 0$ . Therefore, the

optimal pricing of the platform at the supply side in equilibrium is obtained as  $W^* = \frac{p(2-\beta)+\beta C}{2}$ .

For the model to be realistic,  $p > W > C$  clearly needs to be satisfied, and from  $\beta \in (0, 1]$  it follows that  $p > W^* > C$  holds, so optimal pricing is realistic. Bringing  $W^*$  into  $\hat{s}^{SM}(W)$ , the optimal level of supporting service is obtained as  $s^{SM*} = [p^{-\delta\beta} T^\alpha n^{\gamma+\beta-2} \beta(2h)^{-1} (p-C)(n+\beta-1)]^{\frac{1}{2-\beta}}$ .

The proof is completed.

**Proof of Lemma 1**

Based on Proposition 2, substitute  $W^* = \frac{p(2-\beta)+\beta C}{2}$  into the commission rate formula  $\lambda = \frac{W}{p}$  to get the commission rate at equilibrium, we can obtain  $\lambda^* = \frac{p(2-\beta)+\beta C}{2p} = \frac{2p-\beta(p-C)}{2p} = 1 - \frac{\beta(p-C)}{2p}$ .

The proof is completed.

**Proof of Property 1**

From  $\lambda^* = 1 - \frac{\beta(p-C)}{2p}$ , find the first order partial derivative of  $\lambda^*$  with respect to  $p$  to get  $\frac{\partial \lambda^*}{\partial p} = -\frac{\beta C}{2p^2} < 0$ , find the first order partial derivative of  $\lambda^*$  with respect to  $\beta$  to get  $\frac{\partial \lambda^*}{\partial \beta} = -\frac{p-C}{2p} < 0$ , find the first order partial derivative of  $\lambda^*$  with respect to  $C$  to get  $\frac{\partial \lambda^*}{\partial C} = \frac{\beta}{2p} > 0$ .

The proof is completed.

**Proof of Property 2**

Firstly, according to  $s^{DM*} = [p^{1-\delta\beta} T^\alpha n^{\gamma+\beta-2} h^{-1} (n+\beta-1)]^{\frac{1}{2-\beta}}$   $\left[ \frac{2\alpha\sigma C}{2(\alpha\sigma-1)+\beta} \right]^{\frac{-\alpha\sigma}{2-\beta}}$ , we can obtain  $\frac{\partial s^{DM*}}{\partial T} = \frac{\alpha}{2-\beta} \left[ \frac{2\alpha\sigma C}{2(\alpha\sigma-1)+\beta} \right]^{\frac{-\alpha\sigma}{2-\beta}} [p^{1-\delta\beta} n^{\gamma+\beta-2} h^{-1} (n+\beta-1)]^{\frac{1}{2-\beta}} T^{\frac{\alpha(\beta-1)}{2-\beta} + \alpha - 1}$ , since  $\alpha\sigma > 1$  and  $\beta \in (0, 1]$ , therefore, it is easy to obtain that  $\frac{\partial s^{DM*}}{\partial T} > 0$ . Secondly, according to  $s^{SM*} = [p^{-\delta\beta} T^\alpha n^{\gamma+\beta-2} \beta(2h)^{-1} (p-C)(n+\beta-1)]^{\frac{1}{2-\beta}}$ , it can be obtained that  $\frac{\partial s^{SM*}}{\partial T} = \frac{\alpha}{2-\beta} [p^{-\delta\beta} n^{\gamma+\beta-2} \beta(2h)^{-1} (p-C)(n+\beta-1)]^{\frac{1}{2-\beta}} T^{\frac{\alpha(\beta-1)}{2-\beta} + \alpha - 1}$ , similarly, because  $2-\beta > 0$ , therefore,  $\frac{\partial s^{SM*}}{\partial T} > 0$  holds. In summary, it can be concluded that  $\frac{\partial s^{j*}}{\partial T} > 0$ .

The proof is completed.

**Proof of Proposition 3**

According to Propositions 1 and 2, we can get

$$\frac{s^{DM*}}{s^{SM*}} = \left\{ \frac{p \left[ \frac{2\alpha\sigma C}{2(\alpha\sigma-1)+\beta} \right]^{-\alpha\sigma}}{\frac{\beta(p-C)}{2}} \right\}^{\frac{1}{2-\beta}}, \text{ because } \beta \in (0, 1],$$

$$\alpha\sigma > 1, \text{ and } p > C, \text{ thus } \frac{s^{DM*}}{s^{SM*}} > 1 \iff$$

$$\left[ \frac{2\alpha\sigma C}{2(\alpha\sigma-1)+\beta} \right]^{-\alpha\sigma} > \frac{p-C}{2p} \beta, \text{ and similarly, } \frac{s^{DM*}}{s^{SM*}} < 1 \iff$$

$$\left[ \frac{2\alpha\sigma C}{2(\alpha\sigma-1)+\beta} \right]^{-\alpha\sigma} < \frac{p-C}{2p} \beta. \text{ Substituting } P^* = \frac{2\alpha\sigma C}{2(\alpha\sigma-1)+\beta},$$

we can get if  $(P^*)^{-\alpha\sigma} > \frac{p-C}{2p} \beta$ , then  $s^{DM*} > s^{SM*}$ ; if  $(P^*)^{-\alpha\sigma} < \frac{p-C}{2p} \beta$ , then  $s^{DM*} < s^{SM*}$ ; if  $(P^*)^{-\alpha\sigma} = \frac{p-C}{2p} \beta$ , then  $s^{DM*} = s^{SM*}$ .

The proof is completed.

**Proof of Proposition 4**

According to Propositions 1 and 2, we have  $\frac{P^*}{W^*} = \frac{4\alpha\sigma C}{[2(\alpha\sigma-1)+\beta][p(2-\beta)+\beta C]}$ , since  $\beta \in (0, 1]$  and

$\alpha\sigma > 1$ , therefore,  $\frac{P^*}{W^*} > 1 \iff 4\alpha\sigma C > [2(\alpha\sigma-1)+\beta][p(2-\beta)+\beta C] \iff 4p(1-\beta)+2\beta C - (p-C)[2\alpha\sigma(2-\beta)-\beta^2] > 0$ . Let  $X = 4p(1-\beta)+2\beta C - (p-C)[2\alpha\sigma(2-\beta)-\beta^2]$ , then it follows that  $P^* > W^*$  if  $X > 0$ , and  $P^* < W^*$  if  $X < 0$ , and  $P^* = W^*$  if  $X = 0$ .

The proof is completed.

**Proof of Proposition 5**

According to Lemma 2, we can get  $\frac{D^{DM*}}{D^{SM*}} = \frac{2^{\frac{\beta-2\alpha\sigma}{2-\beta}} p^{\frac{\beta}{2-\beta}} [2(\alpha\sigma-1)+\beta]^{\frac{2\alpha\sigma}{2-\beta}}}{(\alpha\sigma C)^{\frac{2\alpha\sigma}{2-\beta}} [\beta(p-C)]^{\frac{\beta}{2-\beta}}}$ , so that  $\frac{D^{DM*}}{D^{SM*}} > 1$ , get

$\left[ \frac{2(\alpha\sigma-1)+\beta}{2\alpha\sigma C} \right]^{\frac{2\alpha\sigma}{2-\beta}} > \left[ \frac{\beta(p-C)}{2p} \right]^{\frac{\beta}{2-\beta}}$ , due to  $\alpha\sigma > 1$  and  $p > C$ , it is obvious that  $\frac{2(\alpha\sigma-1)+\beta}{2\alpha\sigma C} > 0$  and  $\frac{\beta(p-C)}{2p} > 0$  are established, therefore both sides of the inequality at the same time to open  $\frac{2-\beta}{\beta}$  times the square, can be obtained  $\left[ \frac{2(\alpha\sigma-1)+\beta}{2\alpha\sigma C} \right]^{\frac{2\alpha\sigma}{\beta}} > \frac{\beta(p-C)}{2p}$ . In conclusion, when  $\frac{\beta(p-C)}{2p} < \left[ \frac{2(\alpha\sigma-1)+\beta}{2\alpha\sigma C} \right]^{\frac{2\alpha\sigma}{\beta}}$ , then  $D^{DM*} > D^{SM*}$ ; when  $\frac{\beta(p-C)}{2p} > \left[ \frac{2(\alpha\sigma-1)+\beta}{2\alpha\sigma C} \right]^{\frac{2\alpha\sigma}{\beta}}$ , then  $D^{DM*} < D^{SM*}$ ; when  $\frac{\beta(p-C)}{2p} = \left[ \frac{2(\alpha\sigma-1)+\beta}{2\alpha\sigma C} \right]^{\frac{2\alpha\sigma}{\beta}}$ , then

$$D^{DM*} = D^{SM*}.$$

The proof is completed.

### Proof of Proposition 10

The profit function of provider  $i$  is  $\pi_i^{ME}(s_i^{ME}) = \frac{T^\alpha n^\gamma s_i^{ME} p_i^{1-\delta} (P^{ME})^{-\alpha\sigma} (1-\lambda^{ME})}{(\sum_{k=1}^n s_k^{ME} p_k^{-\delta})^{1-\beta}} - \frac{h(s_i^{ME})^2}{2}$ , and the first order condition is  $\frac{T^\alpha n^\gamma p_i^{1-\delta} (P^{ME})^{-\alpha\sigma} (1-\lambda^{ME})}{(\sum_{k=1}^n s_k^{ME} p_k^{-\delta})^{1-\beta}} - h s_i^{ME} = 0$ . In the same way, according to the symmetry conditions  $p_i = p$  and  $s_i^{ME} = s^{ME}$ , the first-order condition can be rewritten as  $T^\alpha n^\gamma p^{1-2\delta} (P^{ME})^{-\alpha\sigma} (1-\lambda^{ME}) \frac{n s^{ME} - (1-\beta) s^{ME}}{(n s^{ME} p^{-\delta})^{2-\beta}} - h s^{ME} = 0$ , which leads to the optimal response to the level of supporting services is  $\hat{s}^{ME}(P^{ME}, \lambda^{ME}) = [T^\alpha n^{\gamma+\beta-2} h^{-1} p^{1-\delta\beta} (P^{ME})^{-\alpha\sigma} (1-\lambda^{ME}) (n+\beta-1)]^{\frac{1}{2-\beta}}$ . The profit function of the platform is  $\pi_p^{ME}(P^{ME}, \lambda^{ME}) = T^\alpha n^\gamma (P^{ME} + \lambda^{ME} p_i - C) (P^{ME})^{-\alpha\sigma} (\sum_{i=1}^n s_i^{ME} p_i^{-\delta})^\beta$ , substituting  $\hat{s}^{ME}(P^{ME}, \lambda^{ME})$  and combining with symmetry, we get  $\pi_p^{ME}(P^{ME}, \lambda^{ME}) = p^{-\beta} (P^{ME} + \lambda^{ME} p - C) (n^\gamma T^\alpha)^{\frac{1}{2-\beta}} (P^{ME})^{\frac{\alpha\sigma}{2-\beta}} [h^{-1} p^{1-\delta\beta} (n+\beta-1) (1-\lambda^{ME})]^{\frac{\beta}{2-\beta}}$ . Finding the first order derivative of  $\pi_p^{ME}(P^{ME}, \lambda^{ME})$  with respect to  $P^{ME}$  and  $\lambda^{ME}$ , the first order conditions is obtained as

$$\begin{cases} P^{ME} \left(1 + \frac{2\alpha\sigma}{\beta-2}\right) + \frac{2\alpha\sigma}{\beta-2} (\lambda^{ME} p - C) = 0 \\ p(1-\lambda^{ME}) - \frac{\beta}{2-\beta} (P^{ME} + \lambda^{ME} p - C) = 0 \end{cases}.$$

Therefore,

the optimal charging strategies of the platform are obtained as  $P^{ME*} = \frac{2\alpha\sigma(2-\beta)(C-p)}{(3-\beta)(\beta-2+2\alpha\sigma)-2\alpha\sigma}$ , and  $\lambda^{ME*} = \frac{(\beta-2+2\alpha\sigma)[p(2-\beta)+C]-2\alpha\sigma C}{p[(\beta-2+2\alpha\sigma)(3-\beta)-2\alpha\sigma]}$ .

Bringing  $P^{ME*}$  and  $\lambda^{ME*}$  into  $\hat{s}^{ME}(P^{ME}, \lambda^{ME})$ , the optimal level of supporting service is obtained as  $s^{ME*} = \left\{ \frac{T^\alpha n^{\gamma+\beta-2} (n+\beta-1) [(2-\beta)(C-p)]^{1-\alpha\sigma}}{h p^{\beta} (2\alpha\sigma)^{\alpha\sigma} [(3-\beta)(\beta-2+2\alpha\sigma)-2\alpha\sigma]^{1-\alpha\sigma}} \right\}^{\frac{1}{2-\beta}}$ .

The proof is completed.

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