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S&T Innovation Platform Sharing Service Contract Mechanism to Achieve Supply Chain Resilience

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Abstract: While achieving fruitful patents in innovation, enterprises can face bottlenecks in industrial transformation. The fundamental cause of such difficulties is the lack of pilot equipment. To this end, the science and technology (S&T) innovation platform introduces equipment sharing to solve the problems in transforming enterprise patents. Based on the premise that service demand is endogenous to platform service effort and user relationship resilience, this paper introduces revenue-sharing and cost-sharing contract mechanisms. It constructs a Stackelberg game model between S&T innovation platforms and enterprise users. Further, we explore the decision-making optimization involving platform service pricing, service effort, and a user's relationship resilience. Our main findings are: (1) service pricing and relationship resilience show supermodularity to the platform revenue while showing submodularity to the user revenue. (2) The optimal user relationship resilience always indicates a decreasing trend in the pricing of platform services. (3) The platform and users have their preferences for contract types. When the platform dominates the game, they tend to adopt a revenue-sharing contract. When the users dominate, they are more willing to implement a cost-sharing contract. (4) As the S&T innovation platform strengthens the connection between the platform and users through the revenue- and cost-sharing contracts, it further enhances the supply chain collaboration among equipment suppliers, technology innovation platforms, and users, thereby achieving the purpose of improving supply chain sustainability and resilience. Technological innovation is an essential means to improve supply chain sustainability and resilience.

Keywords: science and technology platform; supply chain resilience; relationship resilience; synergy mechanism

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1. Introduction

1.1. Background

Developed countries in the United States and Europe continue to suppress China's high-tech development, and core technologies restrict the high-quality development of Chinese enterprises. For China, independent innovation and transformation of technology are imminent. To realize the strategy of innovation-driven development and achieve the goal of "Made in China 2025", China has already embarked on the road of competition for high-end S&T resources and technology. According to the "2021 Global Innovation Index Report" released by the World Intellectual Property Organization (WIPO), China ranks first in the world, with 68,720 patent applications, and the number of invention patent applications has ranked first in the world for ten consecutive years. However, a large number of patent innovation achievements have not brought actual economic value growth. In 2020, the industrial conversion rate of China's effective invention patents was only 34.7%. Among them, the patent conversion rate of enterprises is 63.7%, and the patents of universities are only 13.8%. This wastes the initial investment in S&T innovation, reduces the overall efficiency of S&T innovation resources, and seriously hinders the implementation of China's "innovation-driven development" strategy.

Considering the high risk of the direct transfer of patents to mass production, innovative enterprises hope to introduce the pilot test link for transition. The pilot test of S&T innovation generally needs to be realized through the pilot test platform of large scientific installations. However, it is difficult for innovative small and medium-sized enterprises that lack both capital and transformation facilities to carry out the pilot test of the transformation of innovation achievements. This is the main reason for the low conversion efficiency of technological patent innovation achievements. Therefore, to promote the transformation of innovation achievements, Chinese governments at all levels have built a multi-participation service platform for science and technology innovation, based on the pilot test of large scientific installations (referred to as the science and technology innovation platform). Its essence is a scientific and technological institution or organization that integrates and gathers scientific and technical resources, has the characteristics of openness and sharing, and supports and serves scientific research and technological development activities [1]. By centrally purchasing pilot equipment and providing shared services, the platform enables enterprises to obtain equipment-use rights without having to undertake high investment and realizes the effective transformation from patented technology to industrial achievements. At the same time, the platform can also use its scale effect to improve the utilization rate of large-scale scientific research equipment and fully release the public R&D service potential of the equipment. However, the lack of a market-oriented price mechanism and the lack of incentives for win–win income distribution among multiple stakeholders in the construction of science and technology innovation platforms have restricted the service capacity and service efficiency of the pilot stage of the transformation of scientific and technological achievements. Therefore, it is crucial to consider network effects, multilateral cooperation and complexity, and guide the multi-participants linked by the science and technology platform to co-create the value of the main body; moreover, from the perspective of stakeholders, it is important to design a scientific and reasonable revenue-sharing mechanism and improve the utilization efficiency of scientific and technological resources.

1.2. Literature Review

Innovation is a crucial driving force for the success of modern enterprises, and innovation activities are deeply embedded in innovation networks. The S&T platform can stimulate innovation collaboration and the construction of an innovation network. Bai et al. (2021) [2] proposed that the structural characteristics of global innovation networks, the willingness to integrate networks, and the capability of integrating networks all positively impact business performance. However, the above study focuses on qualitative analysis and does not involve the decision-making optimization of quantitative content, such as service pricing, in the actual operation of the platform. How to improve cooperation performance through a suitable service incentive mechanism remains to be explored. It is difficult for companies with high innovation costs to maintain sustainable innovation capabilities in a closed environment. This dilemma has given rise to the motivation for companies to seek cooperation with external resources. Market competition and open innovation jointly affect the occurrence mechanism of enterprise technological innovation [3]. As an innovation subject, the technology innovation platform widens enterprises' innovation channels and accelerates the industrial transformation process of technological patents [4]. The S&T innovation platform mainly serves enterprises, universities, research institutes, the government, and other cooperative innovation entities, helping them form a cooperative relationship of resource sharing and collaborative innovation. Science and technology enterprises can achieve cross-border interconnections through science and technology platforms to improve innovation efficiency and help achieve breakthroughs in standard technological innovation; the science and technology innovation platform connects the supply and demand market by integrating various innovative scientific and technical resources and provides professional services for the transformation of S&T patent achievements, such as resource sharing and R&D collaboration for the S&T innovation activities of the whole society and it is also a service organization that gathers national S&T innovation resources, serves and connects scientific research and technology transformations, and other innovation activities [5]. Therefore, the technology innovation platform has the characteristics of socialization and marketization and needs to achieve self-sufficiency through a market-oriented operation. Xie et al. (2017) [1] defined four types of innovative platform networks from the two dimensions of network centrality and network structure hole as loose, compact, information-accumulating, and center-led. They believed that the service operation model of the future technology innovation platform needed to be differentiated.

In recent years, quantitative research on platform services has become increasingly abundant. Many scholars have focused on the pricing mechanism of the platform and have demonstrated in different situations such as e-commerce platforms, shared travel platforms, and social network platforms, and found that the platform's pricing design and incentive mechanisms can effectively guide stakeholders to join the platform. Scholars also discussed the impact of platform service efforts, taking the degree of service effort as an important factor affecting market demand. Kuo et al. (2018) [6] studied the product leasing service system composed of remanufacturing enterprises and product users and established the basic assumption that service demand is entirely dependent on the degree of bilateral efforts. In addition, Hagiu et al. (2013) [7] defined the buyer's participation degree on the platform when they studied the two-sided market, focusing on depicting the user's consumption of platform services. The higher the relationship resilience, the higher the cooperation between the two parties. It can be seen that service pricing, service effort and relationship resilience are gradually becoming the key factors for research platform decision-making. However, there is no literature that considers the above three factors in combination, and it is necessary to deeply explore the S&T innovation platform's operational decision-making in the context where its service performance is simultaneously affected by the three factors.

Scholars have increasingly acknowledged the necessity of research on service innovation. Spohrer et al. (2008) [8] believe that service innovation has great potential to affect productivity, quality, growth rate, and rate of return. In addition, services can also create customer value. However, it is difficult for a single enterprise to complete service innovation independently. Lusch et al. (2015) [9] established a framework for service innovation from three preceptive: platform, ecosystem, and value creation. Additionally, Turoń (2022) [10] studied car-sharing services from an open innovation perspective, suggesting an evolving platform providing diverse services by utilizing data gathered from the platform. Similarly, Liang et al. (2021) [11] studied a pricing model for a car-sharing business. They proposed a strategy requiring cross-border integration between the sharing service provider and the manufacturing industry. The application of open innovation on a technology platform can create more value for the participants.

Apart from open innovations, the number of research related to CSR and sustainability has been steadily increasing in recent years [12], with the main driving topics being CSR, sustainability, and the environment [13]. Sardana et al. (2020) [14] pointed out that environmental sustainability directly impacts company performance, while the impact of supplier sustainability on company performance is positively moderated by factory capacity. Furthermore, the research results of Kucharska et al. (2019) [15] show that corporate reputation is a potent mediator of the relationship between corporate social responsibility practice and corporate performance, and the cultural dimension of long-term orientation has the most significant impact on corporate social responsibility practice. To sum up, scholars believe that CSR has an essential effect on the sustainable development of individual enterprises. Still, the connection between CSR and supply chain cooperation and the impact of CSR on supply chain sustainability has not yet been explored.

Service level, as a reflection of the effort input of supply chain channels, requires enterprises to make decisions about service price and service effort level, affecting supply chain profits and contract design. Cachon et al. (2019) [16] conducted a theoretical study on the differentiated pricing market, explored the optimal strategy for platform-differentiated pricing, and achieved differentiated pricing for different types of customers. Marinesi (2019) [17] studied the optimal pricing strategy of service providers under differentiated services with capacity constraints. This involves network effects, including same-side network effects and cross-side network effects. The former is also called the self-network effect, which means that user utility increases with the expansion of the scale of users on the same side. The latter, also known as cross-network effects, refers to the increase in user utility as the scale of users on the other side of the platform increases [18]. Kumar et al. (2021) [19] all believed that the balance of the platform user scale would be affected by the external effects of the platform network. Fainmesser et al. (2020) [20] found that in the equilibrium state, companies charging premiums or subsidies significantly impact consumers, which depends on the level of network effects and the degree of information disclosure. The pricing strategy of platform service has a profound influence on its user scale.

If the S&T innovation platform and users make decisions independently, the motivation of both parties to pursue their profit maximization will easily lead to double marginalization. Therefore, it is necessary to embed a mechanism to solve it, and one of the important means is the supply chain contract. Cachon et al. (2005) [21] were the first to introduce revenue-sharing contracts into supply chains and found that revenue-sharing contracts could optimize supply chain profits in a wide range of research contexts. Focusing on the decentralized decision-making in the equipment sharing of the S&T platform, it is worth exploring whether the idea of a supply chain contract can be used to form an interesting relationship between the subjects and optimize the decision-making. Regarding the related research on the multi-party revenue-distribution mechanism, Xie et al. (2017) [4] studied the problem of contract coordination based on the Stackelberg game model in the dual-channel closed-loop supply chain, designed a revenue-sharing–cost-sharing contract, and found that a reasonable set of revenue-sharing and cost-sharing ratio can effectively improve the efforts of retailers' channel services and recycling services, thereby increasing the profits of supply chain members. Liu et al. (2020) [22] conducted research on revenue sharing and cost sharing from the environmental perspective: cost sharing can encourage firms to produce greener products under the retailer Stackelberg game. Under the manufacturer Stackelberg game, however, revenue sharing is more effective in improving the eco-friendliness of the products. However, the contract-sharing mechanism in the innovation platform has yet to be studied.

The past few years have seen many major restructuring and reshaping of the global economic system, geopolitical tensions, renewed protectionism, and rising costs. These factors have increased the pressure on social and environmental regulation compliance and caused substantial risks to global supply chains. Hence, scholars began to study how to improve supply chain resilience to deal with related risks. The concept of resilience first came from ecology [23], and was later cited and borrowed from research fields of economics and management. Most scholars view resilience as the ability to respond or withstand disruption or disturbance [24,25]. Kamalahmadi et al. (2016) [26] view supply chain resilience as the ability to adapt to reduce the probability of disruption. When studying the resilience of a particular system, the time it takes for the system to return to a steady state is identified as fundamental [27]; scholars then consider the post-disturbance period and how the system reaches a steady state, where equal or better positions in the system are associated with supply chain resilience [28]. In terms of improving supply chain resilience, Xu et al. (2019) [5] proposed that applying big data technology has a sustainable impact on supply chain coordination. Min et al. (2019) [29] found that blockchain technology can mitigate the risks associated with intermediary intervention in supply chains, thereby enhancing supply chain resilience. Rajesh (2017) [30] proposed that the technical capability of enterprises to modify supply chain design and planning capabilities can effectively improve supply chain resilience. It is clear that a resilient supply chain should be able to prepare for, respond to, and recover from disruptions, and then maintain a positive steady state operation at an acceptable cost and time. That technological innovation can effectively provide supply chain resilience.

Vertical alliance and collaboration are found to be greatly beneficial for the companies in the supply chain. Wang et al. (2019) [31] analyzed the impact of government regulation on the two-sided market competition with network externalities and used subsidies as a decision variable to establish a Hotelling model to describe the competition in the taxi market. Cachon et al. (2019) [16] found that the relationship between the enterprise and the service platform can be coordinated. The Pareto optimality of the platform and multi-party participants can be achieved through the supply chain contract. As an integration method of the platform, vertical cooperation alliance also has the typical characteristics of upstream and downstream of the traditional supply chain. At the same time, supply chain integration is functional cooperation across enterprise boundaries, which plays a significant mediating role in the impact on quality certification, and the mediating role of vertical cooperation alliances is even more substantial. Scholten et al. (2015) [32] study the impact of collaboration on supply chain innovation using data from the food industry. Their study also suggests that visibility, velocity, and flexibility are three approaches that increase the supply chain's resilience. Shekarian et al. (2021) [33] claimed collaboration to be the most effective way to face supply chain disruption. Umar et al. (2021) [34] conducted a case study on the influence of supply chain collaboration in a challenging natural environment. Further investigations found that partnerships enhance resilience through communication, financial support, and trust. Platform vertical cooperation alliances and collaboration are effective in reducing transaction costs, coordinating behaviors to improve efficiency, consolidating market positions, and enhancing supply resilience.

1.3. Motivation and Contribution

The research motivation of this paper includes the following two points: First, according to the service characteristics of the science and technology platform, we introduce the "number of equipment services" to describe the service demand and discuss the optimal decision-making and related properties of the platform and users under the service charging model formed accordingly. Second, we introduce revenue-sharing and cost-sharing contract mechanisms for the double profit margin problem and explore the mutual impact of platform and user profits by the cost-sharing and revenue-sharing ratio and the content of their respective decision.

The supply chain collaboration between equipment suppliers and equipment users through the technology innovation platform and contract mechanism can improve corporate performance, reduce overall costs and inventories, and strengthen the interest link between enterprises, thereby enhancing supply chain resilience.

The remainder of this paper is organized as follows. Section 2 describes the relationship between science and technology innovation platforms and their participants. Section 3 introduces the service model of the S&T platform and discusses the service strategy. Section 4 further elaborates on the revenue-sharing contract and its effect on the service model of the S&T platform. Section 5 presents the numerical analysis. Finally, Section 6 provides a summary and conclusions.

2. Model and Parameters

2.1. Problem Description

We consider a patent-sharing service system composed of science and technology innovation platforms and enterprise users, provide large-scale scientific research equipment to enterprises in the form of pilot equipment, offer equipment-sharing services, purchase a certain amount of equipment services, and use the platform to complete the pilot test. As an equipment service provider, the platform has the right to price the service, decides the level of service effort on its own, and bears the corresponding service costs, including the debugging before the equipment is used, the consumables, power, labor in use, and the cleaning and maintenance after use. As the demander of equipment services, users cultivate a certain resilience between themselves and the platform and use this to determine the size of equipment service requirements.

The higher the resilience of the user relationship, the larger the scale of the pilot test, and the higher the success rate of the subsequent industrial transformation of the achievements. Of course, the cost of maintaining the relationship that needs to be invested in advance is correspondingly higher. Traditional product rental services are mostly charged according to the rental unit price, quantity, and duration. However, large-scale scientific research equipment has particularities in volume, value, and use. Considering the above reasons, the S&T platform does not directly provide external leasing of scientific research equipment, but is based on the equipment storage site, is operated by professionals based on user needs to output equipment services, and charges fees based on equipment service volume and service unit price.

2.2. Model Notation

Combined with the problem description, the relevant variables and parameters involved are symbolized in Table 1. Among them, the value range of platform service effort is $L \in (0,\ 1]$. When $L = 1$, the platform will do its best to put in the best effort, so users enjoy the best service; when $L \in (0,\ 1)$, the platform will invest some effort with reservation, and the degree of effort increases with the value of L and increase. The value range of user relationship resilience is $\delta \in (0, 1]$. When $\delta = 1$, the user completely trusts the platform and chooses to conduct the pilot test with the largest scale and belongs to the "loyal user" of the platform; when $\delta \in (0, 1)$, the user relatively trusts the platform and considers participating in the pilot test with an appropriate scale, belonging to the "developmental users" of the platform. To ensure cooperation between the two parties, the service effort of the platform cannot be 0, and the resilience of the user relationship cannot be 0.

Table 1. Definition of decision variables and parameters.

Parameters	Description
p_s	The single-device service price charged by the platform
c	The single equipment service cost borne by the platform
L	The level of service effort of the platform
δ	The resilience of the relationship between users and the platform
$K_1(L)$	The cost function of platform service effort
$K_2(\delta)$	The cost function of user-maintained relationship resilience
$T(L, \delta)$	The number of user's device service purchases
$R(L, \delta)$	User's scientific research achievements transformation profit
$\varnothing$	The proportion of the platform sharing the achievement conversion profit from users
η	The proportion of the total service operation cost shared by users for the platform
Π_P	Profit function of the platform
Π_U	Profit function of users

In this paper, combined with the actual operation of the science and technology platform, the platform profit function is set as $\Pi_P = (p_s - c)T(L, \delta) - K_1(L)$. The platform profit is a per-time fee for providing equipment-sharing services to users, and its cost consists of two parts: the direct service cost and the service effort cost. Set the user profit function as $\Pi_U = R(L, \delta) - p_s T(L, \delta) - K_2(\delta)$, the user income is the conversion income of the final marketization of R&D patents after the pilot test. The cost is also composed of two parts: one is the cost of purchasing equipment services from the platform, and another is the effort cost of maintaining a close relationship with the platform.

2.3. Function Assumptions

To make the research situation conform to the realistic logic and simplify the analysis to a certain extent, the assumptions in Table 2 are made on the properties of the correlation function.

Table 2. Assumptions of main function properties.

Function	Assumptions	Description
$K_1(L)$	$\frac{dK_1(L)}{dL} \geq 0, \frac{d^2K_1(L)}{dL^2} \geq 0$	Platform service effort cost increases with effort and is a convex function
$K_2(\delta)$	$\frac{dK_2(\delta)}{d\delta} \geq 0, \frac{d^2K_2(\delta)}{d\delta^2} \geq 0$	User relationship resilience cost increases with resilience and is a convex function
	$\frac{\partial T(L,\delta)}{\partial L} \geq 0, \frac{\partial^2 T(L,\delta)}{\partial L^2} \leq 0$	The number of device services increases with the platform service effort and is a concave function
$T(L,\delta)$	$\frac{\partial T(L,\delta)}{\partial \delta} \geq 0, \frac{\partial^2 T(L,\delta)}{\partial \delta^2} \leq 0$	The number of device services increases with the resilience of the user relationship and is a concave function
	$\frac{\partial^2 T(L,\delta)}{\partial L \partial \delta} = 0$	The number of device services is not affected by the combination of platform service effort and user relationship closeness
$R(L,\delta)$	$\frac{\partial R(L,\delta)}{\partial L} \geq 0, \frac{\partial^2 R(L,\delta)}{\partial L^2} \leq 0$	The user achievement conversion income increases with the platform service effort and is a concave function

The theoretical model structure of this paper is shown in Figure 1. Taking the Stackelberg game as the basic framework, the platform, as the service provider, plays the leading role in the game, and the user, as the service demander, plays the follower role.

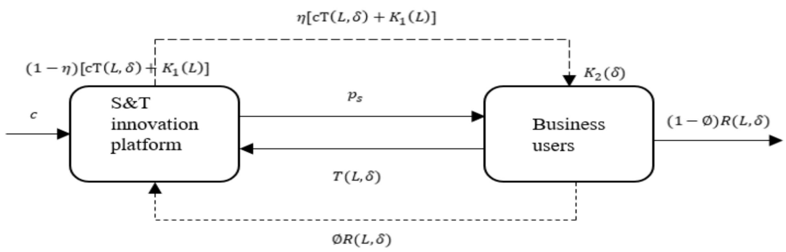


Figure 1. Model framework based on Stackelberg game.

3. Decision-Making Model of Service of S&T Innovation Platform Based on Stackelberg Game

Model Construction

The basic game model between the S&T innovation platform and users can be expressed as follows

$$\max_{(p_s>0,\ L\in(0,1])} \Pi_P = (p_s - c)T(L,\delta) - K_1(L) \tag{1}$$

$$\text{s.t.} \max_{(\delta\in(0,1])} \Pi_U = R(L,\delta) - p_s T(L,\delta) - K_2(\delta) \tag{2}$$

The decision-making sequence of the game is that first, the platform, as the game leader, decides the service price p_s and service effort L according to its profit function Π_P, then, the user acts as a game follower, based on the given platform decision $(p_s,\ L)$, combined with users' profit function Π_U, and decides the level of resilience of the relationship with the platform δ.

Proposition 1. *When the service pricing and service effort of the science and technology platform satisfy the inequations* $p_s \leq \left(\frac{\partial^2 T(L,\delta)}{\partial \delta^2}\right)^{-1}\left(\frac{\partial^2 R(L,\delta)}{\partial \delta^2} - \frac{d^2 K_2(\delta)}{d\delta^2}\right)$ *and* $\frac{d^2 K_1(L)}{dL^2} \geq$

$\frac{(p_s-c)\frac{\partial^2 T(L,\delta^*(L,p_s))}{\partial L^2}G_0-\left(\frac{\partial T(L,\delta^*(L,p_s))}{\partial L}\right)^2}{G_0}$, *respectively, there are optimal* $(p_s{}^*, L^*)$ *and* δ^* *that make* Π_P *and* Π_U*achieve the maximum value, respectively.*

Proposition 1 shows that in the basic game of the platform and the user, there are maximum profits for both parties, and the condition for obtaining the maximum profit is the platform's service pricing p_s has an upper limit, and its service effort cost function $K_1(L)$ has at least a certain convexity. All the proofs are shown in Appendix A.

In connection with the actual operation of the science and technology platform, the rationality of the two conditions is: on the one hand, if the platform service is priced too high, the user scale of the equipment service market will be limited and the potential of the platform service cannot be fully released, which will hinder the future development of the platform. The continued operation, on the other hand, the platform's efforts to improve its services mean that it faces both an increase in service demand and an increase in service costs, which have the opposite impact on the platform's profits.

Property 1. *For the S&T innovation platforms, the higher the service pricing, the greater the contribution of platform service efforts to its profits; the higher the resilience of user relationship with the platform, the greater the contribution of platform service pricing to its profits.*

$$\frac{\partial^2 \Pi_P}{\partial L \partial p_s} \geq 0, \frac{\partial^2 \Pi_P}{\partial p_s \partial \delta} \geq 0 \quad (3)$$

Property 1 shows that the profit function Π_P of the S&T platform has the property of supermodularity with respect to $(L,\ p_s)$ and (p_s, δ). The supermodel property means that adding a variable while adding another variable has a more significant effect than simply adding the original variable. For the S&T platform, when the service effort is improved, users are willing to increase the number of equipment services, thus opening the market for the platform. If the service price is moderately increased at this time, the profit space can be relatively widened. Similarly, when users increase the resilience of their relationship, rather than maintaining the original service price, the platform is more motivated to increase the price to increase profits, thereby accumulating funds to invest in more equipment and further expanding the equipment service market.

Property 2. *For users of the technology innovation platform, the higher the service price, the smaller the contribution of the resilience of the user relationship to their profits.*

$$\frac{\partial^2 \Pi_U}{\partial \delta \partial p_s} \leq 0 \quad (4)$$

Property 2 shows that user profit Π_U has the property of submodularity with respect to (δ, p_s). By improving the resilience of the relationship between users and the platform, they can not only directly increase the transformation income of the achievements after the completion of the pilot test, but also indirectly increase the success rate of industrialization of patented technologies by increasing the number of services. This shows that users' increasing relationship resilience has a double promotion effect on their profits. However, this promotion effect will be inhibited when the platform service pricing is raised. The platform increases the service price to keep the service level unchanged, which will make the users who are followers fall into passive decision-making. Therefore, rational enterprises should base on the specific charging standards for platform equipment services.

Property 3. *For S&T innovation platforms, the higher the unit service cost, the smaller the contribution of platform service efforts to its profits.*

$$\frac{\partial^2 \Pi_P}{\partial L \partial c} \leq 0 \quad (5)$$

Property 3 shows that the profit function Π_P of the science and technology platform has the submodular property of $(L,\ c)$. A platform with a higher unit service cost, the contribution effect of improving service efforts to its profit is inferior to a platform with a lower cost. In addition to dynamically adjusting service pricing and service effort, the platform must manage and control operating costs at any time.

Conclusion 1. *For platform users, service pricing needs to reais simultaneously with service effort to increase the relation resilience, thereby enhancing the resilience of the platform supply chain.*

4. S&T Innovation Platform Service Decision-Making Introducing Contract Mechanism

4.1. Revenue-Sharing Contract Mechanism

Model construction After the introduction of the revenue-sharing contract, the profit functions of the technology innovation platform and users are recorded as Π_P^{rs} and Π_U^{rs}, respectively, and the superscript rs represents the revenue-sharing contract. At this time, the game process can be expressed as follows

$$\max_{(\mathrm{p_s}>0,\ \mathrm{L}\in(0,1])} \Pi_P^{rs} = (p_s - c)T(L,\delta) - K_1(L) + \varnothing R(L,\delta) \tag{6}$$

$$\text{s.t.} \max_{(\delta\in(0,1])} \Pi_U^{rs} = (1-\varnothing)R(L,\delta) - p_s T(L,\delta) - K_2(\delta) \tag{7}$$

The decision-making sequence of the new game is as follows: First, the platform and users determine the revenue-sharing ratio $\varnothing$ through negotiation. The level of this ratio depends on the relative negotiation ability of the two parties. Its influencing factors include enterprise market share, platform network externality strength, respective cost control levels, etc., and thus, determine the income distribution method of the entire scientific research equipment sharing service system. The following decision-making sequence is the same as the previous section. The platform first decides the service price p_s and the service effort level L. On this basis, the user decides on the resilience of the relationship δ, and finally, both parties realize their respective profits.

Proposition 2. *In the game between the S&T innovation platform and users that introduce the revenue-sharing contract mechanism, when the platform's service pricing and service effort satisfy the equations* $\frac{\partial\delta^*(L,p_s)}{\partial p_s} \le 0$ *and* $\frac{d^2K_1(L)}{dL^2} \ge \frac{\left[(p_s-c)\frac{\partial^2 T(L,\delta^{rs*})}{\partial L^2}+\varnothing\frac{\partial^2 R(L,\delta^{rs*})}{\partial L^2}\right]G_0^{rs}-\left(\frac{\partial T(L,\delta^{rs*})}{\partial L}\right)^2}{G_0^{rs}}$, *respectively, there is an optimal* (p_s^{rs*}, L^{rs*}) *and* δ^{rs*} *make* Π_P^{rs} *and* Π_U^{rs} *achieve the maximum value, respectively. The proof is shown in Appendix C.*

Proposition 2 shows that in the case of introducing a revenue-sharing contract, there is still a maximum profit for the S&T innovation platform and users, and the premise of obtaining the maximum value is similar to that of Proposition 1, that is, the service pricing and service effort level of platform decision-making should meet certain conditions, respectively. For the service pricing p_s, by comparing inequalities $p_s \le \left(\frac{\partial^2 T(L,\delta)}{\partial\delta^2}\right)^{-1}\left(\frac{\partial^2 R(L,\delta)}{\partial\delta^2} - \frac{d^2K_2(\delta)}{d\delta^2}\right)$ and $p_s \le \left(\frac{\partial^2 T(L,\delta)}{\partial\delta^2}\right)^{-1}\left[(1-\varnothing)\frac{\partial^2 R(L,\delta)}{\partial\delta^2} - \frac{d^2K_2(\delta)}{d\delta^2}\right]$, it can be found that the conditions that p_s^{rs*} should meet are more stringent than p_s^*, which means that the value range of platform service pricing is narrower after the introduction of the revenue-sharing contract, and the feasible region is closer to the marginal cost, which is conducive to the contract mechanism to play its optimization role. For the service effort level L^{rs*}, the service effort cost function of the platform after the introduction of the revenue-sharing contract still needs to have a certain convexity to prevent the platform service level from showing no differentiation.

4.2. Cost-Sharing Contract Mechanism

Model construction After the cost-sharing contract is introduced, the profit functions of the S&T innovation platform and users are recorded as Π_P^{cs} and Π_U^{cs}, respectively, and the superscript cs represents the cost-sharing contract. The new game process can be expressed as follows:

$$\max_{(p_s>0,\ L\in(0,1])} \Pi_P^{cs} = p_s T(L,\delta) - (1-\eta)[cT(L,\delta) + K_1(L)] \tag{8}$$

$$\text{s.t.} \max_{(\delta\in(0,1])} \Pi_U^{cs} = R(L,\delta) - p_s T(L,\delta) - \eta[cT(L,\delta) + K_1(L)] - K_2(\delta) \tag{9}$$

At this time, the platform and users first determine the cost-sharing ratio η through negotiation and then continue to play the Stackelberg game on this basis, and the decision-making order of both parties in the game remains unchanged.

Proposition 3. *In the game between S&T innovation platforms and users with the introduction of a cost-sharing contract mechanism, when the platform's service pricing and service effort satisfy* $p_s \le \left(\frac{\partial^2 T(L,\delta)}{\partial\delta^2}\right)^{-1}\left[\frac{\partial^2 R(L,\delta)}{\partial\delta^2} - \frac{d^2K_2(\delta)}{d\delta^2}\right] - \eta c$ *and* $\frac{d^2K_1(L)}{dL^2} \ge \frac{[p_s-(1-\eta)c]\frac{\partial^2 T(L,\delta^{cs*})}{\partial L^2}G_0^{cs} - \left[\frac{\partial T(L,\delta^{cs*})}{\partial L}\right]^2}{(1-\eta)G_0^{cs}}$, *respectively, there is an optimal* (L^{cs*}, p_s^{cs*}) *and* δ^{cs*} *make* Π_P^{cs} *and* Π_U^{cs} *achieve the maximum value respectively, the proof of proposition 3 is shown in* Appendix C.

Proposition 3 shows that when the cost-sharing contract is introduced into the game, the profit of the platform and users still has a maximum value, and the premise of the existence of the maximum value is that the platform service pricing and service effort cost functions still need to meet certain conditions. There is an upper limit constraint on the value range of service pricing p_s. This upper limit threshold is lower than the basic model, which means that introducing the cost-sharing contract requires the platform to reduce service pricing to compensate users for sharing the total operating cost.

In both cases of revenue sharing and cost sharing, the service pricing threshold for the maximum profit value is lower than the pricing threshold in the basic model, and depends on the revenue-sharing ratio or cost-sharing ratio, respectively. The cost function $K_1(L)$ of the platform service effort still needs to have a certain convexity, reflecting the fact that after the effort input exceeds a certain level, adding a unit of marginal effort requires more cost input.

Proposition 3 shows that when introducing cost-sharing contracts, the higher the platform service pricing, the lower the optimal relationship resilience for users with the platform. Since the analysis process is similar to Proposition 2, it will not be expanded here.

4.3. Analysis of Properties under Different Contract Mechanisms

In the two game situations where contracts are introduced, for the S&T innovation platform, for its profit functions Π_P^{rs} and Π_P^{cs}, find the mixed partial derivatives of service effort L, service price p_s, revenue-sharing ratio $\varnothing$, and cost-sharing ratio η, respectively. From this, we can deduce the following property 4:

Property 4. *In the game between S&T innovation platforms that introduce a contract mechanism and users, for the platform, the higher the ratio of revenue sharing or cost sharing, the greater the contribution of platform service efforts to its profits and the contribution of service pricing to profit is not affected by revenue-sharing ratio or cost-sharing ratio.*

$$\frac{\partial^2\Pi_P^{rs}}{\partial L\partial\varnothing} \ge 0, \frac{\partial^2\Pi_P^{rs}}{\partial p_s\partial\varnothing} = 0, \frac{\partial^2\Pi_P^{cs}}{\partial L\partial\eta} \ge 0, \frac{\partial^2\Pi_P^{cs}}{\partial p_s\partial\eta} = 0 \tag{10}$$

Property 4 shows that, after introducing the contract mechanism, with the increase of the S&T innovation platform's profit and the ratio of revenue/cost sharing, service effort demonstrates an increasing effect in improving the platform's profit. Moreover, the ratio of revenue sharing and cost sharing does not affect the contribution of service pricing to platform profits.

Further, for the user, the mixed partial derivatives of the relationship resilience with the platform δ, service pricing p_s, revenue-sharing ratio $\varnothing$, and cost-sharing ratio η are obtained for their profit functions Π_U^{rs} and Π_U^{cs}, and the following Property 5 can be obtained.

Property 5. *In the game between the S&T innovation platform and users that introduce the contract mechanism, for users, the higher the price of platform services, the smaller the contribution of the resilience of user relationships with the platform to their profits; the greater the coefficient of revenue sharing or cost sharing, the smaller the contribution of the resilience of user relationships with the platform to their profits.*

$$\frac{\partial^2 \Pi_U^{rs}}{\partial\delta\partial p_s} \le 0, \frac{\partial^2 \Pi_U^{rs}}{\partial\delta\partial\varnothing} \le 0, \frac{\partial^2 \Pi_U^{cs}}{\partial\delta\partial p_s} \le 0, \frac{\partial^2 \Pi_U^{cs}}{\partial\delta\partial\eta} \le 0 \tag{11}$$

Property 5 indicates that under the contract mechanism, service price and relationship resilience have no contribution to the profit of platform users. With the same service effort, raising the service price will cause a decrease in relationship resilience.

Corollary 1. *Regardless of the introduction of the contract mechanism, the optimal user relationship resilience of the S&T platform decreases with the increasing platform service pricing and the ratio of revenue/cost sharing. However, changes in the ratio of revenue/cost sharing do not affect the contribution of service prices to platform profits.*

As we can see in Table 3, corollary 1 shows that improving the design of the service price mechanism is an important method to boost the marketization of the S&T platform. However, if the platform wants to maintain sustainable development and enhance the supply chain's resilience, the platform should increase the service effort while raising the service price. Otherwise, the relationship resilience between the platform and users, which reflects the supply chain's resilience, will decrease as the service price increases. Users will reduce the number of equipment service purchases due to higher prices.

Table 3. User relationship resilience under different contract.

Contract Type	Stackelberg Game	Revenue-Sharing Contract	Cost-sharing Contract
the relationship with p_s and	$\frac{\partial\delta^*(L,p_s)}{\partial p_s} \le 0$	$\frac{\partial\delta^{rs*}(L,p_s,\varnothing)}{\partial p_s} \le 0$	$\frac{\partial\delta^{cs*}(L,p_s,\eta)}{\partial p_s} \le 0$
the relationship with δ and $\varnothing$, η	/	$\frac{\partial^2\Pi_P^{rs}}{\partial p_s\partial\varnothing} = 0$	$\frac{\partial^2\Pi_P^{cs}}{\partial p_s\partial\eta} = 0$
The effect of supply resilience on the ratio of revenue/cost sharing	/	$\frac{\partial^2\Pi_U^{rs}}{\partial\delta\partial\varnothing} \le 0$	$\frac{\partial^2\Pi_U^{cs}}{\partial\delta\partial\eta} \le 0$

Conclusion 2. *Revenue sharing means that users share part of the results from the transformation of the achievements to the platform, while cost sharing means that users share part of the operating costs of equipment services for the platform. Whether the sharing or the sharing ratio is increased, it means that users' profits are diluted to a certain extent. Therefore, although users can improve their profits by promoting the conversion of achievements, with the increase in the proportion of revenue sharing or cost sharing, the profit contribution effect will no longer be significant.*

5. Model Analysis

This section uses the Shanghai high-tech transformation data, as well as the data from the field investigation of the Shanghai Baoshan graphene industry technology platform. We compared the profit of the platform and the user, with the profit of the different contracts.

5.1. Function and Parameters

We use the equipment service purchase frequency function $T(L,\delta)$, the achievement transformation revenue function $R(L,\delta)$ from Yan et al. (2019) [35].

$$T(L,\delta) = \frac{F}{A+B}[A\ln(1+L) + B\ln(1+\delta)] \quad (12)$$

$$R(L,\delta) = \frac{G}{A+B}\left[A\ln(1+L) + B\ln(1+\delta) - \frac{AL}{2} - \frac{B\delta}{2}\right] \quad (13)$$

A and B represent the contribution weight of platform service effort L and user relationship resilience δ to the number of service purchases. F is approximate parameters of platform service scale. G is the approximate parameters of return to scale. The cost function of the platform service effort $K_1(L)$ and the cost function of user-maintained relationship resilience $K_2(\delta)$ are $K_1(L) = \frac{1}{2}K_1L^2$, $K_2(\delta) = \frac{1}{2}K_2\delta^2$. K_1 and K_2 represent the effort cost coefficients of the platform and users, respectively.

According to the website of the Shanghai Municipal People's Government (http://www.shanghai.gov.cn/nw2/nw2314/nw3766/nw3859/nw4886/u1aw372.html (accessed on 26 July 2021)), there were 493 high-tech achievement transformation projects in Shanghai in 2017, and the achievement transformation income was about 86.753 billion yuan, that is, the average achievement transformation income was 176 million yuan per project. However, for medium and minor enterprises, the return to scale of the high-tech achievement transformation is 25% of the average value, which is 0.44 million yuan. The service targets of the science and technology platform are mainly medium and minor enterprise enterprises because these enterprises do not have the strong financial strength to purchase equipment. Based on the above facts, we assume G = 40,000 (in thousand yuan). F takes the value of 250 according to the statistics of the Shanghai Large Laboratory Apparatus Facility Information Service Database. Based on the field investigation of the Shanghai Baoshan graphene industry technology platform, we set K_1 = 500 (in thousand yuan) and K_2 = 1000 (in thousand yuan).

In the practical situation, the price of equipment service ranges from hundreds to thousands of yuan. According to the statistics from Shanghai Large Laboratory Apparatus Facility Information Service Database, the safety and material performance test system of non-metallic products is the most shared equipment in the past year, the price as well as the operation and maintenance cost of which is 4 thousand yuan/batch and 1 thousand yuan/batch, respectively. Therefore, the model parameters are set as shown in Table 4.

Table 4. Settings of parameter values in numerical analysis.

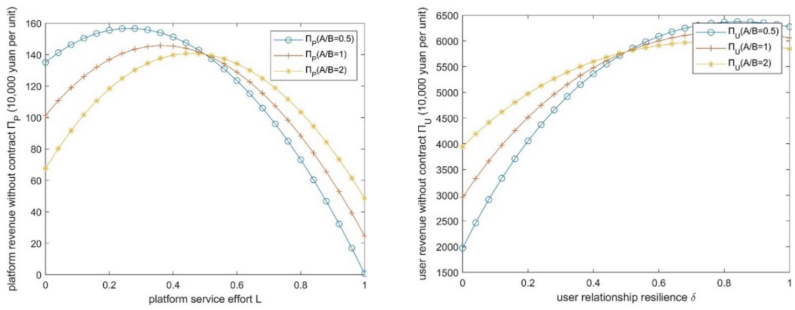
G	F	K_1	K_2	p_s	c	L	δ	A	B
40,000	250	500	1000	4	1	0.5	0.5	1	1
4	1	0.5	0.5	500	1000	1	1	250	40,000

Note: In 1 thousand yuan.

5.2. The Impact of Contribution Weights on Platform and User Profits

Figure 2 examines the impact of platform service effort L and user relationship resilience δ on platform and user's profits under different contribution weights.

First of all, for the platform, Figure 2a shows that, on the one hand, when the ratio of A/B is larger, that is, the greater the contribution of the platform to improving the service effort to the increase in the number of service purchases, the greater the platform's optimal service effort. This means that the greater the impact of platform service effort on demand, the more motivated the platform is to put effort into its service. On the other hand, when A/B takes different values, the profit of the platform intersects at $L = \delta$, and when it is on the left side of the intersection ($L < \delta$), the smaller the ratio of A/B, the better the profit of the platform, on the right side of the intersection ($L > \delta$), the larger the A/B ratio, the more dominant the platform profits. and on the right side of the intersection ($L < \delta$), the opposite is true. This means that when the A/B ratio of the contribution of both parties is small, both the platform and users are motivated to maintain a situation where the platform service effort is less than the users' effort to keep the resilience of the relationship with the platform. When the A/B ratio of the contribution of both parties is relatively large.



(**a**) Platform profit (**b**) User profit

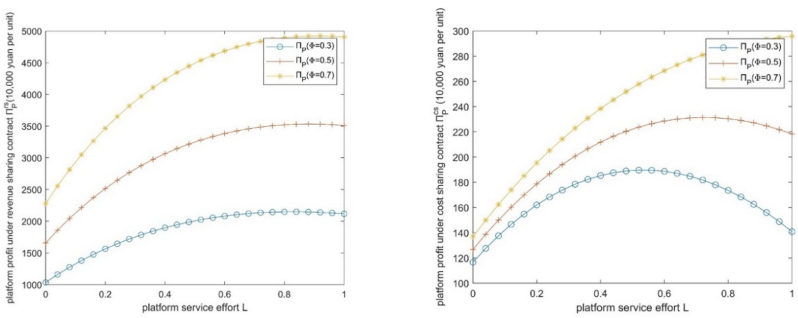
Figure 2. The trend of platform profit Π_P and user profit Π_U with respect to contribution proportion A/B under the basic model.

It is the common goal of both parties that the platform has more service efforts and the users spend less effort on their resilience of relationship with the platform.

5.3. The Impact of Service Effort on Platform Revenue with Revenue and Cost Sharing

In this section we examined the effect of service effort level L on platform on platform revenue under revenue-sharing and cost-sharing contract.

Figure 3a,b shows that, regardless of whether a revenue-sharing or cost-sharing contract is adopted, the platform's profit has a supermodel nature in terms of its service effort and revenue-sharing or cost-sharing ratio. The higher the revenue-sharing or cost-sharing ratio, the greater the contribution of platform service efforts to its profits. This property is shown graphically as, when the level of service effort is fixed, the greater the revenue-sharing or cost-sharing coefficient, the greater the slope of the profit curve, thus verifying property 4. On the other hand, the higher the revenue-sharing or cost-sharing ratio, the greater the platform's optimal service effort, which indicates that the platform's effort investment is affected by the expected return. Platforms with higher expected returns are more motivated to invest, and they are more willing to put in more effort to play the role of increasing income brought about by their supermodel nature. In addition, it can be seen from Figure 3b that the service effort of the platform is not the higher the better. When the service investment is too large, the effect of effort cost on platform profits will be greater than the revenue-generating effect of the effort itself. Therefore, for platforms, the degree of service effort should be reasonably selected to optimize the profit level.



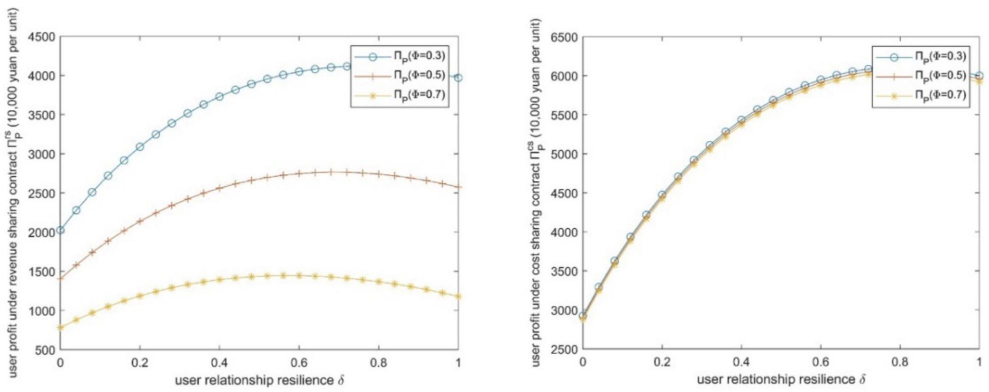
(**a**) The revenue-sharing scenario (**b**) The cost-sharing scenario

Figure 3. Platform profit Π_P with respect to service effort level L and revenue-sharing ratio $\varnothing$ or cost-sharing ratio η.

5.4. The Impact of Relationship Resilience on Platform Revenue with Revenue and Cost Sharing

In this section, we examined the effect of user relationship resilience δ on a platform on platform revenue under revenue-sharing and cost-sharing contracts.

Based on the user's perspective, Figure 4 examines the impact of the users' relationship resilience and revenue-sharing or cost-sharing coefficient on their profits under the two contracts. On the whole, Figure 4a,b reflects that the user's profit has a sub-modular nature with respect to the resilience of the relationship and the revenue-sharing or cost-sharing coefficient. That is to say, with the increase of the ratio of revenue sharing or cost sharing, the contribution of users to their profits by improving the resilience of the relationship between users and the platform shows a decreasing trend, so it verifies the property 5. Although the trend is the same, the profit difference in different situations in Figure 4a is significantly larger than in Figure 4b. This is mainly due to the obvious difference in the order of magnitude between the user achievement conversion benefits of revenue sharing and the total platform operating costs of cost-sharing. Therefore, in theory, whether revenue sharing or cost sharing is adopted, the profit of science and technology platforms and users will be affected by the same trend. However, considering the magnitude difference between benefits and costs, in reality, platforms and users have their preferences when choosing contracts:



(**a**) The revenue-sharing scenario (**b**) The cost-sharing scenario

Figure 4. User profit Π_U with respect to the resilience of relationship δ and revenue-sharing ratio $\varnothing$ or cost-sharing ratio η.

When the platform dominates the game, they tend to adopt the revenue-sharing contract; on the contrary, when the users dominate, they are more willing to choose the cost-sharing contract.

6. Conclusions

In correspondence with our research purpose, this paper builds a scientific research equipment-sharing service system composed of a science and technology innovation platform and enterprise users. Users, as equipment demanders, are faced with the difficulty of implementing patent achievements and need to use large-scale pilot equipment to break through the bottleneck of achievement transformation. As an equipment supplier, the platform provides users with equipment through sharing and is responsible for all supporting services before and after the equipment is used. Combined with the operation mode of the science and technology platform, this paper explores the number of equipment service purchases as the demand, and assumes that the demand is endogenous to the platform's service effort and the resilience of the user relationship between users and the platform. The main research conclusions are as follows: (1) Regardless of whether the contract mechanism is introduced or not, when certain conditions are met, there are optimal decisions for platform service pricing, service effort and users' relationship resilience with the platform. (2) The contribution of platform service pricing and user relationship resilience to platform profits shows a super-modular nature, while the contribution to user profits shows a sub-modular nature. (3) Although, in theory, the two contracts of revenue sharing and cost sharing have the same impact on the profits of the platform and users, in reality, both parties have their preferences in order to optimize their profits as much as possible: when the platform dominates the game, they tend to adopt a revenue-sharing contract; on the contrary, when the users dominate, they are more willing to implement a cost-sharing contract.

The difference between existing research and our research is that existing studies on platforms have mainly focused on e-commerce platforms [36], sharing travel platforms [37], and social platforms [38], and their focus is primarily on platform network effects [20] and efforts in the channel of services consumers [1]. The S&T platform set out to provide equipment-sharing-based patent transformation services for Chinese independent innovation firms. Therefore, distinguished from previous platforms research, it is necessary to consider the mechanism design of service price that can achieve a win–win among multi-stakeholders on the platform. The ultimate purpose of the platform is to use its unique characteristics to guide the scientific and technological innovation entities on both sides to realize value co-creation and improve the utilization efficiency of scientific and technological innovation resources.

There are some limitations to our study. For instance, we only considered how to use the revenue- and cost-sharing contract mechanism to enhance the platform resilience of the S&T platform. However, we focus on examining the impact of platform service efforts and users' relationship resilience with the platform on-demand, ignoring other possible factors, and taking the platform as the only equipment supplier. Future research can add more influencing factors to the demand function and consider the possibility of third-party device hosting. In addition, the equipment quality of the S&T innovation platform in this paper is complete information, yet in practice, this is not always the case, which will increase the operational risk of the platform. We also did not consider the competition platforms. If multiple platforms are competing with each other, users will have multi-homing characteristics, resulting in a cross-side network effect.

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Appendix A

Proof of Proposition 1. According to the reverse induction method, firstly, we obtain the first-order and second-order partial derivatives of the user's profit function Π_U about the user's relationship resilience δ, and obtain the optimal response function $\delta^*(L, p_s)$ of the user's relationship resilience, with respect to the platform service effort L and service pricing p_s.

$$p_s \leq \left(\frac{\partial^2 T(L,\delta)}{\partial \delta^2}\right)^{-1} \left(\frac{\partial^2 R(L,\delta)}{\partial \delta^2} - \frac{d^2 K_2(\delta)}{d\delta^2}\right) \quad \text{(A1)}$$

Next, we substitute $\delta^*(L, p_s)$ into the profit function Π_P of the platform, and obtain the first-order and second-order partial derivatives of the platform effort L and the service price p_s for Π_P, respectively.

Since we are unable to determine the change trend of the user's optimal relationship resilience δ^*, with respect to the platform service pricing p_s, we can obtain the partial derivatives of both sides of the first-order condition of δ^*, with respect to p_s, and the simplification can be appropriate when the platform service pricing satisfies the formula (A1), we have:

$$\frac{\partial\delta^*(L, p_s)}{\partial p_s} \leq 0$$

We then calculate the mixed partial derivatives of Π_P with respect to p_s and L, and further calculate the Hessian matrix of Π_P with respect to p_s and L. The first-order principal sub-form of the Hessian matrix is not positive. When the service effort cost function of the platform satisfies formula (A1), the second-order principal subform is non-negative, and the Hessian matrix H is negative semidefinite, so Π_P is a joint concave function about p_s and L.

$$\frac{d^2K_1(L)}{dL^2} \geq \frac{(p_s - c)\frac{\partial^2 T(L,\delta^*(L,p_s))}{\partial L^2}G_0 - \left(\frac{\partial T(L,\delta^*(L,p_s))}{\partial L}\right)^2}{G_0} \tag{A2}$$

In the formula, $G_0 = \frac{\partial\delta^*(L,p_s)}{\partial p_s}\left[2\frac{\partial T(L,\delta^*(L,p_s))}{\partial\delta} + (p_s - c)\frac{\partial^2 T(L,\delta^*(L,p_s))}{\partial\delta^2}\frac{\partial\delta^*(L,p_s)}{\partial p_s}\right]$.

Then, we combine the first-order conditional expressions of L, p_s and δ, and solve $(L^*, {p_s}^*)$ and δ^* to jointly satisfy the following equations.

$$\begin{cases} ({p_s}^* - c)\frac{\partial T(L^*,\delta^*)}{\partial L} - \frac{dK_1(L^*)}{dL} = 0 \\ T(L^*, \delta^*) + ({p_s}^* - c)\frac{\partial T(L^*,\delta^*)}{\partial\delta}\frac{\partial\delta^*}{\partial p_s} = 0 \\ \frac{\partial R(L,\delta^*)}{\partial\delta} - p_s\frac{\partial T(L,\delta^*)}{\partial\delta} - \frac{dK_2(\delta^*)}{d\delta} = 0 \end{cases} \tag{A3}$$

□

Appendix B

Proof of Proposition 2. According to the reverse induction method, firstly obtain the first-order and second-order partial derivatives of the user's profit function Π_U^{rs} about the user's relationship resilience δ, and according to the first-order condition of δ, the optimal response function $\delta^{rs*}(L, p_s, \varnothing)$ of the user relationship resilience on the platform effort L and the service price p_s under the revenue-sharing contract can be obtained.

$$p_s \leq \left(\frac{\partial^2 T(L,\delta)}{\partial\delta^2}\right)^{-1}\left[(1-\varnothing)\frac{\partial^2 R(L,\delta)}{\partial\delta^2} - \frac{d^2K_2(\delta)}{d\delta^2}\right] \tag{A4}$$

Next, we substitute $\delta^{rs*}(L, p_s, \varnothing)$ into the profit function Π_P^{rs} of the platform, and obtain the first-order and second-order partial derivatives of the platform effort L and service pricing p_s for Π_P^{rs}, respectively. Since we are unable to determine the change trend of the user's optimal relationship resilience δ^{rs*} with respect to the platform service pricing p_s, the partial derivative with respect to p_s on both sides of the first-order condition of δ^{rs*} can be simplified, and when the platform service pricing satisfies inequality (A4), we have:

$$\frac{\partial\delta^*(L, p_s)}{\partial p_s} \leq 0$$

Then, we find the mixed partial derivative of Π_P^{rs} about p_s and L, and further calculate the Hessian matrix of Π_P^{rs} about p_s and L. The first-order principal sub-form of the Hessian matrix is not positive. When the platform service effort cost function satisfies inequality (A5), the second-order principal sub-form is non-negative. At this time, the Hessian matrix H^{rs} is negative semi-definite, and Π_P^{rs} is the joint concave function of p_s and L.

$$\frac{d^2K_1(L)}{dL^2} \geq \frac{\left[(p_s - c)\frac{\partial^2 T(L,\delta^{rs*})}{\partial L^2} + \varnothing \frac{\partial^2 R(L,\delta^{rs*})}{\partial L^2}\right] G_0^{rs} - \left(\frac{\partial T(L,\delta^{rs*})}{\partial L}\right)^2}{G_0^{rs}} \tag{A5}$$

In the inequality, $G_0^{rs} = \frac{\partial \delta^{rs*}}{\partial p_s}\left[2\frac{\partial T(L,\delta^{rs*})}{\partial \delta} + (p_s - c)\frac{\partial^2 T(L,\delta^{rs*})}{\partial \delta^2}\frac{\partial \delta^{rs*}}{\partial p_s} + \varnothing \frac{\partial^2 R(L,\delta^{rs*})}{\partial \delta^2}\frac{\partial \delta^{rs*}}{\partial p_s}\right]$.

Then we combine the first-order conditional expressions of L, p_s, and δ, solve (L^{rs*}, p_s^{rs*}) and δ^{rs*} together to satisfy the following equations.

$$\begin{cases} (p_s^{rs*} - c)\frac{\partial T(L^{rs*},\delta^{rs*})}{\partial L} - \frac{dK_1(L^{rs*})}{dL} + \varnothing \frac{\partial R(L^{rs*},\delta^{rs*})}{\partial L} = 0 \\ T(L^{rs*}, \delta^{rs*}) + (p_s^{rs*} - c)\frac{\partial T(L^{rs*},\delta^{rs*})}{\partial \delta}\frac{\partial \delta^{rs*}}{\partial p_s} + \varnothing \frac{\partial R(L^{rs*},\delta^{rs*})}{\partial \delta}\frac{\partial \delta^{rs*}}{\partial p_s} = 0 \\ (1 - \varnothing)\frac{\partial R(L^{rs*},\delta^{rs*})}{\partial \delta} - p_s{}^*\frac{\partial T(L^{rs*},\delta^{rs*})}{\partial \delta} - \frac{dK_2(\delta^{rs*})}{d\delta} = 0 \end{cases} \tag{A6}$$

□

Appendix C

Proof of Proposition 3. According to the reverse induction method, we first obtain the first-order and second-order partial derivatives of the user's relationship resilience

δ for the user's profit function Π_U^{cs}, and according to the first-order condition of δ, the optimal response function $\delta^{cs*}(L, p_s, \eta)$ of user relationship resilience with respect to platform effort L and service pricing p_s can be obtained.

$$p_s \leq \left(\frac{\partial^2 T(L,\delta)}{\partial \delta^2}\right)^{-1}\left[\frac{\partial^2 R(L,\delta)}{\partial \delta^2} - \frac{d^2 K_2(\delta)}{d\delta^2}\right] - \eta c \tag{A7}$$

Next, we substitute $\delta^{cs*}(L, p_s, \eta)$ into the platform's profit function Π_P^{cs}, and find the first-order and second-order partial derivatives of the platform effort L and service pricing p_s for Π_P^{cs}, respectively. Since we are unable to determine the change trend of the user's optimal relationship resilience δ^{cs*} with respect to the platform service pricing p_s, the partial derivative of p_s on both sides of the first-order condition of δ^{cs*} can be simplified to be appropriate for the platform when the service pricing of satisfies inequality (A7), and we have:

$$\frac{\partial \delta^{cs*}(L, p_s, \eta)}{\partial p_s} \leq 0$$

Then we find the mixed partial derivative of Π_P^{cs} with respect to p_s and L, and further calculate the Hessian matrix of Π_P^{cs} with respect to p_s and L. The first-order principal sub-form of the Hessian matrix is not positive. When the platform service effort cost function satisfies Equation (A8), the second-order principal sub-form is non-negative. At this time, the Hessian matrix H^{cs} is negative semi-definite, and Π_P^{cs} is a joint concave function about p_s and L.

$$\frac{d^2K_1(L)}{dL^2} \geq \frac{[p_s - (1-\eta)c]\frac{\partial^2 T(L,\delta^{cs*})}{\partial L^2} G_0^{cs} - \left[\frac{\partial T(L,\delta^{cs*})}{\partial L}\right]^2}{(1-\eta)G_0^{cs}} \tag{A8}$$

In this inequality, $G_0^{cs} = \frac{\partial \delta^{cs*}}{\partial p_s}\left[2\frac{\partial T(L,\delta^{cs*})}{\partial \delta} + (p_s - (1-\eta)c)\frac{\partial^2 T(L,\delta^{cs*})}{\partial \delta^2}\frac{\partial \delta^{cs*}}{\partial p_s}\right]$.

Then we combine the first-order conditional expressions for L, p_s, and δ, and solve (L^{cs*}, p_s^{cs*}) and δ^{cs*} together to satisfy the following equations:

$$\begin{cases} [p_s^{cs*} - (1-\eta)c]\frac{\partial T(L^{cs*},\delta^{cs*})}{\partial L} - (1-\eta)\frac{dK_1(L^{cs*})}{dL} = 0 \\ T(L^{cs*}, \delta^{cs*}) + [p_s^{cs*} - (1-\eta)c]\frac{\partial T(L^{cs*},\delta^{cs*})}{\partial \delta}\frac{\partial \delta^{cs*}}{\partial p_s} = 0 \\ \frac{\partial R(L^{cs*},\delta^{cs*})}{\partial \delta} - (p_s^{cs*} + \eta c)\frac{\partial T(L^{cs*},\delta^{cs*})}{\partial \delta} - \frac{dK_2(\delta^{cs*})}{d\delta} = 0 \end{cases} \tag{A9}$$

□

References

1. Xie, J.; Kong, H.; Zhang, W. S & T Innovation Platform: Network Characteristics, Operation Governance and Development Strategy: A Case Study from S & T Innovation Practice of Zhongguancun and Zhangjiang Park. *Bus. Manag. J.* **2017**, *39*, 36–49.
2. Bai, X.; Wu, J.; Liu, Y.; Yang, Y.; Wang, M. Research on the Impact of Global Innovation Network on Corporate Performance. *Technol. Anal. Strateg. Manag.* **2022**, *34*, 518–534. [CrossRef]
3. Du, J.; Leten, B.; Vanhaverbeke, W. Managing Open Innovation Projects with Science-Based and Market-Based Partners. *Res. Pol.* **2014**, *43*, 828–840. [CrossRef]
4. Xie, J.; Liang, L.; Liu, L.; Ieromonachou, P. Coordination Contracts of Dual-Channel with Cooperation Advertising in Closed-Loop Supply Chains. *Int. J. Product. Econ.* **2017**, *183*, 528–538. [CrossRef]
5. Xie, J.; Xia, Y.; Ling, L. Service Level Decision of Scientific Instrument Sharing Platform. *Oper. Res. Manag. Sci.* **2021**, *30*, 65–70.
6. Kuo, T.-C.; Chiu, M.-C.; Hsu, C.-W.; Tseng, M.-L. Supporting Sustainable Product Service Systems: A Product Selling and Leasing Design Model. *Resour. Conserv. Recycl.* **2019**, *146*, 384–394. [CrossRef]
7. Hagiu, A.; Spulber, D. First-Party Content and Coordination in Two-Sided Markets. *Manag. Sci.* **2013**, *59*, 933–949. [CrossRef]
8. Spohrer, J.; Maglio, P.P. The Emergence of Service Science: Toward Systematic Service Innovations to Accelerate Co-Creation of Value. *Prod. Oper. Manag.* **2008**, *17*, 238–246. [CrossRef]
9. Lusch, R.F.; Nambisan, S. Service Innovation a Service-Dominant Logic Perspective. *MIS Q.* **2015**, *39*, 155–176. [CrossRef]
10. Turoń, K. From the Classic Business Model to Open Innovation and Data Sharing&Mdash;the Concept of an Open Car-Sharing Business Model. *J. Open Innov. Technol. Mark. Complex.* **2022**, *8*, 36.
11. Liang, L.; Tian, L.; Xie, J.; Xu, J.; Zhang, W. Optimal Pricing Model of Car-Sharing: Market Pricing or Platform Pricing. *Ind. Manag. Data Syst.* **2021**, *121*, 594–612. [CrossRef]
12. Turoń, K.; Golba, D.; Czech, P. The Analysis of Progress Csr Good Practices Areas in Logistic Companies Based on Reports "Responsible Business in Poland. Good Practices" in 2010–2014. *Sci. J. Sil. Univ. Technol. Ser. Transp.* **2015**, *89*, 163–171. [CrossRef]
13. Sánchez-Teba, E.M.; Benítez-Márquez, M.D.; Bermúdez-González, G.; Luna-Pereira, M.d.M. Mapping the Knowledge of Csr and Sustainability. *Sustainability* **2021**, *13*, 10106. [CrossRef]
14. Sardana, D.; Gupta, N.; Kumar, V.; Terziovski, M. Csr 'Sustainability'practices and Firm Performance in an Emerging Economy. *J. Clean. Prod.* **2020**, *258*, 120766. [CrossRef]
15. Kucharska, W.; Kowalczyk, R. How to Achieve Sustainability?—Employee's Point of View on Company's Culture and Csr Practice. *Corp. Soc. Responsib. Environ. Manag.* **2019**, *26*, 453–467. [CrossRef]
16. Cachon, G.P.; Daniels, K.M.; Lobel, R. The Role of Surge Pricing on a Service Platform with Self-Scheduling Capacity. *Manuf. Serv. Oper. Manag.* **2017**, *19*, 368–384. [CrossRef]
17. Marinesi, S.; Girotra, K.; Netessine, S. Threshold Discounting: Operational Benefits, Potential Drawbacks, and Optimal Design. In *Sharing Economy*; Springer: Cham, Switzerland, 2019; pp. 347–377.
18. Xie, J.; Zhu, W.; Wei, L.; Liang, L. Platform Competition with Partial Multi-Homing: When Both Same-Side and Cross-Side Network Effects Exist. *Int. J. Product. Econ.* **2021**, *233*, 108016. [CrossRef]
19. Kumar, V.; Nim, N.; Agarwal, A. Platform-Based Mobile Payments Adoption in Emerging and Developed Countries: Role of Country-Level Heterogeneity and Network Effects. *J. Int. Bus. Stud.* **2021**, *52*, 1529–1558. [CrossRef]
20. Fainmesser, I.P.; Galeotti, A. Pricing Network Effects: Competition. *Am. Econ. J. Microecon.* **2020**, *12*, 1–32. [CrossRef]
21. Cachon, G.P.; Lariviere, M.A. Supply Chain Coordination with Revenue-Sharing Contracts: Strengths and Limitations. *Manag. Sci.* **2005**, *51*, 30–44. [CrossRef]
22. Liu, G.; Yang, H.; Dai, R. Which Contract Is More Effective in Improving Product Greenness under Different Power Structures: Revenue Sharing or Cost Sharing? *Comput. Ind. Eng.* **2020**, *148*, 106701. [CrossRef]
23. Holling, C.S. Resilience and Stability of Ecological Systems. *Annu. Rev. Ecol. Syst.* **1973**, *4*, 1–23. [CrossRef]
24. Kim, Y.; Chen, Y.-S.; Linderman, K. Supply Network Disruption and Resilience: A Network Structural Perspective. *J. Oper. Manag.* **2015**, *33*, 43–59. [CrossRef]
25. Ponomarov, S. Antecedents and Consequences of Supply Chain Resilience: A Dynamic Capabilities Perspective. Ph.D. Thesis, University of Tennessee, Knoxville, TN, USA, 2012.
26. Kamalahmadi, M.; Parast, M.M. A Review of the Literature on the Principles of Enterprise and Supply Chain Resilience: Major Findings and Directions for Future Research. *Int. J. Product. Econ.* **2016**, *171*, 116–133. [CrossRef]
27. Hohenstein, N.-O.; Feisel, E.; Hartmann, E.; Giunipero, L. Research on the Phenomenon of Supply Chain Resilience: A Systematic Review and Paths for Further Investigation. *Int. J. Phys. Distrib. Logist. Manag.* **2015**, *45*, 90–117. [CrossRef]
28. Pereira, C.R.; Christopher, M.; Da Silva, A.L. Achieving Supply Chain Resilience: The Role of Procurement. *Supply Chain. Manag. Int. J.* **2014**, *19*, 626–642. [CrossRef]
29. Min, H. Blockchain Technology for Enhancing Supply Chain Resilience. *Bus. Horiz.* **2019**, *62*, 35–45. [CrossRef]
30. Rajesh, R. Technological Capabilities and Supply Chain Resilience of Firms: A Relational Analysis Using Total Interpretive Structural Modeling (Tism). *Technol. Forecast. Soc. Chang.* **2017**, *118*, 161–169. [CrossRef]
31. Wang, S.; Chen, H.; Wu, D. Regulating Platform Competition in Two-Sided Markets under the O2o Era. *Int. J. Product. Econ.* **2019**, *215*, 131–143. [CrossRef]
32. Scholten, K.; Schilder, S. The Role of Collaboration in Supply Chain Resilience. *Supply Chain. Manag. Int. J.* **2015**, *20*, 471–484. [CrossRef]

33. Shekarian, M.; Mellat Parast, M. An Integrative Approach to Supply Chain Disruption Risk and Resilience Management: A Literature Review. *Int. J. Logist. Res. Appl.* **2021**, *24*, 427–455. [CrossRef]
34. Umar, M.; Wilson, M. Supply Chain Resilience: Unleashing the Power of Collaboration in Disaster Management. *Sustainability* **2021**, *13*, 10573. [CrossRef]
35. Yan, R.; Pei, Z. Retail Services and Firm Profit in a Dual-Channel Market. *J. Retail. Consum. Serv.* **2009**, *16*, 306–314. [CrossRef]
36. Ji, Y.; Li, Y.; Tang, W. Service Investment and Pricing Strategies in E-Commerce Platforms with Seller Competition. *Int. J. Inf. Syst. Supply Chain. Manag. IJISSCM* **2022**, *15*, 1–21. [CrossRef]
37. Leaphart, J.M. Sharing Solutions: An Analysis of Taxing the Sharing Economy in the United States and Europe. *Tul. L. Rev.* **2016**, *91*, 189–215.
38. Chu, S.-C.; Chen, H.-T.; Gan, C. Consumers' Engagement with Corporate Social Responsibility (Csr) Communication in Social Media: Evidence from China and the United States. *J. Bus. Res.* **2020**, *110*, 260–271. [CrossRef]